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An extended car-following model with the consideration of the illegal pedestrian crossing

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ABSTRACT

Pedestrian illegal crossings at midblock are very unpredictable and pose a potential tragic conflict with vehicles besides generally disrupting the normal flow of traffic. The drivers need to not only anticipate but also respond to their actions accordingly to avoid potential conflicts. The objective of this paper was to describe the behavior of the drivers under illegal pedestrian crossing circumstances by proposing an extended car-following model, and then analyze the impacts of the illegal pedestrian crossing on the normal traffic flow at the midblock. In this study, three conditions have been considered, namely: no pedestrians, pedestrians present but waiting, and pedestrians crossing. The numerical results illustrate that the disruptive nature of the illegal pedestrian crossing could worsen when the number of pedestrian is large, the pedestrian platoon size is small, and the speed limitation is high.

1. Introduction

Walking is one of the important modes of traveling that is sensitive to the distance and time. In order to avoid detour and shorten the travel time, pedestrians may adopt mid-block crossing and jaywalking, especially in a route along roads with less pedestrian facilities [1]. Such behavior is quite common in the developing countries and usually random and largely depends on the wisdom of the pedestrians (in deciding when it is appropriate and safe to cross) and the goodwill of the drivers (to yield to the illegal crossing). Therefore, the micro driving behavior will be affected by the illegal pedestrian crossing [2].

To investigate the impacts of pedestrian crossing on traffic flow, the substantial literature on analyzing the properties of vehicular traffic flow and pedestrian have been developed. In a normal urban traffic situation, there will be an intermittent flow of cars. Drivers who are familiar with a road segment that has no provision for pedestrian crosswalks are likely to drive cautiously while being sensitive to the fact that any time a pedestrian may start crossing [3]. For the one who is not familiar, the behavior of pedestrians may surprise him and probably end up in a fatal conflict. The behavior of the car following will depend on the reaction and actions of the lead vehicle according to the dynamics of car-following models. If one of the pedestrian crosses alone when the oncoming vehicle is at a reasonable distance, the lead vehicle may only need to slow down to allow the person to cross but if they are in a platoon, then the lead vehicle may have to stop depending on how close it is to the point of the illegal crosswalk. In such a scenario, a shockwave will be generated by the cars following the lead vehicle and will last as long as it takes the pedestrians to cross. When the density of pedestrians is high, the crossing speed will be lower and they will take longer to complete the crossing process.

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From the driver's point of view, the character of a driver, such as aggressive driving behavior, is significant in this study. An aggressive driver may neither slow down at an illegal crosswalk nor stop for the pedestrians unless they find a worst-case scenario where there is a pedestrian platoon already crossing. However, drivers are more likely to yield when they are driving at lower speeds, have low deceleration rates and to more assertive pedestrians [4]. As vehicles approach the illegal crosswalks, out of caution, drivers may slow down in anticipation [3] of a pedestrian crosswalk operation, especially if there is a pedestrian platoon waiting by the roadside. This response to the roadside stimulus by slowing down [5] will effectively widen the gap between the lead vehicle and the car following if the car in front has already passed the pedestrian, thus encouraging the pedestrian to commence the crossing. If the available gap is 18.3 m and the vehicle speed is less than 4.47 m/s, then 75% of the pedestrians are likely to commence crossing [6]. However, an aggressive driver may accelerate to preempt the commencement of a crossing maneuver and avoid delay.

From the pedestrian's point of view, considering the fact that vehicles have right of way, crossing such road segments poses a safety challenge to pedestrians when they have to search for appropriate gaps between the vehicles before they can execute a safe crossing [7]. For pedestrians who value their safety and comfort, where there are alternative routes, the one along which a higher number of protected pedestrian crossings are available may be more preferable [8]. Many factors contribute to a pedestrian's decisions in order to execute a successful crossing maneuver at a midblock un-signalized and unmarked location. These include the number of lanes, the width of the road, the traffic density and speed, distance and speed of the oncoming vehicle, and the gap between the car in front and the one following behind it. A gap in traffic is generally defined as the space [9] or time [10] between vehicles in a traffic stream approaching a crossing. Temporal gap is the time passed after a pedestrian is ready to cross the road until the nth approaching vehicle reaches the point of conflict between the vehicle and pedestrian [10]. For vehicular traffic, it is the time difference between the leader and follower vehicle with respect to the pedestrian path [11]. The concept of Time to Arrival (TTA) investigates whether pedestrians use time or space gap in deciding whether it is safe to cross. Petzoldt [6] describes the TTA as the time a vehicle takes to travel the full length of the gap with its preceding vehicle. An acceptable gap (for crossing the road safely) may be determined by the pedestrian's gender, level of risk acceptance, the speed of the on-coming vehicle [6], how much the person trusts that the drivers will yield, and the person's perception of how long the gap is [1]. However, that perception may not be correct (the gap might be much longer or shorter than the person thinks it is).

Therefore, a pedestrian needs to compare the two microscopic parameters in order to decide whether it is safe to cross or not. The probability of a pedestrian accepting an available gap is inversely proportional to the speed of the approaching vehicle [10]. When pedestrians wait too long for the critical gap, they can form a pedestrian platoon wherefore they readily accept the available, albeit shorter and riskier, gaps [11]. Studies also indicate that younger male adult pedestrians are likely to accept a risky gap [11,12]. Depending on the size of the gap, number of lanes and the speed of the approaching vehicle, pedestrians cross the roadway in three different ways: single stage, two stages and rolling [1]. It is a challenge to find a single common gap or accurately estimate an acceptable gap in subsequent lanes in a multi-lane and multi-stream traffic flow so that a single-stage crossing can be executed. It is because of limited traffic visibility and the fact that vehicles are not stationary in those lanes. Studies have also been done to describe interactions between motor vehicles and pedestrians outside designated crossing facilities. They focus on pedestrian behavior during gap acceptance [10,13,14], crossing behavior at uncontrolled midblock locations in urban centers [15] in mixed traffic conditions [16], pedestrian jaywalking behavior (gap acceptance and speeds) and the corresponding driver reactions (yielding behavior) [17–19], changes in pedestrian road crossing behavior of an intersection under mixed traffic conditions [20] and human factors such as attitude, age, gender, and physiology that contribute to pedestrian behavior [17,21].

Since 1950s, many traffic flow models have been established to analyze various complex traffic phenomena [22–24]. The existing traffic flow models can be divided into two groups: microscopic models [25–46] and macroscopic models [47–60]. The former focus on exploring the micro properties of traffic flow, including car-following, lane-changing, overtaking, etc. Bando developed the Optimal Velocity model to describe the car-following behavior on a single-lane highway [61]. Helbing proposed Generalized Force Model to address the deficiency of the OV model [62]. Jiang extended the OV model by introducing positive relative velocity into the GF model and came up with the Full Velocity Difference (FVD) Model [63]. To-date, many car-following theory researchers have extended the FVD model to describe the behavior of drivers in different traffic circumstances. However, these studies and the inherent models do not describe the car-following traffic flow phenomena that is caused by the presence of illegal pedestrian crossing since they did not consider this factor. Therefore, this study focuses on the microscopic factors that influence normal traffic flow with respect to illegal pedestrian crossing. Building on previous car-following models, this study assumes that all the cars follow each other at a stable speed without tailgating or overtaking on a one-lane one-way roadway. It also considers the pedestrian crossing maneuver from the moment he chooses the appropriate time to cross up to the end excluding their behavior prior to the crossing. A model developed for urban traffic will be preferable.

2. Model

In actual traffic, drivers drive carefully considering potential traffic stimuli such as illegal pedestrians crossing, slow moving vehicles and those either joining or exiting the traffic stream. Consequently, some drivers may exhibit some cautious characteristics such as slowing down and response delay when approaching pedestrian crossing sites while the aggressive