Game Analysis of Pedestrian Crossing Behavior at Signalized Intersection

Xiaoxia Hu
Chang’an University
Xi’an, China
1964705383@qq.com

Yu Li
Chang’an University
Xi’an, China
745689758@qq.com

Meiye Li
Chang’an University
Xi’an, China
752839347@qq.com

Ge Li
Chang’an University
Xi’an, China
lige904@163.com

ABSTRACT

Road traffic is a dynamical system composed of four elements: human, vehicle, road and environment. Among them, pedestrians, as an important part of the urban traffic system, have a great influence on the normal operation of the traffic system. In this paper, based on the analysis of the reasons of pedestrian crossing violations, this paper constructs the game model of pedestrian and motor vehicle driver, pedestrian and traffic management based on the complete information static game theory, and obtains the Mixed Strategy Nash Equilibriums. The results show that pedestrians cross the street illegally, which is mainly related to the additional income, the safety risk, the increased cost and the traffic management department's punishment for pedestrians violating the street crossing. Finally, according to the analysis for the reasons of pedestrian violations, the measures to improve pedestrian crossing violations are put forward.

KEYWORDS: pedestrian crossing violations; motor vehicle drivers; traffic management department; signalized intersection; Mixed Strategy Nash Equilibrium

1. INTRODUCTION

In 2012, some netizens put forward the word "Chinese-style crossing the road" on micro-blog, which immediately triggered the discussion of social public on traffic, national quality and safety awareness (Li, 2015). Chinese-style crossing the road is that "if there is a group of person, they will cross the road regardless of the traffic lights ". It is actually a kind of ridicule on a part of people running the red light collectively. This phenomenon is not only appeared in China, but the phenomenon is very prominent and frequent in China. Pedestrian crossing violations at signalized intersections due to various reasons, resulting in the conflicts of pedestrian and motor vehicle in
mixed traffic flow, the pedestrian safety is often threatened, the motor vehicle is delayed, and the operation efficiency of the whole transportation system is reduced. “Global status report on road safety 2013” shows that the number of people who die from road traffic accidents each year is as high as 1.24 million, among them 270 thousand are pedestrians, accounting for 22% of the total road traffic deaths. The collision of pedestrians with motor vehicles and traffic accidents are mostly related to cross-street pedestrian. However, in China, urban traffic management often focuses more on motor vehicles, but ignores the pedestrians and non-motor vehicles. The research of pedestrian crossing behavior is not enough, they almost all ignored the contradiction of the growing demand of pedestrian crossing and facilities supplied, causing pedestrian and motor vehicle mixed together.

For the reasons of pedestrian crossing violations, most of research makes psychological analysis. Li Chuncheng divided pedestrians into five types: stable, semi-stable, unstable, anti-conventional and self-accepted, and he compared the behaviors of five types of cross-street pedestrians through psychology (Li, 2003). Zhao Wei et al. studied the factors influencing pedestrians' unsafe behavior when they crossing the road from the point of psychology (Zhao et al, 2006). Some research are pay attention to the transportation facilities. Sun Shijun et al. believed that time, traffic facilities and psychological factors are the main causes of pedestrian crossing violations (Sun et al, 2007). Zhou Zhuping and Wang Wei argued that pedestrian crossing violations largely because the unreasonable traffic facilities and saving time are in dominant positions instead of the security needs (Zhou and Wang, 2006). Li Ping introduced the game theory into the conflict model of pedestrian crossing for the first time, established the pedestrian crossing game models based on pedestrian-first-making-decision and on vehicle-first-making-decision (Li, 2011). The previous research mainly studied the conflict model between pedestrians and motorists, with little consideration for the analysis with the game theory. The analysis focused mainly on the unsignalized intersection, without taking into account the signalized intersection. Based on the research of domestic and foreign traffic research, this paper introduced the game theory method, through the construction of the mathematical game model and the analysis of the equilibrium solution, determining the influencing factors of pedestrian crossing violations at signalized intersection.

2. CAUSES OF PEDESTRIAN CROSSING VIOLATIONS

2.1 Subjective causes

The subjective causes of pedestrian crossing violations mainly include the pedestrians' own characteristics, psychological factors and the emotion of pedestrians when they crossing the street.

Pedestrians are different in age, gender, personality, and educational level. Studies have shown that there is a great possibility that children crossing violations as they are immature, they lack of understanding of the surrounding environment and do not know the social norms. Young people crossing violations because of their own physical advantages so that they often ignored the risk. The elderly is calmer than others, they has low crossing speed and less violations (Yi, 2016). Female is more cautious than male, and male is more aggressive and adventurous, so male crossing violations is more frequent than female. Pedestrians in character are divided into five types: stable, semi-stable, unstable, anti-conventional and self-accepted, crossing behaviors of different types are different. The higher the human’s education level is, the lower the probability of the occurrence of pedestrian crossing violations.

The psychological influencing factors of pedestrian crossing violations mainly include conformity psychology, fluke mild, psychology of saving time and energy, psychology of adventure.

1. Conformity psychology

When pedestrians waiting on the road for crossing the street, if the number of pedestrians and non-motor vehicles is enough, pedestrians will psychological believe that they can cross the road safely through the traffic gap. When pedestrians walk together, under the domination of conformity psychology, they will rely on each other, neglect the traffic safety and accident is caused. Studies have shown that if there are pedestrians who follow traffic rules, the probability of pedestrian crossing violations will greatly reduce (Andrew.HW, 1991). And pedestrian conformity psychology is a major influencing factor of pedestrian crossing violations (Holland.C et al. 2007).

2. Fluke mild
Fluke psychology is often accompanied by other psychologies, such as for saving time and energy, pedestrians may shorten the walking distance and waiting time, resulting in pedestrians crossing the street illegally or even crossing guardrails. This psychological misunderstanding mainly depends on the tiny occurrence probability of a traffic accident or of being punished (Chu et al. 2015). The reason why a pedestrian has a fluke mild is that he will not have any danger and not be punished even if he breaks the rules. When pedestrians have fluke mild, they will eagerly for quick success and instant benefits and cannot make the right judgment.

3. Psychology of saving time and energy

Psychology of saving time and energy is that people want to gain maximum benefit by consuming the least energy. They are mainly feel troublesome and want to be convenient and save time. The psychology shows that people are impetuous in the modern society. People pursue for ways that are fast and convenient, and has formed a mindset and behavioral habits. In the process of pedestrian crossing the street, psychology of saving time and energy mainly be embodied in run a red light, or do not go zebra crossing to cut corners and don’t crossing the road through pedestrian overcrossing or pedestrian subway or other crossing facilities (Li et al. 2007).

4. Psychology of adventure

There are many similar places between psychology of adventure and fluke mild. Fluke mild is the psychology that ignoring the danger and traffic laws, people who has fluke mild are speculative and hoping that the danger does not happen to themselves. Psychology of adventure is that people who know pedestrian crossing violations is illegal and dangerous, but they also will do. The misunderstanding is has higher risk.

Pedestrian emotions mainly include excitement, anger, impatience, tension and hesitation (Feng et al. 2006). When pedestrians are excited, they will ignore the traffic conditions on the road and crossing the street adventurously, or do not pay attention to the nearby pedestrian crossing facilities and run the red light. In the process of crossing the street, conflicts among pedestrians will inevitably produce, pedestrians will have impulsive and angry emotions, and then they will in the way or make crossing violations deliberately, hindering the operation of road traffic, and even causing traffic accidents. Pedestrians are in a hurry will prone to get impatient, senseless, ignoring traffic conditions, and then they will make pedestrian crossing violations and lead to traffic accidents. When pedestrians are not sure whether they can cross the road safely, they often have the psychology of fear or nervousness when pedestrians crossing the street. Moderate tension will make people excited and enhance the sense of responsibility. Excessive tension will lead to inaccurate judgment, movement disorders and crossing the street illegal.

2.2 Objective causes

1. Natural environment

Natural environment mainly includes geographical conditions and climatic conditions. The geographical conditions of the road are generally limited by the local terrain and cannot be changed. Climate conditions mainly refer to seasonal changes, rain, snow, fog and haze, dust and so on. Such as cold weather, rain, snow, haze, sand and dust weather and other bad conditions will weaken the sensitivity and coping ability of pedestrian from the psychological and physiological, resulting in pedestrian crossing violations.

2. Traffic facility environment

Traffic facility environment mainly refers to the external physical environment for the transportation participants to make various traffic behaviors, including various road facilities and traffic management facilities. As pedestrian crossing facilities are deficient, pedestrians are more like crossing the street illegally. Unreasonable signal time setting will also produce pedestrian irregularities as the crossing time is not enough. Traffic surveillance and control system and road liner will be the influencing factors which effect pedestrian crossing violations.

3. Cultural environment

Traffic culture environment mainly refers to the traffic laws and regulations, traffic enforcement, moral concepts, traffic rules publicity, living habits and other cultural atmosphere. It is a kind of soft environment and its impact on people is subtle and difficult to change. Whether the traffic laws and regulations are fair and sound, or whether traffic enforcement is fair and strict has a certain influence.
on the occurrence of urban traffic anomie behavior. Biased or not perfect traffic laws and regulations, traffic is lax or the punishment is too light are the reasons for pedestrian crossing violations. The publicity of traffic laws and regulations also has an impact on traffic behavior. Morality is the code of conduct for traffic participants in traffic activities, if the traffic participants do not consciously abide by the traffic regulations and traffic morality, then the public transport order will be out of the question.

2.3 Problem description

Pedestrians will not abide by the traffic rules and choose to do crossing violations because of the conformity psychology, fluke mild, psychology of saving time and energy and other reasons. Although the behavior can meet the psychological needs of pedestrians, it has a great safety risk and will impede the operation of traffic. Pedestrians will not choose to cross the street when they think the risk is high and the motor vehicle does not give way. At the same time, in order to ensure the safety of pedestrians and smooth roads, the government will supervise the pedestrians’ behavior, but it will cost a lot of money. Therefore, pedestrian crossing violations will be occurred driven by various psychological needs under the circumstance of low safety risk and penalty costs.

As pedestrians, motor vehicle drivers and traffic management departments choose their behaviors with a certain probability. Thus, this paper used the method of complete information static game to get the mixed strategy Nash equilibrium.

3. MIXED STRATEGY NASH EQUILIBRIUM FOR PEDESTRIANS AND VEHICLES

3.1 Basic assumptions

1. Traffic participants include crossing pedestrians and vehicle drivers, and players are all rational in pursuit of self-interest maximization.
2. There are two strategies for pedestrians when they waiting for crossing the street at signal intersections: obeying traffic rules and waiting or crossing the street illegally.
3. Vehicle drivers can choose crossing or avoiding at green light time, and when the pedestrian follow traffic rules, vehicle drivers needn’t avoid, the probability of crossing the signal intersections is 1.
4. E is the income of pedestrians obeying the traffic rules; S is additional revenue of pedestrians breaking the traffic rules, such as the benefits of saving time; D represents the cost paid by the safety risks increasing while pedestrians crossing the street illegally; V is the income of drivers crossing the street; L represents drivers' risk for crossing the intersection.
5. The proportion of pedestrians who choose “cross the street illegally” is $x_1$, then the proportion of pedestrians who choose “waiting follow the rules” is $1-x_1$; When pedestrians cross the street illegally, the proportion of vehicle drivers taking the "pass" strategy is $y$, and the proportion of vehicle drivers taking the “avoid” strategy is $1-y$; When pedestrians comply with traffic rules and waiting, vehicle drivers only select “cross” strategy.

3.2 Construction of model

According to the above hypothesis, the payoff matrix of the game between pedestrians and vehicle drivers can be obtained, as shown in the Table 1:

<table>
<thead>
<tr>
<th></th>
<th>Vehicle</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Pass</td>
</tr>
<tr>
<td>Pedestrian</td>
<td>Cross</td>
</tr>
<tr>
<td></td>
<td>wait</td>
</tr>
</tbody>
</table>

Table 1. Payoff matrix model of pedestrians and vehicles
The expected return for the cross-street pedestrians using the strategy “cross” and “wait” are $W_{H1}$ and $W_{H2}$, respectively:

$$W_{H1} = (E + S - D)y + (E + S)(1 - y) = E + S - Dy$$

$$W_{H2} = E \cdot 1 + E \cdot 0 = E$$

The expected return for the vehicle drivers using the strategy “pass” and “avoid” are $W_{V1}$ and $W_{V2}$, respectively:

$$W_{V1} = (V - L)x + V(1 - x) = V - Lx$$

$$W_{V2} = 0 \cdot 1 + 0 \cdot 0 = 0$$

3.3 Model solutions and analysis

For cross-street pedestrians, there is $W_{H1} = W_{H2}$, that is $E + S - Dy = E$ We can get $y^* = \frac{S}{D}$.

If the probability that the driver chooses to pass is less than $\frac{S}{D}$, the optimal choice for cross-street pedestrians is to cross the street illegally; If the probability that the driver chooses to pass is more than $\frac{S}{D}$, the optimal choice for cross-street pedestrians is to cross the street legally; If the probability that the driver chooses to pass is equal to $\frac{S}{D}$ cross-street pedestrians randomly choose to cross the street illegally or comply with the rules.

For vehicle drivers, there is $W_{V1} = W_{V2}$, that is $V - Lx = 0$ We can get $x^* = \frac{V}{L}$.

If the probability that pedestrians cross the street illegally is less than $\frac{V}{L}$, the optimal choice for drivers is to cross the street; If the probability that pedestrians cross street illegally is more than $\frac{V}{L}$, the optimal choice for drivers is to avoid crossing the street; If the probability that pedestrians cross street illegally is equal to $\frac{V}{L}$ drivers randomly choose to “pass” or “avoid”.

Therefore, the mixed strategy Nash equilibrium is $x^* = \frac{V}{L}$, $y^* = \frac{S}{D}$, that is, pedestrians crossing violations with a probability of $\frac{V}{L}$, then drivers cross the street with a probability of $\frac{S}{D}$.

When the light for vehicles is green, drivers choose to cross the signalized intersection by default, and when pedestrian crossing violations, vehicle drivers will pass the intersection with a certain probability. The driver how to choose the "pass" or "avoid" decision is related to the income and risk drivers obtained as they crossing the intersection. The income is mainly the time-saving, and the risk is the risk rate of traffic accidents. The vehicle is permitted by the green light, which isn’t illegal traffic, and needn’t take the penalty risk. The greater the income of crossing the intersection is, the greater the probability of vehicle drivers crossing is, and on the contrary, the probability is smaller.

It is noted that when pedestrians obey the traffic rules, vehicle driver who is allowed to pass will cross the intersection with the probability of 1, that is, vehicle drivers will choose "pass “rather than “avoid”.

Pedestrian crossing violations are related to the additional benefits and the cost of the increasing safety risks. The additional benefits from the illegal crossing are mainly include time-saving and psychological needs of pedestrians. The higher the additional benefits are, the greater the probability that pedestrians choose to cross the street is; the lower the safety risk is, the greater the probability of illegal crossing. Safety risk is the lower the better, so only the additional benefits is reduced, the probability of pedestrian crossing violations can be reduced. The following measures can be taken to reduce the additional benefits of pedestrian crossing violations:

1. Improving crossing infrastructures for the pedestrian, making it more perfect and humanized, while ensuring its reasonable saving time and security needs. First of all, the awning could be set. In the face of bad weather, pedestrians will only want to pass through the crosswalk, which easily lead to pedestrian crossing violations. Secondly, we can set the pedestrian islands in the middle of the pedestrian crossing and other secondary crossing facilities. The crosswalk is divided into two parts so that pedestrians do not hurry to cross the road or cross by force. Thirdly, it should be reasonable to set up and improve the pedestrian crossing facility signs which guide pedestrians to comply with traffic rules, reduce pedestrian anomie behavior.

Finally, pedestrian bridge or underground passage could be set at the intersections in commercial and large traffic flow place. At the smaller intersection, the traffic light time should be set reasonably,
and pedestrian crossing time should be considered, the time cannot be set too long to ensure that pedestrians have patience to wait for the next green time in a certain period of time.

(2) Do a good job on traffic law education and form a long-term mechanism. First, strengthen traffic safety education at the basic stage. Second, strengthen the source of education. Improve the quality of individuals, the legal awareness, safety awareness and civilized consciousness, which is the source of traffic management. People need deep understanding the consequences of breaking the law and need to know the illegal behavior which will pay a heavy price. Thirdly, strengthen the guiding role of public opinion via televisions, radios, newspapers, magazines, networks and other media. Through the safety education, long-term exposure, education, guidance and other work to pedestrian crossing violations, reduce pedestrian crossing violations gradually.

4. MIXED STRATEGY NASH EQUILIBRIUM FOR PEDESTRIANS AND TRAFFIC MANAGEMENT DEPARTMENT

4.1 Basic assumptions

1. There are two strategies for pedestrians when they waiting for crossing the street at signal intersections: obeying traffic rules and waiting or crossing the street illegally.

2. There are two kinds of decision to traffic management department: do management violations or no-management.

3. The traffic management department can only punish pedestrian crossing violations with a certain probability because of the cost.

4. E is the income of pedestrians obeying the traffic rules; S is additional revenue of pedestrians breaking the traffic rules, such as the benefits of saving time; K stands for the loss to society caused by pedestrian choosing violations, such as affecting the smoothness of traffic; C is the management cost of traffic management department; F represents the traffic management department's penalty for pedestrian crossing violations.

5. If the proportion of pedestrians who choose to “cross” is x, the proportion of pedestrians who choose to “wait” is 1-x; If the probability that traffic management chooses “do management” is z, the probability of taking “no management” is 1-z.

4.2 Construction of model

Based on the above assumptions, the payoff matrix of the game of pedestrians and traffic management departments can be obtained, as shown in Table 2:

<table>
<thead>
<tr>
<th>Traffic Management Department</th>
<th>Do management</th>
<th>No management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian</td>
<td>Cross</td>
<td>((E+S-F,K-C-F))</td>
</tr>
<tr>
<td></td>
<td>Wait</td>
<td>((E,-C))</td>
</tr>
</tbody>
</table>

The expected return for the cross-street pedestrians using the strategy "cross" and "wait" are \(W_{P1}\) and \(W_{P2}\), respectively:

\[W_{P1} = (E + S - F)z + (E + S)(1 - z) = E + S - Fz\]

\[W_{P2} = Ez + E(1 - z) = E\]

The expected return for the traffic management department using the strategy “do management” and “no management” are \(W_{G1}\) and \(W_{G2}\), respectively:

\[W_{G1} = (-K - C + F)x + (-C)(1 - x) = (-K + F)x - C\]

\[W_{G2} = (-K)x + 0(1 - x) = -Kx\]
4.3 Model solutions and analysis

For cross-street pedestrians:

\[ W_{G1} = W_{G2} \]

That is:

\[ E + S - F_2 = E \]

We can get:

\[ z^* = \frac{S}{F} \]

If the probability that traffic management department chooses to “do management” is less than \( \frac{S}{F} \), the optimal choice for cross-street pedestrians is to cross violations. If the probability that traffic management department chooses to “do management” is more than \( \frac{S}{F} \), the optimal choice for cross-street pedestrians is to obey the traffic rules. If the probability that traffic management department chooses to “do management” is equal to \( \frac{S}{F} \), pedestrians randomly choose to cross violation or obey the traffic rules.

For traffic management:

\[ W_{G1} = W_{G2} \]

That is:

\[ (-K + F)x - C = -Kx \]

We can get:

\[ x^* = \frac{C}{F} \]

If the occurrence probability of pedestrian crossing violations is less than \( \frac{C}{F} \), the optimal choice for the traffic management department is “no management”. If the probability of pedestrians crossing violations is more than that \( \frac{C}{F} \), the optimal choice for the traffic management department is “do management”. If the occurrence probability of pedestrian crossing violations is equal to \( \frac{C}{F} \), the traffic management department randomly selects the strategy of “no management” or “do management”.

Therefore, the mixed strategy Nash equilibrium is: \( x^* = \frac{C}{F} \), \( y^* = \frac{S}{F} \), that is, pedestrians crossing violations with a probability of \( \frac{C}{F} \) and the traffic management department manages the traffic with the probability of \( \frac{S}{F} \).

In the game between pedestrians and traffic management, the main reason for traffic management neglects pedestrian crossing violation is that the management costs are very high and the penalties are very low. There are few effective punishments.

Whether pedestrians choose to crossing violations depends on extra income obtained and the punishment of traffic management department. The higher the additional income is, the lower the penalty cost is, the greater the probability of pedestrian crossing violations is. So there is a need for efficient penalties. On the one hand, legal construction should be strengthened. First, cost of pedestrians crossing violations must be increased. Second, the operability of traffic laws and regulations should be improved. On the other hand, traffic laws should pay more attention to pedestrians: first of all, increasing the intensity of non-motor vehicle and pedestrian law enforcement, do a good education to pedestrians those who attempt to escape traffic penalties. Second, traffic management department should enhance the technical content and the efficiency of law enforcement. For example, a system can be developed that identifies pedestrians’ body features, avatars, fingerprints, and so on to determine pedestrian identity. Finally, traffic law enforcement officers should establish the correct concept of law enforcement, enforce laws justly and strictly.

5. CONCLUSIONS

In the case of pedestrian crossing violations, a mixed game Nash equilibrium model of complete information static game is used to analyze the game models of pedestrians, motor vehicle drivers and traffic management departments, and draw the following conclusions:

1. What crossing behavior pedestrian choose is depend on additional benefits, safety costs and penalty cost. The higher the benefit is and the lower the cost of safety and penalty is, the greater the probability of pedestrian crossing violations is.
2. Pedestrian crossing violations are not only related to pedestrians themselves, it is largely due to the unreasonable road infrastructure, so pedestrian crossing facilities must be improved and humanized.

3. Traffic management departments have too high management costs for pedestrian crossing violations, and penalty benefits are very low, so it is necessary to carry out more severe penalties on pedestrian crossing violations.

This paper studied pedestrian crossing violations based on the complete information static game. Dynamic changes of pedestrian crossing in the long run did not be considered. In fact, pedestrians cannot grasp all traffic information, so we can only do qualitative analysis. In addition, some influencing factors such as non-motor vehicles how to affect the pedestrian crossing violations need to be further studied.

REFERENCES


Feng, S.M. Pei, Y.L. (2006). “The analysis of the psychologies of pedestrians when they are crossing the streets”. Cross Strait Symposium on Intelligent Transportation System.


