Lehrstuhl für Ergonomie
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Intercultural Comparison of Road User Behavior Centred Vehicle-Pedestrian Conflict in Urban Traffic

Xiaobei JIANG

TECHNISCHE UNIVERSITÄT MÜNCHEN

A dissertation submitted to the Fakultät für Maschinenwesen, Technische Universität München in fulfillment of the requirements for the Degree of Doktor-Ingenieurs (Dr.-Ing.)

Supervisor: Univ.-Prof. Dr. phil. Klaus Bengler
Univ.-Prof. Dr. rer.nat. i.R. Heiner Bubb

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ABSTRACT

As vulnerable road users, pedestrians are easily involved in traffic accidents on urban crosswalk where the motor vehicle-pedestrian conflicts typically occur. Nowadays, the Advanced Driver Assistance Systems (ADAS) may hold great potential to reduce the accident frequency and severity by providing guidance or appropriate actions to the drivers. Considered the different driving cultures between China and Germany, design of ADAS for new and growing market in China triggers an “intercultural comparison” related to the road user behavior and traffic safety.

This study aims to the fundamental theories of road user behavior in motor vehicle-pedestrian (VEH-PED) conflict and analyze the main road user behavioral characteristics based on the real traffic data, which can be applied to conflict behavior modeling and traffic safety evaluation. Video observation and image processing are employed at seven field study sites in Beijing, China, and Munich, Germany, the data series of road user trajectories in conflict situation are studied to form the standard data matrix. The microscopic data including pedestrian behavioral parameters, driver behavioral parameters and situational factors are investigated. The study tries to address how the conflict participants behave differently between China and Germany, and gives a view of intercultural comparison on conflict behavior.

The intercultural analyses are carried out mainly in the following aspects:

From the macroscopic level

Urban traffic situation comparison
Pedestrian safety situation comparison
Driving culture comparison

From the behavioral level

Differences in pedestrian conflict behavior
Speed performance
Waiting performance
Gap acceptance
Time-related measures and their relationships

Differences in driver conflict behavior
Driver yielding behavior
Driver deceleration rate and its relationships with other parameters
TTC-related relationships

Special case analysis

Non-compliance conflict situations in China

According to the observation data, model predicting the driver yielding behavior on basis of binary logit model and model calibrates the pedestrian waiting behavior on basis on Weibull distribution are proposed and verified to be effective. Two conflict indicators, the minimum VEH-PED distance and critical conflict radius are mathematically introduced for conflict discrimination. The measures to improve traffic safety on unsignalized crosswalk in China are discussed through traffic control and design, traffic facility, traffic education and law enforcement.

The research would lay the groundwork in the target of creating ADAS adaptation data base and it will hopefully be the impetus for further intercultural analyses from urban traffic side.

CONTENTS

GLOSSARY

Chapter3

TA	Time-to-Accident
CP	Conflict Point
VHE	Vehicle.
PED	Pedestrian
TTC	Time-To-Collision
PED	Post-Encroachment-Time
(x, y)	Road coordinate
(u, v)	Image coordinate
$a_{i,j}$	Coefficients of coordinate transformation matrix
$b_{i,j}$	Coefficients of coordinate transformation matrix
N	Minimum sample size
p	Proportion of the number of vehicles in the certain conflict to the traffic flow volume observed
q	*1-p*
k	Constant related to a certain confidence level
E	Allowable error of the conflict proportion

Chapter4

VS	Vehicle speed
PS	Pedestrian speed
LADP	Pedestrian lateral distance to CP
LODV	Vehicle longitudinal distance to CP
$TTCP_{PED}$	Pedestrian time to CP
$TTCP_{VEH}$	Vehicle time to CP
w_0	Half the width of a vehicle
L_0	Vehicle length

Chapter5

DEC	Deceleration rate
ACC	Acceleration rate

Chapter6

U_i	Utility of choosing alternative *i*
β_{in}	Coefficient
i	Number of alternatives
n	Number of the independent variables
B	Logistic coefficient
Wald	Wald chi-square
Sig.	p-value
$P(h \leq \tau)$	Probability of gap less than or equal to the critical gap
h	Gap of two successive vehicles
τ	Critical gap of two successive vehicles
α	Shape parameter of the distribution
β	Scale parameter of the distribution
γ	Location parameter of the distribution
$f(\tau)$	Probability density at τ
A_1	First sample moment about the origin
A_2	Second sample moment about the origin
$\int_0^\infty hf(h)d_h$	Mean of the random variable
$\int_0^\infty h^2f(h)d_h$	Variance of random variable
$\overline{h_x}$	Average pedestrian waiting time at situation (1)
$\overline{h_d}$	Average pedestrian waiting time at situation (2)
$\bar{x}$	Average number of gaps
d	Waiting time
$x_i(0),\ y_i(0)$	positions of the two road users at time 0
$x_i(t),\ y_i(t)$	position of the two road users at time *t*
θ_i	Angle between the road user movement direction and x-axis positive direction
$v_i(t)$	Velocity of the road user at time *t*
$a_i(t)$	Acceleration of the road user at time *t*
$D(t)$	Distance between two road users
d_{min}	Minimum VEH-PED distance
t_m	At time t_m reaches the d_{min}
φ	Angle
$R(\varphi)$	Critical conflict radius
l_0	Minimum stopping distance
$y' - x'$	Relative coordinate system
$\overrightarrow{v_1}$	Relative velocity of road user 1
$\overrightarrow{v_2}$	Relative velocity of road user 2
θ_{2m}	Moving direction angle of road user 2
$v_{\theta_{2m}}$	Velocity component along θ_{2m} direction

Chapter7

g_{min}	Minimum pedestrian green time
w	Width of the crosswalk
v	Average pedestrian crossing speed
I	Change interval
g	Phase green time
q	Pedestrian volume
r	Pedestrian phase red time
N	Average number of pedestrians in each row
t_f	Average following time for each row

1 INTRODUCTION

1.1Characteristics of urban traffic

Gradual developments in society, economy, culture, and science have brought about variations in progress in many fields all over the world. Thus, in terms of urban traffic, significant differences also exist between developed and developing countries.

1.1.1 Urban traffic in developed countries

With industrialization, both transportation and traffic facilities have achieved major developments. Traffic in the western world or developed countries is characterized by a variety of motorized vehicles (such as passenger cars, buses, and trucks, etc) because of the crucial status of motorized vehicles—the dominant percentage of auto modes. As shown in Tab. 1-1, in Europe and North America, the automobile mode makes up the largest proportion of various travel modes. Motivated by congestion in urban areas due to heavy motor traffic, researchers have applied the traffic control techniques to solve the problems and made efforts to improve the public transit systems. Today, car mobility has reached maximum levels in developed countries and the aftereffects of high energy costs, congestion, and aging of the population become the countervailing forces to car dependency, especially in urban areas. Compared with the situations in developing countries which are undergoing the initial stage that had already been experienced in developed countries like the growth of urban population, the growth of car ownership and development of infrastructure, significant efforts are being made to develop more intelligent, energy-saving, and accident-free urban traffic environment in developed countries (Rodrigue, 1998).

1.1.2 Urban traffic in China

Compared with traffic situations in developed countries, where road traffic are highly regulated and adequate infrastructure is provided, urban traffic in China is more complex and volatile with the following characteristics:

Highly mixed traffic

Mixed traffic means all types of road users, including motorized vehicles, non-motorized vehicles, and pedestrians share the same carriageway; this phenomenon is an extremely important characteristic of urban traffic in China. Chinese traffic is characterized by wide variations in speed, size, and maneuverability of the vehicles in a mixed traffic stream coupled with a lack of lane discipline, resulting in traffic behavior unlike that in developed cities, where a vehicle occupies a single lateral position on the road (Hossain, 1996). Other developing countries in Asia also feature highly mixed traffic.

Tab.1-1 Modal split distributions for urban travel in Europe and North America (Tomlinson, 2003)

Country	Percentage of Trips by Travel Mode				
	Bicycle	Walking	Transit	Auto	Other
Netherlands	30	18	5	45	2
Denmark	20	21	14	42	3
Germany	11	22	16	49	1
Switzerland	10	29	20	38	3
Sweden	10	39	11	36	4
Austria	9	31	13	39	8
England and Wales	8	12	14	62	4
France	5	30	12	47	6
Italy	5	28	16	42	9
Canada	1	10	14	74	1
U.S.A.	1	9	3	84	3

Large proportion of pedestrians and bicyclists

Walking serves many trip purposes in daily life, regardless of gender and age. While the rapid evolution of technology has brought about tremendous benefits in terms of presenting trip mode options, walking remains an inseparable aspect of all trips from origin to destination. In China, walking and cycling are the two major trip modes, accounting for about 60% of all trips made daily despite the fact that proportions of passenger vehicles and public transit have increased gradually over the years. (In China, non-motorized vehicles include bicycles, three-wheeled cycles, electrical bicycles, scooters, and other; bicycles account for above 90% of all non-motorized vehicles.) Tab. 1-2 illustrates the proportions of travel modes in some megacities in China.

Tab.1-2 The proportions of some travel modes in several megacities in China (Li, 2006)

City	Walking	Bicycle	Public Transit	Motorcycle	Passen-ger Vehicle	Statistic Year
Beijing	43.13	28.72	15.34	0.98	10.8	2002
Shanghai	29.2	30.6	18.5	5.2	8.6	2005
Shenyang	29.22	38.88	18.8	2.86	15.92	2004
Nanjing	26.31	40.78	24.43	2.71	4.3	2001
Xi’an	22	33	23	5	6	2000

Huge trip volume

Due to their high population density, megacities must address a serious traffic problem: the huge trip volumes. For example, according to the annual report of urban traffic in Shanghai, China (SUTDAR, 2007), the trip volume in 2007 was 44.65million person-trips per day; in 2008, this volume rose to 45.93million person-trips per day. Traffic facilities may be burdened by such heavy trip volumes, posing threats to human safety.

Traffic non-compliance
Road users competing for limited space with others and non-observance of right-of-way are common occurrences in China. Road users' negative attitudes toward traffic regulations and legislations could result in significant problems in traffic education and traffic safety (Yang, 2011; Mei, 2011).

These problems can neither be ignored nor evaded, and new solutions are necessary to reduce traffic risks and promote safe trips.

1.2 Different driving cultures between China and Germany

The driving culture has surfaced as a focus of scholarly inquiry within the social sciences over the latest decade (Featherstone, 2004; Miller, 2001; Sheller, 2006; Moeckli, 2007). A comparison between the Chinese driving culture and the German driving culture in many aspects from the traffic side is listed in Tab.1-3.

Tab.1-3 Comparison of the driving cultures

Chinese Developing Driving Culture	**VS**	**German Developed Driving Culture**
Rapid motorization stage	Motorization Level	Highly motorized societies
Mixed traffic environment	Traffic Situation	Comparatively simple condition
Motor vehicle oriented → Pedestrian oriented	Orientation of Traffic Design and Planning	Pedestrian oriented
A rush of less skilled drivers	Experience	Well trained
Cannot satisfy the growing traffic demand	Traffic Facility	Sufficient and in continuous improvement
Poor knowledge of correct traffic behavior	Traffic Education	Complete systems of traffic education
Frequent traffic violation	Traffic Discipline	High traffic discipline
Many deficiencies in traffic laws	Traffic Enforcement	Long term existing laws and punishment categories

Motorization Level
The emergence of motorization is one of the more significant transformations in the 20th century. Developed for over 75years in Europe, automobiles have become a universal phenomenon. In contrast, motorization in China began only in the 1970s; to date, the country is still in the rapid motorization stage (Schipper, 2004; Sperling, 2011).

Traffic Situation

As mentioned in **Section 1.1.2**, the traffic situation in China can be identified as typically highly mixed, both in urban and rural areas. In Germany, the traffic situation is relatively simple, featuring a much lower proportion of pedestrians and bicyclists.

Orientation of Traffic Design and Planning

At the initial stage of motorization, urban design and traffic planning leaned toward accommodating vehicles via the construction of wider roads and bigger blocks. However, these activities resulted in the degradation of the quality of the pedestrian environment and a decline in available walking space. Today, Germany is focused on a pedestrian-oriented mode and China is attempting to balance its promotion of motorization with preservation of the walking culture (Guo, 2006).

Experience

If the number of private vehicles increases by 15% to 20% every year, especially in dense cities (Schipper, 2004), the urban traffic environment can be expected to become heavily concentrated with new drivers with poor driving skills and without adequate driving experience. In Germany, drivers are well trained and experienced drivers account for a large proportion of all motorists.

Traffic Facilities

The development of traffic facilities is closely linked to the level of motorization of a country. In Germany, the sufficient road infrastructure can provide an acceptable level of service for road users and traffic facilities are continuously improved for safety. In China, however, current traffic facilities cannot feed the growing traffic demands considered the rapid increase in motorization (Chen, 2009).

Traffic Education

A complete traffic education system covering all ages is well developed in Germany and children’s education is especially highlighted (Funk, 2002). In contrast, no such systems have been well developed in China and only those who desire driver’s licenses are required to take driving courses. About 90% of the populations in China do not have adequate knowledge of traffic behaviors (Ni, 2009).

Traffic Discipline

Frequent violations can be observed in Chinese traffic activities, particularly by vulnerable road users. Redcrossing and vehicle lane occupancy are the most two common violations for pedestrians and bicyclists. As well, drivers seldom give way to other road users. In comparison, German road users have better traffic discipline.

Traffic Enforcement

Traffic law StVO (Straßenverkehrs-Ordnung) has been enforced in Germany since 1934, undergoing continuous modification and improvement. The Law of the People's Republic of China on Road Traffic Safety and the Regulation on the Implementation of the Road Traffic Safety Law went into effect only in May 2004, much later than in Germany. Both fines and credit deductions are used in these two countries as punishment for traffic violations. However, many deficiencies remain in terms of traffic enforcement in China.

1.3 Current safety situation of pedestrian

Pedestrian accidents have been identified as an extremely important issue in urban traffic safety. Among the total number of fatalities in road traffic accidents, the proportion of pedestrian deaths is particularly high. Thus, priority should be given to this road user group in research studies on safe urban transportation (Yang, 1997). In China, pedestrians alone make up of 26% of all traffic accident fatalities and 16% of all injuries, most of them resulting from conflicts with motor vehicles. Researchers believe that, on average, a pedestrian is killed and injured in traffic accidents every 25 and 7minutes in China, respectively. Numbers of fatalities and injuries in traffic accidents involving Chinese pedestrians from 1999 to 2009 are shown in Fig.1-1.

In Germany, pedestrian deaths make up about 14% of all traffic accident fatalities. Figs.1-2 depicts the numbers of fatalities in road traffic accidents by road user category in Germany (UNECE, 1999-2007). A sharp decrease in the fatalities of drivers and passengers of passenger cars may be observed from 1999 to 2007; however, downtrends in both cyclist and pedestrian deaths are not as distinct as expected. Taking another developed country as an example, each year, an estimated 80,000 to 120,000 pedestrians are injured and 4,600 to 4,900 people die in motor vehicle crashes in the United States (NHTSA, 2002, NEISS, 2002). Pedestrians account for 11% of all motor vehicle deaths; in cities with populations exceeding 1 million, pedestrians account for about 35% of all traffic-related deaths (IIHS, 2001).

Why is pedestrian lethality so high in China? The answer may be found in the different accident modes occurring under mixed traffic situations. In developed countries, the most common traffic accident mode is collision between vehicles, which results in higher proportions of driver and passenger fatalities. For instance, in Germany, this ratio is about 70%, according to Fig.1-2. In comparison, in mixed traffic situations in China, accident modes are much more complicated and the most common accidents involve vehicles and other road users.

Figs.1-3 and 1-4 compare pedestrian fatalities between Germany and China per 100,000 people (from 1999 to 2007) and 100,000 motorized vehicles (from 1999 to 2009). Pedestrian safety problems are clearly more serious in China. Considering the pedestrian fatality rate per 100,000 motorized vehicles, China has a death rate about 18 times higher than that in Germany.

Urban traffic situations with mixed traffic flows and various traffic signs and signals are much more complex than normal highway traffic situations, causing traffic conflicts and even traffic accidents to occur more frequently in urban areas. Even crosswalks, where traffic participants are overloaded by multi-traffic information, pose serious threats to pedestrian safety (Yuan, 2009).

Fig.1-1 Fatalities and injuries caused by traffic accident involving pedestrians in China (MPSPRC source, 2010)

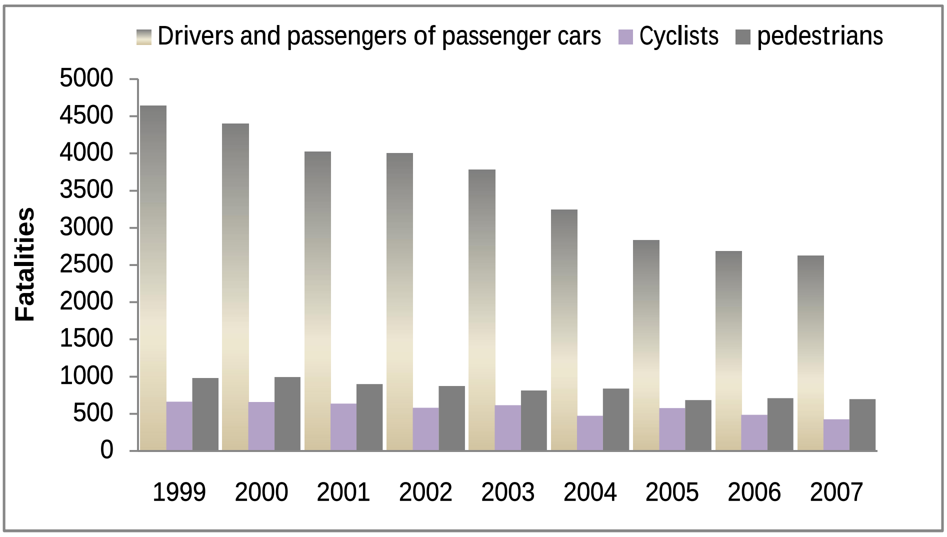


Fig.1-2 Fatalities in Road Traffic Accident by Category of Road Users in Germany (1999-2007) (UNECE Source, 1999-2007)

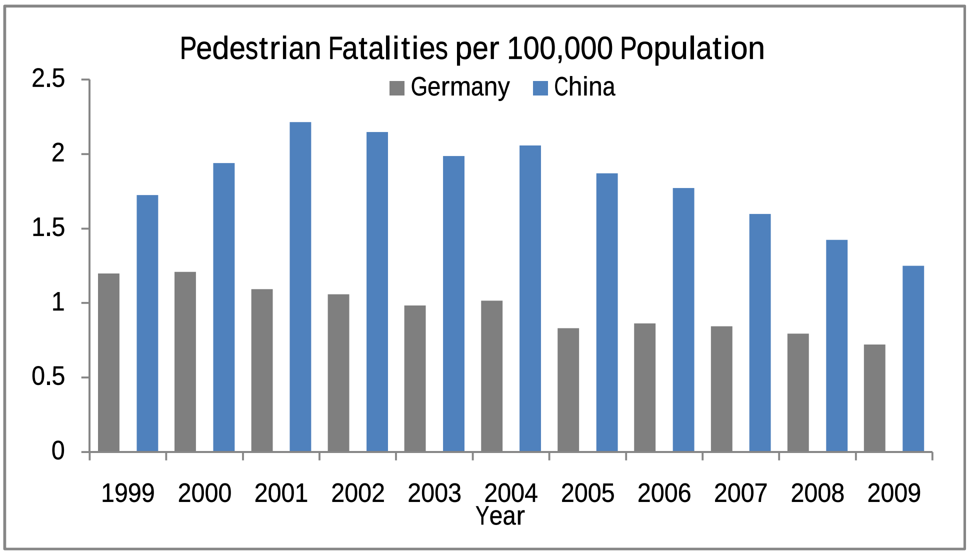


Fig.1-3 Comparison of pedestrian fatalities per 100,000 populations between Germany and China (MPSPRC source, 2010; Destatis, 1999-2009)

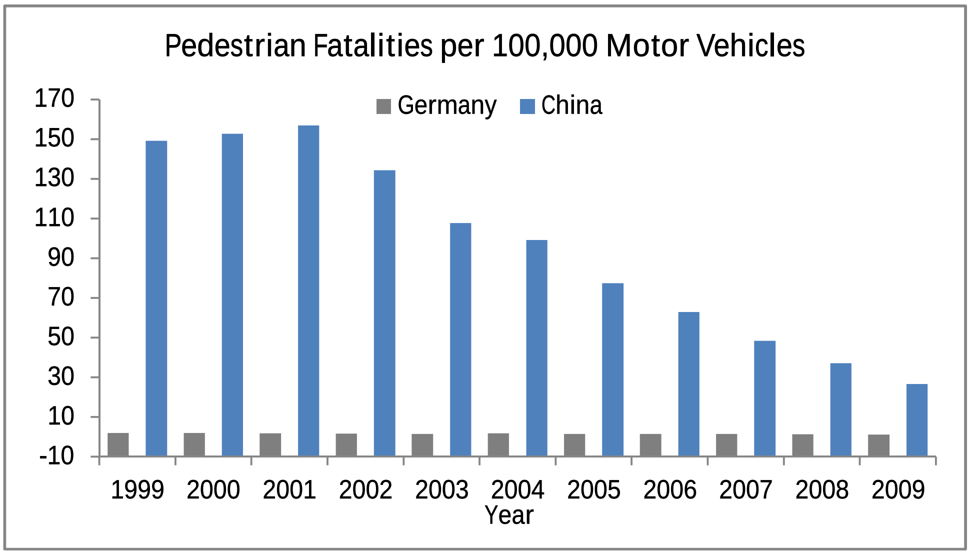


Fig.1-4 Comparison of pedestrian fatalities per 100,000 motor vehicles between Germany and China (MPSPRC source, 2010; Destatis, 1999-2009)

1.4 Summary of the thesis

1.4.1 Motivation

Ensuring traffic safety has long been pursued by experts all over the world. The serious predicament of pedestrians in urban traffic has motivated many researchers to determine ways to solve the existing problems. According to statistics, drivers are involved in 95% of all traffic accidents that are strictly related to driver behaviors and over 70% of the traffic crashes reported are caused by driver errors. Thus, the goal of the guidance provided by the assistance systems should be the reduction of driver errors by compensating for errors in the cognition, decision-making, and execution of the driver.

With the development of theoretical behavioral and human factor analyses, assistance systems present a significant contribution toward active safety and address a variety of issues concerning different driving demands. The actions of assistance systems are based on a continuous analysis of road user behaviors and traffic situations, allowing balance between individual driver behaviors and the information interpreted from the environment.

Over the last few decades, the research field has been involved in interdisciplinary combination and moves forward to an integrated level. However, the functionality and design of Advanced Driver Assistance Systems (ADAS), which area standard feature in today’s vehicles, are mainly based on studies in western countries. Culture adaptation must be made to validate the need for the application and improve the design of ADAS in developing countries. To address the adaptation process, studies to discover differences in road user behavior in certain traffic activities are a favorable first step. The development of such studies may contribute not only to the improvement of ADAS but also to the safety and security of road users.

1.4.2 Objectives

This study aims to the fundamental theories of road user behavior in VEH-PED conflicts and analyze the main road user behavioral characteristics based on the real traffic data, which can be applied to conflict behavior modeling and traffic safety evaluation. Video observations are employed during field data collection in Beijing, China, and Munich, Germany. From trajectory analyses, microscopic data, including pedestrian behavioral and driver behavioral parameters, are used in the situation description. Both time-related and distance-related measures are further investigated. Special cases in China, where traffic non-compliance is common, are also studied as a complement to normal motor vehicle-pedestrian conflicts.

The objectives of this research are to identify differences in road user behaviors between China and Germany and perform intercultural comparisons for ADAS adaptation. The situation-countermeasure relationship is analyzed with the intention of answering the question “Under what types of conflict situations will a road user make what decision?” Measures to improve traffic safety on unsignalized crosswalks in VEH-PED conflicts are also discussed.

The research approaches are shown in Fig.1-5.

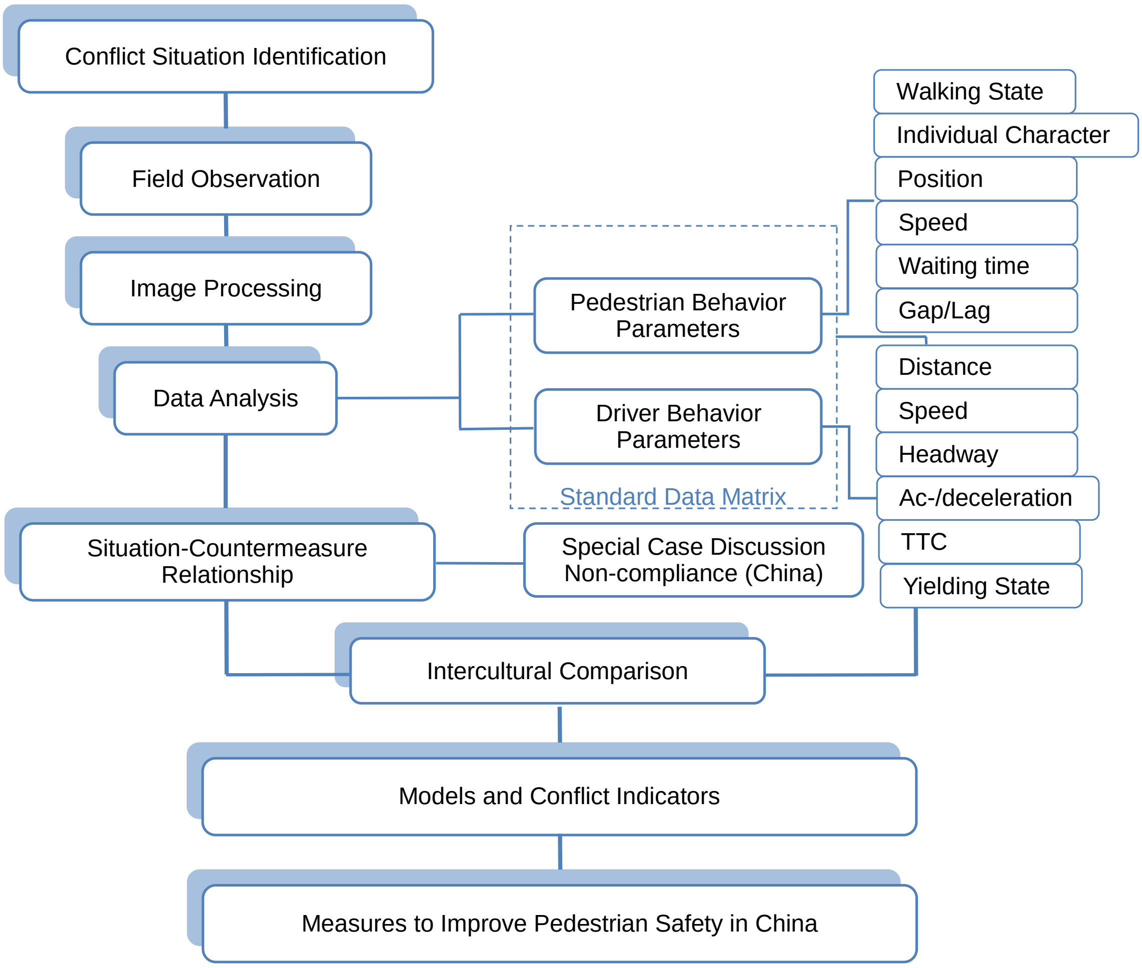


Fig.1-5 Research approaches

1.4.3 Outline

Chapter 1 generally introduces the current situation of urban traffic and pedestrian safety, makes comparisons between different driving cultures, and provides a summary of this dissertation.

Chapter 2 presents the background of this study. It reviews the relationship between traffic accidents and conflicts, discusses the evolution of studies on driver behavior, and introduces the general characteristics of pedestrians. It also reviews studies on traffic conflicts with pedestrians and driver behavior in VEH-PED conflicts.

Chapter 3 discusses the methodological aspects of the conflict process and data collection methods. Conflict descriptions are performed to better understand the conflict process, followed by measure definitions. Video observations are adopted in field studies and how field observations are conducted is detailed.

Chapter 4 analyzes pedestrian behaviors in VEH-PED conflicts in terms of pedestrian speed performance, pedestrian waiting behavior, pedestrian gap acceptance, and pedestrian time-to-collision (TTC) measures. Intercultural comparisons of pedestrian conflict behaviors are made between China and Germany. Non-compliance pedestrians are also statistically discussed.

Chapter 5 studies the driver behavior in VEH-PED conflict through driver yielding behavior, driver deceleration rate choice, driver accelerating behavior, TTC. Intercultural comparisons of driver conflict behaviors are made between the two countries of interest. Driver behaviors in pedestrian non-compliance situations are measured at the end of this chapter.

Chapter 6 presents the driver yielding model based on the binary logit model and discusses the effects of situational factors on the model. Considering the gap distribution, the pedestrian waiting time mode is proposed. Two conflict indicators, minimum VEH-PED distance and critical conflict radius, are mathematically defined and analyzed for conflict discrimination.

Chapter 7 explains factors influencing road user safety in conflict situations and suggests measures to improve traffic safety on unsignalized crosswalks in VEH-PED conflicts in terms of four aspects.

Chapter8 includes conclusions and some recommendations for further work.

2 BACKGROUNDS AND LITERATURE REVIEW

2.1 Traffic conflicts

2.1.1 The continuum of traffic events

In the understanding of a continuum of traffic events related to someone, somewhere, sometime, somehow, traffic process is continuous series represented by various models. Based on the assumption that conflicts are prior to accident occurrences, Amundsen and Hyden (Amundsen, 1977) described this relationship by means of specific subsets of events. As shown in Fig.2-1, accident is a subset of serious conflict which belongs to the conflict set.

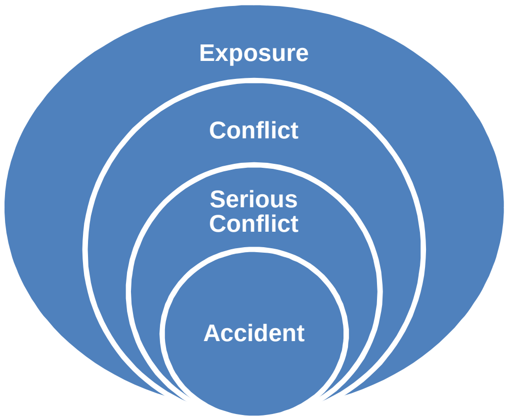


Fig.2-1 Set representations showing conflicts in relation to exposure

Another representation was suggested by Hyden (1987) with the non-conflicts taking up a large proportion. Fig. 2-2 is the safety pyramid describing the continuum of traffic events from exposure to accidents. This model can explain the conflict explicitly but the limitations are still obvious: how to discriminate the different severity levels of conflict is not clear and quantitative criteria is still insufficient.

Different event statuses can be observed in a certain traffic encounter process, and the adjacent event status may vary from one to another. In a VEH-PED encounter situation, the whole process would be described as encounter status—conflict status—undisturbed passage status.

2.1.2 Traffic conflict definition

The first concept of traffic conflicts was proposed by Perkins and Harris (1967) based on evasive actions taken by drivers, and it's an alternative to accident data, which in many cases are unreliable or unsatisfactory. The evasive actions taken by the drivers sometimes were not for avoiding accidents, but for reducing the risk potential. The concept of conflict as critical incidents not necessarily involving collision has been employed in the highway traffic analyses to identify the hazardous locations (Baker, 1977).

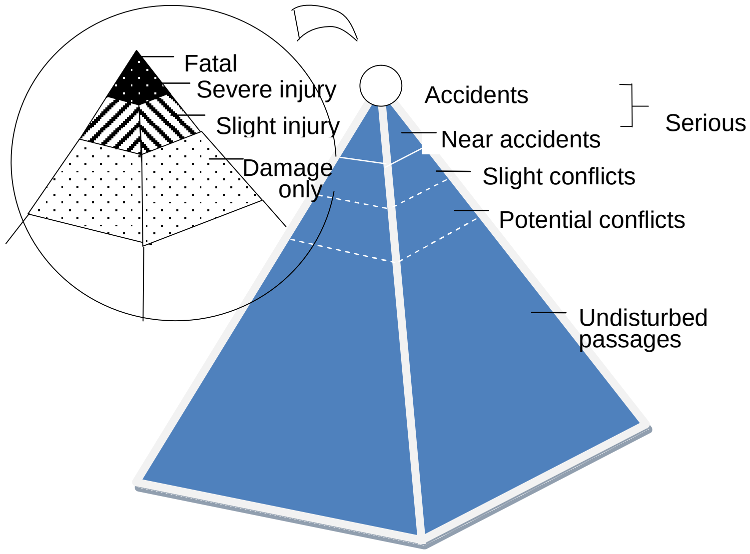


Fig.2-2 Pyramidal representation of traffic events

The international definition of a traffic conflict was proposed at the First Workshop on Traffic Conflict by Amundsen and Hyden in 1977. The traffic conflict was generally agreed as "an observable situation in which two or more road users approach each other in space and time to such an extent that there is a risk of collision if their movements remained unchanged". Although it is a widely accepted concept for traffic conflict, it may still have some limitations, for example, to distinguish whether a situation is a conflict one or not remains unclear (Chin, 1997). In the early studies, many researchers have sought for a better definition of conflicts and more robust methods to measure traffic conflicts. Criterions classified into subjective and objective methods have been proposed for the measurement. The method equating evasive actions to conflicts may have some logical problems, so some experts took the process leading to a collision into account (Brown and Cooper, 1990). A traffic accident (traffic collision, crash) is that when a road user collides with another road user or geographical/architectural obstacle, it will result in injury, property damage, or even death. Not all the conflicts will result in an accident, only in certain conditions affected by many factors. So the conflicts are just potential collisions but with a lower danger.

As mentioned the event status may vary during the whole process, in this study, we describe the VEH-PED conflict event as:

> *An observable situation in which a conceivable collision may occur if the driver or pedestrian(s) do not take evasive actions (ac-/decelerating, swerving, etc.) to avoid at a certain time of the whole encountering process.*

2.2 Studies on driver behavior

Driver is a critical component of the traffic system and there is no one generally accepted model for the entire driver behavior. The literatures with “driver”, “behavior” in the abstract are countless. If we consider the field-analysis theory proposed by Gibson and Crooks in 1938 as the initial study to the driver behavior, this research field has evolved for about seventy years.

2.2.1 Hierarchical driver behavior

Study on how the drivers behave physically and psychologically in relation to particular environments, vehicles or services should go firstly on the hierarchical driver behavior analysis. Michon (1985) used a simple two-way classification of driver behavior models distinguished between behavioral oriented and psychological oriented concerning input-output and internal state respectively. Tab.2-1 illustrates Michon’s proposal. And, according to three driving demand levels, the strategic, maneuvering and control level, a hierarchical structure of the road user task was given in Fig. 2-3 by Michon. The strategic level was defined for the general planning stage of a trip including the determination of trip routes, trip modal, risks involved, etc. At the tactical level, the driver reacts to the traffic conditions instantaneously to achieve a comfortable driving or to prevent risks. The third control level is just for the automatic action execution.

Related to the hierarchical by Michon, Ranney (1994) classified the selected driving tasks for three levels based on three different aspects, see Tab. 2-2. Skill-based behavior is applied in all familiar situations; rule-based behavior dominates in standard interactions with other road users as well as in some rare situations; knowledge is applied when driving in unfamiliar traffic networks (Panou, 2005).

Then a fourth level was proposed and defined by the European project GADGET (Christ et al. 2000). It is corresponding to individual disposition, a crucial factor for safe driver behavior, see Tab. 2-3.

Accordingly, this study can be framed at the tactical level to analyze the behavior of both the driver and pedestrian reacting to conflict conditions.

Tab. 2-1 Summary of driver behavior model types (Michon, 1985)

	Taxonomic	Functional
Input-Output (Behavioral)	Task Analyses	Mechanistic Models Adaptive Control Models - Servo-Control - Information Flow Control
Internal State (Psychological)	Trait Models	Motivational Models Cognitive (Process) Models

Tab.2-2 Classification of selected driving tasks (Ranney 1994)

	Strategic Level	**Maneuvering Level**	**Control Level**
Knowledge-based	Navigating in unfamiliar area	Controlling skid	Novice on first lesson
Rule-based	Choice between familiar routes	Passing other vehicles	Driving unfamiliar vehicles
Skill-based	Route used for daily commute	Negotiating familiar intersection	Vehicle handing curves

Tab. 2-3 The GADGET-matrix (Christ, 2000)

		Knowledge and Skills	**Risk-Increasing Factors**	**Self-Assessment**
Hierarchical Levels of Driver Behavior	**Goals for Life and Skills for Living**	**Awareness about relation between personal tendencies and driving skills** Ÿlifestyle/life situation Ÿpeer group norms Ÿmotives Ÿpersonal values Ÿ…	**Risky tendencies like** Ÿacceptance of risks Ÿhigh level of sensation seeking Ÿcomplying to social pressure Ÿuse of alcohol and drugs Ÿ…	**Awareness of** Ÿimpulse control Ÿrisky tendencies Ÿdangerous motives Ÿrisky habits Ÿ…
	Driving Goals and Context	**Awareness of** Ÿeffects of journey goals Ÿplanning and choosing routes Ÿeffects of social pressure by passengers inside the car Ÿ…	**Risks associated with** Ÿphysical condition(fitness, arousal, alcohol, etc.) Ÿpurpose of driving Ÿdriving environment (rural/urban/highway) Ÿsocial context and company Ÿ…	**Awareness of** Ÿpersonal planning skills Ÿtypical driving goals Ÿalternative transport modes Ÿ…
	Mastery of Traffic Situations	**Knowledge about** Ÿtraffic regulations Ÿtraffic signs Ÿanticipation Ÿcommunication Ÿsafety margins Ÿ…	**Risks associated with** Ÿwrong expectations Ÿvulnerable road users Ÿviolations Ÿinformation overload Ÿunusual conditions Ÿinexperience Ÿ…	**Awareness of** Ÿstrong and weak points of manoeuvring skill Ÿsubjective risk level Ÿsubjective safety margins Ÿ…
	Vehicle Manoeuvring	**Skill concerning** Ÿcontrol of direction and position Ÿvehicle properties Ÿphysical phenomena Ÿ…	**Risks associated with** Ÿinsufficient skills Ÿenvironment conditions (weather, friction, etc.) Ÿcar condition (tyres, engine, etc.)	**Awareness of** Ÿstrong and weak points of car control skills Ÿ…

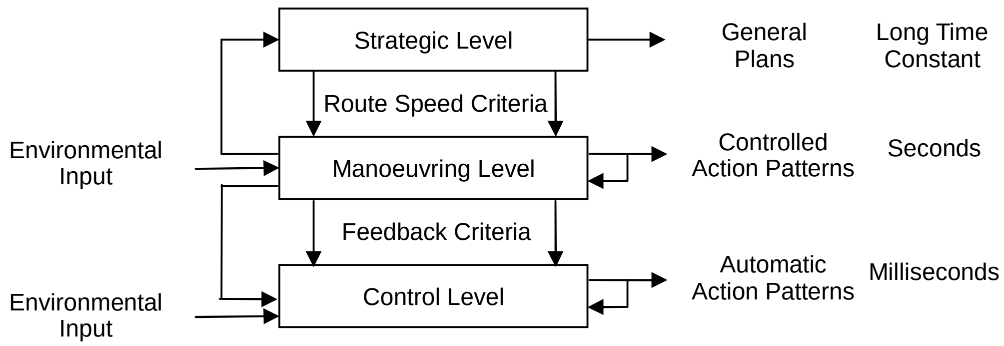


Fig.2-3 The hierarchical structure of the road user task (Michon,1985)

2.2.2 Achievement

Previous researches focused on the perception-handling aspects or accident-causing behaviors, but it has never been clear whether theories should explain everyday driving, or accident-causing behaviors, or both (Ranney, 1994). In the 1960s and 1970s the motivational models which concerned the psychological factors of drivers emerged but the cognitive approach seemed to be little impetus to the driver behavior studies. Then in 1985, the psychological mechanisms in driving-the driving demands were analyzed by Michon. And in 1987, the model of Rasmussen (Rasmussen, 1987) distinguishes three levels of cognitive control determining complex task performance. These studies promoted the development of driver behavior theory.

With the development of new technology in information technology, psychology, sensor and tracking systems, the driver behavior studies from both the academic and industrial sides are blossoming out in the 21th century. The achievements covered around the driver maneuvers at tactical level (Oliver 2000), driver cognitive analysis (Truls Vaa, 2001; Pompei, 2002; Plavsic, 2010b), driver situational awareness (Underwood, 2003; Kass, 2007; Walker, 2009), visual behavior (Plavsic, 2010a), mode for the integrated representation of driver behavior (Talal Al-Shihabi, 2001; Olivier, 2005), driver-ADAS interaction (Bengler, 2007) and driver-infrastructure communication (Busch, 2008) etc.

The theories and technologies are now applied to the automotive industry and contribute to the improvement of driving safety. The ADAS now covers a full range of systems varying from systems providing information, advice and warnings; systems that assist and/or intervene in vehicle control and maneuvering tasks; all the way to systems that support fully automatic driving. Typical examples are collision warning systems, lane departure warning systems, ACC, vision enhancement, pedestrian detection etc. For instance, the ACC was equipped in BMW 7-Series since Nov. 2001; PRE-SAFE Brake in some Mercedes-Benz vehicles since 2006. Although driver behavior researches undergo further refinements and ameliorations, it is believed that the achievements will make the driving task more comfortable and safe.

2.2.3 Trends

To human beings - a highly intelligent and maximum free agent, never a simple method can model his/her activities. Though the achievements of driver behavior studies brought gratifying changes to the accident prediction and driving assistant, no generally-accepted model can describe the driver behavior accurately. It is suggested that, the driver behavior studies will absorb interdisciplinary theories and technologies like psychology, ergonomics, traffic technology and engineering, computer science, etc, such an integrated model is expect to be presented sometime in future. And the driver assistance systems will be aligned with a permanently updated interaction within the system of driver, vehicle and road traffic environment (Bubb, 2011).

The further efforts will be made in the areas as driving situation awareness, driver behavior in more critical situations, the reliability and validity of driver assistant systems, models for driver cognitive behavior, interaction between driver and assistant systems, well-accepted and harmonious interface of assistant systems for drivers, and so on.

Improvements will be made for a safe, reliable, economic and efficient assistant system which will materialize an accident-free traffic environment we desire.

2.3 Studies on pedestrian behavior

2.3.1 Overview of pedestrian traffic analyses

The monograph *Pedestrian Planning and Design* by Fruin (1971) can be regarded as the foundation work for pedestrian traffic studies. Fig. 2-4 portrays a general framework of pedestrian traffic analyses categorized into pedestrian data collection as well as macroscopic and microscopic studies.

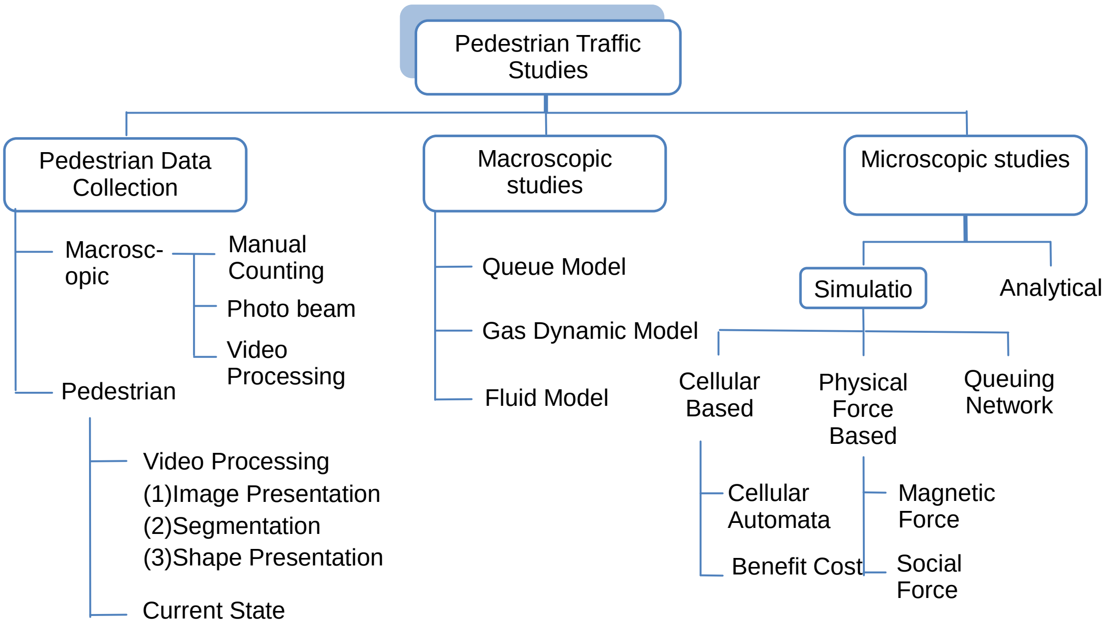


Fig.2-4 General framework of pedestrian traffic analyses

2.3.2 General characteristics of pedestrians

Compared with the other road users, pedestrian movement is much more flexible, adaptable, random complex and will be easily influenced by the environment. Generally, pedestrian characteristics can be concluded as follows:

- Pedestrians travel in a short distance at low speed with small speed deviation according to the physical strength;
- Pedestrians occupy less traffic resources than other road users and have higher accessibility without temporal and spatial limits;
- Walking routes and positions can be decided individually by the pedestrians;
- Pedestrians may be dominated by the "group psychology" when walking in groups and they may form a group activity by releasing the individual control;
- Self-organization behavior can be observed in pedestrian crowds;
- Safety and collision avoidance requirements among pedestrians are lower than those among motor vehicles;
- Pedestrians are vulnerable road users because of their unprotected state and suffered from the consequence of the accident most severely.

2.3.3 Basic pedestrian walking parameters

The design of traffic systems and facilities, especially the pedestrian control devices like pedestrian signals, underpasses, crosswalks, etc, demonstrate the relevance of pedestrian characteristics to traffic and highway engineering practice. Apart from visual and hearing characteristics, walking characteristics is an important element of engineering design.

Pedestrian walking speed

Pedestrian walking speed is one of the most important parameters of pedestrian traffic. Fruin (1971) suggests that people are able to walk at their characteristic speed if density is below 0.5ped/m^2. Walking speed will be influenced by many factors: basic pedestrian characters such as age, gender and physical condition; trip characteristics such as trip purpose, route familiarity, trip length and encumbrances; route characteristics such as width, gradient, pavement, locations, attractiveness, pedestrian density and obstacles, etc; and environmental characteristics.

In China, according to field observation statistics, walking speed for the vast majority of people is between 0.8 m/s and 1.8 m/s. And in terms of different pedestrian facilities, like the sidewalk, crosswalk and corridor in transit terminal, the average walking speed are 1.22m/s, 1.35~1.45m/s and 1.27m/s respectively (Wang, 2010). Significant differences have also been observed between male and female average walking speeds: for males 1.27m/s and females 1.18m/s. And the stride frequency is 80 to 150 strides per minute with the stride length 0.67m for males and 0.61m for females.

Spatial needs

According to HCM2000, the body depth and shoulder breadth for minimum space standards defined in Fig. 2-5 are considered as the essential parameters for the pedestrian facility design. A simplified body ellipse is used as the basic space for a single pedestrian, 49.6cm x 24.5cm, with total area of 0.12m^2 for males and 43.8cm x 23.9cm for females, respectively. This represents the practical minimum for standing pedestrians. But for pedestrians’ walking phase, a certain amount of forward space is required to maintain a reasonable spatial distance which is defined as a buffer zone. 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 (HCM2000). It is a parameter to evaluate a pedestrian facility and an area of 0.75m^2 is applied as the buffer zone for each pedestrian. Figure 2-6 illustrates the pedestrian walking space requirement and it includes the pacing zone and the buffer zone.

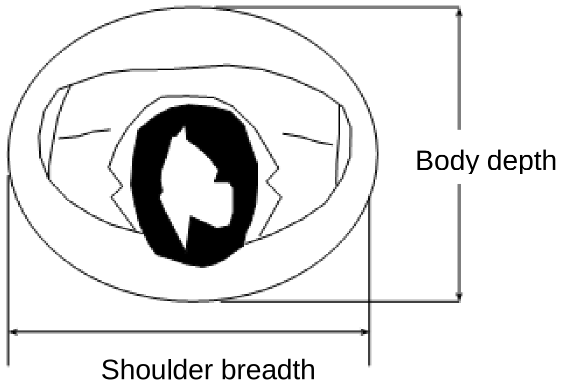


Fig.2-5 Pedestrian body ellipse for standing areas

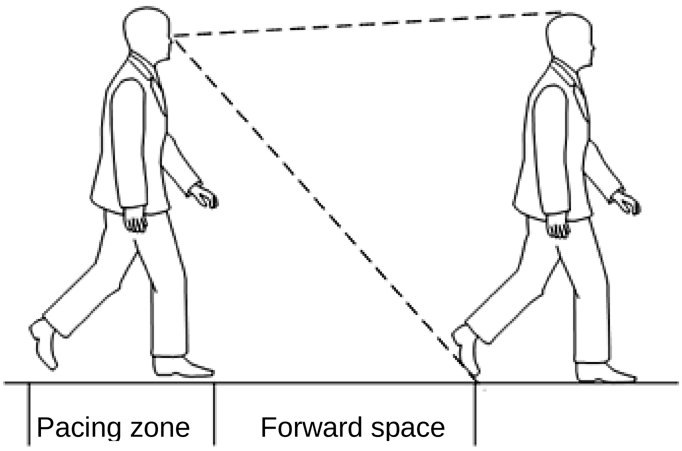


Fig.2-6 Pedestrian walking space requirements

LOS

Level of service (LOS) is a quality measure describing operational conditions within a traffic stream, generally in terms of speed and travel time, freedom to maneuver, traffic interruptions, comfort and convenience. It's a standard to characterize operational conditions within a traffic stream or the service of a certain traffic facility.

LOS is divided into six levels from A representing the best operating conditions to F as the worst.

The LOS criteria for pedestrian flow are closely related to some quantitative measures as the walking speed, space per pedestrian, flow rate. Meanwhile, the criteria are also defined by some subjective measures which are imprecise to take the personal feeling and psychological perception into account.

Tab. 2-4 Analyses of the factors contributing to Pedestrian characteristics

Characteristics / Factors	**Speed**	**Spatial needs**	**Attention**
Age	Adults walk at the speed of 1.0～1.2 m/s. The speed of children has a wide variation while the aged prefer a lower speed.	The spatial requirement for adults is 0.9～2.5 m^2/s. And the children require less. However, old people need more space.	Adults attach importance to traffic safety and will adjust the steps and visions according to the external environment. But the children tend to move at will.
Gender	The males are walking faster than females.	Spatial needs for male are larger than female.	Almost the same
Trip purpose	Pedestrians going to and from work, walk at higher speed.	Complicated	Pedestrian will focus attention for commuting trip purpose. But not so care for daily normal purpose.
Cultural literacy	Complicated	The spatial requirement of those people who are well educated and have better cultural literacy is larger. On contrary, people with less culture literacy may not consider other persons.	Normally, those people who are well educated will pay more attention to the traffic situation.
Region	Pedestrians in urban areas may walk at a higher speed than the pedestrians in rural areas.	Complicated	The urban pedestrians focus more attention than the rural pedestrians.
Mood	Pedestrians will walk faster when feel nervous than normal conditions.	The spatial requirement is on the contrary, pedestrians will need more space when they are in nervous than normal conditions.	When pedestrians feel nervous, their attention to the traffic situation will be less focused.
Street scene	The speed decreases while the pedestrian encounters an attractive street scene.	The spatial requirement is smaller in an attractive street scene.	There are too many distractions in an attractive street scene for pedestrians.
Traffic condition	Slow speed in congestions.	Small spatial requirements in congestions.	Focus attention in congestions

2.3.4 Factors influencing pedestrian characteristics

The regular patterns represented to the pedestrian characteristics are the average walking speed of individuals or groups, the spatial requirement, the attentions, etc. There are considerable differences in pedestrian characteristics due to trip purpose, land use, type of group, age, and other factors. Table 2-4 illustrates the factors contributing to pedestrian traffic characteristics.

2.4 Traffic conflict with pedestrians

Studies on vulnerable road users started in the 1980s, but publications related to traffic conflicts with these road users are not directly relevant. On pedestrian traffic analysis, much emphasis was given to the characteristics and the compatibility of pedestrians in mixed traffic conditions. Research can be summarized in three main aspects:

- the impact to vehicle flow by pedestrian in the road segment;
- the capacity, geometric improvements, signage of the signalized intersections under mixed traffic conditions;
- simulation of urban mixed traffic.

As a part of mixed traffic studies, research on traffic conflicts with pedestrians reveals similar to the mixed traffic studies, but differences still exist. Generally the studies of traffic conflicts with pedestrians are summarized in three directions.

The first one is to analyze the characters of the road users involved in the conflicts. In the "Information Society Technology" project funded by the European Community, both the conflict characteristics of vulnerable road users and the vehicles were investigated (Gavrila, 2003). The second direction is the conflict mechanism analysis. Lord (1996) conducted a field text at T-and X-intersections to analyze the pedestrian conflict with left-turning traffic and indicated a positive correlation between traffic conflicts and accident exists. Then in 1998, the statistics, a pedestrian is four times more likely to be hit by a left-turning vehicle than by a right-turning vehicle was proposed by him (Lord, 1998). Considered the serious situations, other experts made further efforts in this research direction. A basis for a warning system at intersections was set by the analysis on the impact of pedestrian presence on movement of left-turning vehicles Ragland (2005). In addition, many researchers are engaged in the conflicts between pedestrians and right-turning vehicles as well. Based on the real traffic data, Su (2008) studied the conflicts between right-turn vehicles and pedestrians at signalized Intersection; a statistical speed-distance model based on conflict point was represented. The last direction is the traffic engineering improvement related to conflict safety. Three engineering countermeasures were proposed including speed control, separation of pedestrians from vehicles, and measures that increase the visibility and conspicuity of pedestrians (Retting, 2003). The rapid development of sensor and tracking technologies enable the deployment of analysis on vehicle-pedestrian conflict and conflict safety. The pedestrian protection system (Gandhi, 2007), pedestrian detection system (Broggi, 2009) are all documented in the scientific literature.

Although this research field is now moving forward for the improvement of road user security, considering vehicles as the main road users, the data of traffic conflicts between vehicles and pedestrians is not enough. Nonetheless, conflict studies are still continuing to be used for the safety upgrade.

2.5 Driver behaviour in VEH-PED conflict

Within the last several decades, the driver behaviour analysis evolved extensively. The research field has been involved in interdisciplinary combination and is moving forward to an integrated level. Compared with the rich literatures of driver behaviour in vehicle conflicts, the analysis on driver behaviour centred conflicts with pedestrian is relatively less documented, and framed in several aspects like the interrelationship between driving speeds and pedestrian safety (Pasanen, 1992); drivers' detecting and yielding behaviour to the pedestrian (Houten, 2000; Geruschat, 2005); driver performance to some pedestrian traffic facilities (Huey, 2007); turning time and acceptable gaps for drivers under various situations (Ragland, 2005) etc.

The safety performance conducted by the driver in the pre-phase of conflict can reduce the encounter risk and may even avoid such danger. Therefore, investigation to the factors influencing driver behaviour may provide a root understanding of the conflict process. It is instructive to note that many studies have been done on the driver yielding behaviour and the causation factors.

Most of the traffic accidents to a certain extent depend on vehicle speeds; in the description of pedestrian safety problems, vehicle speed also plays an important role. Many studies on the motor vehicle–pedestrian conflict were centered drivers' speed performance and its effect on yielding safety. Pasanen indicated that at a collision speed of 50km/h the risk of fatal injury for a pedestrian is almost eight times higher than at a speed of 30km/h. High vehicle speed was proved to influence the pedestrian safety greatly according to the empirical evidence (Engel, 1990) and field observation (Westra, 1993). Further, the relationship between speed level and pedestrian death risk was analyzed (Johannessen, 2008). A microscopic traffic simulation model (Aronsson, 2006) was proposed to examine the vehicle speed characteristics of interactions with pedestrians, cyclists and other road users. How the speed behaviour influenced to give precedence was investigated by the yielding frequency under different encounter situations related to pedestrian presence (Varhelyi, 1998) and speed limit (Johannessen, 2008). Although speed can be considered as an important parameter in yielding behaviour, it is not the only factor that directly determines the driver behaviour because in the vehicle–pedestrian conflict process, other situational information would be interpreted by the driver from the environment. Some researches gave different considerations to describe the driver behaviour in the conflict phase. Persson (1988) reviewed on communication between road users, and found that the yielding likelihood increased if information of the pedestrian's intention was increased by combining various signs. Many other factors (Katz, 1975; Himanen, 1988; Geruschat, 2005) were presented to have an influence on the drivers to give way to crossing pedestrians: the type of crossing and lane, distance between oncoming vehicle and pedestrian, orientation of pedestrian, number of pedestrians, pedestrian distance from the curb, etc. Logit models (Himanen, 1988; Sun, 2003; Schroeder, 2008) were employed to analyze and evaluate the behaviour of pedestrians and vehicle drivers at crosswalks, and it would be the first step to model the vehicle-pedestrian encounter process as well as the accident prediction.

2.6 Summary

Road user behavior analyses in traffic research field have a long history, within which the driver behavior is a hot study point dedicated by many researchers who aim to both the external driver behavior modeling and the internal mental expression. There are many aspects in driver behavior analyses varying from the macroscopically strategic level to the microscopic maneuver, from the information for decision-making input to the action for some actual purposes output. Nowadays this research direction has drawn attentions from multiple disciplines. The developed countries are at the lead of this study field and followed by the developing countries. Considered the severe traffic situation in urban areas, analysis on traffic conflict could be a solution to the safety problems. It also provides an active protection to the pedestrians involved in an unsafe level. In developing countries, because the pedestrians and bicyclists stand a high proportion of the total road users, the analysis on the conflicts with pedestrians seems to be as the focus in recent researches. Great efforts have been made to calculate conflict points, definition for the conflict areas, safety assessment methodologies, and traffic delay by the interference among the road users, etc. The analyses on both the participants in VEH-PED conflicts are comparatively less documented which might be similar to the vehicle-to-vehicle conflict studies. But considered the characteristics of pedestrians, the whole process even the psychological influence to the road users is completely different. So this study direction wins to go deep into.

3 METHODOLOGICAL ASPECTS AND FIELD OBSERVATION

3.1 Conflict description

3.1.1 Taxonomies of conflicts

To analyze the whole conflict process, taxonomies of conflicts should be the first stage. There are many kinds of methods to classify different types of conflicts. In this study, focusing the urban traffic situation, traffic conflicts in urban areas are analyzed.

According to different criteria for taxonomies, traffic conflicts can be divided into following categories:

According to severity of the conflict: serious conflict and non-serious conflict;
To discriminate the severity of the conflict, measures such as the Time-to-Accident, Distance-to-Accident, accelerate and speed etc. are taken into account for conflict definition. For instance, Time-to-Accident (TA) value together with the conflicting speed is used to determine whether or not a conflict is "serious".

According to the locations where the conflicts happen: the road segment conflict and the intersection conflict;
The former can be sub-divided according to the types of the urban roadway (arterials, inferior road, etc) and the latter can be identified by different forms of the intersection (T-intersection, X-intersection, etc).

According to the conflict angle: head-on conflicts, side-on conflicts, rear-end conflicts and conflicts with fixed objects;
The conflict angle is the angle between two directions of road users' movement in conflict and they are: the head-on conflict angle$\theta \in [135°, 180°]$, the rear-end conflict angle$\theta \in [0°, 45°]$, the side-on conflict angle$\theta \in [45°, 135°]$, the fixed objects conflict angle$\theta \in [0°, 90°]$, see Fig. 3-1.

According to the participants in conflicts: vehicle-to-vehicle conflicts, vehicle-to-bicycle conflicts, vehicle-to-pedestrian conflicts, etc

In that only the conflicts between vehicles and pedestrians on urban un-/signalized crosswalks on road segment will be analyzed in this study and the roadway is perpendicular to the pedestrian crosswalk, the conflict can be identified as a mid-block VEH-PED conflict with right conflict angle.

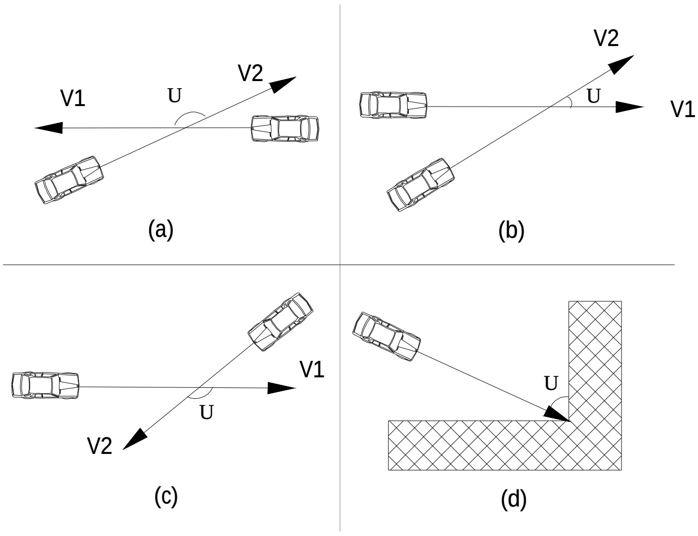


Fig.3-1 Taxonomies of traffic conflicts according to conflict angles

3.1.2 Conflict point

The conflict event can either occur in a particular single location in time and space —a conflict point—or during a range of times and locations—a conflict line (Hernandez,1982). In the conflicts between vehicles and pedestrians, due to the differences of size and quality between pedestrians and vehicles, the appearance of merging behavior can hardly be observed between these two participants, accordingly, the conflicts just occur in a certain time and location. In this study only the point conflict will be discussed.

According to previous researches on pedestrians on crosswalks, the entire road users scramble for the right of way, then a definition of conflict point can be concluded.

> *Traffic conflict point is a point that a potential traffic accident happens, and it represents a fixed location where a crossing, splitting or merging road user in one road or lane has a conflict with the other road user in the same road or lane.*

Fig. 3-2 depicts a VEH-PED conflict situation on a field crosswalk and point CP is the potential conflict point.

3.1.3 Conflict process based on road user behavior

Fig.3-2 illustrates a VEH-PED conflict event on the crosswalk. The evasive actions will be taken by the road users to avoid a collision. From the driver side, the driver may press the brake pedal after s/he becomes aware of the pedestrian’s presence or s/he may swerve or take both the two actions. Focusing on the braking behavior only, the conflict event can be described as: pedestrian A attempts to cross the road by crosswalk and there is a straight-going vehicle B encountering, and if no evasive actions will be taken, one road user will projected arrive at CP; but fortunately at time t_2 the driver begins to brake until the collision is avoided. Fig.3-3 depicts the timeline of the vehicle's entire process previously mentioned with the space to conflict point as its y-axis.

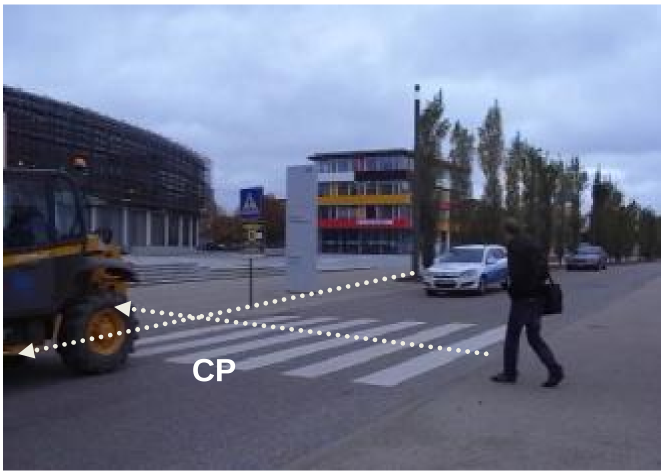


Fig.3-2 VEH-PED conflict situation with CP

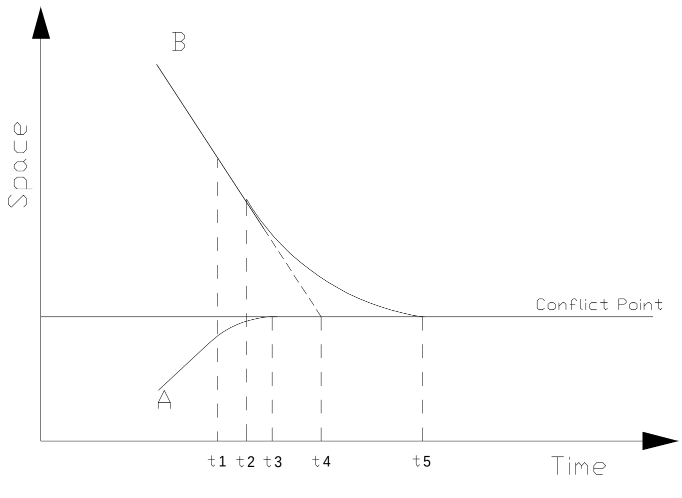


Fig.3-3 Deceleration situation in a conflict

The times t_1 – t_5 are defined as follows:

At time t_1, vehicle B notices that there is a potential collision with the pedestrian on the crosswalk.

At time t_2, vehicle B begins to brake for avoiding the collision.

At time t_3, the pedestrian A arrives at CP.

At time t_4, vehicle B will arrive at CP if no evasive actions taken by the driver.

At time t_5, vehicle B actually arrives at CP.

If the vehicle is close to a potential conflict point and the pedestrian is far away, the pedestrian will spend more time to reach the conflict point. In this case the driver may accelerate to pass the conflict point before the pedestrian's arrival. Or in a pedestrian stream situation, the time gap between two pedestrians is large enough for the vehicle, an acceleration action may be chosen by the driver. Fig.3-4 represents the acceleration situation in which the vehicle B conflicts with the pedestrian A.

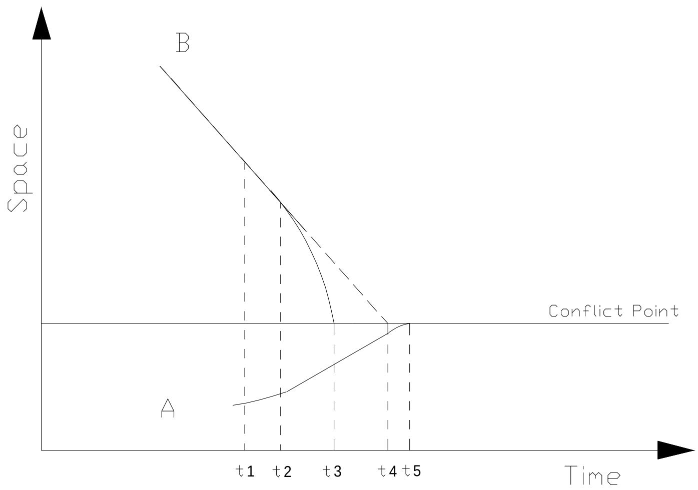


Fig.3-4 Acceleration situation in a conflict

The times t_1 – t_5 are defined as follows:

At time t_1, vehicle B notices that a potential collision with the pedestrian may occur.

At time t_2, vehicle B accelerates to avoid collision.

At time t_3, vehicle B actually arrives at CP.

At time t_4, vehicle B will arrive at CP if the driver doesn't speed.

At time t_5, pedestrian A actually arrives at CP.

3.2 Measures definitions

3.2.1 Time-related measures

In previous **section 3.1.1**, the time-related measurement TA can be used as the standard to assess the severity of traffic conflicts. Because the time-related measure is such a variable in which other parameters like velocity and distance can be combined, and is more intuitive for studies, it is proved to be the fundamental measure for analyzing road user behavior in traffic conflicts. Refer to Traffic Conflict Technique (TCT), there are some other important measures frequently applied.

Time-To-Collision (TTC)

Time-To-Collision measure describes how imminent a collision is and Hayward (1972) defined TTC as:"The time required for two vehicles to collide if they continue at their present speed and on the same path". In TCT, TTC is used as an effective measure for rating the severity of conflicts and the lower the TTC, the higher the risk of a collision will be. The definition of TTC can be applicable for all road users, and in the analysis on VEH-PED conflicts, TTC is calculated as the projected arrival time of the vehicle B t4 minus and the time related to a given pre-conflict by vehicles and pedestrians uniquely for a conflict as t4-t3 in Fig. 3-3. This is, if it continues with the same speed at the time of initial deceleration to avoid collision and the time pedestrian A arrives at CP.

Post-Encroachment-Time (PET)

In view to the both sides of the traffic conflict participants, the time differential of one road user to the place where another road user once occupied is the Post-Encroachment-Time (PET). As described in Fig. 3-3, PET is defined uniquely for a conflict point as t5-t3. This is the time between the departure of the encroaching road user from CP and the arrival of the other road user with the right-of-way at CP.

Gap-Acceptance

According to the Gap Acceptance theories on non-signalized crosswalks, the gap in VEH-PED conflicts is the length of time between two successive road users and from the vehicle side, the gap is defined as the time interval from the departure of the rear bumper of the leading vehicle to the arrival of the front bumper of the following vehicle at CP. The Gap-Acceptance is one which is chosen by the driver to actually initiate and pass through the CP. It's an important measure in the decision-making behavior and the minimum acceptable gap is the critical gap. (Ragland, 2006)

Waiting Time

Pedestrians waiting time on the roadside plays an essential role in crossing decision. The waiting time is defined as the time elapsed from the pedestrian reaches the roadside curb of the crosswalk to the point that s/he starts to cross the road. It is also an important parameter in pedestrian facility planning and design.

3.2.2 Situational measures of road users

According to the conflict process, when encountering a sudden present of pedestrian, the driver will experience notice, decision-making, and manoeuvre. These three procedures and the information processed by the driver are conducted on basis of the situational measures while the time-related measures like TTC cannot be perceived intuitively. The following measures related to the road user activities will be analyzed:

Distance-related measures (at any given time within conflict process)
Vehicle longitudinal distance to CP;
Pedestrian Lateral distance to CP;

Speed-related measures
Vehicle initial speed before encounters;
Pedestrian initial speed before encounters;
Vehicle instantaneous speed;
Pedestrian instantaneous speed;

Ac-/deceleration-related measure (at any given time within conflict process)
Vehicle (driver) ac-/deceleration rate

Decision-related measures
Driver yielding decision (giving precedence to crossing pedestrian or not);
Pedestrian crossing decision (waiting or crossing)

The kinematic conflict situation can be established for describing where the conflict participants are and how they approach CP at a certain time point according to the situational measures. However, to make a clear explanation to the conflict environment, following parameters should be considered:

Vehicle flow rate;
Pedestrian flow rate;
Layout parameters of the crosswalk/roadway;
Traffic signal design;
Location of the crosswalk (land use, category or grade of the roadway, transit terminal nearby, etc)

3.3 Data collection methods

3.3.1 Introduction of data collection methods

Many experiments have been implemented to obtain real traffic data and researchers have used various methods for data collection. The most widely adopted method is video recording, the advantages of which include the full recording of real traffic data and development of models or equations that can fit real traffic situations. However, traffic data extracted from video observations are static because overhead video data do not provide sufficient resolution (i.e., pixel size limitations) to enable accurate dynamic models (Hasan, 1997). Another method of collecting information on road user behaviors (e.g., driver behavior) is the use of an instrumented vehicle equipped with sensors and tracking technologies, such as relative distance and speed measuring radars. However, conducting such experiments is prohibitively expensive. As well, since few subjects are chosen to perform these experiments in certain roads, the data obtained only include a small sample of driver and traffic situations.

With the development of novel techniques, the Global Positioning System (GPS)/Image Processing has also been applied in traffic data collection and analysis (Wolshon, 2000). While this method provides more accurate data and is weather resistant, however, road user specific behaviors involving psychological factors, such as alcohol influence, cannot be recorded. Some researchers have used data from driver simulators or computer simulations. Unfortunately, uncertainties about whether or not the traffic data in the simulator or simulation reflect real traffic scenarios remain. While all of these models described achieve their purpose to some extent, common limitations in their applicability are also present.

In this study, considering current conditions and previous research experience, video recording and image processing are utilized as the major data collection methods for traffic conflict and road user behavior analyses.

3.3.2 Video plotting procedures

The basic configuration of the video plotting device is given in Fig.3-5. A computer forms the central part of the system. One of the laborious tasks in analyzing video storage device is the precise positioning of the storage device at the right angle. The video recorder operates under full computer control. Any given image can be automatically searched by the computer through the use of a special digital time code stored in each video field during the recordings.

A time-related corrector is used to enhance the sync part of the video signal before it is processed by the rest of the system. The video processor, which features a frame grabber and 25frames per second AVI format, enables flexible use of the equipment such that many features can be implemented in its software.

After video processing, the reference line, which marks the observation area, is added to the preliminary video selection. In the observation area, video images are deformed because of the observation angle and elevation. For example, rectangular is as will present as trapezoid or parallelogram. Consequently, boundary marks in the field research area need to be reflected in the video image, also called the reference line. The field position of road users can then be deduced by their coordinates in the video image through coordinate transformation.

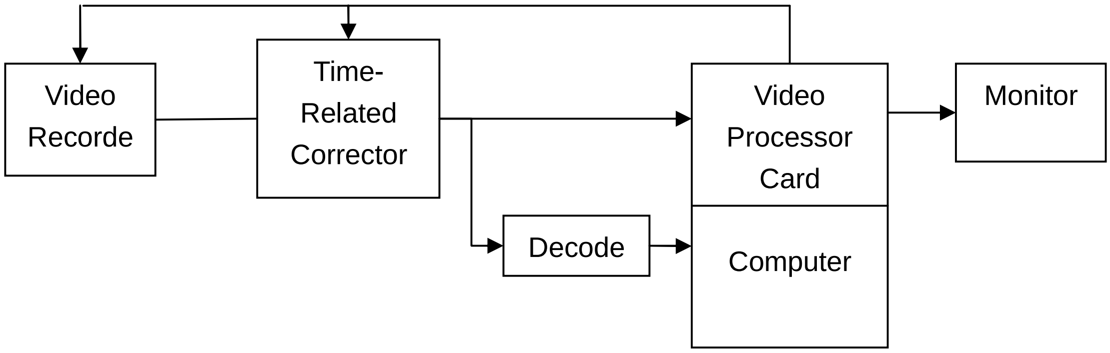


Fig.3-5 Basic configuration of the video plotting device

3.3.3 Coordinate transformation

In earlier studies on the quantitative analysis of film or video recordings, grid transformations are commonly used for the conversion of image coordinates to road coordinates. The global polynomial model is applied to transform image coordinates to road coordinates via the general equation below:

$$u = p(x, y) = \sum_{i=0}^{N} \sum_{j=0}^{N-i} a_{ij} x^i y^i$$
$$v = q(x, y) = \sum_{i=0}^{N} \sum_{j=0}^{N-i} b_{ij} x^i y^i \qquad \text{Eq.3-1}$$

where (*x,y*) denotes the road coordinate and (*u,v*) denotes the image coordinate. The value *n* influences the accuracy of the global polynomial method in the *n*-th power function. Generally, when *n* equals 2, six control points with image coordinates and road coordinates are measured and the transformation process is as follows:

$$Ta = x$$
$$Tb = y \qquad \text{Eq.3-2}$$

Where, $$T = \begin{bmatrix} \sum_{e=1}^{L} 1 & \sum_{e=1}^{L} v_e & \sum_{e=1}^{L} v_e^2 & \sum_{e=1}^{L} u_e & \sum_{e=1}^{L} u_e v_e & \sum_{e=1}^{L} u_e^2 \\ \sum_{e=1}^{L} v_e & \sum_{e=1}^{L} v_e^2 & \sum_{e=1}^{L} v_e^3 & \sum_{e=1}^{L} u_e v_e & \sum_{e=1}^{L} u_e v_e^2 & \sum_{e=1}^{L} u_e^2 v_e \\ \sum_{e=1}^{L} v_e^2 & \sum_{e=1}^{L} v_e^3 & \sum_{e=1}^{L} v_e^4 & \sum_{e=1}^{L} u_e v_e^2 & \sum_{e=1}^{L} u_e v_e^3 & \sum_{e=1}^{L} u_e^2 v_e^2 \\ \sum_{e=1}^{L} u_e & \sum_{e=1}^{L} u_e v_e & \sum_{e=1}^{L} u_e v_e^2 & \sum_{e=1}^{L} u_e^2 & \sum_{e=1}^{L} u_e^2 v_e & \sum_{e=1}^{L} u_e^3 \\ \sum_{e=1}^{L} u_e v_e & \sum_{e=1}^{L} u_e v_e^2 & \sum_{e=1}^{L} u_e v_e^3 & \sum_{e=1}^{L} u_e^2 v_e & \sum_{e=1}^{L} u_e^2 v_e^2 & \sum_{e=1}^{L} u_e^3 v_e \\ \sum_{e=1}^{L} u_e^2 & \sum_{e=1}^{L} u_e^2 v_e & \sum_{e=1}^{L} u_e^2 v_e^2 & \sum_{e=1}^{L} u_e^3 & \sum_{e=1}^{L} u_e^3 v_e & \sum_{e=1}^{L} u_e^4 \end{bmatrix} \qquad \text{Eq.3-3}$$

$$\begin{aligned} a &= [a_{00}, a_{01}, a_{02}, a_{10}, a_{11}, a_{20}]^T \\ b &= [b_{00}, b_{01}, b_{02}, b_{10}, b_{11}, b_{20}]^T \end{aligned} \qquad \text{Eq.3-4}$$

$$\begin{aligned} x &= [\sum_{e=1}^{L} x_e, \sum_{e=1}^{L} x_e v_e, \sum_{e=1}^{L} x_e^2 v_e, \sum_{e=1}^{L} x_e u_e, \sum_{e=1}^{L} x_{e_e} u_{e_e} v_e, \sum_{e=1}^{L} x_e v_e^2] \\ y &= [\sum_{e=1}^{L} y_e, \sum_{e=1}^{L} y_e v_e, \sum_{e=1}^{L} y_e^2 v_e, \sum_{e=1}^{L} y_e u_e, \sum_{e=1}^{L} y_{e_e} u_{e_e} v_e, \sum_{e=1}^{L} y_e v_e^2] \end{aligned} \qquad \text{Eq.3-5}$$

Substituting the given road coordinates and image coordinates into the transformation equations, the transformation matrix and the coefficients a_{ij} and b_{ij} can be calculated.

The control points should be maximally spread over the observation area to achieve a relatively accurate transformation matrix. To validate the transformation and optimize the transformation process, additional reference points are included. In field road scenes, it is generally possible to find natural markings that are clearly legible from the video image.

3.4 Field observation

3.4.1 Field observation introduction

Two major methods are used to determine study sites. The first method considers the VEH-PED accident rate estimated by urban traffic statistic information. Study sites obtained by this method tend to feature higher accident rates and lower sense of security to the public. The second method conducts an intercultural analysis on the basis of the current traffic environment. Similar traffic environments between two countries are selected, focusing on the road user flow rate, proportion of passenger cars, and land use of the selected locations. When circumstances permit, field observation sites determined by these methods should cover as many traffic categories as possible to collect sufficient traffic data. In this study, the second method is chosen for field site determination. Other considerations are made as follows:

- The roadway (with crosswalks) should be without slopes;
- No obstacles must be found within the visual clearance of the video camera during the observation time;
- Both single-pedestrian and pedestrian groups can be recorded in the selected study sites;
- Both single-driving and platoon driving can be observed;
- Traffic signs/markings and traffic signals should be clearly visible to all road users;
- Reference lines or points (natural markings) for coordinate transformation and image processing may be set in the observation area;
- No roadside parking must occur during the observation time;
- Light and road pavement conditions should be taken into account.

A driver would theoretically need to notice amid-block crosswalk 38m before reaching it at a speed of 11m/s and have a clear view of both sides of the crosswalk from that distance to effectively scan for pedestrians (Nowakowski, 2005). Considering the average speed of the vehicle at the study sites (about or lower than 11m/s), a lane length of at least 40m before the crosswalk is selected in the study to estimate the entire conflict process. The observation time can be composed of certain time segments at peak and/or non-peak hours on weekdays (non-holidays) based on the traffic flow rate. Fig. 3-6 shows a sketch map to depict the location of the observation point. Here, the camera view covers the entire length of a zebra crosswalk and a 50m approaching lane before a mid-block crosswalk.

As the observed zebra crosswalks are perpendicular to the road lane and the evasive driving of a subject vehicle could be treated as a lane-based movement, the encounter situation occurs at a right angle. Passenger cars in both single-driving and platoon-driving states are defined as subject vehicles in the study. Pedestrians who use the zebra crosswalk to cross the road (or are less than 2m from the zebra crosswalk) are recorded as sample pedestrians.

Fig.3-6 Location of the camera and the observation view for the mid-block crosswalk

3.4.2 Description of the field observation sites

Seven field observation sites are selected for this study, including three unsignalized mid-block crosswalk and one signalized mid-block crosswalk in Beijing. In Munich, three unsignalized mid-block crosswalks are selected. Table 3-1 shows the general descriptions of these sites including similar vehicle flow rates, pedestrian flow rates, average vehicle speeds, and passenger car proportions. Although the traffic environment and crosswalk geometry are different, according to observations, the average pedestrian crossing speed in each country remains constant over a certain range and does not vary with the width of the crosswalk. Thus, the observation data from these two countries are assumed to be independent of location and are analyzed as single sample set.

Two vehicle–pedestrian conflict situations are defined in this study as:

Situation Ⅰ: A single vehicle conflicts with a pedestrian/pedestrian group;

Situation Ⅱ:Vehicles in a platoon conflict with a pedestrian/pedestrian group.

During the observation period, the influence of non-motorized vehicles is ignored because of the low flow rate.

3.4.3 Sample size

According to the statistics theories, the minimum sample size in the traffic conflict analysis is:

$$N = \frac{pqk^2}{E^2} \qquad \text{Eq.(3-6)}$$

Where N denotes the minimum sample size; p denotes the proportion of the number of vehicles in the certain conflict to the traffic flow volume observed; q denotes 1-p; k denotes the constant related to a certain confidence level and E is the allowable error of the conflict proportion. Here we take the vehicle intersection conflict as an example, an X-intersection has twelve traffic flow directions and one conflict is related to two flow directions, so p=2/12. If the confidence level equals 95%, so the constant k is 1.96, and the allowable error is set as 5%, so the minimum sample size can be calculated by:

$$N = \frac{pqk^2}{E^2} = 212$$

For a typical X-intersection, each kind of conflicts should contain 212 samples as least. If the allowable error is assumed as 10%, the minimum sample size is 53.

The value of the minimum sample size can also be introduced in the VEH-PED conflict analysis.

3.5 Summary

A traffic event generally consists of four components: someone, sometime, somewhere, and somehow. To analyze a traffic conflict event, the major measures to describe the conflict process without exception belong to these four components. Some methodological aspects of the video observation technique as developed for this study are proposed. In this study, we aim to determine road user behaviors in VEH-PED conflicts; thus, collection is conducted to analyze the descriptions of behavioral states under certain conflict situations and construct situation-countermeasure relationships. Time-related and situational measures are defined and seven observation sites in Beijing and Munich are selected for the field study.

Tab.3-1 General description of field observation sites

Sites	Weigongcunroad (Beijing)	Xuyuannanroad (Beijing)	Changwastreet (Beijing)	Arnulfstraße (Munich)	Kieferngartenstraße (Munich)	Boltzmannstraße (Munich)	Weigongcunroad (Beijing) Non-compliance
Road Category/Grade	Minor arterials	Minor arterials	Inferior road	Arterials	Inferior road	Inferior road	Minor arterials
Location	University nearby	Mixed land use	Residential area	Mixed land use	Residential area	University nearby	University nearby
Pedestrian signal	No	No	No	No	No	No	Yes
Public transit nearby	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lane Length	50m	58m	50m	50m	70m	70m	50m
Crosswalk Length	12m	14m	7m	20m including refuge inland	8.6m	6m	12m
Crosswalk Width	5m	5m	5m	10m	4m	5m	5m
Veh. Flow Rate	Average flow rate at 800-1200 pcu/h/d with 1500-2000 pcu/h/d as peak rate						
Ped. Flow Rate	131-276 ped/h	159-315ped/h	c.a. 200ped/h	c.a.200ped/h	152-298ped/h	147-329ped/h	107ped/h
Average Veh. Speed	20-35km/h						
Passenger car proportion	91.7%	87.0%	95.0%	82.4%	89.1%	92.5%	94.2%
Observation Time	Working days 2:30-4:30 p.m. (peak hour not included)	Working days 2:30-4:30 p.m. (peak hour not included)	Working days 15:00-17:00 p.m. (peak hour included)	Working days 6:30-8:30 a.m. (peak hour not included)	Working days 16:00-18:00 p.m. (peak hour included)	Working days 16:00-18:00 p.m. (peak hour included)	Working days 15:00-17:00 p.m. (peak hour included)

4 COMPARISON OF PEDESTRIAN BEHAVIOR IN VEH-PED CONFLICT

4.1 Introduction

This chapter tries to answer how the conflict participants behave differently between China and Germany, and gives a general view of intercultural comparison of pedestrian conflict behavior.

The following parts are organized by the pedestrian speed performance (**Section 4.2**), pedestrian waiting behavior (**Section 4.3**), pedestrian gap acceptance behavior (**Section 4.4**) and TTC analysis (**Section 4.5**). The non-compliance pedestrian as the special case in China are drawn to make comparison with the normal conflict situations (**Section 4.6**). Emphasis is given towards the parameters determining crossing pedestrian states as well as the relationship among TTC and other situational measures.

4.2 Pedestrian speed performance

Pedestrian walking speed is one of the three basic characteristics of pedestrian traffic, and pedestrian walking speed related to certain pedestrian traffic facilities (pedestrian sidewalk, pedestrian crosswalk, passenger corridor, etc.) is also one kind of fundamental parameters to define the pedestrian behavioral states.

4.2.1 Speed distribution

The frequency distribution reflects the occurrence probability of a measured value for a given condition. In traffic modeling and simulation, frequency distribution can be used to define some characteristics of the road users as the system input.

In previous pedestrian traffic studies in Beijing, China (Jiang, 2009; Xiong, 2008), frequency distributions of pedestrian walking speed related to certain pedestrian facilities have been statistically analyzed. Fig. 4-1 (a), (b) and (c) show the walking speed distribution in different pedestrian facilities: the residential sidewalk, the signalized crosswalk in business district and building hall in a selected university respectively. The data are distributed normally about the mean 1.22m/s, 1.42m/s and 1.23m/s, with the standard deviation of 0.26m/s, 0.32m/s and 0.29m/s respectively.

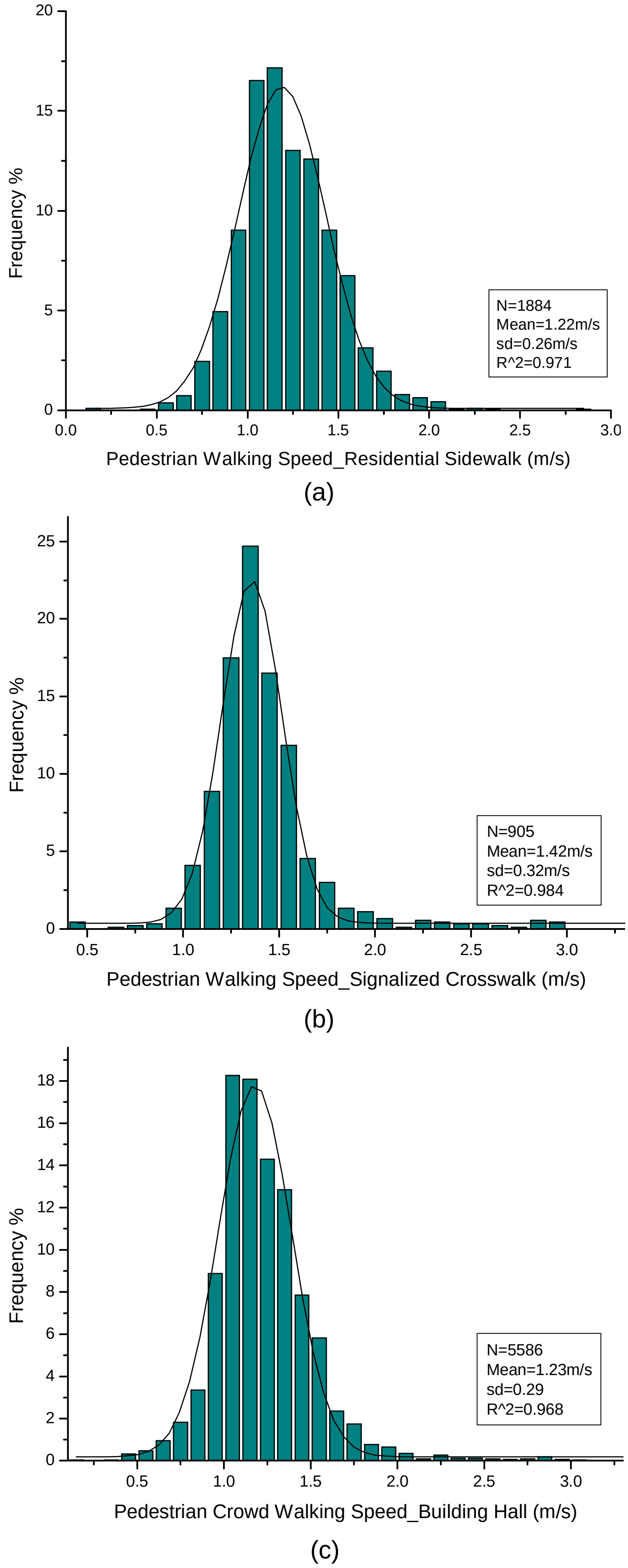
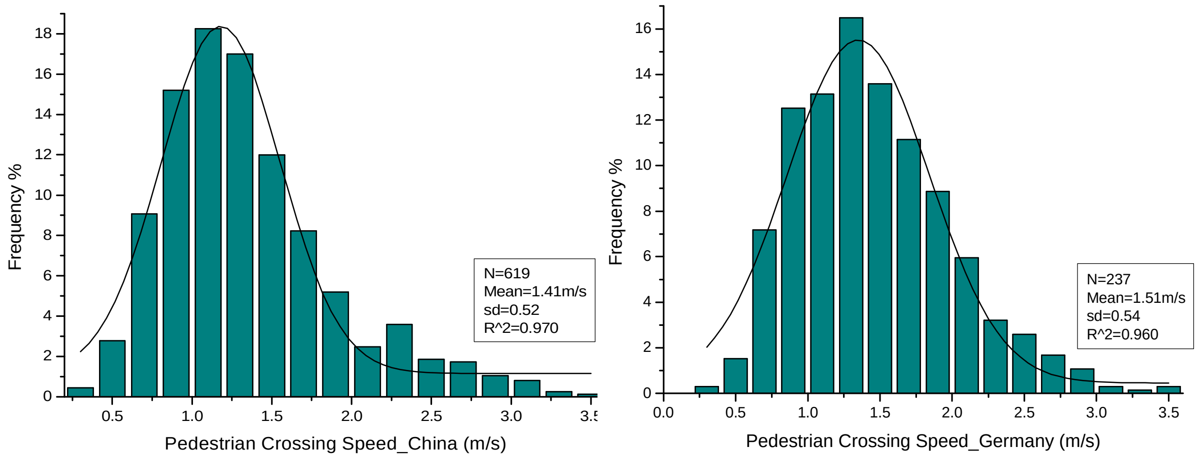


Fig.4-1 Pedestrian walking speed distribution in Beijing

Fig.4-2 (a) and (b) plot the frequency distribution of pedestrian crossing speed in conflict cases both in China and in Germany. Same as the side-walking speed, signalized crossing speed and crowd walking speed, the data fit the normal distribution but with a higher standard deviation, 0.52m/s and 0.54m/s respectively for two countries. The reason could be concluded as, in this study the subject pedestrian is caught in a more complicated situation and the speed is more spread apart.



(a) (b)

Fig.4-2 Pedestrian crossing speed in conflict situation

*One pedestrian group is recorded as one sample.

4.2.2 Speed by different pedestrian categories

Various factors contributing to pedestrian traffic activities mentioned in previous sections, such as pedestrian age, gender, trip purpose, street scene, and traffic conditions, among others, were studied. Among these factors, pedestrian gender and age have been proven to have significant influences on pedestrian safety (Martin, 2006). In pedestrian speed studies, these factors have also been investigated by many scholars (Knoblauch, 1996; Fitzpatrick, 2006; Tarawneh, 2001; Simon, 2012).

In this work, we chose gender, age, and group size as variables with which to summarize pedestrian classifications and conduct an intercultural comparison. The final rubric for pedestrian categories is shown in Table 4-1. According to HCM2000, the pedestrian walking speed is highly dependent on the proportion of elderly pedestrians in the walking population; thus, it assumes 20% of all elderly pedestrians as the threshold for a decrease in walking speed from 4.0ft/s to 3.0ft/s. In this study, the proportion of elderly pedestrians was less than 20% so the samples are considered normal crossing pedestrians.

Fig.4-3 illustrates a comparison of pedestrian crossing speeds in terms of gender and age. Significant differences can be seen from the bar diagrams.

- For the same pedestrian categories, the average crossing speed of German pedestrians in conflict situations is about 7% to 9% higher than that of Chinese pedestrians;
- Females display average crossing speeds about 7% lower than males both in Germany and China;
- The crossing speed of elderly pedestrians in China is 9% lower than the average speed of all samples; in Germany, the crossing speed of elderly pedestrians is 11% lower than the average speed.
- Differences in standard deviation are not significant.

Tab.4-1 Summary of pedestrian categories

Variables	**Gender**		**Age**		**Group Size**	
Categories	Male	Female	≤60	60+	1	2+
Count	124/345	112/274	209/571	28/48	196/489	41/130
Proportion	52.57%/ 55.8%	47.43%/ 44.2%	88.37%/ 92.27%	11.63%/ 7.73%	82.76%/ 79.01%	17.24%/ 20.99%

*German numbers are in front.

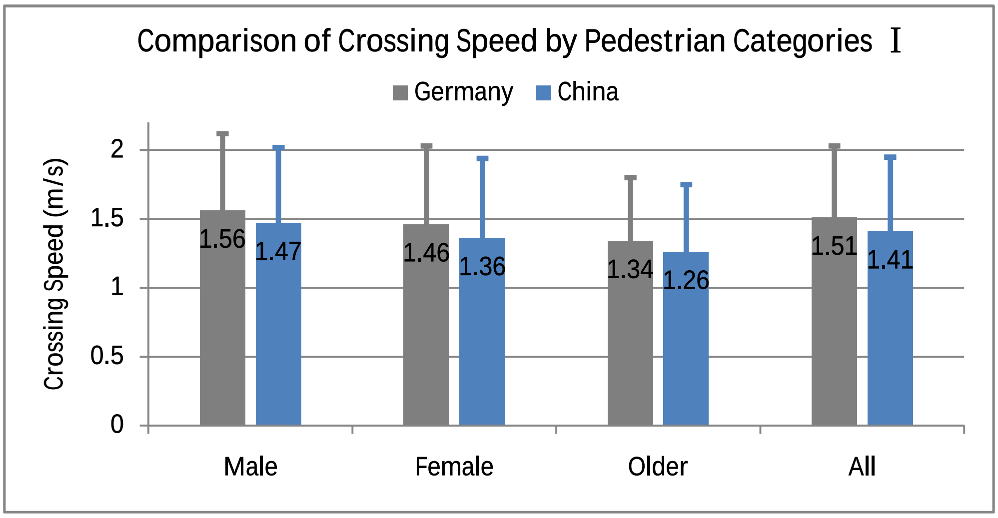


Fig.4-3 Comparison of pedestrian crossing speed by gender and age

Fig.4-4 illustrates a comparison of pedestrian crossing speeds in terms of group size. Similar to the results in Fig.4-3, a 7% to 8% speed difference is found between German and Chinese pedestrians, both in single- and group-crossing activities. Groups of pedestrians have lower speeds and overall standard deviations compared with pedestrians walking alone (Tim, 2006; Tim, 2011). This phenomenon may be attributed to the "group psychology" of pedestrians when walking in groups and the release of individual control to form a group activity. Interactions among pedestrians in groups may also slow down their walking behavior. No exactly significant difference in this phenomenon is observed between Germany and China, and pedestrian groups in both countries show a slightly slower walking speed (2%) than single pedestrian.

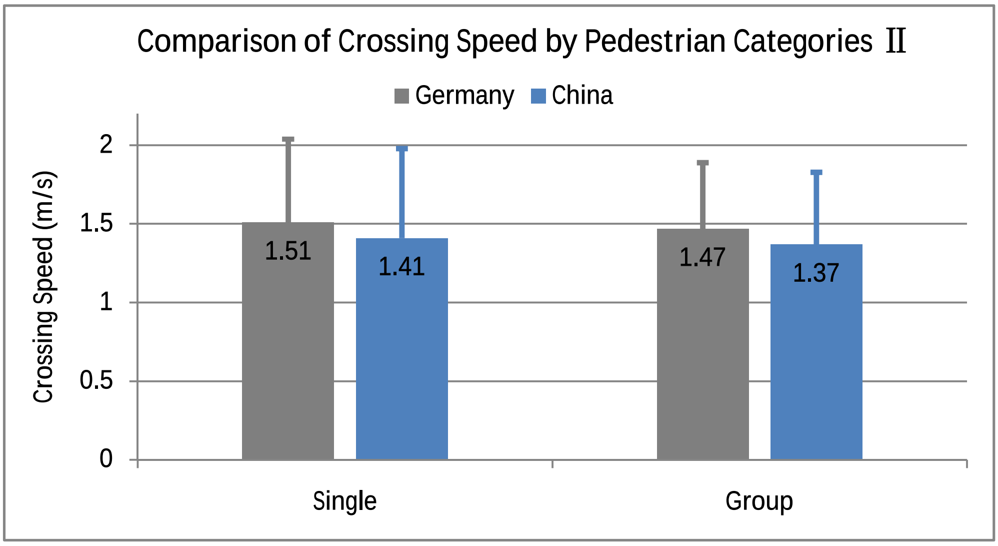


Fig.4-4 Comparison of pedestrian crossing speed by group size

4.2.3 Speed by different walking phases

The process of crossing from the pedestrian side can be categorized into three parts. These parts reflect different walking phases in pre-conflict and post-conflict situations. The three walking phases are as follows (shown in Fig.4-5):

Pre-conflict situation

- Phase I: Side-walking towards the crosswalk from A to B (about 7m to the crosswalk, 10pedestrian stride lengths)
- Phase II: Crossing from roadside curb B to potential conflict point CP

Post-conflict situation

- Phase III: Crossing from potential conflict point CP to the opposite road to finish the crossing process

The walking purposes in these three phases differ. In the first phase, pedestrians try to use the zebra crosswalk to cross the road and decide where and when to start crossing. In the second phase, pedestrians aim for a safe crossing and make decisions to avoid collision. In the last phase, the pedestrians aim to stay away from the potential risks and to end the crossing task as soon as possible. Consequently, the pedestrians' basic behavioral characteristics, such as their walking speed, are different. The analysis of pedestrian speed as it relates to the walking phases can provide an understanding of the speed variation in the entire conflict process.

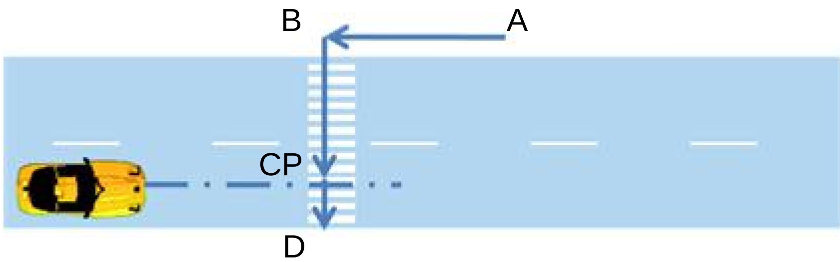


Fig.4-5 Pedestrian walking phases in VEH-PED conflict

Fig.4-6 illustrates the walking speed in the three aforementioned phases and compares German data and Chinese data.

- In the first and second phases, the average walking speed of German pedestrians is about 8% higher than that of Chinese pedestrians, and this difference decreases to 6% in the last phase.
- When the pedestrians turn to the second phase after side-walking, the walking speed changes slightly for both the German and Chinese pedestrians (a variation of less than 1%).
- The average crossing speeds before and after the potential conflict point differ greatly; the increasing trend of the crossing speed of Chinese pedestrians from phase II to phase III is about two times greater than that of German pedestrians, and the increasing proportions are 5.8% and 3.3%, respectively.

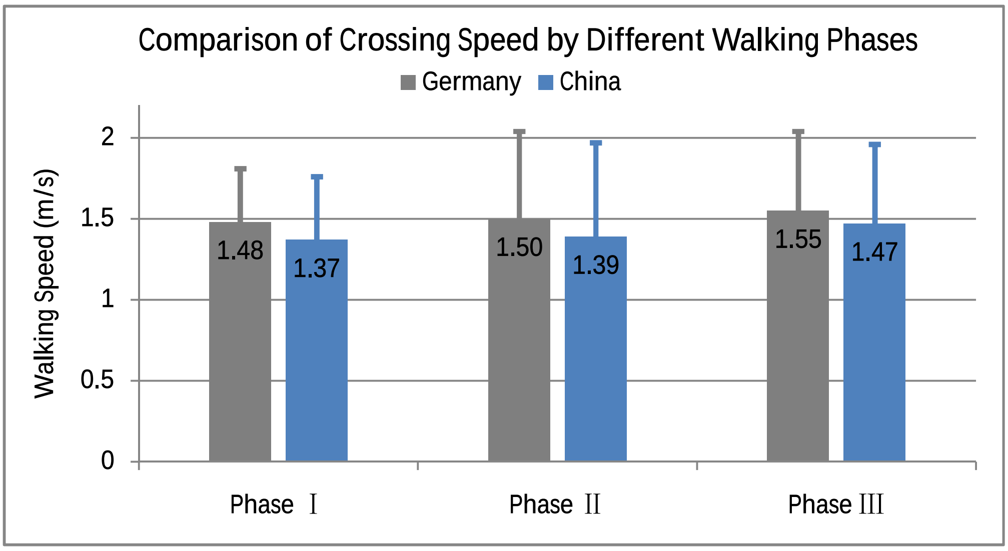


Fig.4-6 Comparison of pedestrian speed by walking phases

A special phase cannot be ignored in the conflict process in China. When a pedestrian crosses the road from the curbside to the middle of the roadway, s/he may swerve and walk along the vehicle lane to find another place to cross (Fig.4-7). In such a case, the pedestrian may be caught in an extremely dangerous situation. Among the pedestrian samples in China, 5.7% are found to undergo this phase; the walking speed on the roadway along the vehicle lane is equal to 1.29m/s, which is about 7% lower than the average crossing speed. Pedestrian samples in this phase are rarely collected during the observation time in Germany.

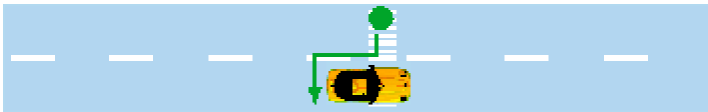


Fig.4-7 Special case in China —walking along the vehicle lane on the road

Phases II and III should be considered for the unaltered walking direction. Fig.4-8 depicts the walking speed of different pedestrians in these two phases. The following conclusions can be drawn:

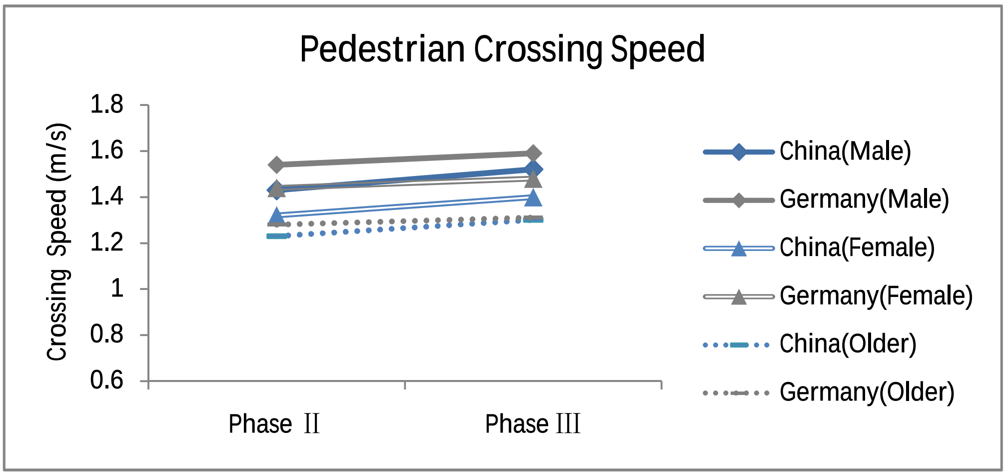


Fig.4-8 Comparison of pedestrian crossing speed before and after CP

- The walking speed of the German samples in each pedestrian category for either phase is higher (except the crossing speed of elderly pedestrians in Phase III).
- A faster growth rate can be observed among Chinese samples after passing the potential conflict point (all pedestrian categories), and Chinese pedestrians seem to be more aggressive in conflict situations.
- Chinese male pedestrians have the fastest growth rate at 6.3%. The slowest growth rate at approximately 2.3% is observed in the category of Germany elderly pedestrians.
- Male pedestrians behave more severely when changing their crossing

speeds compared with female pedestrians in both Germany and in China.

4.3 Pedestrian waiting behavior

Many studies have been conducted to analyze the pedestrian waiting behavior in crossing situations related to various pedestrians facilities like the signalized intersection crosswalks, the unsignalized midblock crosswalk, roundabout crosswalk etc(Sun, 2011; Shi, 2007; Hamed, 2001; Ni, 2010). To the given traffic situations in this study, significant differences can be found in pedestrian waiting performance in China compared with German case.

4.3.1 Waiting decision choice

The different driving culture of Germany and China noticeably affect road user behavior in many ways. With regard to pedestrian waiting behavior in the road-crossing process, interesting differences exist. Tab.4-2 lists the proportions related to five waiting decisions in Germany and China.

Tab.4-2 Comparison of the pedestrian waiting decisions

Waiting decision	**Germany**	**China**
Crossing directly, waiting time=0s (in all conflict cases)	69.88%	17.71%
Waiting to cross, waiting time ≠0s (in all conflict cases)	30.12%	82.29%
Waiting for less than two vehicles (only in conflict with vehicle platoon)	83.67%	10.83%
Waiting for more than two vehicles, including two vehicles (only in conflict with vehicle platoon)	16.33%	89.17%
Crossing after the vehicle platoon passing the crosswalk (only in conflict with vehicle platoon)	6.12%	70.83%

- In all conflict situations, most of the Chinese pedestrians (more than 80%) will stop at the roadside and wait to cross. On the contrary, a majority of pedestrians in Germany (about 70%) will cross directly without stopping before entering the crosswalk.
- In conflict with vehicle platoons, only about 10% of Chinese pedestrians will wait for less than two vehicles. By contrast, 80% of the German pedestrians will cross the road directly and use the gap between the first and second vehicle in the platoon to cross the road.
- About 70%ofpedestrians caught in VEH-PED conflicts in China are forced to wait until the entire vehicle platoon passes the crosswalk. Comparatively, six in one hundred pedestrians will make such a choice.

The proportion results can be considered the opposite of one another. In China, according to the traffic rules at unsignalized crosswalk, the pedestrians as the vulnerable road users have the right of way and the drivers are required to give precedence to the pedestrians. In reality, however, pedestrians do not seem to "trust" drivers, and they prefer to wait rather than cross without stopping. In Germany, the willingness of drivers to give way to pedestrians at zebra crossing is very high and "yielding to pedestrians" is a common acceptable driving practice. Thus, the waiting decision for most of German pedestrians is unnecessary.

4.3.2 Waiting time

Studies have suggested that waiting time affects the behavior of pedestrians when they are attempting to cross a road. Observations conducted in many countries prove that waiting time within a maximum period of 30s and 45s invokes a feeling of impatience among pedestrians (Martin, 2006; Asaba, 1998; Baass, 1989). In China, this period is 60s to 90s (Li, 2011). Some studies in other developing countries have also analyzed the pedestrian waiting time (Ibrahim, 2005).

Fig.4-9 plots the pedestrian waiting time related to the vehicle flow rate. According to the field observation, the sample size of the pedestrians who may stop walking and wait in the middle of the roadway in Munich is very small. Thus, only the pedestrian waiting time at the roadside is recorded. A comparative discussion is presented below:

- At a low vehicle flow rate (≤1500pcu/h/d), the average waiting time of Chinese pedestrians at the roadside curb is about nine times higher than that of German pedestrians. At a high vehicle flow rate (2000pcu/h/d), this number decreases to about eight.
- The average waiting time of German pedestrians when arriving at a crosswalk is less than 2s, during which the pedestrians pause for a moment to scan the road and then head toward the road to cross. On the contrary, pedestrians in China wait until the gap is acceptable.
- When the vehicle flow rate is about 1500pcu/h/d, the waiting times at the 85^{th} percentile for German and Chinese pedestrians are 1.66s and 18.9s, respectively (Fig.4-10).

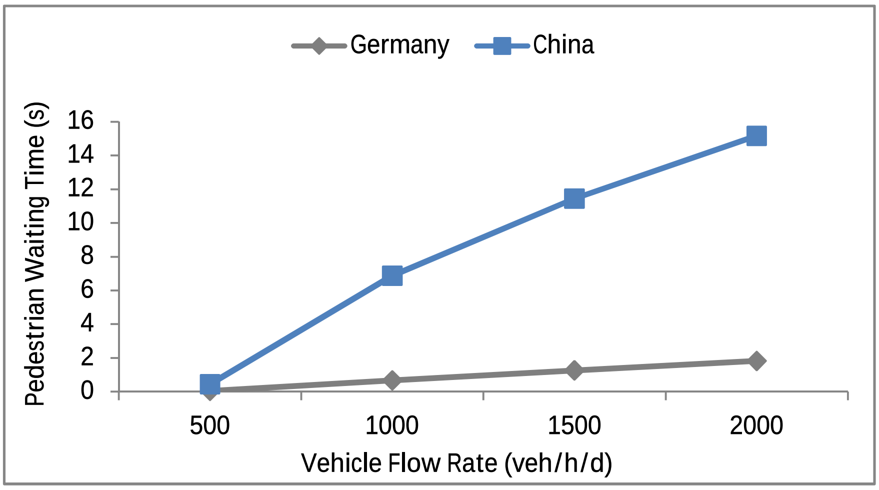


Fig.4-9 Comparison of pedestrian waiting time (Roadside)

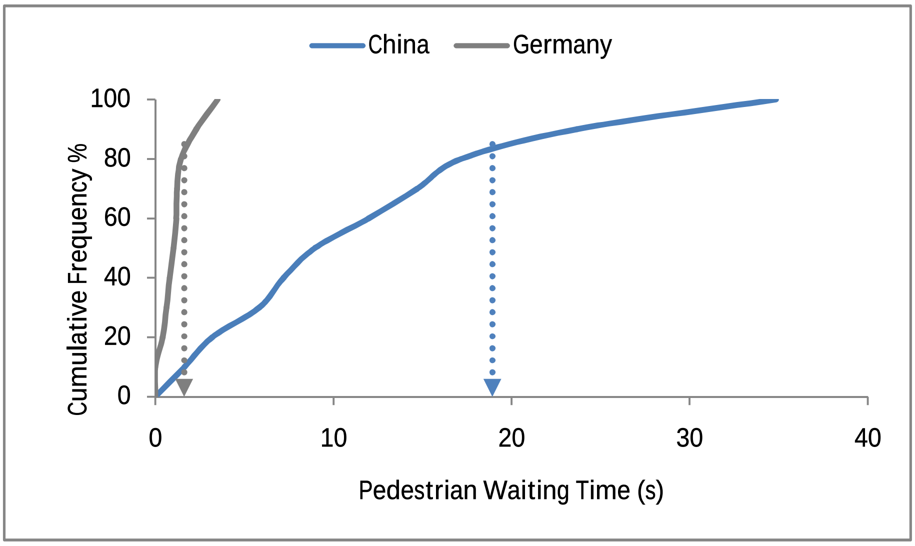


Fig.4-10 Comparison of cumulative frequency of pedestrian waiting time

4.4 Pedestrian gap acceptance

Compared with vehicle gap acceptance, pedestrian behavior varies. Such a variation may be attributed to drivers who accept smaller gaps because they have higher speeds and can thus move more quickly than pedestrians can (Kadali, 2012). Many studies on this topic have been conducted, with a focus on the statistical analysis (Brewer, 2006), influencing factors (Oxley, 1997; Oxley, 2005; Yannis, 2010), and different methods used to determine the acceptable gap (Pant, 1994; Sun, 2003; Tian, 1999). In the present study, only the pedestrian crossing gap in conflict situations is investigated.

Generally, in a car-following phase, the driver in a platoon will continuously be influenced by the vehicle in front until the rear bumper of the front vehicle reaches the conflict point on the crosswalk. A major conflict then arises between the following vehicle and the pedestrian. The acceptable gap partially characterizes this situation. According to **section 3.2.1**, the definition of the gap here is related to two successive vehicles not only in platoon driving situations but also in single driving situations. Tab.4-3 gives a statistical description of the pedestrian crossing gaps classified as “accept” (the gap used by pedestrians to cross the road) and “reject” (the gap not used by pedestrians to cross the road). The following points can be highlighted:

- A slightly smaller acceptable gap for Chinese pedestrians;
- Unobvious difference in rejected gap between Chinese and German pedestrians;
- A 5.0s critical gap to determine acceptance for both Chinese and German pedestrians.

Tab.4-3 Comparison of pedestrian gap choice

		China		Germany	
		Accept	Reject	Accept	Reject
Mean		7.28	3.41	7.77	3.33
Std. Deviation		2.29	1.32	2.00	1.54
Percentile	10	4.85	2.08	4.80	1.88
	90	9.928	5.157	10.419	5.093

Tab.4-4 presents the statistics of the pedestrian acceptable lag and rejected lag in Germany and in China. In distinguishing the two decisions, the 3.0s lag may be considered as the boundary for Chinese (threshold>3.0s) and German pedestrians (threshold<3.0s).

Tab.4-4 Comparison of Pedestrian lag choice

		China		Germany	
		Accept	Reject	Accept	Reject
Mean		3.96	1.88	3.28	1.89
Std. Deviation		0.76	1.13	1.08	1.04
Percentiles	10	3.08	0.50	2.25	0.74
	90	5.00	3.43	4.82	2.82

4.5 TTC analysis

TTC is defined as ”the time required for two vehicles to collide if they continue at their present speed and on the same path”. In Traffic Conflicts Techniques, TTC is suggested to be a surrogate measure of conflict severity. The analysis of TTC may offer a better understanding of the process that the conflict participants ultimately avoid a potential collision.

4.5.1 Empirical TTC calculation

All kinematic parameters of the vehicle are deduced from the trajectories, where the conflict vehicle is recorded as a point. But in terms of collision analysis, the vehicle geometry should be taken into consideration.

At a certain time in the encountering process, the current state of vehicle and pedestrian can be defined by their speed VS, PS and distance LODV, LADP. If the present movements keep unchanged, when

$$|TTCP_{PED} - TTCP_{VEH}| \leq \Delta t_1 and\ TTCP_{VEH} \geq TTCP_{PED}$$

$$TTCP_{PED} = \frac{LADP}{PS},\ TTCP_{VEH} = \frac{LODV}{VS}, \Delta t_1 = \frac{\frac{w_0}{2}}{PS}$$

is fulfilled, a collision may occur, see Fig.4-11(a).

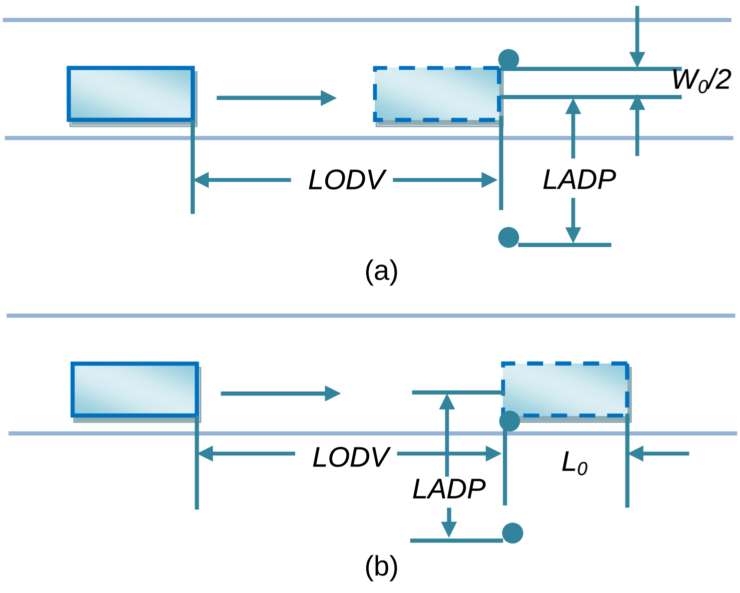


Fig.4-11Collision situation identification

And when

$$|TTCP_{PED} - TTCP_{VEH}| \leq \Delta t_2\ and\ TTCP_{VEH} < TTCP_{PED}$$

$$\Delta t_2 = \frac{L_0}{VS}$$

is fulfilled, a collision may be observed, see Fig.4-11 (b).

The TTC is stated as:

$$TTC = \begin{cases} TTCP_{VEH}, TTCP_{VEH} \geq TTCP_{PED} \\ TTCP_{PED}, TTCP_{VEH} < TTCP_{PED} \end{cases} \quad \text{Eq.(4-1)}$$

To each trajectory data pair, the time to the conflict point of the road user and their difference can be calculated. Fig.4-12 is the time history sketch of TTCP for both the pedestrian and the vehicle. At t3, the pedestrian arrives at the potential conflict point, and after Δt_1, the pedestrian may pass the entire vehicle width at t4. During t1-t2, the difference of the TTCP between pedestrian and vehicle is less than Δt_2 and Δt_1 respectively. So the TTC can be obtained. Here, a 1.0s is recommended for both Δt_1 and Δt_2.

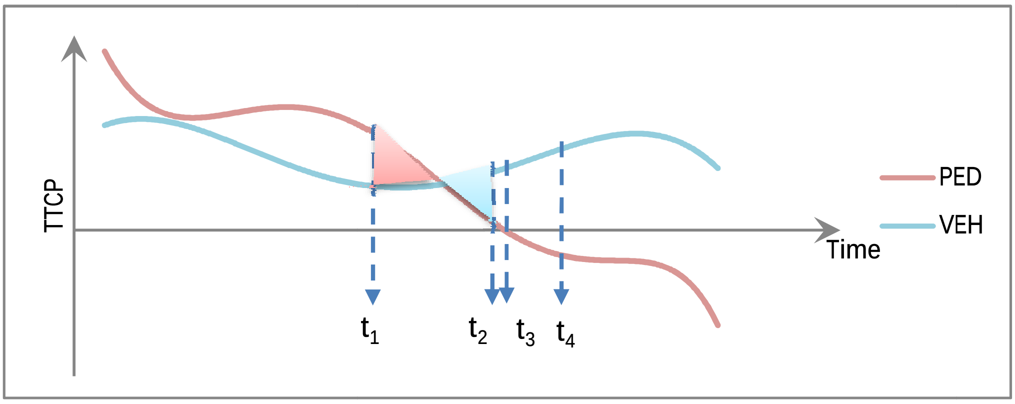


Fig.4-12 Time history of TTCP

4.5.2 Comparison of TTC distribution

Fig.4-13 elaborates the frequency distributions of the TTC in Germany and in China, and the distributions fit the Weibull distribution with the following functions:

$$y_{Germany} = 1 - e^{-(0.35789x)^{1.9019}} \quad \text{Eq.4-2}$$

$$y_{China} = 1 - e^{-(0.30127x)^{2.14709}} \quad \text{Eq.4-3}$$

According to the statistics of the observed conflict situations, the mean of TTC_Germany and TTC_China are 2.97s and 3.16s respectively, with the minimum TTC 1.12s and 1.09s.

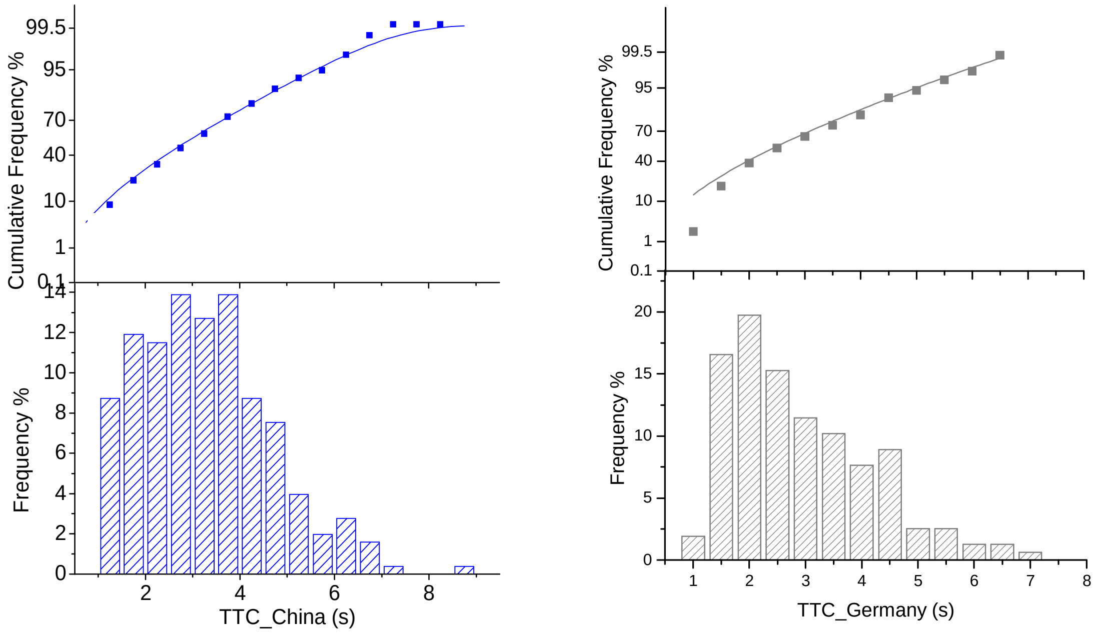


Fig.4-13 Frequency distribution of TTC

4.5.3 Relationship between TTC and PED-based parameters

Focusing on the situation that pedestrians conflict with single vehicle, Fig.4-14 plots the relationship between the pedestrian lateral distance to the conflict point and the TTC in China (N=263) and in Germany (N=172). The slope of trendline for German samples is slightly smaller than the Chinese samples. With the pedestrian walking towards the conflict point, the TTC decreases gradually. Fig.4-15 is the relationship between TTC and the pedestrian speed. When the pedestrian speed increases, the VEH-PED conflict will become more serious for a lower TTC.

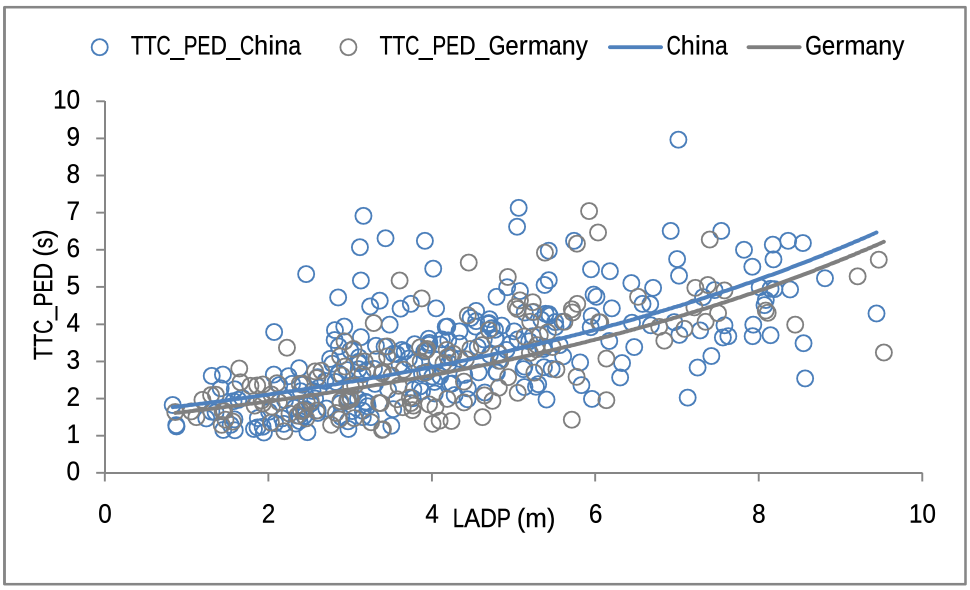


Fig.4-14 Relationship between TTC and LADP

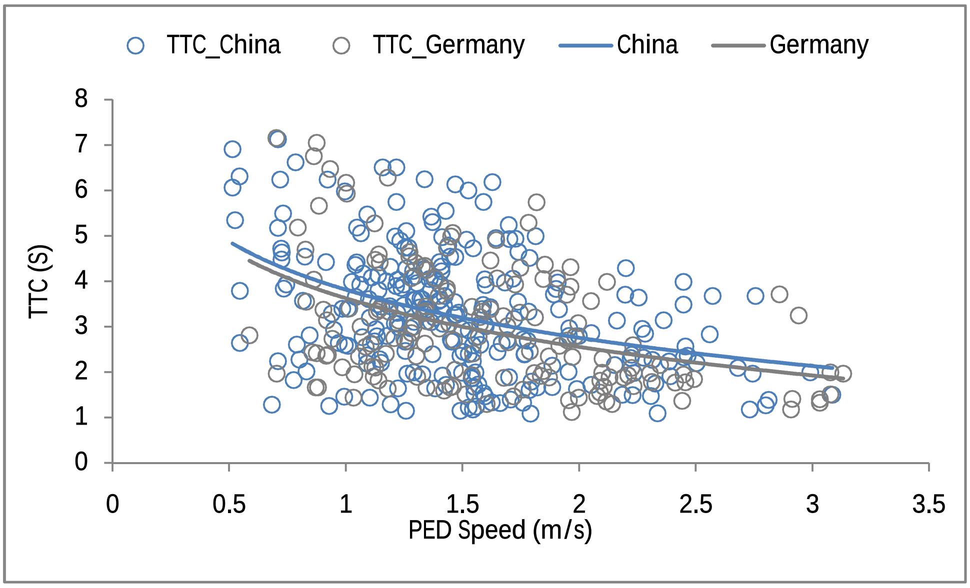


Fig.4-15 Relationship between TTC and PS

4.6 Non-compliance pedestrians

In developing countries, drivers and pedestrians tend to fight over limited spaces, with the former always preventing the latter from having the right of way. At a signal controlled crosswalk (with both vehicle signal and pedestrian signal), a driver may take the signals for granted, focus on the vehicles in front, and fail to detect the jaywalking pedestrian. As a result, the driver may not appropriately decide to give priority to the jaywalking pedestrians. Furthermore, the pedestrians may easily be caught in an extremely dangerous situation, as investigated in this study of a special case in China. Since the 1950s, violating behavior has been examined by many scholars all over the world (Liu, 2008; Kim, 2008; Yang, 2006; Theofilatos, 2012; Monroe, 1955). Research on pedestrian non-compliance covers non-compliance statistical analyses (Yang, 2006; Diaz, 2002), pedestrian non-compliance psychology (Yuan, 2008), and relationship between non-compliance and accidents (Zaidel, 2001), to name a few. As an important part of investigation on traffic cultural adaption, non-compliance behavior should be highlighted in further studies.

4.6.1 Speed performance

According to the field observation, non-compliance pedestrian behavior at signalized crosswalks can be categorized into several types, such as redcrossing, waiting on the roadway, and walking along the vehicle lane when the traffic light is green. In the present study, redcrossing pedestrians in conflict situations serve as the study samples.

The redcrossing speed fits the normal distribution, and the average redcrossing speed of 1.50m/s is 6.4% higher than the unsignalized crossing speed in the conflict situation (see Fig.4-16). The speed difference can be attributed to the strong willingness of redcrossing pedestrians to get away from the risk immediately and to their intention to shorten their travel time to achieve greater utility, which is closely related to travel time savings.

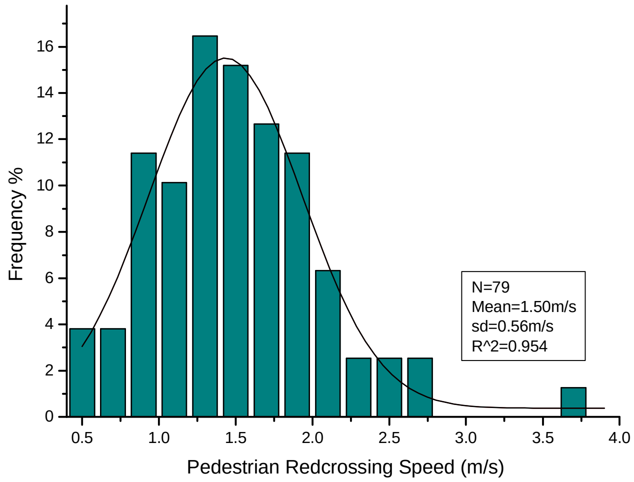


Fig.4-16 Pedestrian redcrossing speed in conflict situation

4.6.2 Crossing gap choice in non-compliance

Tab.4-5 gives an overview of the severity of the redcrossing situation according to the gap acceptance. All figures are almost one third lower than those in Tab.4-3. This result implies that the pedestrians in this case cannot wait for a relatively sufficient gap, so they behave much more aggressively in the crossing activity. Furthermore, the short acceptable gap raises the possibility of traffic collisions. We can deduce that if the gap is wider than 3.5s, the pedestrians will choose to cross.

Tab.4-5 Crossing gap in non-compliance situations

		Gap (s)	
		Reject	Accept
Mean		2.25	4.1
Std.Deviation		0.75	0.93
Percentiles	10	1.40	3.27
	90	3.46	5.24

4.7 Summary

Based on the road user trajectory estimation, the empirical results reveal the behavioral difference between China and Germany. Pedestrian speed distribution in conflict situation is proved to fit the normal distribution. The Chinese pedestrian speed is statistically recorded as 7%-9%, lower than the German samples in certain pedestrian categories and walking phases. Significant differences of pedestrian waiting behavior are addressed and interculturally interpreted. The proportion of waiting decisions can be considered to be the opposite of one another between these two countries. Pedestrian gap/lag thresholds in normal and critical situations (non-compliance situation) are suggested according to the analyses on the gap/lag choice behavior. After introducing the method for TTC calculation, comparisons of the relationship among TTC and PED-based measures are made including the relationship between TTC and LADP and the relationship between TTC and PS. TTC for both samples fit the Weibull distribution and slight differences can be found in the relationship analyses.

5 COMPARISON OF DRIVER BEHAVIOR IN VEH-PED CONFLICT

5.1 Introduction

This chapter gives an understanding of how the drivers behave in the VEH-PED conflict situation both in China and in Germany at the maneuver level. The differences are detailed explained referring to the behavioral measures.

In this chapter, the driver yielding behavior (**Section 5.2**), driver deceleration rate choice (**Section 5.3**), the accelerating activities in collision avoidance (**Section 5.4**), TTC analysis from the driver side (**Section 5.5**) are investigated. The non-compliance situations are also discussed by different decelerating and TTC performance with comparison to normal case (**Section 5.6**). The relationships among time-related measures and situational measures are highlighted in the comparison of driver conflict behavior.

5.2 Driver yielding behavior

Many literatures are proved to give evidence to the different driver behavior in developing countries. To provide insights into the Chinese driving culture, the key behavioral differences compared with the developed countries are analyzed. Firstly, the yielding behavior is observed to have enormous differences. Tab.5-1 lists the proportion statistics of the yielding behavior related to six categories in Germany (N=268) and China (N=849).

Tab.5-1 Comparison of driver yielding behavior between German and China

Categories	**Germany**	**China**
Yielding to crossing pedestrians (All conflict vehicle samples)	92.54%	10.53%
Not yielding to crossing pedestrians (All conflict vehicle samples)	7.46%	89.47%
Yielding situation (Single vehicle samples)	73.13%	45.46%
Yielding situation (Platoon vehicle samples)	82.22%	56.81%
Not yielding situation (Single vehicle samples)	26.87%	54.54%
Not yielding situation (Platoon vehicle samples)	17.78%	43.19%

- Almost all German drivers will yield to the crossing pedestrian in conflict situations (over 90%), but on the contrary in China only one in ten drivers will do so. About 90% Chinese drivers are not willing to give precedence to the other road users;

- In yielding situations, the proportions of Chinese drivers in single (45.46%) and platoon driving (54.54%) who may give precedence to crossing pedestrians shows a difference of 9%. In Germany, more samples in single driving (73.13%) will give precedence to pedestrians. The reason for this phenomenon should lie in the high yielding proportion in all conflict cases, most of the drivers are used to yielding not only for single driving drivers but also for the drivers in platoon. But when the driver is in platoon driving, s/he to a large extent does not have the chance to make yielding decision because the platoon leading driver may yield already.
- Single driving drivers comparatively perform less willingness to give precedence than the drivers in vehicle platoon for the higher proportion in Not-yielding situations both in China and in Germany. But the explanations for the sharp proportion difference in Germany are similar as mentioned in the second point. The drivers in vehicle platoon may lose the control to give the right of way, and the driving behavior is obviously depending on the front driver.

The road user behavior in a VEH-PED conflict situation from the pedestrian side, the pedestrians probably do not “trust” the drivers in China. On the other hand, considered the driver’s attitude towards pedestrians, this “distrust” may be widely accepted by the drivers and it will be interpreted as the pedestrians’ giving up the right of way. As a result, the Chinese drivers could be emboldened to conduct a non-yielding behavior.

5.3 Driver deceleration rate choice

In the naturalistic traffic environment, when a motorist encounters a pedestrian and tries to press the brake pedal, the driver prefers to slowing down rather than stopping unless s/he is caught in a serious situation. This conflict event can be described as “pursuit — encounter — deceleration — undisturbed passage”. The driver evasive action in the deceleration phase is measured based on the trajectory data series.

5.3.1 Space histories of deceleration rate

The deceleration rate is one of the essential parts to describe the driver evasive action in conflict during the approaching process and it is also a basic parameter for the measures rating the severity of driver activity.

The average deceleration rates for each space section in the entire approaching process from the far side (of the road) to the potential conflict point are calculated. Fig.5-1 characterizes the average deceleration fluctuation with regard to the distance to the conflict point for all single vehicle conflict with pedestrians including both the yielding and not-yielding situations. It shows the vehicle driver will brake 30-40m away from the conflict point till approach 5m before the point, then the driver will slightly accelerate to pass the conflict point. The deceleration rate represents the available maneuver taken by the drivers at the moment they thought they could avoid a collision.

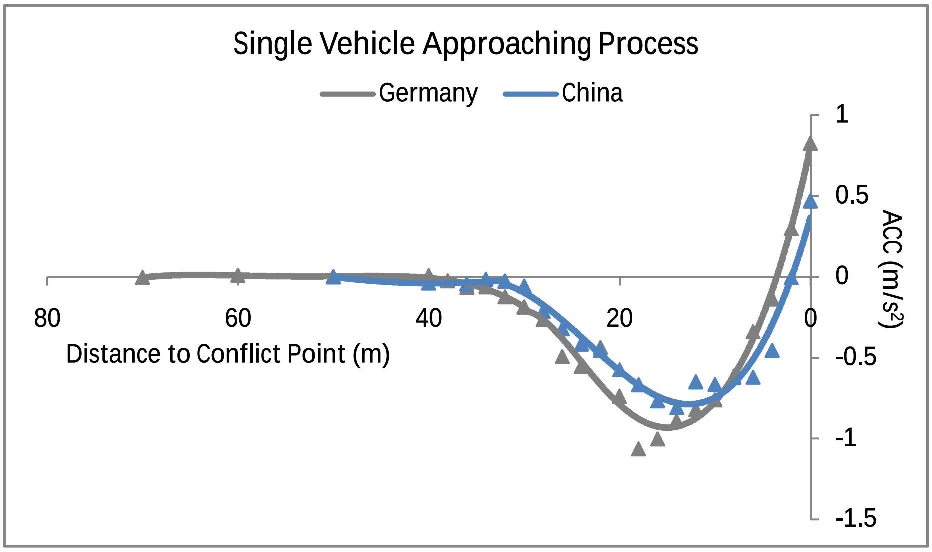


Fig.5-1 Space history of the average deceleration rate (all conflict situations)

- The average deceleration rate for Chinese drivers varies more smoothly than German drivers because in China the not-yielding drivers who may not conduct a considerable braking activity account for a large proportion and they may accelerate to avoid a collision, thus the average deceleration rate will be reduced.
- The maximum average deceleration rate will also be influenced by the not-yielding drivers in China and it is much lower than that in Germany.
- German drivers react to the conflict situation earlier than Chinese drivers and the average deceleration rate begins to increase at about 32m in front of the conflict point in China and 35-40m in Germany.

Fig.5-2 depicts the space history of the average deceleration rate for single vehicle conflicting with pedestrians in Germany. The real line is the average deceleration rate for all conflict situations and the dashed line is the rate in yielding situations. The large proportion of yielding drivers results in the approximate value of the two curves.

The following Fig.5-3 portrays the trend curve of the average deceleration in China. The same as Fig.5-2, the real line is the average deceleration rate for all conflict situations and the dashed line is the rate in yielding situations. The major differences between these two curves are the average deceleration rate and the acceleration when driving closed to the conflict point. As aforementioned, the average maximum deceleration rate in all conflict situations may be balanced by the not-yielding driver's acceleration pattern.

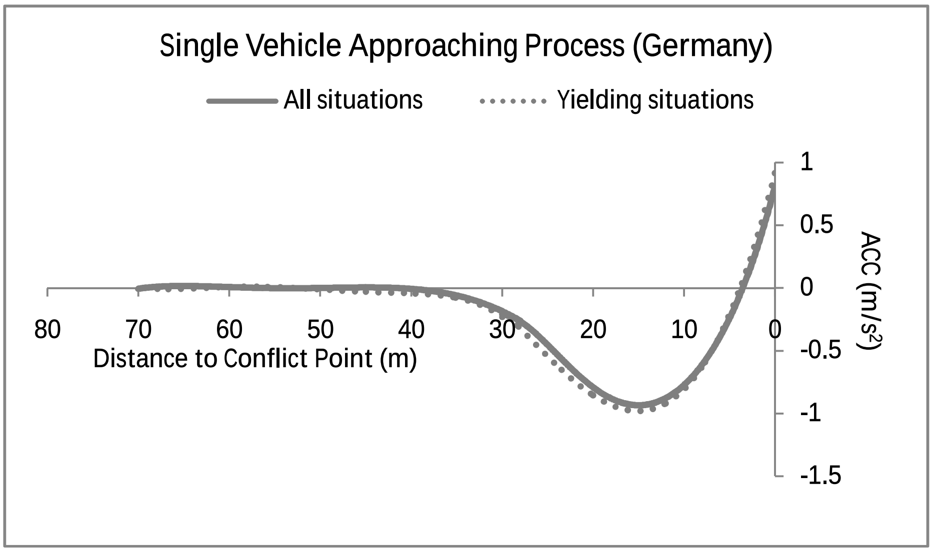


Fig.5-2 Space history of the average deceleration rate in Germany

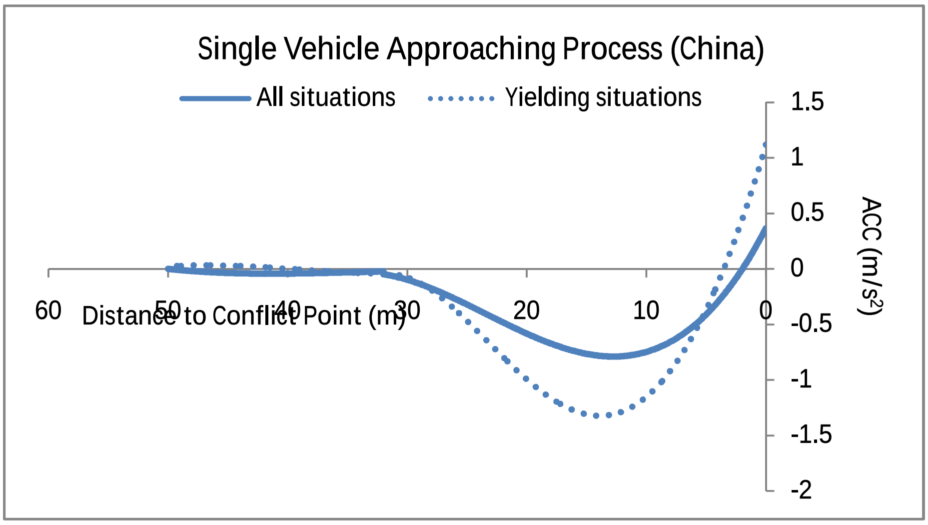


Fig.5-3 Space history of the average deceleration rate in China

Then the comparison of the yielding driver's average deceleration rate in approaching process is made and the trend curves are plotted in Fig.5-4. The differences between China and Germany are discussed as follows:

- The Severity of yielding behavior for German drivers is much less than

Chinese drivers and it implies the German drivers may press and release the brake pedal more softly. On the contrary, Chinese drivers prefer pressing the pedal harder.

- The maximum average deceleration rate is quite different. The data in China is higher than that in Germany.
- The start point of the deceleration in China is around 30m to the conflict point and in Germany it is in the section of 35-40m.
- The occurrence of the maximum deceleration in Germany is at 16-18m away from the conflict point, and in China it is getting 2m closer in the space section of 14-16m.
- Positions, where the driver starts to accelerate, are quite the same in these two countries and the Chinese drivers will choose a slightly larger acceleration.

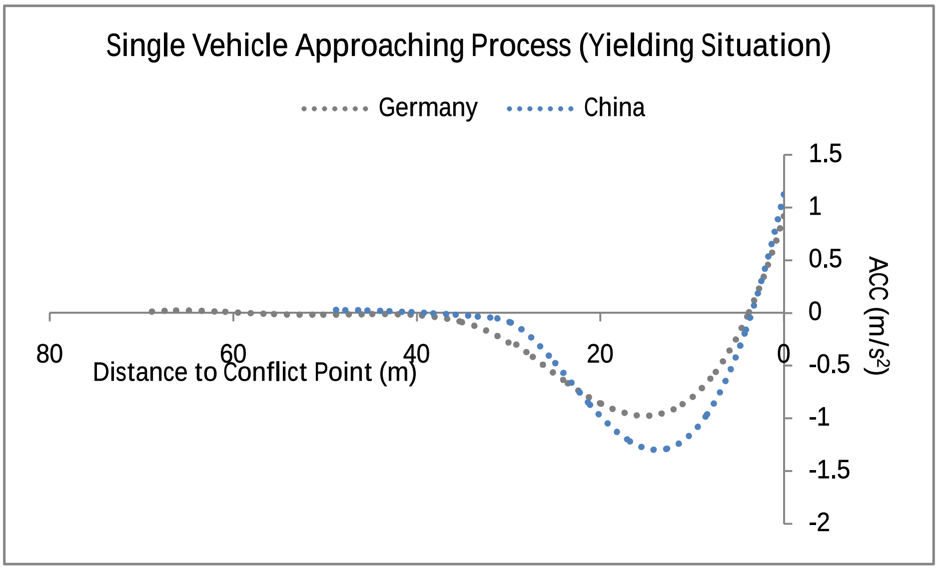


Fig.5-4 Space history of the average deceleration rate (yielding situations)

5.3.2 Maximum average deceleration rate

Chinese drivers exhibit aggressive driving behavior in yielding situations, which contributes to the differences of the maximum average deceleration rate. Fig.5-5 gives a comparison of this parameter between China and Germany in three situation categories.

As discussed in subsection **5.3.1**, the maximum average deceleration rate for all conflict situations in China is lower than that in Germany. And in yielding situations, Chinese data are 13-18% higher than German data. The higher the vehicle flow rate, the higher maximum average deceleration rate will be chosen by the drivers both in China and in Germany, and when the vehicle flow rate reaches 1500 pcu/h/d, the maximum average deceleration in yielding situations is 1.4 times of the data in all observed yielding situations.

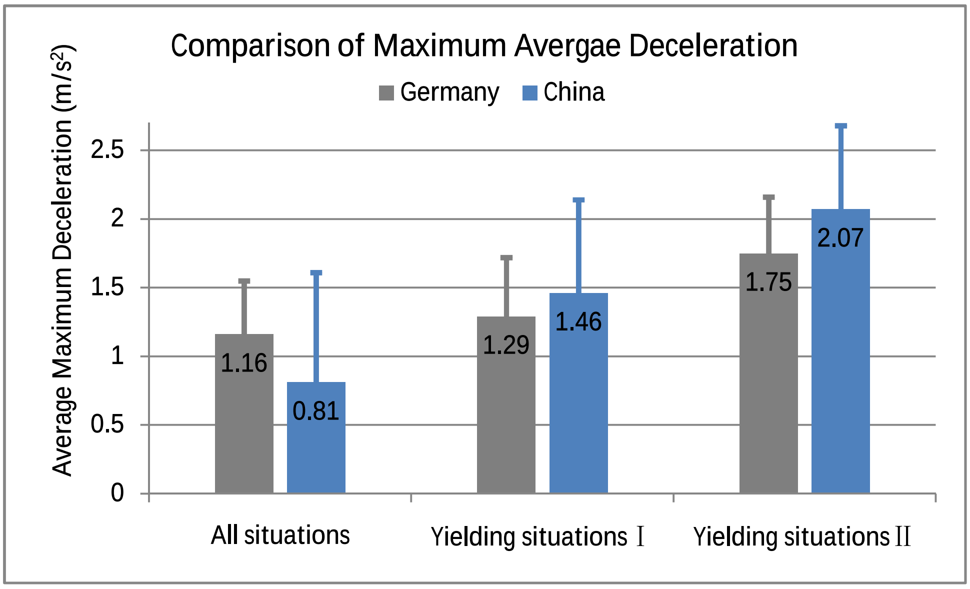


Fig.5-5 Comparison of the maximum average deceleration rate by situations

Yielding situation Ⅰ: All yielding situations

Yielding situation Ⅱ: Yielding situations when the vehicle flow rate is about 1500pcu/h/d

5.3.3 Deceleration rate related to situational factors

The deceleration rate which represents the severity of the driver braking behavior will be influenced by many factors. Here focus on the external traffic characteristics of the conflict participants, the time-/distance-related measures and speed are selected as the situational factors to discuss how the deceleration rate varies with the course of them.

The study found that when the drivers are involved in VEH-PED conflicts at higher speeds, they decelerated harder. And this result is similar to those of (Malkhamah, 2005; Horst, 1989,). In the approaching process, higher speed will lead to more severe conflicts because the time related measures like TTC will be lower and the driver has to brake harder to avoid a collision. Fig.5-6 plots the relationship between the deceleration rate and vehicle speed at the onset of the conflict situation considering that the drivers make evasive action by decelerating only (driver's accelerating not included, N=128 in China and N=124 in Germany). The deceleration rate is to a certain extent linearly related to the vehicle approaching speed and to a given vehicle speed, Chinese drivers will choose a higher deceleration rate.

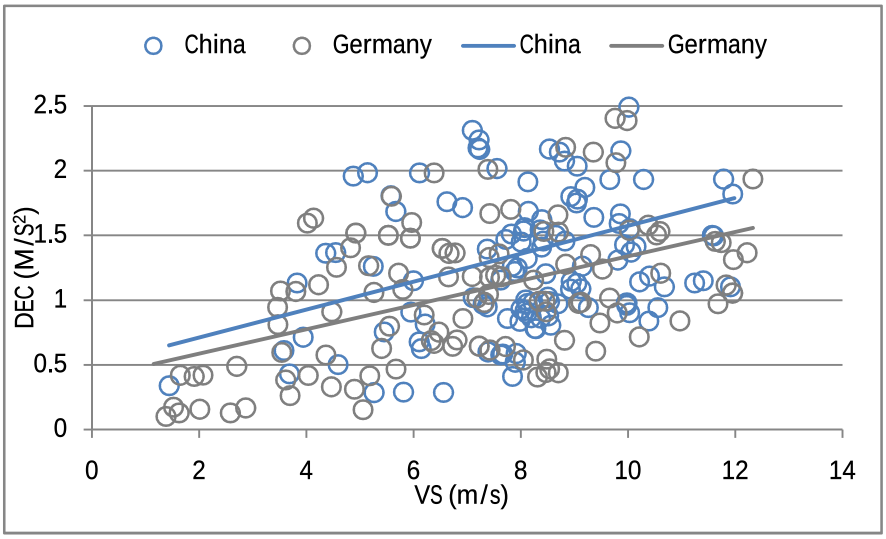


Fig.5-6 Relationship between DEC and VS

When the driver recognizes a pedestrian on the road, the distance measures which define the instantaneous position of the two conflict participants can be visually perceived by the drivers. Two distance measures, the vehicle longitudinal distance to the conflict point and the pedestrian lateral distance to the conflict point are selected to construct discrete points set corresponding to the deceleration rate.

The interactive maps with the vehicle longitudinal distance to the conflict point as its x-axis and the pedestrian lateral distance to the conflict point as its y-axis display the deceleration rate to a certain vehicle-pedestrian location (see Fig.5-7 (a) and (b)). The deceleration rate is denoted by color.

- The effective decelerating area (shadow part) for the driver in Germany has a wider spread compared with the China case. It indicates that the German drivers will response to the crossing pedestrians in a larger distance range, about 25m×8m in Germany versus 18m×7m in China.
- The furthest pedestrian lateral distance to trigger a braking reaction by the driver is 7-8m, but the German driver will consider a further pedestrian.
- Harder braking occurs when the vehicle is 15-18m away from the conflict point and the pedestrian is about 2-5m to the conflict point in China, however, in Germany, it will take place along the pedestrian-driver angle at 0.1-0.2rad with the pedestrian 2-7m and the vehicle 10-25m to the conflict point.

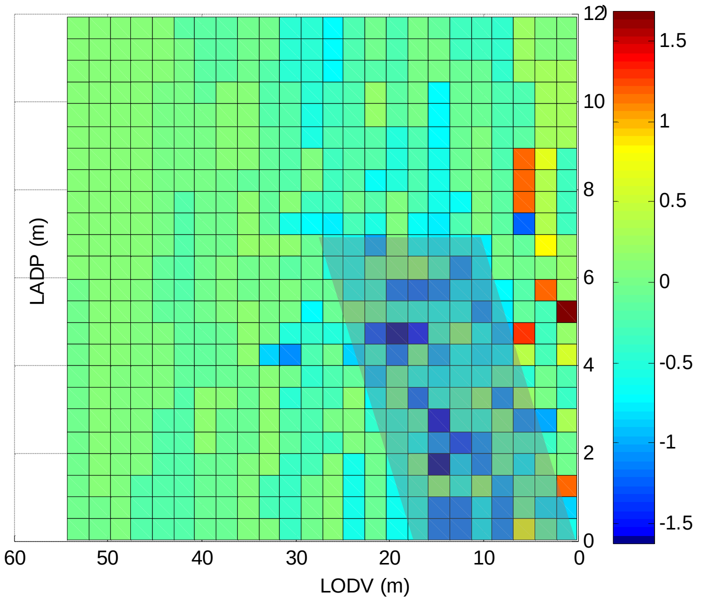


Fig.5-7 (a) DEC related to LODV and LADP in China

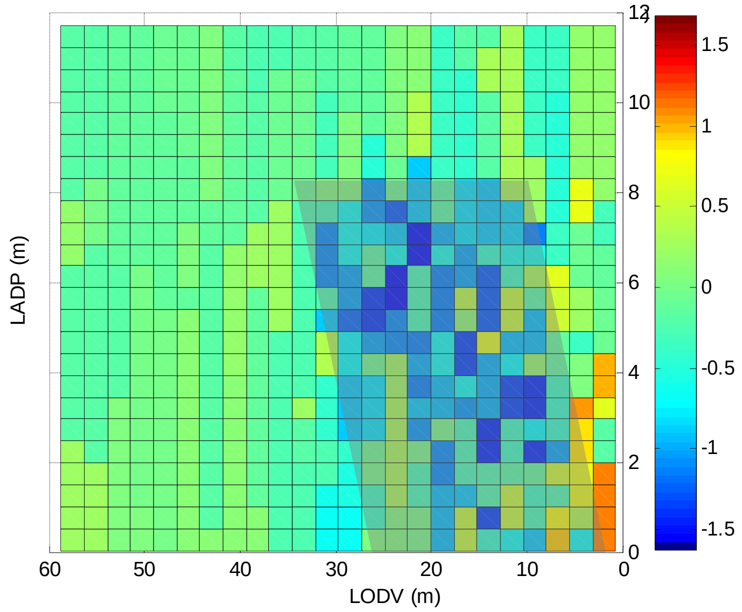


Fig.5-7 (b) DEC related to LODV and LADP in Germany

The time-related measures, vehicle time to conflict point and pedestrian time to conflict point are considered in analysis on the combination influence to the deceleration rate. Fig.5-8 (a) and (b) depict the DEC influenced by the $TTCP_{\_VEH}$ and $TTCP_{\_PED}$. The dashed line is the theoretical occurrence of the conflict ($TTCP_{\_VEH}$=$TTCP_{\_PED}$).

- Because most of the German conflict process can be defined as the drivers yielding to non-stop pedestrians, the shadow area covering blue grids on the map forms a relatively regular choice set for deceleration.

- Although the common cases that the drivers passing through the yielding pedestrians account for a great proportion in China, the other conflict situations generated from the binary choice (yielding or not-yielding) for both the pedestrians and drivers should not be ignored. As a result, the deceleration grids and acceleration grids in Fig.5-8 (a) spread over the shadow area and no exact relations can be obtained.

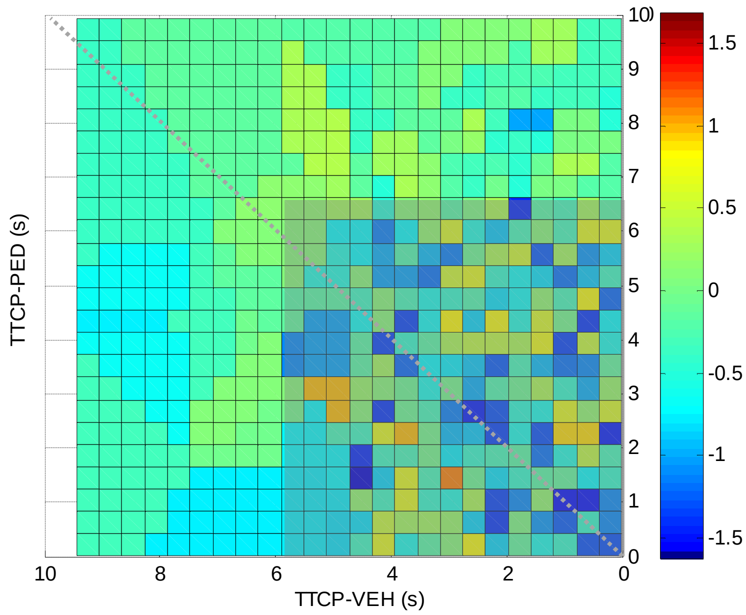


Fig.5-8 (a) DEC related to $TTCP_{\_VEH}$ and $TTCP_{\_PED}$ in China

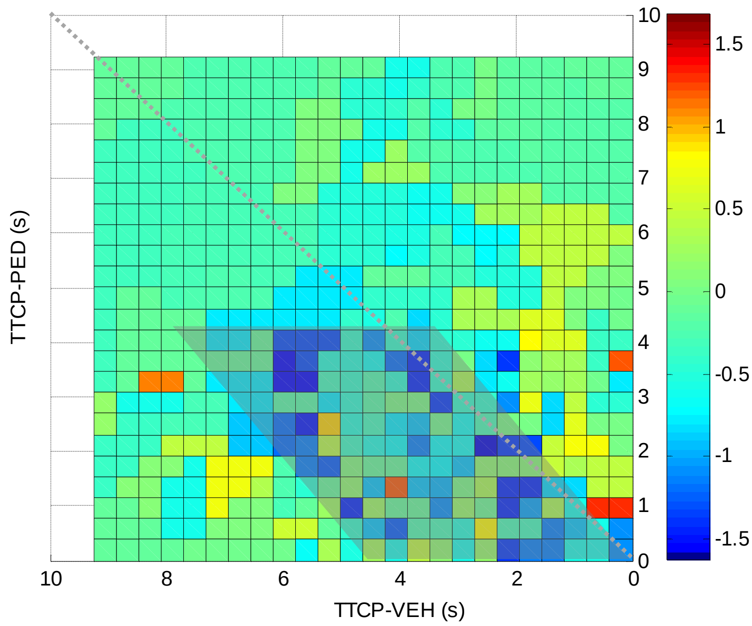


Fig.5-8 (b) DEC related to $TTCP_{\_VEH}$ and $TTCP_{\_PED}$ in Germany

5.4 Accelerating to avoid collision

Speeding up to avoid a collision in China is a frequent maneuver taken by the driver. By accelerating to get the right-of-way, the driver may not be caught in the traffic delay or even forced to stop. It is a common evasive action which can be observed when the pedestrians slow down and probably plan to wait for crossing. Fig.3-4 in the previous subsection illustrates this acceleration phase. Fig.5-9 plots the acceleration distribution at the onset of the conflict situation considered the drivers make evasive action by accelerating only. The average acceleration rate is $1.19m/s^2$ with the std. $0.91m/s^2$.

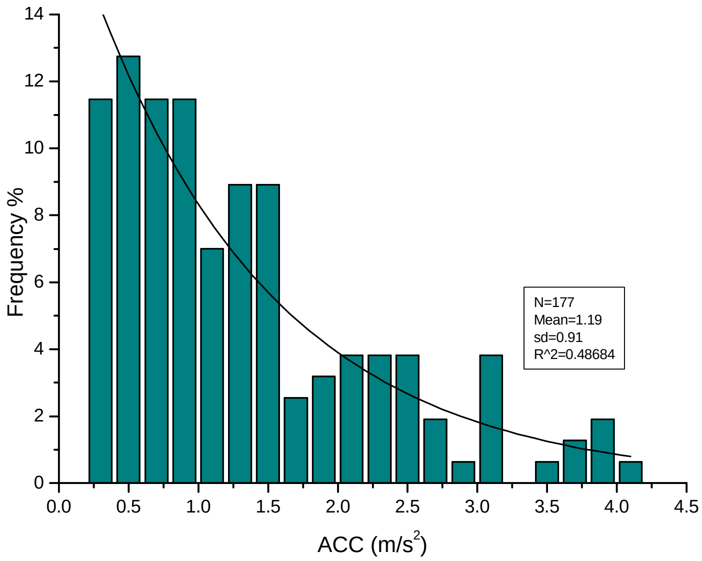


Fig.5-9 Frequency distribution of ACC at onset of conflict

5.5 Relationship between TTC and VEH-based parameters

TTC is proved to be affected by some traffic parameters in vehicle-vehicle conflict especially in the car-following phase. These parameters like the vehicle speed, headway, deceleration, visual angle, etc. (Vogel, 2003; Van Winsum, 1996; Cooper, 2002; Green, 2009) In Chapter 4 the TTC influenced by the PED-based parameters are discussed and in this chapter the VEH-based parameters are drawn for analyzing the relationship.

It is intuitive that the TTC varies over the vehicle longitudinal distance to the conflict point in Fig.5-10. Similar to the relationship between TTC and LADP, the TTC decreases during the vehicle approaching process and the curves in the two countries are quite similar. At a given distance, TTC for Chinese cases is 0.2s higher.

TTC corresponding to the vehicle speed is plotted in Fig.5-11. Intriguing, this trend is opposite to that observed in the relationship between TTC and the pedestrian speed.

The higher the vehicle speed, the larger TTC is.

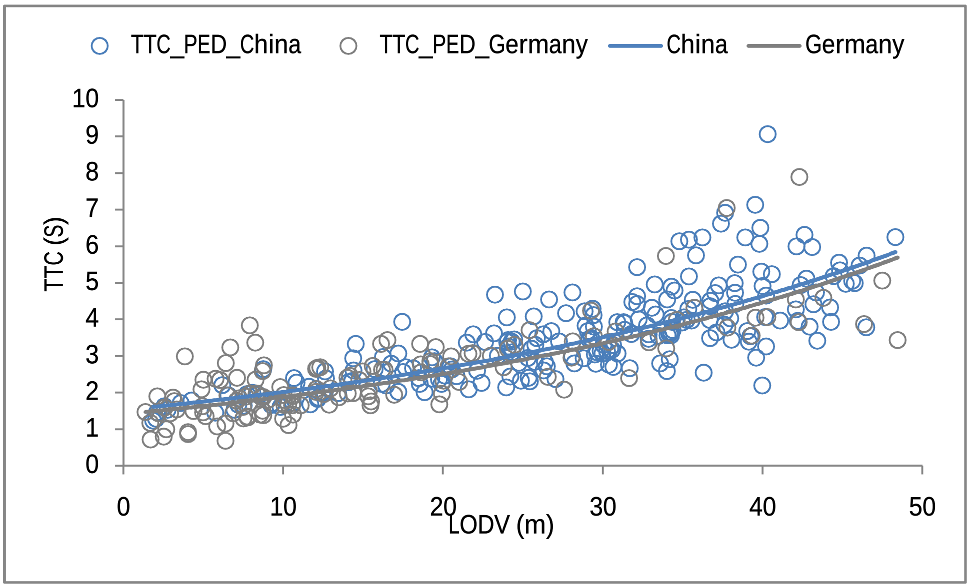


Fig.5-10 Relationship between TTC and LODV

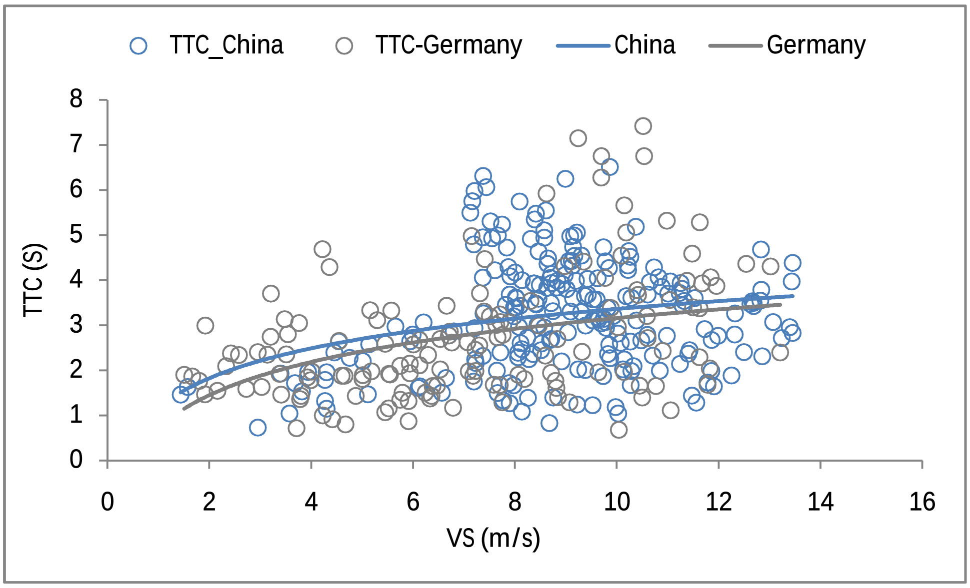


Fig.5-11 Relationship between TTC and VS

The following two figures, Fig.5-12 (a) and Fig.5-12 (b) are the TTC-DEC relationship with different vehicle speeds in China and in Germany respectively. The fitting curves shows the smaller TTC occurs when the driver choose a harder braking, whereas a larger TTC is corresponding to the lower DEC. When the DEC stays constant, the driver at a lower speed is expected to be in a comparatively safer conflict condition for the TTC is larger than that of the driver with higher speed. From the two figures, it can be recognized that the difference among the vehicle speed categories in China is more obvious than that in Germany.

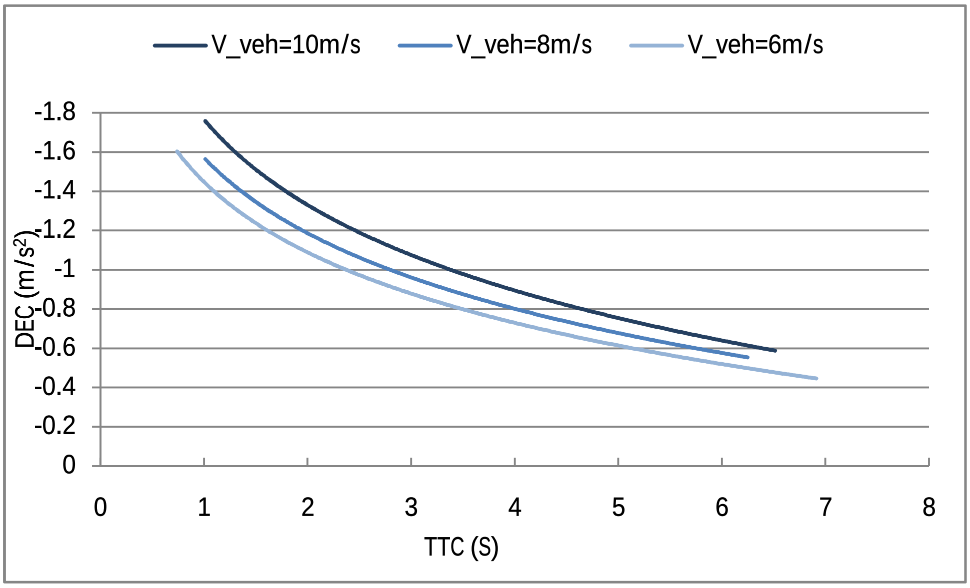


Fig.5-12 (a) TTC-DEC relationship with different vehicle speed in China

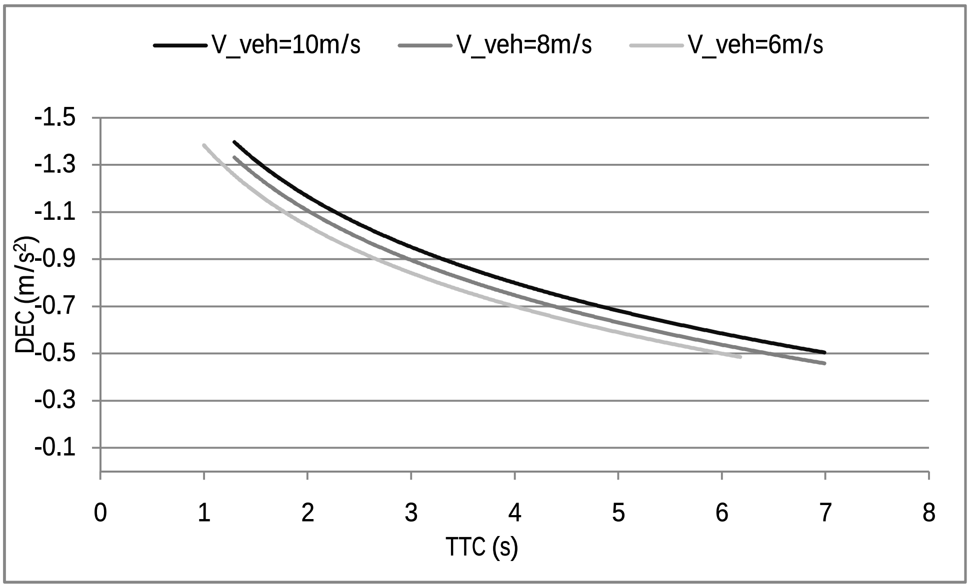


Fig.5-12 (b) TTC-DEC relationship with different vehicle speed in Germany

5.6 Driver behavior in conflict with non-compliance PED

Considered the significant large proportion of the driver error resulting in traffic accidents and a noticeable pedestrian traffic violation, how can we imagine such a situation that a driver conducts an incorrect maneuver in response to a redcrossing pedestrian at urban traffic environment? This kind of traffic event needs to be highlighted in the cultural adaptation.

5.6.1 Deceleration rate performance

The average deceleration rate in each space section in conflict with non-compliance pedestrians has been statistically calculated and a comparison between unsignalized normal conflict situations and non-compliance situations has been made. The following two figures characterize the average deceleration fluctuation with regard to the vehicle longitudinal distance to the conflict point. In Fig.5-13 the fitting curves illustrate the deceleration rate in all situations related to pedestrians' unsignalized crossing and redcrossing. While in Fig.5-14, the drivers' yielding situations are discussed.

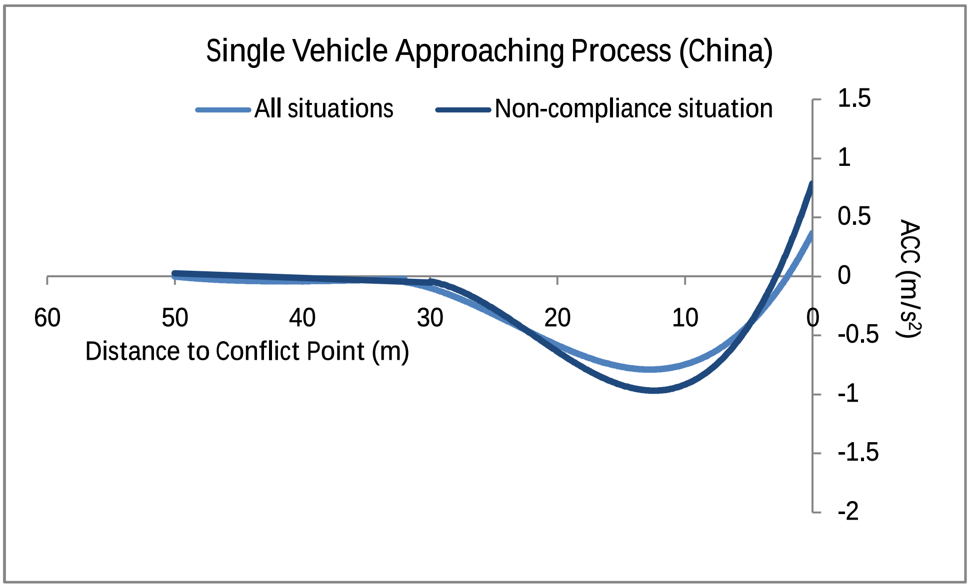


Fig.5-13 Comparison between all situations and non-compliance situations

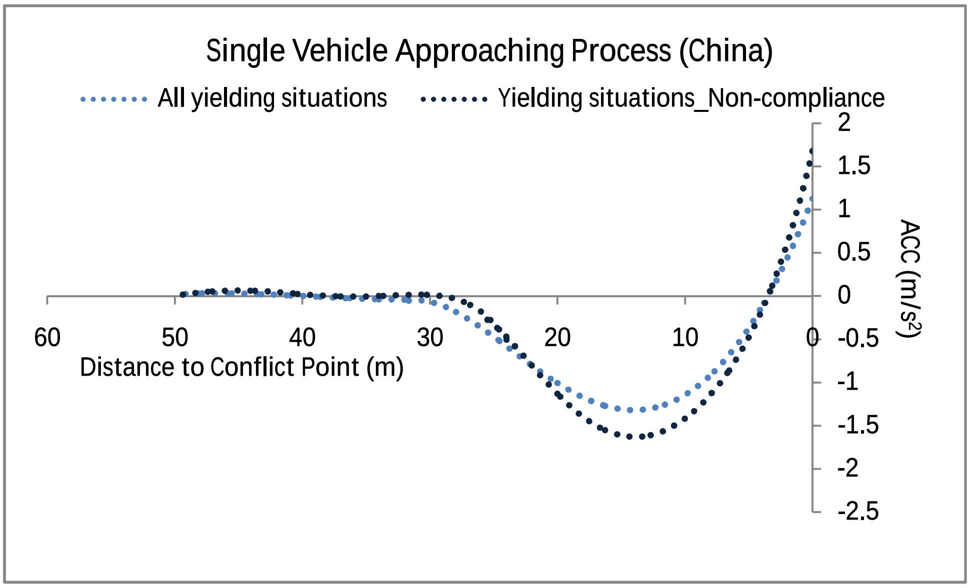


Fig.5-14 Comparison between all yielding situations and yielding situations with non-compliance

- Severe driver braking activities can be found in conflict with the redcrossing pedestrians for the slope of the non-compliance fitting curves (deep blue) in both figures are larger.
- In non-compliance situation, similar to what has been discussed in subsection 5.3.1, the deceleration rate will be compensated with the acceleration caused by the driver speeding up to pass through the crosswalk. It results in a smoother fitting curve compared with the yielding situation.
- It can be distinguished that the distance where the braking starts to work in non-compliance conflict situations is shorter to the conflict point than that in unsignalized conflict situations especially in the yielding phase.
- Drivers in non-compliance situation conduct a higher maximum average deceleration rate in comparison with the unsignalized conflict situations. Fig.5-15 shows a 20% increase in the non-compliance situations.

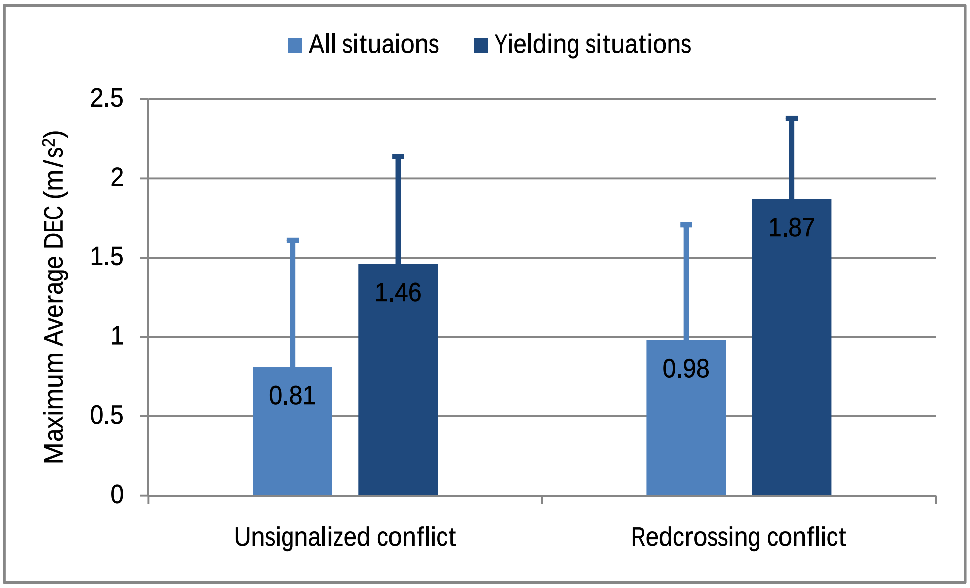


Fig.5-15 Maximum average DEC performance

5.6.2 TTC in pedestrian con-compliance situation

Considered the critical situation with the redcrossing pedestrians, TTC will perform quite different with the normal conflict situation. Fig.5-16 elaborates the frequency distribution of the TTC in conflict with non-compliance pedestrian phases in China(N=82), and it fits the Weibull distribution with R^2=0.983. According to the statistics, the mean of TTC is 2.07s with the standard deviation of 0.73s and the minimum TTC is 1.09s. Compared with the average TTC in general VEH-PED conflict situations in China, the average TTC in noncompliance phase is 34% lower and the minimum TTC is quite the same.

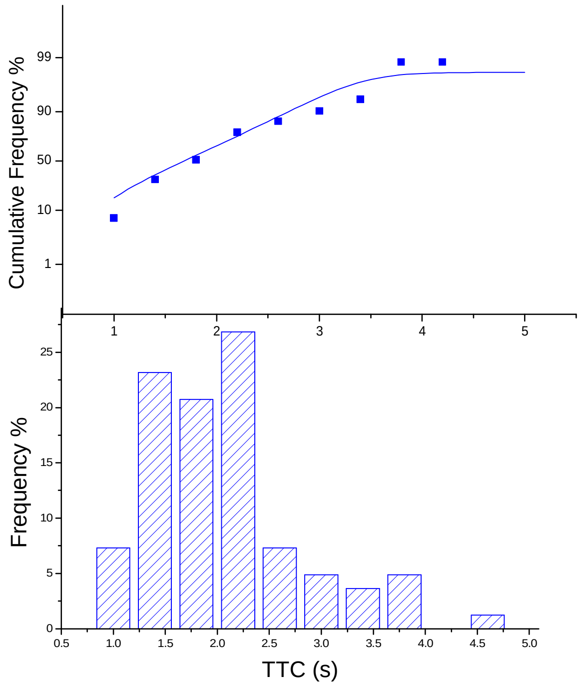


Fig.5-16 Frequency distribution of TTC in non-compliance phase

5.7 Summary

According to the field observation, driver behavior comparison in VEH-PED conflict can be summarized in many aspects within which the yielding behavior is the most significant one. Almost all German drivers will give precedence to the crossing pedestrian in conflict situations, but the situation is totally different in China. And this will cause the accelerating collision avoidance phase compensating the deceleration rate to form a smooth curve of DEC in China by all conflict situations considered. By 2-D interpolation function and curve fitting, the relationship among DEC and situational measures have been intercultural discussed. Meanwhile, the variation trend of TTC related to DEC and VS have also been estimated. Special cases in China, driver behavior in non-compliance situations are further examined to identify safety problems in this situation.

6 BEHAVIORAL MODELING IN VEH-PED CONFLICT AND CONFLICT INDICATOR ANALYSES

6.1 Introduction

The chapter aims to describe the conflict behavior at a quantitative level. The binary logit model based on the situational factors is applied to modeling the driver's yielding behavior to the conflict pedestrian and intercultural comparison is made for the effect of model variables to the yielding decision in **section 6.2**. Pedestrian waiting time based on Weibull distribution is discussed in **section 6.3**. **Section 6.4** introduces two traffic conflict indicators which can be used in the traffic conflict discrimination and conflict evaluation.

6.2 Yielding behavior modeling

6.2.1 Binary Logit Model (BLM)

Considered the hazardous process work with interpretation of the situation and decision making, the driver may face the situational causations for the decision of yielding behaviour. When a pedestrian or pedestrian groups present to be in crossing phase and a potential conflict may occur, the driver should process both the conflict participants' states and make evasive decision to avoid collision. In this case, the situational factors have to been detected, characterized and processed for decision-making. The final decision made by the driver can only be the binary choice: giving precedence or not. The BLM which has two discrete choices (generally 1 and 0) as its dependent variable can be applied in the study. The probability of choosing either choice is based on a utility function:

$$U_i = \beta_0 + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_n x_n = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \qquad \text{Eq.6-1}$$

Where, U_i is the utility of choosing alternative *i*;
β_{in} is the coefficient;
i is the number of alternatives;
n is the number of the independent variables.

Then the model in terms of odds can be written as:

$$\text{Logit}[P(i = 1)] = \log\left(\frac{P(i = 1)}{1 - P(i = 1)}\right) = \beta_0 + \sum_{i=1}^{n} \beta_i x_i \quad \text{Eq.6-2}$$

Or in term of the probability of the outcome:

$$P(i = 1) = \frac{1}{1 + exp^{-U_i}} \quad \text{Eq.6-3}$$

6.2.2 Driver yielding behavior based on BLM

Single driving case

Four situational factors as model attributes have been conducted in the binary logit model to predict the pedestrians' yielding behaviour in the single vehicle-pedestrian conflict situation:

- *PS: m/s, in crossing state;*
- *VS: m/, in single driving;*
- *Lateral Distance of the Pedestrian to the Conflict Point (LADP), m;*
- *Longitudinal Distance of the Vehicle to the Conflict Point (LODV): m*

The discrete choice set (1, 0) is defined as the output of the model, with 1 for the decision of yielding to the crossing pedestrian and 0 for not yielding. The utility function for this model is expressed by:

$$U_1 = \beta_0 + \beta_1 \cdot PS + \beta_2 \cdot VS + \beta_3 \cdot LADP + \beta_4 \cdot LODV \quad \text{Eq.6-4}$$

After logistic regression according to the observed field data, the probability of yielding can be predicted in Eq.6-5 and Eq.6-6.

Single vehicle conflict with the crossing pedestrian in China:

$$P(i = 1) = \frac{1}{1 + exp\,(-5.020 + 1.272PS + 0.121VS - 1.339LADP + 0.147LODV}] \quad \text{Eq.6-5}$$

Single vehicle conflict with the crossing pedestrian in Germany:

$$P(i = 1) = \frac{1}{1 + exp\,(7.332 - 0.587PS - 0.612VS - 0.644LADP + 0.189LODV}] \quad \text{Eq.6-6}$$

Platoon driving case

When the conflict participants turn to the crossing pedestrian and the vehicle in platoon, then the following four factors are selected:

- *PS: m/s, in crossing state;*

- *VS: m/, in platoon driving;*
- *Lateral Distance of the Pedestrian to the Conflict Point (LADP), m;*
- *Longitudinal Distance of the Vehicle to the Conflict Point (LODV): when the driver is in platoon driving and may conflict with crossing pedestrians, if the vehicle in front is just safely passing the pedestrian, then the subject driver will encounter the pedestrian directly. In this case, the value of LODV is in the distance set [0, Gap in Distance], m.*

The probability of the driver yielding behavior can be calculated by Eq.6-7 and Eq.6-8.

Vehicle in platoon conflict with the crossing pedestrian in China:

$$P(i = 1) = \frac{1}{1 + exp\,(3.624 + 0.324PS - 0.272VS - 1.241LADP + 0.051LODV}] \quad \text{Eq.6-7}$$

And vehicle in platoon conflict with the crossing pedestrian in Germany:

$$P(i = 1) = \frac{1}{1 + exp\,(8.204 - 0.442PS - 0.533VS - 2.423LADP + 0.452LODV}] \quad \text{Eq.6-8}$$

6.2.3 Parameter analyses and intercultural comparison

Tab.6-1 and Tab.6-2 label the independent variables in the equations, PS, VS, LADP and LODV with the coefficients, the Wald test statistic with associated p-values, and they also give the percentage correct and Nagelkerke's R^2 value of the model. It is predicted that the accuracy of the models amounts to 90% .

The Nagelkerke modification that does range from 0 to 1 is a more reliable measure of the relationship. Nagelkerke's R^2 will normally be higher than the Cox and Snell measure which are not listed here. Nagelkerke's R^2 is the most-reported of the R-squared estimates. For example in Tab.6-1, it is 0.628, indicating a relatively moderately strong relationship of 62.8% between the predictors and the prediction.

Tab. 6-1 Comparison of the logit model estimation in single driving case

	China			Germany		
	B	**Wald**	**Sig.**	**B**	**Wald**	**Sig.**
PS	1.272	13.710	.000	-.587	2.197	.138
VS	0.121	1.700	.192	-.612	41.465	.000
LADP	-1.339	51.099	.000	-.644	19.031	.000
LODV	0.147	26.193	.000	.189	33.571	.000
Percentage Correct		97.5			94.1	
Nagelkerke R Square		0.628			0.675	

From Tab. 6-1, in single driving case, the variables PS, LADP and LODV are significant in modeling the Chinese driver samples compared with the variables PS, LADP and LODV statistically significant for German samples.

The effect of VS to the drivers' yielding behavior is non-significant (Sig.>0.05) in China and it can be explained as in the entire yielding decision considerations, the vehicle movement factors do not stand an essential part. However in Germany, the non-significant variable is PS. According to the observation, most of German drivers will yield to pedestrians in conflict situation. Therefore, it is instructive to note that to a certain extent, the drivers make the yielding decision regardless of the variation of the pedestrian crossing speed.

The results of the model variables analyses in platoon driving (Tab. 6-2) do not show such a difference as Tab.6-1 depicts. When pedestrian group prepare to cross the road, their crossing speed is not the top consideration in drivers' decision-making phase both in China and Germany.

Tab. 6-2 Comparison of the logit model estimation in platoon driving case

	China			Germany		
	B	**Wald**	**Sig.**	**B**	**Wald**	**Sig.**
PS	.324	2.240	.134	-.442	.154	.695
VS	-.272	29.370	.000	-.533	4.536	.033
LADP	-1.241	157.063	.000	-2.423	7.972	.005
LODV	.051	21.860	.000	.452	7.792	.005
Percentage Correct		91.9			94.5	
Nagelkerke R Square		0.690			0.850	

6.3 Waiting time model

6.3.1 Weibull distribution

The gap in VEH-PED conflicts can be considered as a surrogate measure to describe the arrival of the conflict vehicle compared with the headway based on the gap definitions in 3.2.1 and 4.4. In order to model the pedestrian crossing behavior, further investigations need to be given in the vehicle gap/headway distributions. According to the Weibull distribution, the probability distribution of the gap less than or equal to the critical gap fits the following equation (Wang, 2004).

$$P(h \leq \tau) = 1 - exp\left[-\left(\frac{\tau - \gamma}{\beta - \gamma}\right)^{\alpha}\right] \qquad \text{Eq.6-9}$$

$$\gamma \leq \mathrm{t} < \infty, \alpha > 0, \beta > 0, \gamma \geq 0, \beta > \gamma$$

Where, $P(h \le \tau)$ is the probability of gap less than or equal to the critical gap;

h denotes the gap of two successive vehicles;

τ denotes the critical gap of two successive vehicles;

And, α is the shape parameter of the distribution;

β is the scale parameter of the distribution;

γ is the location parameter of the distribution.

Based on the probability theory and calculus, the probability density function of the gap is:

$$f(\tau) = \big(P(h \le \tau)\big)' = \begin{cases} \frac{\alpha}{\beta-\gamma}\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right], & \tau \ge 0 \\ 0 \quad , & \tau < 0 \end{cases} \qquad \text{Eq.6-10}$$

Where, $f(\tau)$ is the probability density at τ.

In Weibull distribution, when α=1, β=1 and γ=0, the probability distribution can be simplified as,

$$P(h \le \tau) = 1 - exp(-\tau) \qquad \text{Eq.6-11}$$

which fits the negative exponent distribution with γ=1.

When α=1, β=1 and $\gamma \neq 0$, the probability distribution can be simplified as,

$$P(h \le \tau) = 1 - exp\,[(\tau - \gamma)] \qquad \text{Eq.6-12}$$

And it shows the shifted negative exponent distribution with γ=1 is a special case of Weibull distribution. Consequently, the Weibull distribution can be widely applied.

To create the Weibull distribution model, parameter calibration should be taken. In accord with probability theory, the integral over the domain of probability density function equals 1.

$$\int_0^{\infty} f(h) d_h = 1 \qquad \text{Eq.6-13}$$

While,

$$\int_0^{\infty} f(h) d_h = \int_0^{\infty} \frac{\alpha}{\beta-\gamma}\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h$$

Eq.6-14

$$= exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]_{\infty}^{0} = exp\left[-\left(\frac{-\gamma}{\beta-\gamma}\right)^{\alpha}\right]$$

Thus,

$$exp\left[-\left(\frac{-\gamma}{\beta-\gamma}\right)^{\alpha}\right] = 1$$ Eq.6-15

From the mathematical statistics, the first sample moment about the origin is the mean of the random variable and the second sample moment about the origin is the variance of random variable. Then the following functions exist.

$$A_1 = \int_0^{\infty} h f(h) d_h$$

$$A_2 = \int_0^{\infty} h^2 f(h) d_h$$

Where, A_1 is the first sample moment about the origin;
A_2 is the second sample moment about the origin;
$\int_0^{\infty} h f(h) d_h$ is the mean of the random variable;
$\int_0^{\infty} h^2 f(h) d_h$ is the variance of random variable.

Then,

$$\int_0^{\infty} h f(h) d_h$$

$$= \int_0^{\infty} h \frac{\alpha}{\beta-\gamma}\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h$$

$$= h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Bigg|_{\infty}^{0} + \int_0^{\infty} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h$$

$$= h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Bigg|_{\infty}^{0} + \frac{\beta-\gamma}{-\alpha} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{\alpha}\Bigg|_{0}^{\infty}$$

$$= \frac{\beta-\gamma}{\alpha} exp\left[-\left(\frac{-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}$$

and

$$\int_0^{\infty} h^2 f(h) d_h$$

$$= \int_0^{\infty} h^2 \frac{\alpha}{\beta-\gamma}\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h$$

$$= h^2 \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Bigg|_{\infty}^{0} + 2\int_0^{\infty} h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h$$

$$= h^2 \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Bigg|_{\infty}^{0}$$

$$+ 2\frac{\beta-\gamma}{-\alpha}\left(h \times \left[exp\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Bigg|_{0}^{\infty} - \int_0^{\infty} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] d_h\right)$$

$$= 2\left(\frac{\beta-\gamma}{\alpha}\right)^2 \left[exp\left(\frac{-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}$$

$$A_1 = \frac{1}{n}\sum_{i=1}^{n} X_i$$

$$A_2 = \frac{1}{n}\sum_{i=1}^{n} X_i^2$$

Accordingly,

$$\frac{\beta-\gamma}{\alpha}\left[exp\left(\frac{-\gamma}{\beta-\gamma}\right)\right]^{-\alpha} = \frac{1}{n}\sum_{i=1}^{n} X_i \qquad \text{Eq.6-16}$$

$$2\left(\frac{\beta-\gamma}{\alpha}\right)^2\left[exp\left(\frac{-\gamma}{\beta-\gamma}\right)\right]^{-\alpha} = \frac{1}{n}\sum_{i=1}^{n} X_i^2 \qquad \text{Eq.6-17}$$

Solving simultaneous equations Eq.6-15, Eq.6-16 and Eq.6-17, the parameters α, β and γ can be calibrated.

6.3.2 Application of Weibull distribution

By data discretization to the gaps, frequency distribution of the gaps can be deduced. Weibull distribution functions are applied to the data fitting. The results indicate that the gaps follow the probability distribution of $P(h \le \tau) = 1 - exp\,(-\frac{\tau}{3.31})$ in China and $P(h \le \tau) = 1 - exp\,(-\frac{\tau}{4.67})$ in Germany (Fig.6-1 and Fig.6-2 respectively) through the Chi-squared test at a significance level of 0.05.

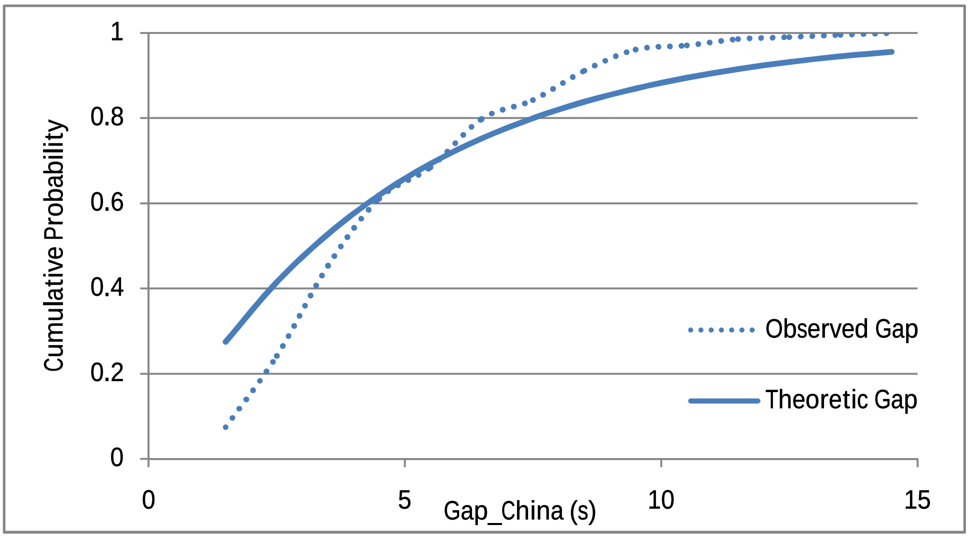


Fig.6-1 Weibull distribution of gap in China

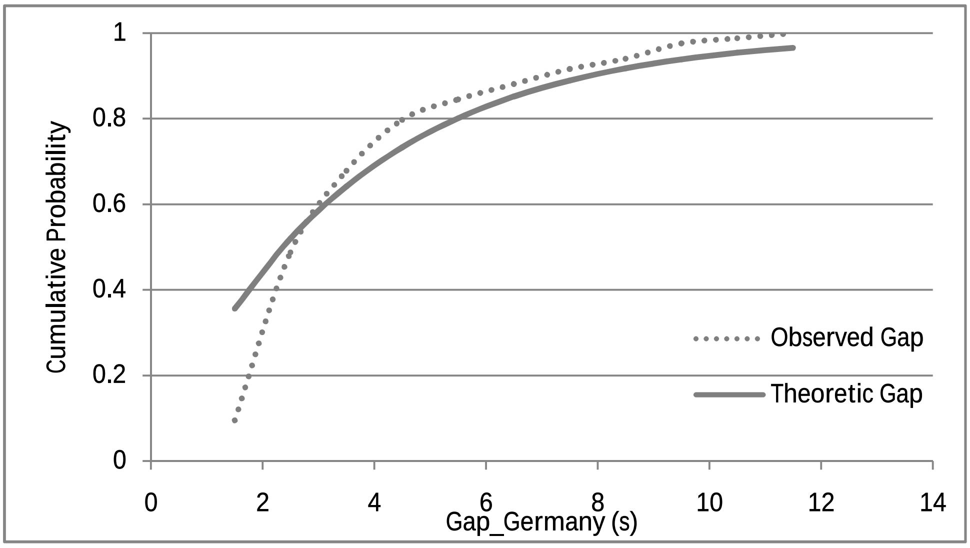


Fig.6-2 Weibull distribution of gap in Germany

6.3.3 Pedestrian waiting time based on Weibull distribution

The gap is proved to fit the Weibull distribution with the parameters α, β and γ in previous subsection. The average pedestrian waiting time at gap h and critical gap τ can be calculated in two different conditions.

(1) When the gap is smaller than the critical gap τ, the average pedestrian waiting time is given by:

$$\overline{h_x} = \frac{q\int_0^\tau hf(h)dh}{q\int_0^\tau f(h)dh}$$

$$= \frac{\int_0^\tau h \frac{\alpha}{\beta-\gamma}\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] dh}{\int_0^\tau \frac{\alpha}{\beta-\gamma}\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha-1} exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] dh}$$

$$= \frac{h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\tau^0 + \int_0^\tau exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] dh}{exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\tau^0}$$

And,

$$\int_0^\tau exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right] dh$$

$$= \int_0^\tau \left[\exp\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{-\alpha} dh$$

$$= \int_0^\tau (\beta-\gamma)\left[\exp\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{-\alpha-1} d\exp\left(\frac{h-\gamma}{\beta-\gamma}\right)$$

$$= \frac{\beta-\gamma}{-\alpha}\left[exp\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}\Big|_0^\tau$$

Therefore,

$$\overline{h_x} = \frac{h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\tau^0 + \frac{\beta-\gamma}{-\alpha}\left[exp\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}\Big|_0^\tau}{exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\tau^0}$$

$$= \frac{-\tau \times exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right] - \frac{\beta-\gamma}{\alpha}\left[exp\left(\frac{\tau-\gamma}{\beta-\gamma}\right)\right]^{-\alpha} + \frac{\beta-\gamma}{\alpha}\left[exp\left(\frac{-\gamma}{\beta-\gamma}\right)\right]^{-}}{exp\left[-\left(\frac{-\gamma}{\beta-\gamma}\right)^{\alpha}\right] - exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]} \quad \text{Eq.6-18}$$

(2) When the gap is larger than the critical gap τ, the average pedestrian waiting time is given by:

$$\overline{h_d} = \frac{q\int_\tau^\infty hf(h)dh}{q\int_\tau^\infty f(h)dh}$$

$$= \frac{h \times exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\tau^\infty + \frac{\beta-\gamma}{-\alpha}\left[exp\left(\frac{h-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}\Big|_\tau^\infty}{exp\left[-\left(\frac{h-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\Big|_\infty^\tau}$$

$$= \frac{-\tau \times exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right] + \frac{\beta-\gamma}{\alpha}\left[exp\left(\frac{\tau-\gamma}{\beta-\gamma}\right)\right]^{-\alpha}}{exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]} \qquad \text{Eq.6-19}$$

The probability of pedestrians crossing the road is equal to the probability when $h > \tau$. This probability is given by:

$$P = P(h > \tau) = exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right] \qquad \text{Eq.6-20}$$

The probability that the pedestrian has to wait for k gaps can be achieved by

$$P(x = k) = \left\{1 - exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\right\}^{k} \times exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right] \qquad \text{Eq.6-21}$$

Then the average number of gaps $\bar{x}$ can be deduced as follows:

$$\bar{x} = \sum_{k=1}^{\infty} k\left\{1 - exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]\right\}^{k} exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]$$

$$= \frac{1 - exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]}{exp\left[-\left(\frac{\tau-\gamma}{\beta-\gamma}\right)^{\alpha}\right]} \qquad \textit{Eq.6-22}$$

In view of the average number of gaps the pedestrian has to wait and the average waiting time to certain gap *h*, the whole waiting time for crossing is the multiplication of these two values in Eq.6-23.

$$d = \bar{x} \times \overline{h_x} \qquad \text{Eq.6-23}$$

According to the Weibull distribution function in China, the three parameters α, β and γ are equal to 1, 3.31 and 0 respectively. Assuming that the critical gap is τ=5s, the average pedestrian waiting time in the situation can be derived as 7.77s. Compared with the field conflict observation with 5s as the critical gap for the pedestrians deciding to wait or not, the average waiting time for single pedestrian in conflict situation is 7.20s. The model makes an error of 6.9% in describing the pedestrian waiting behavior.

6.4 Traffic conflict indicator analyses

6.4.1 Minimum VEH-PED distance

In the VEH-PED conflict analysis, the road users are simplified as two points (the midpoint of the front bumper for the vehicles). In the rectangular plane coordinate system shown in Fig.6-3, according to the kinematic theories, the trajectory of the road users $x_i(t)$, $y_i(t)$ (*i*=1,2) can be expressed as

$$x_i(t) = x_i(0) + \int_{t_0}^{t}(v_i(0) + \int_{t_0}^{t} a_i(t)dt)dt \cdot cos\theta_i \qquad \text{Eq.6-24}$$

$$y_i(t) = y_i(0) + \int_{t_0}^{t}(v_i(0) + \int_{t_0}^{t} a_i(t)dt)dt \cdot sin\theta_i \qquad \text{Eq.6-25}$$

Where, $x_i(0)$, $y_i(0)$ denote the positions of the two road users at time 0;
$x_i(t)$, $y_i(t)$ denote the position of the two road users at time *t*;
θ_i is the angle between the road user movement direction and x-axis positive direction;
$v_i(t)$ denotes the velocity of the road user at time t;
$a_i(t)$ denotes the acceleration of the road user at time t.

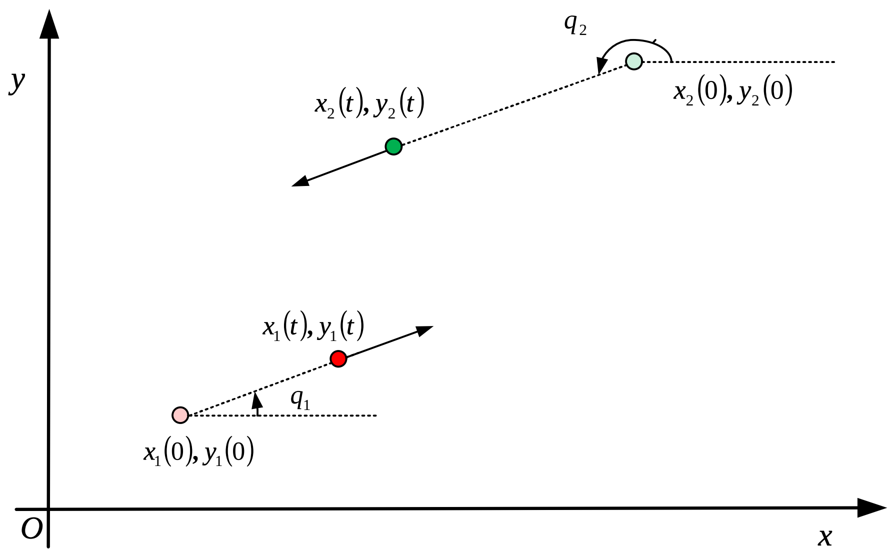


Fig.6-3 Movement of the road users in coordinate system

The distance between these two points at time *t* equals:

$$D(t) = \sqrt{\left[x_2(t)-x_1(t)\right]^2+\left[y_2(t)-y_1(t)\right]^2} \qquad \text{Eq.6-26}$$

If $a(t)$ equals a constant value *a*, the trajectories would be

$$x_i(t) = x_i(0) + \left[v_i(0)t + \frac{1}{2}at^2\right]\cos q_i \qquad \text{Eq.6-27}$$

$$y_i(t) = y_i(0) + \left[v_i(0)t + \frac{1}{2}at^2\right]\sin q_i \qquad \text{Eq.6-28}$$

The distance between the two road users at time *t* follows Eq. 6-29:

$$D^2(t) = \left[x_2(t) - x_1(t)\right]^2 + \left[y_2(t) - y_1(t)\right]^2 \qquad \text{Eq.6-29}$$

If the road users move with constant velocity, the trajectories would be:

$$x_i(t) = x_i(0) + v_i(0)t\cos q_i \qquad \text{Eq.6-30}$$

$$y_i(t) = y_i(0) + v_i(0)t\sin q_i \qquad \text{Eq.6-31}$$

Derivation of time for $D^2(t)$, set $\frac{dD^2(t)}{dt} = 0$,

$$t_m = \frac{\left[x_2(0) - x_1(0)\right]\left(v_1\cos q_1 - v_2\cos q_2\right) + \left[y_2(0) - y_1(0)\right]\left(v_1\sin q_1 - v_2\sin q_2\right)}{\left[v_1^2 + v_2^2 - 2v_1v_2\cos\left(q_1 - q_2\right)\right]t} \qquad \text{Eq.6-32}$$

When $t = t_m$, $D(t)$ reaches the minimum distance $d_{\min}$:

$$d_{\min} = \frac{\left|y_2(0) - y_1(0) - \frac{v_2\sin q_2 - v_1\sin q_1}{v_2\cos q_2 - v_1\sin q_1}\left[x_2(0) - x_1(0)\right]\right|}{\sqrt{1 + \frac{\left(v_2\sin q_2 - v_1\sin q_1\right)^2}{\left(v_2\cos q_2 - v_1\cos q_1\right)^2}}} \qquad \text{Eq.6-33}$$

$$d_{\min} = y_1\left(v_i, q_i\right) \qquad \text{Eq.6-34}$$

Two variables v_i, θ_i contribute to the function of minimum distance between two road users in constant velocity motion. In conflict situations, the distance measures can reflect the severity of the conflict. The shorter the distance between two road users, the severer the conflict is.

According to subsection 4.5.1, the instantaneous TTC can be calculated by the time difference of TTCP. It means if the road users keep the speed unchanged, collision may occur. In this situation, the minimum distance between VEH and PED are estimated by Eq.6-33. The d_{min} is plotted in Fig.6-4 with 90% of d_{min} lower than 2m. So 2m could be suggested as the threshold for collision discrimination.

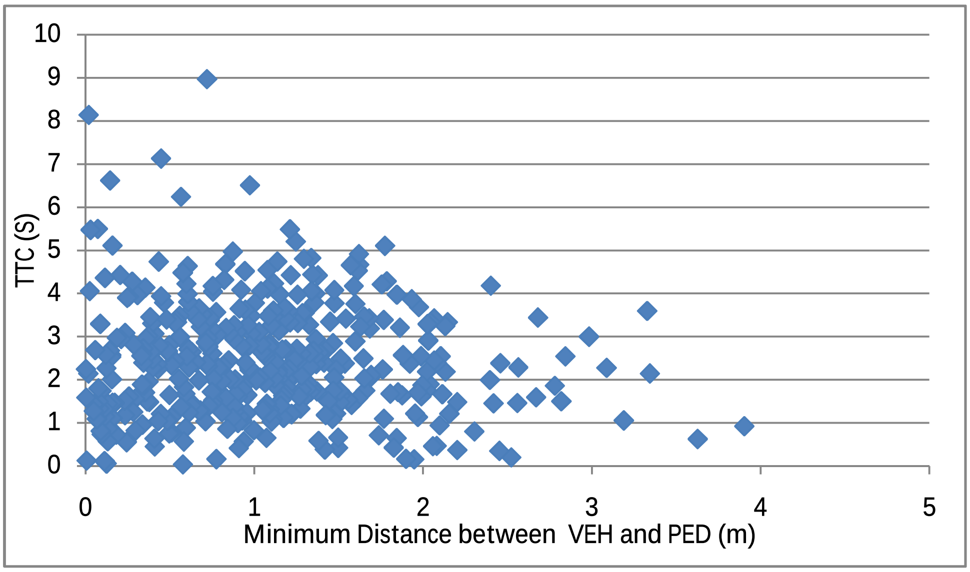


Fig.6-4 Minimum distance between VEH and PED related to TTC

6.4.2 Critical conflict radius

Each road user has a certain buffer zone in performing traffic activities and if other road users move into the zone, it brings a certain pressure to the subject road user. In traffic conflict process, the critical conflict zone can be defined as a risk perception zone when other road users approach the zone to some extent, evasive action should be taken by the subject road user. And the critical conflict zone is only identified by the angle φ and critical conflict radius $R(\varphi)$.

The moving direction of the road user will influence the safety distance between the conflict participants. As shown in Fig.6-5, the road user 1 is static, and the maximum safety distance will be required only if the road user 2 approaches along the dashed line to road user 1. In other words, the collision may take place when the trajectory of the road user 2 goes through the position point of road user 1.

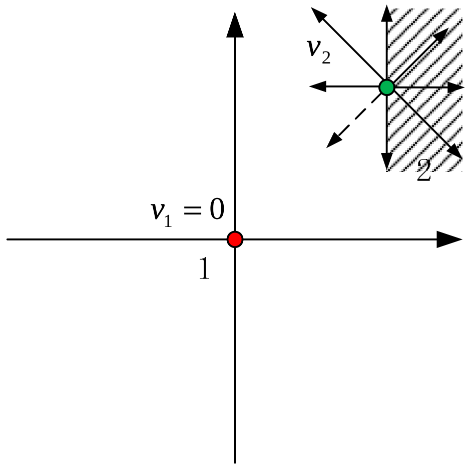


Fig.6-5 Moving direction affecting to the safety distance

The maximum safety distance is estimated as the critical conflict radius. In this case, road user 2 just needs to keep a safe braking distance with the acceleration rate a_2, so the critical conflict radius can be described as:

$$R(j) = \frac{v_1^{\;2}}{2a_2} + l_0 \qquad j \in \left(0^{\circ}, 360^{\circ}\right] \qquad \text{Eq.6-35}$$

Where the l_0 is the minimum stopping distance.

If the road user 1 is not static, the relative coordinate system $y' - x'$ is determined in Fig.6-6. The collision may be observed only when the moving direction angle of road user 2 is at θ_{2m} with his position angle φ.

The critical conflict radius can be defined as the following function:

$$R(j) = f_1\left(v_1, v_2\left(q_{2m}\right), j\right) \qquad \text{Eq.6-36}$$

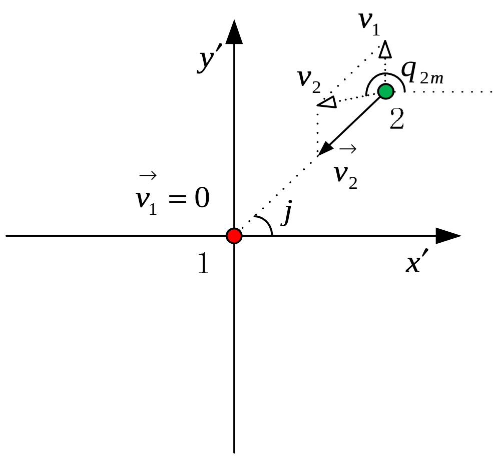


Fig.6-6 Critical conflict radius analysis in relative coordinate system

At the relative coordinate system, the relative velocity of the two road users is:

$$\vec{v_1} = 0$$

$$\vec{v_2}\ (v_2 \cos q_2, v_2 \sin q_2 - v_1)$$

1) When $j \in \left[0, \frac{p}{2}\right)$, $q_{2m} = p + j - arc\sin\left(\frac{v_1}{v_2}\cos j\right)$

$$\left|\vec{v_2}\right| = v_2 \cdot \frac{\cos\left[j - arc\sin\left(\frac{v_1}{v_2}\cdot\cos j\right)\right]}{\cos j} \qquad \text{Eq.6-37}$$

2) When $j \in \left(\frac{p}{2}, p\right)$, $q_{2m} = -p + j - arc\sin\left(\frac{v_1}{v_2}\cos j\right)$

$$\left|\vec{v_2}\right| = v_2 \cdot \frac{\cos\left[-j + arc\sin\left(\frac{v_1}{v_2}\cdot\cos j\right)\right]}{\cos j} \qquad \text{Eq.6-38}$$

3) When $j \in \left[p, \frac{3p}{2}\right)$, $q_{2m} = -p + j - arc\sin\left(\frac{v_1}{v_2}\cos j\right)$

$$\left|\vec{v_2}\right| = v_2 \cdot \frac{\cos\left[-j + arc\sin\left(\frac{v_1}{v_2}\cdot\cos j\right)\right]}{\cos j} \qquad \text{Eq.6-39}$$

4) When $j \in \left(\frac{3p}{2}, 2p\right)$, $q_{2m} = -p + j - arc\sin\left(\frac{v_1}{v_2}\cos j\right)$

$$\left|\vec{v_2}\right| = v_2 \cdot \frac{\cos\left[j - arc\sin\left(\frac{v_1}{v_2}\cdot\cos j\right)\right]}{\cos j} \qquad \text{Eq.6-40}$$

5) When $j = \frac{p}{2}$, $q_{2m} = \frac{3p}{2}$, $\left|\vec{v_2}\right| = v_2 + v_1$ Eq.6-41

6) When $j = \frac{3p}{2}$, $q_{2m} = \frac{p}{2}$, $\left|\vec{v}_2\right| = \left|v_2 - v_1\right|$ Eq.6-42

It is known as $R(j) = \frac{\left|\vec{v}_2\right|^2}{2a_2} + l_0$ Eq.6-43

The critical conflict radius can be derived as follows:

$$R(\varphi) = \begin{cases} \dfrac{\left(v_2 \cdot \dfrac{\cos\left[f - arc\sin\left(\dfrac{v_1}{v_2} \cdot \cos f\right)\right]}{\cos f}\right)^2}{2a_2} + l_0, & j \in [0,2p)\ and\ j \neq \pm\dfrac{p}{2}, \\ \dfrac{(v_2 \pm v_1)^2}{2a_2} + l_0, & j = \pm\dfrac{p}{2} \end{cases}$$ Eq.6-44

Set $\frac{v_2}{v_1} = \frac{3}{2}$, the critical conflict zone can be simulated in Fig.6-7.

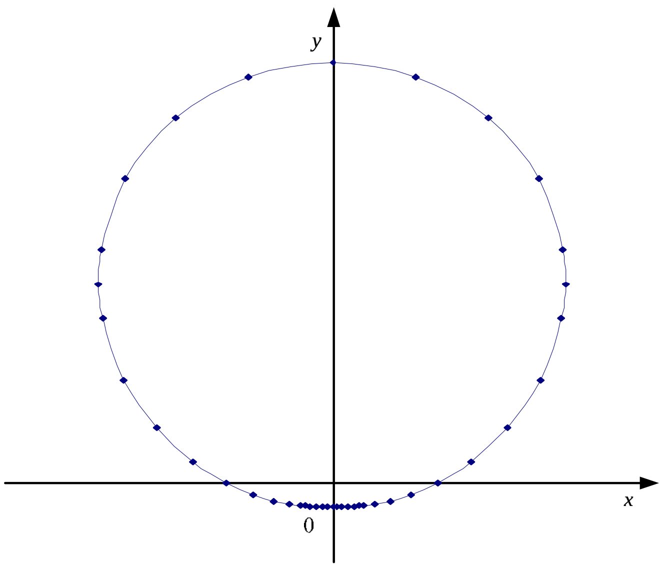


Fig.6-7 A sample of critical conflict zone

The velocity decomposition should be conducted if the road user 2 does not move with the angle θ_{2m}, see Fig.6-8. The velocity component $v_{\theta_{2m}}$along θ_{2m} direction determines the value of $R(\varphi)$.

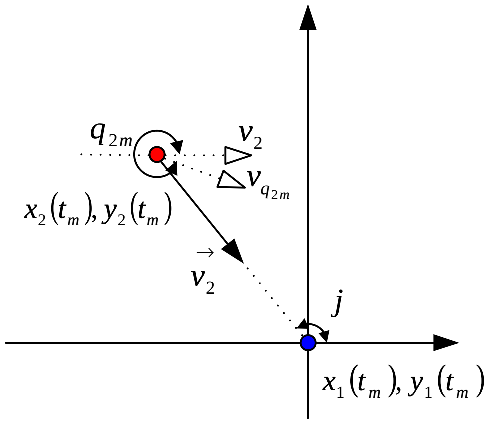


Fig.6-8 Velocity decomposition

At time t_m, the coordinates of road user 1 and 2 are:

$$x_1(t_m) = 0 \quad x_2(t_m) = x_2(0) + v_2 t_m \cos q_2$$
$$y_1(t_m) = 0, \quad y_2(t_m) = y_2(0) + v_2 t_m \sin q_2 - v_1 t_m \qquad \text{Eq.6-45}$$

$$v_{q_{2m}} = v_2 \cdot \cos\left|q_2 - q_{2m}\right| \qquad \text{Eq.6-46}$$

According to Eq.6-38,

$$q_{2m} = -p + j - arc\sin\left(\frac{v_1}{v_{q_{2m}}}\cos j\right) \qquad \text{Eq.6-47}$$

Then $|\overrightarrow{v_2}|$ is achieved by Eq. 6-48.

$$\left|\overrightarrow{v_2}\right| = \left| v_{q_{2m}} \cdot \frac{\cos\left[j - arc\sin\left(\frac{v_1}{v_{q_{2m}}} \cdot \cos j\right)\right]}{\cos j} \right| \qquad \text{Eq.6-48}$$

Finally the critical conflict radius can be modified as:

$$R(\varphi) = \begin{cases} \dfrac{\left(v_{q_{2m}} \cdot \dfrac{\cos\left[f - arc\sin\left(\dfrac{v_1}{v_{q_{2m}}} \cdot \cos f \right) \right]}{\cos f} \right)^2}{2a_2} + l_0, & f \in [0, 2p),\ f \neq \pm\dfrac{p}{2}, \\ \dfrac{\left(v_{q_{2m}} \pm v_1 \right)^2}{2a_2} + l_0, & j = \pm\dfrac{p}{2} \end{cases} \quad \text{Eq.6-49}$$

The critical conflict radius is introduced as one measure for the traffic conflict discrimination combined with the minimum VEH-PED distance. When d_{min} is smaller than the critical radius, a conflict may occur.

6.5 Summary

In order to establish a “situation—countermeasure” relationship, four situational factors PS,VS,LADP and LODV are applied as variables in logit modeling of the driver yielding behavior. By statistical estimation, the binary logit model can predict the driver’s yielding decision accurately. The influences of the variables on the model vary not only between countries but also between different driving states (single driving and platoon driving). From the pedestrian side, Weibull distribution model is proved to be effective both in China and Germany in describing the gap distribution which could be a surrogate measure to describe the arrival of the conflict vehicle. Based on the Weibull distribution functions, pedestrian waiting time is calculated compared with the field observation data. Two indicators, the minimum VEH-PED distance within conflict process and critical conflict radius are presented for conflict discrimination.

7 MEASURES TO IMPROVE TRAFFIC SAFETY IN VEH-PED CONFLICTS IN CHINA

7.1 Introduction

The development of the automotive industry and the increasing number of private cars in China are beneficial to the advancement of motorization in the country. However, the consequence of this advancement is serious traffic safety problems. Compared with traffic safety in developed countries, traffic safety status in China still remains at a lower level. Many countermeasures have been taken to improve this situation, but in reality, the measures that have been adopted thus far are not comprehensive and are insufficient. With the increasing number of car drivers and with continuous urban sprawling, the reduction of road user fatalities and injuries must be a long-term effort.

Measures to improve road user safety in VEH-PED conflicts are discussed by reviewing the factors that affect traffic safety from the perspectives of traffic control and design, traffic facility, traffic education, and law enforcement. This chapter aims to provide instructive solutions to a number of safety problems around conflict activities, with the final goal of achieving a higher safety level.

7.2 Factors influencing traffic safety in conflict situation

7.2.1 Intrinsic factors discussion

Traffic non-compliance

One of the main causes of traffic accidents caused by pedestrians is pedestrian non-compliance when crossing vehicle lanes. Although the pedestrian fatality ratio related to such a behavior in the entire country is about 5.35%, the casualty rate by this traffic accident is relatively high because of the vulnerability of pedestrians. Moreover, this non-compliance behavior negatively affects traffic operation and efficiency.

Crossing a road without using crosswalks, crossing fatalities, and signal violations can be considered major non-compliance behavior of pedestrians. Frequent non-compliance activities can be observed in China, and these activities even become habitual. Three habitual actions will result in pedestrian violation.

- Relying on luck in relation to committing traffic violations and taking risks to achieve greater utility by shortening the crossing distance or time;

- Group psychology in following the non-compliance behavior of other pedestrians;
- Overconfidence in dealing with accident-avoidance activities

From the perspective of drivers, non-compliance behavior related to VEH-PED conflicts is prioritized when drivers must give way to pedestrians.

Limitation in traffic accident risk perception
Limitations in risk perception will lead to an incorrect decision when reacting to certain critical situations. Generally speaking, risk perception is influenced by individual psychological state, experience, and education.

In traffic activities, for example, pedestrians are more sensitive to height and distance rather than to speed. The same problems can be found in drivers. As mentioned in **Section 2.5**, vehicle speed is closely related to yielding safety. The faster is the speed, the more severe is the risk. In addition, perception limitation in terms of vehicle speed and confidence in one's driving skills may result in drivers' violation of a speed limit.

Experience and education also influence perception limitations. An experienced and well-trained driver obviously has a better understanding of traffic risks than a new driver.

7.2.2 Extrinsic factors discussion

Insufficient pedestrian traffic facilities
Vehicle orientation is still employed in traffic planning, construction, and operation in some cities in China. With infrastructure issues, however, lesser consideration is made to improve the walking environment. The service provided cannot also meet the growing demands in pedestrian traffic. The insufficient number of facilities is depicted as follows:

- *Lack of pedestrian crossing facilities such as crosswalks, underground corridors, and pedestrian bridges*
  This deficiency makes inconvenient the act of deciding where and how to crossroads. For instance, if no crossing facilities are provided for long distances, pedestrians may resort to jaywalking.
- *Lack of crossing signs or markings*
  This deficiency results in the inadequate information received by pedestrians when crossing.
- *Lack of pedestrian separation and protection facilities*
  The design of pedestrian guard rails and refuge islands may provide a physical barrier against potential hazards and may reduce the conflict risk

with vehicle flow.

“Relaxed” traffic enforcement

Although a traffic violation is clearly defined by laws and rules, punishment for traffic non-compliance is still made based on different criteria. Chinese society is known to be strongly based on social rules, customs, and relationships, all of which may widely influence the enforcement of traffic laws and rules for road users. Differences exist in the guidance and forms of treatment for road users. For example, for pedestrian redcrossing behavior, the most common actions of the police would be to educate and prevent pedestrians from committing violations (if a police officer is present on the roadside). However, non-compliance is usually ignored (Jiang, 2007). For drivers, redcrossing will cause credit deductions with fines, or they may even be forced to attend some driving courses. The enforcement of traffic rules and laws to guide drivers’ yielding behavior (yielding to pedestrians) is seldom done in China today.

7.3 Measures from traffic control side

7.3.1 Pedestrian signal control

When the pedestrian flow rate increases to a certain higher level, the pedestrian signal needs to be facilitated and it may provide temporal isolation to the pedestrians. Incorrect pedestrian signal design will have a negative effect on traffic capacity. The minimum pedestrian green time and the phase green time are two important parameters for signal design.

Pedestrian green time should meet the demand for safe crossing, and the minimum pedestrian green time is the function of the crosswalk width and average pedestrian crossing speed. It is designed as:

$$g_{min} = 7 + \frac{w}{v} - l \qquad \text{Eq.7-1}$$

Where, g_{min} is the minimum pedestrian green time, s;
w is the width of the crosswalk, m;
v is the average pedestrian crossing speed, m/s;
l is the change interval, general in 5s

When the pedestrian flow rate is relatively high with a large proportion of pedestrian groups, the pedestrian phase green time follows Eq.7-2.

$$g = 7 + \frac{w}{v} + (\frac{qr}{N} - 1)t_f - l \qquad \text{Eq.7-2}$$

Where, g denotes the phase green time, s;
q denotes the pedestrian volume;

r denotes the pedestrian phase red time, s

N denotes the average number of pedestrians in each row;

t_f denotes the average following time for each row

Because of an overlong width of the crosswalk or a large pedestrian volume, the computed value of the phase green time is big. As a result, pedestrians twice crossing should be considered. And the cycle length of the pedestrian signal is highly dependent on the cycle length of the upstream signalized intersection/crosswalk.

7.3.2 Speed limits

Traffic speed is a major influence on both the number and the severity of traffic conflicts. Pedestrians are particularly at risk when encountering drivers who are traveling at high speeds. In China, speeding accounts for about 10% of fatalities which represents a large decrease from a peak of 17.2% in 2004 (He, 2012). Strong enforcement strategies related to speed limits have contributed to the improvement of the pedestrian safety level. In Europe, the probability of a pedestrian fatality has been reduced from 85% at 50km/h to less than 10% at 30km/h (ETSC, 1999).

In VEH-PED conflict situations in China, as discussed in **Section 5.4,** acceleration is a widely accepted collision avoidance behavior for Chinese drivers. Therefore, setting the speed limit at a crosswalk will regulate the behavior of drivers in terms of maintaining a controllable speed while in conflict with crossing pedestrians.

Support measures following the implementation of speed limits should be conducted to encourage compliance among drivers. A number of automatic monitoring system units have been placed throughout Beijing in recent years. Speed cameras that take pictures and detect irregularities have also been introduced. All these procedures may help establish an integrated speed enforcement program.

7.4 Measures from traffic facility side

7.4.1 Guard rails

In urban areas where a large number of pedestrians is concentrated, providing guard rails in the form of chains, fences, or other similar means of deterring pedestrians may be necessary to prevent indiscriminate crossing (Zheng, 2003; Gehl, 2004). Compared with underground pedestrian corridors and pedestrian bridges, both of which create an absolute spatial isolation from vehicle flow for pedestrians, guard rails channelize pedestrian flow to a certain crosswalk but do not provide full protection to the crossing pedestrians. Guard rails can be cost-efficiently designed for optimal performance and can easily be configured. Fig.7-1 illustrates the typical design of guard rails. Fig.7-1(a) shows guard rails at a staggered crossing, and Fig.7-1(b) illustrates the ones installed along a sidewalk.

The detailed design and installation of pedestrian guard rails have already been studied for developed countries (DoT, 1995, 2009; Hall, 2005; Zheng, 2003). With the distinctly dangerous conflict situations in China, the following pointsshould be considered in the construction of pedestrian guardrails.

(a) (b)

Fig.7-1 Examples of pedestrian guard rails

- pedestrian violation behavior such as frequently climbing over guardrails,
- accessibility to public transit stops/terminal,
- large pedestrian volume during peak hours,
- crowd behavior in the channelization provided by guardrails, and
- traffic wardens assisting in regulating the traffic.

7.4.2 Signs and markings

Traffic signs and markings play a vital role in providing route choice information, in reminding drivers of the rules, regulations and guidelines, and in warning drivers of potential risks.

According to the National Standard for Road Traffic Signs and Markings (GB5768-1999) in China, road traffic signs have seven types: warning signs, prohibition sign, mandatory sign, guide sign, auxiliary sign, tourist sign and road construction sign. Road traffic markings have three types: the warning markings, prohibition markings and mandatory markings. As regulated in StVO in Germany, signs have five types: warning signs, recommendation signs, regulation signs, signs for transportation facilities, symbols and additional signs. The following steps should be adopted to improve traffic safety in conflict situations in China:

- Signs and markings should be legible to understand the traffic environment. Adequate crossing information must be provided.

- Ÿ Signs and markings should be visibly noticed by road users because roadside parking and other facilities may block road users' view.

7.5 Measures from education side

Traffic education is an important method to guide road users on correct traffic activities. The method is facilitated by providing integrated understanding or knowledge on traffic regulations. Traffic education is also an effective approach to address the bad habits of road users and to compensate for limitations in risk perception. Traffic education will contribute to traffic awareness and to the reduction of risk rates.

For VEH-PED conflicts, traffic education should include the following aspects:

- interpretation of the right of way,
- correct driver yielding behavior,
- understanding of traffic signs and markings,
- methods for using the crossing facilities for pedestrians, and
- elaboration of the consequences of incorrect behavior.

Traffic education is a long-term activity that requires cooperation among different groups such as the government, traffic engineers, police, school teachers, educational organizations, and traffic research departments.

The following applications of traffic education in China are suggested:

- Traffic education systems must be integrated into school education systems from kindergarten to secondary school. School education systems offer only basic traffic education comprising traffic curriculum and practical exercises.
- More information about giving due consideration to pedestrians and cyclists should be added into the curriculum of driving schools.
- The education can be conducted through different approaches by TV advertisement, handy massages, internet courses, community studies, leaflets delivery, etc.

7.6 Measures of traffic law enforcement

Representing a significant development in traffic enforcement, the Road Traffic Safety Law took effect on May 2004 in China. Over the last few years, China has exerted great effort to reduce traffic accident rates and to create a safe traffic environment. The country has not only improved infrastructure construction but has also strengthened traffic operations and policy. However, the two approaches are seemingly unbalanced.

Traffic law enforcement in relation to the second approach aims to provide guidance and direction concerning the legal behavior of traffic participants as well as to reduce traffic non-compliance.

In traffic conflicts between motor vehicles and pedestrians, an essential problem should be highlighted.

According to the Article 44 of Road Traffic Safety Law:

Article 44 *When passing a road crossing, motor vehicle drivers shall follow the traffic signal lights, traffic signs and traffic line markings, or the direction of traffic police; and when passing a road crossing where there are no traffic signal lights, traffic signs, traffic line markings or direction of traffic police, they shall slow down and let pedestrians and the vehicles enjoying priority pass first.*

Yielding is required of drivers by the law when they encounter crossing pedestrians. However, no matter how comprehensive the law is, compliance with such a regulation will not be achieved if no serious consequences for traffic violators are established. A stronger law enforcement is urged to achieve behavioral correction. The following are some suggestions:

- A monitoring system can be applied to collect not just speeding data but also drivers' yielding violations.
- A hard credit punishment and fine should be implemented.
- Police or traffic assistants/wardens should be engaged in the elimination of non-compliance to supplement automotive traffic detection by camera systems.

Furthermore, building and maintaining public trust and confidence in law enforcement should also be considered of fundamental importance.

8 CONCLUSIONS AND OUTLOOK

8.1 Conclusions

The analysis of road user behavior in conflicts is a systematic task, with the conflict process conforming to behavior taxonomies and causation factors. Taking "intercultural comparison" as the main keyword, the current study is framed around this concept. The field data analyses based on field observations show the significant differences inroad user behavior in VEH-PED conflicts between China and Germany.

The conclusions based on theoretical and empirical studies are as follows:

- *Different traffic situation and driving culture*
  Significant differences can be found in the pedestrian safety situations between China and Germany. Eight aspects from traffic side are compared to address the differences in driving cultures.

- *Different pedestrian conflict behavior*
  Pedestrian speed that fits the normal distribution is statistically recorded as a 7% to 9% difference between the two countries. Significant differences are observed and analyzed in pedestrian waiting behavior. A vast majority of Chinese pedestrians prefer to wait before crossing. German pedestrians perform the opposite, with the waiting pedestrians only accounting for 30%. Pedestrian gap/lag thresholds are suggested according to analyses of gap/lag choice behavior. Pedestrian-based measures such as the PS and LADP are proven to affect TTC according to the analyses of the relationships among these measures. Pedestrian non-compliance in the case of China is studied for a better understanding of critical conflict situations.

- *Different driver conflict behavior*
  Driver behavior differences in VEH-PED conflicts are summarized according to yielding behavior, acceleration/deceleration rates, and TTC variations with VEH-based measures. Moreover, the causations of the differences are interpreted. Because of the compensation of acceleration rate, the space history of DEC in all conflict situations in China performs more smoothly than that in Germany. In yielding situations, the severity of the yielding behavior of German drivers is much less than that of Chinese drivers. With2-D interpolation function and curve fitting, the relationship between DEC and situational measures has been interculturally discussed. For comparison

with normal situations, non-compliance situations are further examined to identify driver behavior.

A binary logit model is proposed to predict driver yielding behavior both in single driving status and in platoon driving status connected to certain pedestrian categories. Four situational factors, namely, PS, VS, LADP and LODV, are applied as variables in the model. According to the model estimation, the influences of the variables vary not only between countries but also between different driving statuses. From the pedestrian side, a pedestrian waiting time model based on Weibull distribution is proven effective compared with the field observation data. Two indicators, namely, the minimum VEH-PED distance and the critical conflict radius, are mathematically introduced for conflict discrimination. In addition, a 2m threshold of the minimum VEH-PED distance is deduced as the distance measured in conflict evaluation.

8.2 Outlook

Considered the limitations of the research:

- limitations in the field data collection for some individual behavioral characters from the psychological perspective sides;
- limitations in the type of study sites.

Future studies should consider the following four major aspects to achieve an integrated understanding of road user conflict behavior based on the “intercultural” concept:

- different interpretations and identifications of traffic conflict severity based on road users’ cognitive architecture;
- comparison of criteria for conflict severity evaluation;
- more situational factors considered for conflict behavior modeling and for intercultural discussion about how factors quantitatively influence road user behavior;
- an extended investigation of ADAS cultural adaptation in other traffic activities.

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A-1. Pedestrian safety statistics in China

Pedestrian Fatalities and injuries in China (1999-2009)						
Year	Total Fatalities	Pedestrian Fatalities	Total Injuries	Pedestrian Injuries	Population /10000	Stock of Motor Vehicles/10000
1999	83,529	21,686	286,080	37,554	125786	1452.94
2000	93,953	24,580	418,721	55,104	126743	1608.91
2001	105,930	28,274	546,485	75,137	127627	1802.04
2002	109,381	27,575	562,074	75,779	128453	2053.17
2003	104,372	25,673	494,174	68,040	129227	2382.93
2004	107,077	26,741	480,864	76,431	129988	2693.71
2005	98,738	24,451	469,911	83,491	130756	3159.66
2006	89,455	23,285	431,139	82,391	131448	3697.35
2007	81,649	21,106	380,442	70,838	132129	4358.36
2008	73,584	18,913	304,919	56,303	132802	5099.61
2009	67,759	16,683	275,125	47,594	133450	6280.61

A-2. Pedestrian safety statistics in Germany

Pedestrian Fatalities and injuries in Germany (1999-2010)						
Year	Total Fatalities	Pedestrian Fatalities	Total Injuries	Pedestrian Injuries	Population	Stock of Motor Vehicles
1999	7772	983	521127	39312	82087361	50609142
2000	7503	993	504074	38115	82163475	51364673
2001	6977	900	494775	37101	82259540	52487295
2002	6842	873	476413	36343	82440309	53305930
2003	6613	812	462170	35015	82536680	53655835
2004	5842	838	440126	34077	82531671	47914216
2005	5361	686	433433	33916	82500849	48180546
2006	5091	711	427428	33937	82437995	48444904
2007	4949	695	431419	33804	82314906	48989016
2008	4477	653	409047	32770	82217837	49330037
2009	4152	591	397671	31647	82002356	49602623
2010	3648	476	371170	29663	81802257	50184419

B. Video Data Series — Example of a vehicle-pedestrian conflict situation

FN	T(s)	PC	X_p (m)	Y_p (m)	WD	SC	EC	X_v (m)	Y_v (m)	GW	PSV
50	2	1m	-3.277	11.963	tc			57.242	5.219	GWY	0
60	2.4	1m	-3.209	11.674	tc			51.610	5.355	GWY	0
70	2.8	1m	-3.251	11.072	tc			45.104	5.785	GWY	0
80	3.2	1m	-3.021	10.622	tc			40.527	5.387	GWY	0
90	3.6	1m	-3.129	9.671	tc			35.049	5.618	GWY	0
100	4	1m	-3.012	9.219	tc			30.406	5.361	GWY	0
110	4.4	1m	-2.955	8.850	tc			25.805	5.398	GWY	0
120	4.8	1m	-3.055	8.766	tc	120		21.482	5.479	GWY	0
130	5.2	1m	-3.370	8.118	tr			18.062	5.108	GWY	0
140	5.6	1m	-3.312	7.480	tr			15.385	5.031	GWY	0
150	6	1m	-3.189	7.226	tr			12.901	5.442	GWY	0
160	6.4	1m	-3.329	6.516	tr			11.117	5.352	GWY	0
170	6.8	1m	-3.190	5.577	tr			9.479	5.321	GWY	0
180	7.2	1m	-3.233	4.672	tr			8.418	5.158	GWY	0
190	7.6	1m	-3.427	3.811	tr			7.033	5.247	GWY	0
200	8	1m	-3.436	3.445	tr			6.013	5.086	GWY	0
210	8.4	1m	-3.609	2.874	tr			4.850	5.293	GWY	0
220	8.8	1m	-4.050	2.008	tr			3.338	5.267	GWY	0
230	9.2	1m	-3.981	1.646	tr			1.775	5.185	GWY	0
240	9.6	1m	-4.170	1.255	tr			-0.180	5.296	GWY	0
250	10	1m	-4.479	0.850	tr			-2.665	5.488	GWY	0
260	10.4	1m	-3.861	0.377	tr			-4.431	5.130	GWY	0
270	10.8	1m	-4.594	0.230	tr		270	-6.815	5.277	GWY	0
280	11.2	1m	-4.418	-0.021				-10.306	5.426	GWY	0