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CONSTRUCTION OF CLASSIFICATION METHOD FOR URBAN ROAD INTERSECTIONS

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Abstract: In order to scientifically and reasonably test and evaluate the driving ability and behavior of intelligent vehicles in urban scenarios, it is necessary to first cover all types of scenes for the most complex intersection scenes in the city. However, due to the current research mostly using simple intersection shapes for scene classification, it is difficult to achieve exhaustive and traversal of all types of scenes at intersections. This article innovatively proposes the use of road rights composed of a limited number of combinations of directional arrows and traffic signals in the lane as the classification basis for intersections. Through research and summarization, all combination types are obtained, and the frequency distribution of all combination types is statistically analyzed in the automobile demonstration area. Based on this, the classification is carried out, laying the foundation for the testing and evaluation of intelligent vehicles in urban working conditions.
Keywords: Testing and evaluation; Intersection classification; Urban scene; Right of way

1 INTRODUCTION

Unlike highway traffic scenes, urban road traffic scenes are mainly divided into road section driving and intersection traffic. Among them, intersections are very complex traffic scenes, with not only complex road structures but also numerous traffic participants and uncontrollable factors, making them prone to traffic accidents. Therefore, vehicles not only need to predict intersections and record driving routes, but more importantly, understand the intersection scene and choose appropriate driving strategies to prevent typical traffic incidents from occurring. Therefore, for the testing and evaluation of urban scenarios, if you want to construct typical evaluation scenarios at intersections. It is necessary to first use effective classification methods to classify the intersection scene.

The most common classification method currently is to classify scenes based on the shape of intersections. Zhou Jianhua et al.[1] simply divided intersections into cross shaped, circular, X-shaped, T-shaped, Y-shaped and other forms. Liu Chunxu[2] proposed to divide typical intersections into cross shaped intersections, T-shaped intersections, roundabout intersections, Y-shaped intersections, misaligned intersections, X-shaped intersections, and multi way intersections. At the same time, complex intersections are divided into distorted Y-shaped complex intersections, distorted roundabout complex intersections, distorted cross shaped complex intersections, distorted 5-way complex intersections, and distorted 4-way complex intersections. Ying Shen et al.[3] provided a classification of intersections, which are classified into the following categories based on geometric shapes: Y-shaped intersections, T-shaped intersections, cross intersections, X-shaped intersections, roundabouts, and compound intersections; According to the structure, the intersection is divided into non channelized intersection and channelized intersection. Later, it was proposed to decompose complex intersection scenes into multiple sub scenes for autonomous vehicle driving decisions, select corresponding sub scenes based on driving intentions, match intersection classifications, and help cars better understand intersection scenes.

Ma Xuehan et al.[4] proposed a method for classifying intersections based on natural driving research, which summarizes the elements of intersection traffic into geometric type, traffic control type, and lane type. For convenience, each type is represented by a code, that is, a combination of letters can be used to determine a certain intersection type. This method is relatively scientific, but the classification is too simple to cover all roads in the city. In addition, he also analyzed several intersection traffic scenarios through China FOT video statistics and obtained a distribution table of intersection types.

In terms of intersection classification, the Ministry of Transport of the People's Republic of China has released multiple standards that provide detailed explanations and classifications of intersection geometry types, traffic control types, and lane types. Road Traffic Signs and Markings Part 2: Road Traffic Signs "[5] classifies directional signs, including straight ahead, left turn, right turn, straight ahead and left turn, straight ahead and right turn, left and right turn, roundabout driving, and other directional signs. The basic shapes and meanings of common directional arrows are given in "Road Traffic Signs and Markings Part 3: Road Traffic Markings"[6], and some arrows are shown in Figure 5. The "Specification for the Setting and Installation of Road Traffic Signal Lights"[7] lists the combination forms of motor vehicle signal lights and direction indicator signals, and divides them into conventional and special situations. Partial situations are shown in Figure 6 and Figure 7. The above relevant standards of the Ministry of Transport provide ideas and references for subsequent scene classification.

In summary, current research mostly uses simple intersection shapes for scene classification. However, different numbers of lanes and signal lights within the same shape at intersections can lead to vastly different scenes, making it difficult to exhaustively and traverse all types of scenes using intersection shape classification. Even the subsequent

proposal to decompose complex intersection scenes into multiple sub scenes still adopts the intersection shape classification method, which is consistent with the above problem. Later, researchers proposed a more scientific and effective method of classifying intersections based on their geometric types, traffic control types, and lane types. However, at that time, the research was relatively general and lacked refinement and comprehensiveness.This article takes this as a breakthrough point, seeking to use a limited number of indicators to classify intersections, striving to achieve an exhaustive list of urban intersection scene types.

2 CLASSIFICATION IDEAS FOR URBAN ROAD INTERSECTIONS

As mentioned earlier, this article breaks away from the previous focus on the structure of intersections, the number of lanes at intersections, the number of directions at intersections, and selects a limited number of representative and universal relevant indicators as the basic basis for classification. By observing urban road intersections, it can be observed that although there may be differences in the number of lanes and directions at the intersection, the basic driving behaviors performed by a single vehicle passing through the intersection are limited, with a maximum of four driving behaviors: straight ahead, left turn, right turn, and U-turn.

The execution of each driving behavior at the intersection is determined by the road rights formed by the direction indicated by the directional arrows in front of the intersection stop line and the clear priority of traffic signals at the intersection. The types of directional arrows and traffic signals in the lane are limited and can be exhaustively listed. Therefore, no matter what kind of intersection can be encountered on urban roads, the road rights formed by the combination of directional arrows and traffic signals in the lane can be used as the classification basis for intersections.

Therefore, it is necessary to first count all types of directional arrows and traffic lights that have appeared in the city, including conventional and special types. Then, all types of directional arrows and traffic lights can be combined in sequence to cover all possible road rights at intersections, achieving full coverage of urban road intersections and laying the foundation for the construction of subsequent intelligent driving intersection evaluation schemes.

3 CLASSIFICATION COLLECTION RESULTS OF URBAN ROAD INTERSECTIONS

Due to the use of dual indicators of directional arrows and traffic signals as classification criteria for intersections in urban roads, it is necessary to first exhaustively list the types of these two indicators at the intersection, and then combine the collected results of the two indicators to classify the intersection.

3.1 Types of Directional Arrows at Urban Road Intersections

This section mainly summarizes the types of directional arrows that exist on conventional motor vehicle lanes at intersections on urban roads, excluding non motor vehicle lanes and lanes for unconventional vehicles such as bus lanes. At the intersection of urban roads, due to the provisions of "Road Traffic Signs and Markings Part 3: Road Traffic Markings" (GB 5768.3-2009), there are 9 basic shapes and meanings of directional arrows for intersections, including multiple bidirectional directional arrows in addition to single directional arrows, covering most common types of standards.

In addition, the regulations also include two special types of lanes: variable lanes and tidal lanes. Variable lanes are generally marked with text within the lane, and indicator signs or signal lights are set up above or in front of the variable lane to indicate the direction in which the current lane can be driven. The tidal lane, with a double yellow dashed line composed of two parallel yellow dashed lines as its indicator line, generally uses corresponding variable signs and lane direction signal control facilities to cooperate and achieve the function of indicating the current lane direction.

However, in some complex road sections, such as intersections with complex geometric shapes or limited number of lanes, standard directional arrows may not be able to fully convey information. At this point, the traffic management department will make judgments based on actual needs and engineering, so there may be some non-standard directional arrows at intersections on real city roads to better guide drivers. Therefore, when calculating the types of directional arrows at intersections, it is also necessary to summarize unconventional types that are not included in regulations. Through extensive field research and online searches, except for situations where there are no directional arrows at intersections, the following eight non-standard types were extracted, including seven types of directional arrows and one type of lane:

(1) No U-turn: Indicate that no U-turn is allowed ahead (as shown in Figure 1)

(2) No Left Turn: Indicates that no left turn is allowed ahead (as shown in Figure 2)

(3) No Right Turn: Indicates that right turns are prohibited ahead (as shown in Figure 3)

(4) Straight (limited time no left turn): Indicates that vehicles are prohibited from turning left in front of the lane for a specific period of time and can only proceed straight (as shown in Figure 4)

(5) Left turn and no U-turn: Indicates that only left turns are allowed and no U-turns are allowed ahead (as shown in Figure 5)

(6) Straight ahead+left turn+right turn: indicates that you can go straight ahead or turn left or right (as shown in Figure 6)

(7) Left turn, straight ahead, no U-turn: indicates that you can go straight ahead or turn left, but not make a U-turn (as shown in Figure 7)

(8) Borrowing left turn lane: Left turning vehicles borrow the opposite lane to make a left turn, usually using supporting facilities such as traffic signals, LED screens, signs and markings to indicate the right of way of the current lane (as shown in Figure 8).

Figure 1 No U-turn

Figure 2 No Left Turn

Figure 3 No Right Turn

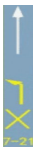


Figure 4 Straight (Limited Time No Left Turn)

Figure 5 Left Turn and No U-turn

Figure 6 Straight Ahead+Left Turn+Right Turn

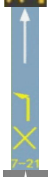
Figure 7 Left Turn, Straight Ahead, No U-turn

Figure 8 Borrowing Left Turn Lane

Based on the above conventional and unconventional types, the number of directions that can be controlled simultaneously according to the directional arrows can be divided into zero level, first level, second level, third level, and special type. For convenience, each type of directional arrow is represented in uppercase code form, with most codes using the first letter of the English alphabet as a shorthand, such as Straight, Left, Right, U-turn, and multi-level categories mostly in the form of overlapping first letters. The specific categories, names, codes, diagrams, and directional arrows of the classification are shown in Table 1.

Table 1 Classification of Directional Arrows at Urban Road Intersections

Category	Name	Code	Sketch map

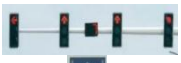
Level 0	Unmarked line	N	
Level 1	Straight	S	
	Left	L	
	Right	R	
	U-turn	U	
	No U-turn	nU	
	No Left Turn	nL	
	No Right Turn	nR	
Level 2	Left turn+U-turn	LU	
	Straight+Left turn	SL	
	Straight+Right turn	SR	
	Straight+U-turn	SU	
	Left turn+Right turn	LR	
	Left turn and No U-turn	LnU	
Level 3	Straight (limited time no left turn)	SpnL	
	Straight ahead+Left turn+Right turn	SLR	
	Left turn, straight ahead, no U-turn	SLnU	
Special type	Changed lane	CL	
	Tide lane	TL	
	Borrowing left turn lane	JL	

3.2 Types of Motor Vehicle Signal Lights at Urban Road Intersections

Similarly, through statistics and induction, a combination classification table of motor vehicle signal lights at urban road intersections can be obtained, as shown in Table 2.

Table 2 Classification Table of Motor Vehicle Signal Light Combinations at Urban Road Intersections

Category	Name	Code	Sketch map

Standard	Single circular signal light	d	
	Circular+left turn signal light	ld	
	Circular+right turn Signal Light	rd	
	Circular+left turn+right turn signal light	ld	
	Straight+left turn+right turn signal light	lsr	
Non-standard	No/constant yellow signal light	n	
	U-turn specific signal light	u	
	Circular+U-Turn signal light	ud	
	Circular+left turn+U-turn signal light	uld	
	Straight+right turn+U-turn signal light	usr	
Special type	Lane signal light	cd	
	Circular+left turn&U-turn signal light	lu_d	
	Straight+left turn+left turn&U-turn signal light	lu_ls	
	Changed lane signal light	cl	
	Tide lane signal light	tl	
	Borrowing left turn lane signal light	jl	

3.3 Summary of Types of Urban Road Intersections

After obtaining 20 types of directional arrows and 16 types of motor vehicle signal lights at the intersection mentioned above, the combination of the two can be used to determine the right of way at the intersection and effectively classify the intersection. The classification results after combination are shown in Table 3. The code naming and right of way for each combination type are provided in Table 3. The blue code represents the type of road rights that are not controlled by traffic lights, while the red code represents the type of road rights that are not scientific or reasonable enough. Therefore, the types with red codes are temporarily not included in the common intersection types.

According to statistics, there are a total of 189 combination codes, of which 82 are red codes. Therefore, there are 107 common types of intersections, including 23 blue code types that are not controlled by traffic lights. Therefore, when analyzing intersections in the future, the types of intersections summarized above can be used for analysis.

Table 3 Classification Table of Urban Road Intersection Types

	Signal light	Standard						Non-standard							Special type		
Directional arrows	Code	d	ld	rd	ldr	lsr	n	u	ud	uld	usr	cd	lu_d	lu_ls	cl	tl	jl
Level 0	N	d-N	ld-N	rd-N	ldr-N	lsr-N	n-N	/	ud-N	uld-N	usr-N		lu_d-N	lu_ls-N			
Level 1	S	d-S	ld-S	rd-S	ldr-S	lsr-S	n-S	/	ud-S	uld-S	usr-S		lu_d-S	lu_ls-S			
	L	d-L	ld-L	rd-L	ldr-L	lsr-L	n-L	/	ud-L	uld-L	/		lu_d-L	lu_ls-L			
	R	d-R	ld-R	rd-R	ldr-R	lsr-R	n-R	/	ud-R	uld-R	usr-R		lu_d-R	lu_ls-R			
	U	d-U	ld-U	rd-U	ldr-U	lsr-U	n-U	u-U	ud-U	uld-U	usr-U		lu_d-U	lu_ls-U			
Level 2	nU	d-nU	ld-nU	rd-nU	ldr-nU	lsr-nU	n-nU	/	ud-nU	uld-nU	usr-nU		lu_d-nU	lu_ls-nU			
	nL	d-nL	ld-nL	rd-nL	ldr-nL	lsr-nL	n-nL	/	ud-nL	uld-nL	usr-nL		lu_d-nL	lu_ls-nL			
	nR	d-nR	ld-nR	rd-nR	ldr-nR	lsr-nR	n-nR	/	ud-nR	uld-nR	usr-nR		lu_d-nR	lu_ls-nR			
	LU	d-LU	ld-LU	rd-LU	ldr-LU	lsr-LU	n-LU	/	ud-LU	uld-LU	usr-LU	/	lu_d-LU	lu_ls-LU			
	SL	d-SL	ld-SL	rd-SL	ldr-SL	lsr-SL	n-SL	/	ud-SL	uld-SL	usr-SL		lu_d-SL	lu_ls-SL			
	SR	d-SR	ld-SR	rd-SR	ldr-SR	lsr-SR	n-SR	/	ud-SR	uld-SR	usr-SR		lu_d-SR	lu_ls-SR			
	SU	d-SU	ld-SU	rd-SU	ldr-SU	lsr-SU	n-SU	/	ud-SU	uld-SU	usr-SU		lu_d-SU	lu_ls-SU			
	LR	d-LR	ld-LR	rd-LR	ldr-LR	lsr-LR	n-LR	/	ud-LR	uld-LR	usr-LR		lu_d-LR	lu_ls-LR			
Level 3	LnU	d-LnU	ld-LnU	rd-LnU	ldr-LnU	lsr-LnU	n-LnU	/	ud-LnU	uld-LnU	/		lu_d-LnU	lu_ls-LnU			
	SpnL	d-SpnL	ld-SpnL	rd-SpnL	ldr-SpnL	lsr-SpnL	n-SpnL	/	ud-SpnL	uld-SpnL	usr-SpnL		lu_d-SpnL	lu_ls-SpnL			
	SLR	d-SLR	ld-SLR	rd-SLR	ldr-SLR	lsr-SLR	n-SLR	/	ud-SLR	uld-SLR	usr-SLR		lu_d-SLR	lu_ls-SLR			
	SLnU	d-SLnU	ld-SLnU	rd-SLnU	ldr-SLnU	lsr-SLnU	n-SLnU	/	ud-SLnU	uld-SLnU	usr-SLnU		lu_d-SLnU	lu_ls-SLnU			
Special type	CL														cl_CL		
	TL															tl_TL	
	JL																jl_JL

4 CLASSIFICATION AND PROPORTION OF URBAN ROAD INTERSECTIONS

After obtaining the above classification types of intersections, research can be conducted on each type, and the frequency and distribution density of each type in the urban road environment can be calculated. This can further obtain the urban coverage of each intersection type and divide them according to frequency.

In the intersection research stage, the first step is to select a suitable research scope. Due to the need to fully consider the diversity of the number and distribution of intersections within the scope and the operability of the research work, combined with the representativeness of the selected area, it is decided to choose Shanghai Intelligent Connected Vehicle Demonstration Zone in China as the research object. On the one hand, the scope of the demonstration zone is relatively limited, which can achieve exhaustive and research work on all intersections within the range. On the other hand, as a venue support for the development of intelligent connected vehicle technology in China, the intelligent connected vehicle demonstration zone is determined to promote the research and application of intelligent connected vehicle technology. It covers numerous testing scenarios and application scenarios on test roads, and can fully serve as a representative area of urban road environment.

Combining online statistics and field research to complement each other, this article summarizes a total of 1863 combinations of 297 smart intersections in the Shanghai Automobile City Experimental Zone. According to the previous naming rules, the number and frequency of each combination type are all counted. The statistical results are shown in Table 4.

Table 4 Types of Urban Intersection Combinations in Shanghai Automobile City Experimental Zone

Type	Count	Frequency
d-N	311	16.69%
ld-S	228	12.24%
d-SR	215	11.54%
d-S	160	8.59%
ld-L	161	8.64%
n-N	156	8.37%
d-SL	146	7.84%
d-L	147	7.89%
ld-SR	124	6.66%
d-R	74	3.97%
ld-R	24	1.29%
n-S	25	1.34%
n-SR	16	0.86%
n-L	9	0.48%

d-LR	9	0.48%
ld-LnU	7	0.38%
ldr-S	6	0.32%
n-SL	7	0.38%
d-nU	6	0.32%
n-R	4	0.21%
ldr-L	4	0.21%
rd-R	3	0.16%
ldr-SR	3	0.16%
rd-S	2	0.11%
ldr-R	2	0.11%
d-LnU	2	0.11%
ld-LR	2	0.11%
n-LR	2	0.11%
rd-L	2	0.11%
ldr-U	1	0.05%
ld-LU	1	0.05%
d-SLnU	1	0.05%
d-SLR	1	0.05%
ld-SL	1	0.05%
d-T1	1	0.05%
Total	1863	

By analyzing the frequency of each type, it was found that three types, d-N, ld-S, and d-SR, had a frequency greater than 10%, with a total of 9 types exceeding 5% and 12 types exceeding 1%. When categorizing intersection combination types based on frequency, combination types greater than 10% are defined as extremely common types, 5% -10% are defined as relatively common types, 1% -5% are defined as common types, 0.1% -1% are defined as uncommon types, and less than 0.1% are defined as rare types.

5 CLASSIFICATION EXTRACTION RESULTS OF URBAN ROAD INTERSECTIONS

The purpose of classifying urban road intersections is to achieve full coverage of all types of intersections on urban roads with limited classification methods and quantities, providing a basis for developing evaluation methods for urban navigation assistance systems. In the testing and evaluation process, different evaluation criteria need to be developed for the difficulty level of driving at different intersections. Therefore, it is necessary to classify all intersection combinations into levels based on their frequency of occurrence and difficulty level.

Firstly, referring to the classification of test scenarios under high-speed road conditions, in the 2020 revised version of the Navigation Intelligent Driving Evaluation Regulations[8], the test scenarios are divided into four types: basic scenarios, challenge scenarios, innovation scenarios, and backup scenarios. At urban road intersections, this article divides the collected combinations of urban intersections in the experimental zone into three testing scenarios: basic scenarios, challenge scenarios, and innovative scenarios. Among them, scenes that occur frequently and are relatively simple for existing vehicles will be classified as basic scenes; Classify scenes with moderate frequency of occurrence and certain challenges and difficulties as challenge scenes; Classify low frequency, challenging, and difficult scenarios as innovative scenarios.

Based on the frequency of occurrence and driving difficulty of the 34 reasonable existence types excluding d-T1 in the Shanghai Automobile City test zone, the test scenarios are divided as shown in Table 5. Among them, 23 types are basic scenarios, 8 are challenge scenarios, and 3 are innovation scenarios.

Table 5 Classification of Test Scenarios for Intersection Types in Shanghai Automotive City Experimental Zone

Basic scenario	d-N	ld-S	d-SR	d-S	ld-L	n-N	d-SL	d-L
	ld-SR	d-R	n-S	n-SR	n-L	ldr-S	n-SL	n-R
	ldr-L	rd-R	ldr-SR	rd-S	ldr-R	n-LR	rd-L	
Challenge scenario	ld-R	d-LR	ld-LnU	d-nU	d-LnU	ld-LR	ld-LU	d-SLR
Innovative scenario	ldr-U	d-SLnU	ld-SL					

6 CONCLUSION

In response to the problem of full coverage of scene types for the most complex intersection scenes in cities, this article innovatively proposes using the road rights composed of a limited number of combinations of guide arrows and traffic lights in the lanes as the classification basis for intersections. Through research and summarization, all types of combinations of guide arrows and traffic lights at intersections are first obtained, and then all combination types are obtained by pairwise combination. The frequency distribution of all combination types is analyzed through statistics of the automobile demonstration zone, and based on this, the classification is carried out, laying the foundation for the testing and evaluation of intelligent vehicles in urban work conditions.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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