Some Thoughts on the Design for At-grade Intersections of Urban Road

Huilin Feng1,*, Huiqing Feng2,a

1Shanghai Municipal Engineering Design Institute (Group) Co., Ltd., 901 North Zhongshan Road (2nd), Yangpu District, Shanghai, 200082, China
2School of Mechanics and Civil Engineering, China University of Mining and Technology (CUMT), No1, Daxue Road, Xuzhou, Jiangsu, 221116, China

*Corresponding author e-mail: philipsfenghl@hotmail.com, aqinggif@163.com

Abstract. Road intersections, as nodes in the road network, are the key to improving operational efficiency. Extensive practice has shown that a reasonable design of the intersection scheme will help to release the road capacity and improve the smoothness of traffic for various participants including motor vehicles and slow traffic. This paper, based on relevant domestic and foreign codes and other achievements, has put forward some thoughts on the design principles, design ideas and follow-up development of intersection engineering, aiming to provide a certain reference for relevant management, analysis and design work. Urban roads are the lifeblood of urban economic life and one of the important signs of development of urbanization. In the process that urban municipal roads are continuously being built into a network and road traffic demand is continuously being tapped and released, the "throat" effect of at-grade intersections of the road is constantly emerging. At the at-grade intersections, under the background of low traffic speed and a large number of people flows and vehicle flows interweaving at the intersection, designing a scientific and reasonable traffic organization scheme for intersections will help to improve the efficiency of the intersection and even the road section. However, the change in the design space brought about by the property line planning concepts such as "narrow roads, dense road networks" and "street all-factor planning and design", as well as the trend of increasing complexity of urban underground pipelines and underground facilities, have put forward new requirements for the design of road intersections. But at the same time, for some intersection schemes designed according to the new design concept, due to the lack of a clear basis for examination and approval, there is a space for discussion. In view of this, it is necessary to think about and sort out the planning and design process of at-grade intersections, and on the basis of fully examining the three stages of planning design, engineering design and management control design, to put forward suggestions on planning design in the new era and new situation. The author is mainly engaged in the stage of engineering design, so this paper will put forward some thoughts on the at-grade intersection design from the perspective of engineering design and management control design.
1. Research Objects and Boundaries

According to the provisions of current Specification for Design of Intersections on Urban Roads (CJJ 152-2010) (hereinafter referred to as the Specification), the at-grade intersection design should include the areas where each road intersects at the intersection and the space enclosed by its entrance and exit roads as well as pedestrian and bicycle crossing facilities, this provision specifies the basic scope of at-grade intersections. However, the Planning, Design and Management Mechanical Regulations for At-grade Intersections on Urban Street in Wuhan (Trial Implementation) stipulates that the scope for graphic design of urban street at-grade intersection is the plane area enclosed by property lines for road planning which starts from 5 meters away from the end of the widened transition zone or 5 meters away from the end of the property line widened transition zone. The engineering design and management control design of the intersection, including intersection channelization, U-turn lane design, pedestrian crossing, design of secondary-crossing safety island, landscape design, lighting design, and traffic control and management design, belong to the fine design in the design space reserved by the property line planning.

Figure 1. Schematic Diagram of Research Objects Scope of Intersections

With the continuous deepening of urban development, the number of various types of pipelines and underground facilities under municipal roads has shown a rapid growth trend, and the laying of pipelines under roads has led to a large number of pipelines intersecting under at-grade intersections. Therefore, in addition to the above-mentioned conventional design categories, integrated pipeline design should be added to the at-grade intersection design, so that pipelines can be buried in place once as far as possible, so as to minimize the reduction of traffic capacity due to the construction of pipeline maintenance in the use stage of intersections.

Theoretically, based on the deliverables of engineering design and management control design for intersections, the property line scope of the road is determined in reverse, which is the best choice to consider both demand and land conservation. However, in the process of actual implementation, as the depth of constructive detailed planning needs to take into account the continuity of area planning and the need for in-depth coordination and matching with the follow-up area special planning. At present, the processes of various fine engineering designs and management control designs are mostly adaptively designed within the property line scope determined by standardized methods.
2. Research Status at Home and Abroad
Directing road traffic by traffic signals dates back to the 19th century. In 1868, the first light-controlled intersection appeared in London, England. Subsequently, in countries with relatively developed automobile traffic, on the premise of continuous flow traffic, the research on intersection design was made, and methods such as left-turning and right-turning accommodation lanes and widening in a channelization were proposed. In traffic management, the combination of signal control and rule control is adopted, such as multi-phase control, prohibition of left-turn or right-turn, etc. to improve traffic capacity at intersections. [1]

At present, the channelization design of intersections is more representative in such countries as the United States, Germany, and Japan, and relevant countries have adopted relatively perfect specifications to promote fine engineering design. For example, Japan, in the Planning and Design of At-grade Intersections, has made a lot of elaboration on the widening of the entrance road of at-grade intersections, setting appropriate “islands” in areas where normal traffic flow is not used can play a role in providing pedestrians with a place to avoid vehicles and rectifying the traffic flow. The Manual for Traffic Control Facilities (MUTCD Manual) of the United States has elaborated the design parameters and applicable scope of various channelization facilities. Meanwhile, in the Geometric Design of Highways and Streets, universal design principles are formulated for the intersection design as general design rules to be followed when designing intersections. [2] In the German Code for Road Design, there are clear provisions in the chapter on the at-grade intersection design, stipulating that at the no signal-controlled intersection, the number of straight lanes shall be consistent with that of road section lanes, and the intersections controlled by signal lights shall be widened on the original basis.

In terms of optimization of intersection organization, in 1974, Al-Salman et al. studied the rule of right-turning vehicles in light-controlled intersections and proposed a model for calculating the delay of right-turning traffic flow during the red light, and simultaneously evaluated the safety of different right-turning lane forms. [3] In 1995, Shebeeb et al. studied the impact of left-turning lanes on safety efficiency and put forward the viewpoint that the left-turning efficiency can be improved by setting accommodation lanes. [4] In 1997, SuvarajeetSen et al. proposed an intersection signal algorithm suitable for dynamic planning of intersections, which can improve traffic efficiency at intersections through parametric calculation. [5]

The study at home on at-grade intersections started relatively late. More systematic study on related design optimization is mainly focused on specifications and literature, such as the national standard Code for Planning of Intersections on Urban Roads (GB 50647-2011) and the industry codes Specification for Design of Intersections on Urban Roads (CJJ 152-2010), Code for Design of Intersections on Urban Roads (CJJ 37-2016), Shanghai's Design Specification for At-grade Intersections on Urban Streets, Wuhan's Planning, Design and Management Mechanical Regulations for At-grade Intersections on Urban Street in Wuhan, etc., and relevant specifications have provided a concise basic reference for engineering design. Furthermore, Manual of Urban Traffic Design compiled by Yang Xiaoguang of Tongji University formally described the design method and technology for the optimization of intersections at the design level including channelization design, signal timing and other measures. Relevant specifications and writings have provided relatively diverse measures and implementation plans for the design and management of intersections.

3. Design Principles and Ideas of Intersections
At the at-grade intersections of the road, all kinds of vehicles and pedestrians from multiple directions will gather, pass and make a turn here, which will inevitably lead to mutual interference between different traffic participants, reducing the traffic efficiency. Therefore, as the "throat" part of the road traffic system, the correct and reasonable scheme for intersection design has positive significance for improving the capacity of the intersection and even the road section.

Basic requirements for intersection design: On plane, it is necessary to ensure that various types of vehicles and pedestrians can pass through the road in the shortest time and distance, and that the capacity is matched with the roads connected. Vertically, above the ground it is required that the requirements of
vehicle's stable driving and road drainage shall be met, below the ground, it is required that the spanning relationship of various pipelines should be reasonable, which is convenient for long-term and rapid maintenance.

3.1. Basic design principles

3.1.1. Adhering to people-oriented and promote people-oriented design. In the current process of design of municipal roads, the traffic concept of "vehicle-oriented" to "human-oriented" has changed into a design trend, because there are many kinds of traffic modes interweaving at the intersection, it has also become the focus of promoting people-oriented design in practice. [6] In most of the current design schemes for municipal roads, the most core design principle is to ensure the function of motor vehicles, most of the relevant designs require that, on the basis of the widening of the lane, large radius of curb should be set to ensure the rapid turning of vehicles, under the premise that the area enclosed by the property line at the intersection is certain, this measure has reduced the traffic space for pedestrians and non-motorized vehicles. [7] The relevant design is feasible in the superblock community in the old urban area, because under the planning idea of the superblock, the internal roads of the community are only used for arrival and departure, the demand for road microcirculation is relatively small, and the at-grade intersection shall meet the rapid distribution and special needs by increasing the area ratio. However, in the new era, block system is widely implemented in planning, new construction and renewal areas, Opinions of the CPC Central Committee and the State Council on Further Strengthening the Management of Urban Planning and Construction released in 2016 directly proposed that closed residential quarters should not be built any more, and the built residential quarters and unit communities should be gradually opened, and the microcirculation of roads should be opened up, so that the trend of forming a homogeneous traffic distribution system has been continuously strengthened. This trend will also guide the intersection design to return to people-oriented design, and pay more attention to the comfort needs of slow traffic such as pedestrians or non-motorized vehicles.

3.1.2. Adhering to the innovation of design concept, from engineering and organizational design to functional design. At present, the general design ideas of at-grade intersections mainly focus on engineering structure design and motorized function design. There are specific design paradigms and relatively fixed flow of work in the relevant design. On this basis, according to the width of the property line and the requirements of various pipeline intersecting as well as opening exposed to the ground, sidewalks and non-motorized lanes are arranged, and the traffic organization scheme is formulated, resulting in relatively weak slow traffic functions. Therefore, in the process of intersection design, on the basis of coordinating all kinds of traffic needs, it focuses on the people-oriented traffic function, optimizes the spatial arrangement of the intersection by function-oriented, guarantees the continuity and comfort of slow traffic such as pedestrians and non-motorized vehicles, and meets the stop, pass and turn needs of pedestrian on the premise of safety. At the same time, the organization is strengthened through the speed limit rules, etc. so as to meet the needs of road drivers to smoothly and orderly pass through the intersection. Function-oriented design is a comprehensive design involving many categories, based on the collection of information about the road section involved in the intersection, which requires to flexibly using hard measures such as channelization and soft measures such as laws and regulations to achieve relevant functions.

3.1.3. Reserving sufficient space for long-term development. In the process of road design, due to the relatively stable land use planning, the spatial relationship with the surrounding land parcel is certain, however, with the continuous development of road sections and areas, the functional requirements of the road itself are uncertain, with the continuous development and reorganization of the production and living functions of the area, the optimization and upgrading of functions of the area will inevitably bring about changes in travel demand. Therefore, the intersection design needs to reserve the necessary space resources through preliminary planning and redundant design, etc. on the basis of meeting the demand
reflected by forecast of the long-term traffic volume, as the necessary prerequisite for subsequent adjustment and optimization.

3.2. Functional design ideas of intersections

According to the Planning, Design and Management Mechanical Regulations for At-grade Intersections on Urban street in Wuhan, the at-grade intersection design consists of plane design, vertical design, lighting and safety engineering design, greening and environmental design, traffic control and management design, etc., the relevant contents are to divide the intersection design into various sub projects for design. Here I attempt to elaborate the design idea of at-grade intersections from the perspective of functional design.

3.2.1. Design idea of slow traffic function of intersections. Slow traffic system is an integral part of the at-grade intersection. The purpose of slow traffic design is to make slow traffic cross the street safely, separate people and vehicles, and to reduce the interference between different traffic participants. The ground traffic of slow traffic will inevitably interfere with the ground traffic flow, three-dimensional street-crossing facilities such as overpass and underpass can be used to separate the slow traffic from the ground traffic flow, so as to avoid the impact of slow traffic on the ground traffic flow. However, the relevant three-dimensional street-crossing facilities need higher cost to achieve barrier-free traffic, and the traffic distance crossing the intersection is longer than that of the ground traffic. Therefore, in addition to the intersections with strong demand for motor vehicles such as the arterial-road intersection, setting three-dimensional street-crossing facilities should be avoided as far as possible. In the process of ground street-crossing design, the turning radius of the curb can be reduced and the street-crossing distance can be shortened. This measure can shorten the pedestrian street-crossing distance and enhance their confidence in crossing. What’s more, the design of elevating the intersection with small width can be adopted to ensure the smoothness of the crosswalk, and the laying of the blind path can be optimized according to the conditions in combination with the crossing facilities, so as to fully meet the pedestrian street-crossing needs.

At the ground light-controlled intersection, separation of motor vehicles and slow traffic has been realized in the same phase, but there is still the possibility of interweaving between non-motorized vehicles and pedestrians, which has an impact on the efficiency and safety of slow traffic participation. Therefore, measures such as paving asphalt of different colors or setting signs and markings can be taken to separate the pedestrian street-crossing channel from the non-motorized vehicle lane, which can more effectively solve the problem of interweaving between pedestrian and non-motor vehicles and improve the efficiency of slow traffic passing through the intersection.

Figure 2. Schematic Diagram of Reduced Curb Radius at Intersections
3.2.2. Design idea of motorized traffic function of intersections. The design of motorized traffic function of intersections mainly includes channelization design, widening design and U-turn lane design. In the current design process, the channelization scheme for the entrance road and exit road of the intersection is mostly formulated by referring to the specifications, and the right-turning, left-turning and straight accommodation lanes are set to reduce the mutual interference of motor vehicle flows in different directions.

In the channelization design, if the channelized turn scheme is used to set up channelization islands for dredging traffic, whether it is a solid island or a marking island, restricted by sight distance and other factors, it is difficult to make full use of the area inside the channelization island, which does not conform to the principle of intensive land use. Therefore, it is recommended to apply it to the intersection with higher speed level and more turning vehicles, and design it as much as possible in combination with secondary crossings and greening.

At lane-widening intersections, it is necessary to investigate and verify the 15-minute traffic volume and turning characteristics during rush hours, and set up left-turning and right-turning lanes reasonably to improve turning efficiency. At the same time, the length of transition zone stipulated by the current Specification for Design of Intersections on Urban Roads (CJJ 152-2010) is relatively general, and the relevant values are obviously not suitable for the case of large widened width. Therefore, it is suggested to use S-curve of connecting circle and circle to check the length of transition zone, and refine the length of transition zone with different speeds and widened widths.

Aiming at the design of widened section, under the background of "narrow road and dense road network", in the current planning and design, it is encouraged to relieve the traffic demand by increasing the density of road network, which reduces the demand concentration and design complexity of road intersections to a certain extent, the reduction of demand concentration also has reduced the demand of intersection space, so there are conditions of not widening and reducing the land space at intersections. However, in the urban built-up area, insufficient planning reservation conditions make it impossible to form a "dense road network" by means of continuous construction, etc., so increasing the area ratio of intersections is almost the only choice to meet the demand of distribution of traffic flow and people flow. Meanwhile, the widening strategy should be adjusted in a differential manner according to the location of the intersection, for example, the intersection near the historic buildings to be protected, the relevant widening should be subject to the rules of protecting the historic buildings, and the widening should be minimized on the premise of considering the demand.

What's more, in order to open the microcirculation of the road and improve the capacity of the road, most cities on the arterial and sub-arterial roads have set up hard isolation, so that a lot of U-turn traffic has been generated. In the past, the U-turn lane designed often extended to the intersection, which was set separately or set by merging with the left-turning lane. However, with the increase in traffic flow, the current design trend of arterial and sub-arterial roads is to set the U-turn lane outside the intersection to separate the U-turn and left-turning traffic flow. Turning of different types of vehicles, apart from the
different driving trajectories, is also related to the driving speed. The faster the vehicle travels, the greater the turning radius of its U-turn, which can be concretely rechecked by using AUTORUN software from Transoft Solutions of Canada.\cite{1}

In the process of designing the motorized traffic function at intersections, the optimization of curb radius and other modes can be used to meet the demand of slow traffic. However, relevant measures may reduce the turning radius of motor vehicles, and similar situations also occur in the setting of U-turn lanes. It can be determined that the reduction of vehicle speed can effectively reduce the turning radius of the vehicle, so it is suggested to improve the speed limit rules of intersections through policies, rules, etc., so as to better maintain the effective implementation of other functions of intersections.

3.2.3. Comprehensive design ideas for intersection pipeline. As urban development continues to expand, urban underground pipeline engineering and underground facilities are becoming increasingly complex. Furthermore, municipal pipelines are often laid simultaneously along municipal roads, under the road intersection, there will often be a large number of pipelines traversing, so a special comprehensive pipeline design is required. At the same time, at the intersection of pipeline or utility tunnel, external extension structure is often set to cross and connect to users, and the property line for road planning is still effective for underground facilities. Therefore, in planning and design, it is recommended to consult with the planning and design institute of underground pipelines to verify whether the property line scheme can meet the setting requirements of exposed-to-the-ground facilities of underground pipelines, in the design stage, it shall be confirmed whether the long-term operation and enclosure maintenance of the pipeline will cause the interruption of lane or slow channel, and then will affect the traffic efficiency of the intersection.

4. Some Thoughts on Intersection Design

4.1. Thoughts on the design of property line cutting corners at the intersection

There are some controversies over the setting of the property line at the intersection in the planning and design. There is a point of view that, from the perspective that the sight distance can ensure the safety, property line cutting corner should be set, relevant concepts are also reflected in the Code for Planning of Intersection on Urban Roads (GB 50647-2011) and the local technical standards of various cities, relevant standards generally require that the property line cutting corner at the intersection on the arterial road and sub-arterial road is generally 20-25m, the property line cutting corner at the intersection of branch roads is generally 10-15m. However, some people believe that the property line cutting corner at the intersection is not a necessary condition to meet traffic demand.\cite{8}

In the design of the property line cutting corner, I personally think that the analysis should still be made based on the traffic function of the intersection. From the perspective of the traffic function of motor vehicles, as insufficient efforts have been made to govern the phenomenon of speeding up to grab the lane at this stage in China. In the change stage of signal lights, it is still common that slow traffic and motor vehicle traffic grab the lane, therefore, retaining the cutting corner can provide more space for pedestrians to stop and reduce the possibility of pedestrians crossing the line to grab the lane. And the cutting corner belongs to the scope of road engineering, restricted by the relevant provisions such as the driving sight distance, so no tall buildings and structures can be built within the scope of property line cutting corner, objectively guaranteeing the sight distance safety at intersections.

At the same time, because the property line of the road also has certain management and constraint effect on underground pipelines and facilities, and at the intersection the pipelines generally cross one another and change direction, it is necessary to set cross nodes. The relevant nodes often need to be widened on the basis of the existing pipelines, and the property line cutting corner at the intersection can better meet the needs of relevant local widening. Meanwhile, subsequent capacity-increasing and maintenance spaces are reserved, therefore, it is sustainable to retain the design concept of the property line cut corner.
However, the scope of the property line cutting corner, in the specific engineering design, often has the problem of single function, in my opinion, the function of the land parcel near the intersection can be combined to enhance the function of the cutting-corner area, for instance, micro-commerce, micro-square and even public service micro-nodes are set up, and full use of the advantages of people flow at the intersection is made to improve the convenience of services.

4.2. Thoughts on the widening of intersections
Because of setting the light control at the intersection and other reasons, the vehicle speed is slower than that in the general road section, so the capacity is also smaller than that in the general road section. Therefore, channelizing intersections and increasing the number of lanes will help to match the capacity of road sections and intersections and improve traffic efficiency. However, in practice, some road sections are located in densely populated areas, and the tidal characteristics of road traffic are obvious. If the road size is simply considered based on the peak-hour volume, it will inevitably increase the size of roads and intersections, but the overall utilization rate is not high, at the same time, the wider roadway also reduces the pedestrian activity space to a certain extent, reducing the slow traffic comfort of the residential area. At present, the tidal lane measures used for arterial roads are perfect measures, which are relatively complex to operate and are not suitable for large-scale spreading. It is recommended that, in the subsequent design, consideration should be given to the intelligent reconstruction of intersections in combination with the intelligent marking technology, the widened width of lanes is divided by the change of the markings, the width of the opposite lane is compressed during peak period, and the space resources of intersections are fully utilized.

5. Conclusion
Reasonable intersection design is the key to long-term stable operation of the road. The road design that our country has been conducting under the idea of motorized traffic as domination for a long time needs to be updated, then it can better adapt to the development trend of urban traffic in the new era of “narrow roads and dense road networks”. Combined with the relevant codes and research results at home and abroad, this paper has put forward some thoughts on the design principles, design ideas and follow-up development of intersection engineering. Through the optimization of geometry and traffic organization at intersections, it will help to improve the efficiency of road traffic and even overall driving quality. Subsequently, with the continuous deepening of project participation, related optimization studies are expected to be spread to three-dimensional intersections, railway intersections and various types of
abnormal intersections. The scope of study also spreads from simple geometry and organizational optimization to deeper fields such as signal timing and driving vision optimization and so on.

References

[1] Wanming Zhang. Study on Optimal Design of Traffic Organization of Intersections on Urban Streets [D]. South China University of Technology, 2012.
[2] American Association of State Highway and Transportation Officials. A Policy on Geometric Design of Highways and Streets[R]. Washington DC: AASHTO, 2011.
[3] Al-Salman, Salter R J. Control of right-turning-vehicles at signal-controlled intersections [J]. Traffic Engineering & Control. 1974.115 (15). 683-686
[4] Sheeeb, Ousama. Safety and efficiency for exclusive left-turn lanes at signalized intersections [J]. Institute of Transportation Engineers. 1995.65 (7). 50-56
[5] Suvrajeet Sen, K. Larry Head. Controlled optimization of phases at an intersection [J]. Transportation Science. 1997.31 (1). 5-17
[6] Xia Shengguo. Exploration of Street Design Method in the Context of Livable City [J]. Urban Transportation, 2019 (5).
[7] Zhou Sien. Some Thoughts on the Property line Planning for At-grade Intersections on Urban Streets [J]. Urban Transportation, 2019 (5): 39-46.
[8] Sun Hui, Wang Jia. Cutting Corner vs. Right Corner -- Case Study on "Inertial Thinking" in Regulatory Detailed Planning [J]. Urban Planning, 2005 (05): 55-58.