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Legibility of Chinese-English direction signs: how the spatial presentation of bilingual typography in two different scripts affects sign legibility

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Declaration

I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.

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Abstract

Chinese-English bilingual traffic signs (CEBTS) are widely applied in public spaces in China. However, few studies have addressed the design of bilingual signs using two different scripts. The main research question is **how can sign legibility be improved by the spatial presentation of bilingual location name(s) comprised of Chinese and English.**

The research begins with *an exploratory stage* addressing how the design of CEBTS can be analysed and identifying the design challenges of CEBTS aiming to identify variables to focus on. This stage includes a literature review and CEBTS design survey. *An experimental stage* examines the effects of adjusting the spatial presentation of Chinese/English legends on CEBTS legibility. The adjustments include changes in connecting spacing (vertical distance connects Chinese/English into a bilingual legend), separating spacing (vertical spacing separates bilingual legends), and text alignment.

The approach to the experiments was a threshold method combined with a search task and accuracy check. Participants were asked to indicate which direction they might take by viewing a series of video stimuli and making an immediate response when they had identified each target. The stimuli simulated the view a driver would have on a road in which they were driving towards a road sign at consistent speed. The response time and accuracy were recorded.

The findings suggest that the spatial arrangement of dual-script legend(s) affects sign legibility. The connecting/separating spacing can be utilised to group/distinguish dual-script information, and the text alignment should be according to sign complexity for a better legibility. The descriptive framework of the sign graphic system provides a design checklist for both academics and practitioners launching or reviewing a sign program for a legibility purpose. The insights of this research could be extended to bilingual signs using other scripts in both developed and developing countries, therefore having global impacts.

Keywords: bilingual traffic sign, dual-script typography, sign legibility, sign layout

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Introduction

Challenges and research questions

One prominent feature of Chinese traffic signs is that most of them are in a Chinese-English bilingual format (Fig. 0-1). China's rapid economic growth over the past decades has attracted a large number of expatriates from different countries. At least 845,000 expats are living in China according to the latest National Census of 2021 (National Bureau of Statistics of China, 2021). Shanghai and Beijing are the two largest population centres for expats, home to over 209,000 and 107,000 in 2018 respectively (Sampi Marketing Inc., 2018). Additionally, based on the statistics released by the National Bureau of Statistics of China, the number of inbound tourist arrivals totalled 143 million in 2019[1], increasing by 1% over 2018 (Travel China Guide, 2020).

Figure 0-1. *Bilingual traffic signs in Beijing and Shanghai. The text and graphic presentation in the two examples differ, such as the shape and style of the arrow, the spatial relationship between location names and the use and positions of other pictorial elements. Additionally, although published Standards cover the usage of both Chinese and Latin scripts, there is still misuse of the guidance in practical application. For example, condensing of English letters, inconsistent word and letter spacing in the English text, and inconsistent typeface and type size in the Chinese text. For more details see Chapter 3. Photographed by the author in 2018.*

[1] In contrast, the total number of international visitors to the US was 79.3 million in 2019 according to the National Travel & Tourism Office; 40.86 million overseas residents visited the UK (Office for National Statistics); and in 2018, France, as the most visited country in Europe, attracted 89.4 million tourists based on the statistics released by the World Tourism Organisation.

The increasing growth in movement and travel of people in Chinese cities, Shanghai and Beijing for example, prompts Chinese authorities to strive to design bilingual signs that depict information in both Chinese and English for local and international users. Chinese-English bilingual traffic signs (CEBTS) play an important role in multicultural Chinese cities. They provide more accessibility and guide people with different cultures, languages and destinations to navigate through familiar or unfamiliar environments. The effective design of CEBTS can allow people to find common meaning in symbols and terminology, thereby helping them to identify, distinguish, and make decisions faster.

Although bilingual traffic signs have been used in China for decades and they are widely applied to public areas, their design has changed little and, in many cases, the two languages do not work together coherently. Noticeable ambiguities and inconsistencies in current practice can be observed (Fig. 0-1), which may reduce sign efficiency and could ultimately have an impact on user performance and safety (Chapter 3).

Figure 0-2. *A Welsh/English road sign (Bilingual road sign in Wales, Man vyi, 2007). Retrieved from:https://en.wikipedia.org/wiki/Traffic_sign#/media/File:Caernarfon_one_way_sign.jpg*

Although there is a large amount of research which investigates monolingual signs, few studies consider sign legibility when adding another script to a sign, and, when they do, it seems that their considerations are limited and tend to concentrate on bilingual signs using the same scripts. The design of bilingual traffic signs using the same scripts (e.g., Welsh and English) began to attract researchers' interest starting around 1972. Rutley (1972) published *An Investigation into Bilingual (Welsh/English) Traffic Signs* which is one of the first scholarly discussions of the design for bilingual traffic signs. Figure 0-2 shows a bilingual sign used in Wales. Driver behavioural works, and research in the field of displaying bilingual text, has also been carried out on variable message signs (Dudek, 1991; Garvey & Mace, 1996; Jamson, 2004; Jamson, Tate, & Jamson, 2005). On the whole, these studies on bilingual traffic signs have confirmed that driver (user) requires more reading time on bilingual signs, and two methods could be applied to minimise the reading time: sequencing the languages and demarcating the two languages (Anttila, Luoma, & Rämä, 2000; Lesage, 1981; Rutley, 1972; Smahel & Smiley, 2011).

These studies all focus on bilingual traffic signs where the two languages use the same scripts (although the combinations of letters are different). The findings and solutions are concentrated on differentiating the two languages to assist users to find the information they needed, so that the increased reading time caused by the double information could be reduced. The findings and solutions, however, might not be sufficiently applicable to CEBTS where the character sets are very different, and the type size of Chinese location names are always larger than the size of their corresponding English location names. According to the Gestalt theory of similarity, typographic differences in shape and size allow readers to relate and group objects (Frascara, 2015), which indicates that people can distinguish between Chinese and English easily without spending additional reading time.

Compared with traffic sign designs that have already developed over many decades in western countries and have cultivated a relative standardisation (see the following section), the development of traffic sign design in China is in its initial stage and has yet to use a systematic approach. The efforts to standardise road traffic signs began in the 1980s in Mainland China. *Road traffic signs and markings* is one of the first National Standards that relates to traffic signs. It was issued in 1986 and was revised in 1999 and 2009 respectively. There are relatively limited and inexplicit visual specifications in the Standards that could support designers' decision-making. Reviews of existing Standards, such as *GB5768-Road Traffic Signs and Markings: Road traffic signs* (2009) and *JTCD82-Specification for Layout of Highway Traffic Signs and Markings* (2009), indicate that there are visual guidelines that relate to typeface for bilingual location names. The design of letterforms was based on the British road sign letters, *Transport*, on traffic signs before 2007. Then, taking reference from *Highway Gothic* (America traffic sign alphabet), the specific letterforms for traffic signs have been gradually implemented across the country. The design of pictorial elements, such as arrows and symbols, is based on Jock Kinneir and Margaret Calvert's design (see the following section for the detailed descriptions of *Transport*, *Highway Gothic*, and Kinneir and Calvert's design). In contrast, the guidelines do not sufficiently cover how to present sign elements in an appropriate way, especially the spatial presentation of Chinese and English location names on a traffic sign (see Section 3.1 for a comprehensive review of Chinese traffic sign Standards).

According to a theory of information design, information can (and must) be presented in a way that is tailored to the specific context so that correct decisions and control actions can be carried out 'without unacceptable delay' (Gether and Baker, 1972, p. 42). Due to this, the spatial presentation of the two languages can be utilised as a means to enhance sign legibility. However, few studies consider dual-script sign legibility in relation to the spatial presentation of Chinese and English scripts. Where research has taken place, the scope is fairly limited and tends to concentrate on the quantity of location names (Liu, Zhang, & Wei, 2015; Lyu, Xie, Wu, Fu, & Deng, 2017; Shi, 2013; Wang, Hu, Ge, & Li, 2015; Wang & Rau, 2011; Wang, 2014), and the choice of typeface (Dobres, Chahine, Reimer, Gould, & Zhao, 2016; Lai, 2008; Li & Li, 2010; Liu, Yu, & Zhang, 2016; Zhang, 1993).

This research, aims to fill the gaps presenting in both research and practice, dealing with bilingual traffic signs using different scripts (Chinese/English). It is also driven by the wish to optimise sign legibility through spatial presentation of the two scripts, and as an outcome, provides a meaningful way to guide future CEBTS design. Specifically, the main research question is:

how can sign legibility be improved by the spatial presentation of bilingual location name(s) comprised of Chinese and English?

This question is refined by addressing two secondary research questions:
a. how can the design of CEBTS be analysed? and
b. what are the design challenges of CEBTS?

Although the endeavours of this research into bilingual traffic signs are focused on the specific Chinese/English scripts in the Mainland China context, its methods and outcomes (I hope) could be applicable to bilingual signs using other scripts in a global context. The following section provides an international context for considering CEBTS by looking at the development of traffic sign system in western countries during the latter part of the twentieth century.

Traffic sign system in western countries

Research on monolingual traffic signs has a long history in western countries, Europe, America, and the UK for example. A historical overview of traffic sign system in these countries serves to contextualise CEBTS.

- European traffic signs

European traffic signs present a relative degree of uniformity and standardisation. They use the same simple set of road symbols that have generally become the basis of the World Standard for pictorial signs (Fig. 0-3). The first attempt at international traffic signs was triggered by the International League of Tourist Associations in the 1890s, discussing Italian arrow signs (Lay, 2004b). Since then, many consultations have been held in an attempt to attain road sign uniformity in relation to sign colour and shapes (e.g., circular and triangular). After the Second World War, international sign standardisation and signing conventions were introduced in the Geneva Convention in 1949. Subsequently, the Vienna Conventions on Road Signs and Signals were signed in 1968 and

1995, recognising that an International Standard was necessary for improving road safety and aiding road traffic internationally.[2] According to Lay (2004b), the number of warning signs increased nearly twice at Vienna than Geneva.

Figure 0-3*. Symbol signs in Belgium (left) and France (right). Photographed by the author, 2016.*

- *American traffic signs*

Apart from European Standards, the American system is used effectively in many countries around the world. In 1921, the first American signing manual was composed. The *Manual on Uniform Traffic Control Devices* (MUTCD) was first published by the US Federal Highway Administration (FHWA) in 1935. The *Standard Highway Signs* (SHS) (first edition in 2004 and the supplement version in 2021) is a compilation of the signs used in transportation in accordance with the MUTCD. These two federal documents govern the design, placement, and use of traffic control devices for both road and highway use. They specify detailed guidance for the design of the message displayed on the sign, though they allow some flexibility for the overall sign layout.

The typeface used is specified in these two federal documents. A typeface family known as the Standard Highway Alphabet (commonly called *Highway Gothic*) was developed in 1958 by Ted Forbes. In the early 1990s, the *Clearview* typeface was developed to address the needs of older drivers and to make road signs more legible. Fig. 0-4 shows two traffic signs with *Highway Gothic* and *Clearview* respectively. In 2004, FHWA granted interim approval that approved an alternative typeface, *Clearview*, for use on positive contrast applications (white character on a dark background). However, FHWA revoked this approval afterwards which may be because though *Clearview* performed better than *Highway Gothic* in legibility studies, it was not the optimal solution for all signage (Dobres, Chrysler, Wolfe, Chahine, & Reimer, 2017).

[2] Most European countries refer to the 1968 Vienna Convention on Road Signs and Signals — it has been adopted by Albania, Austria, Belarus, Belgium, Bosnia and Herzegovina, Bulgaria, Croatia, the Czech Republic, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Italy, Latvia, Lithuania, Luxembourg, Montenegro, the Netherlands, North Macedonia, Norway, Poland, Portugal, Romania, Russia, San Marino, Serbia, Slovakia, Slovenia, Sweden, Switzerland, Turkey, Ukraine and the United Kingdom. The convention has not been adopted by Ireland, Moldova and Spain (*Comparison of European road signs*, online source).

***Figure 0-4**. Clearview typeface (left) and Highway Gothic typeface (right) on road signs, in Saint-Simon-de-Bagot, Quebec, Canada (A new Clearview typeface sign beside an old FHWA typeface, SASgrafix, 2009). Retrieved from: https://en.wikipedia.org/wiki/Traffic_sign#/media/File:A20_Ouest_km143.jpg*

The MUTCD and SHS specify the use of mixed-case letters (words with initial capitals and small letters) for location names to improve the legibility,[3] and also include several dimensions of other sign elements (arrows and symbols for example) based on specific message sizes. Meeker, Pietrucha, and Garvey (2006, 2010) propose a proportion-based grid format to address the inconsistent sign layout issues. The format originates from the thought that the sign layout should be updated along with the development of sign typefaces. Most importantly, the grids proposed in SHS are individual solutions for specific applications that lead to viable difficulties when applied to various conditions. Thus, a common layout system based on the proportional relationship that is made uniform for all dimensions according to the height of the initial capital letter is produced.

To a large degree, the influence of road sign programs in the US has been extended across North, Central and South America (Horberry, Castro, Martos, & Mertova, 2004). For example, the design of *RutaCL*, a highway typeface used in Chile, is designed based on *Highway Gothic* but special attention is paid to increasing letter differentiation and diacritical marks (Gálvez, Ramírez, & Gallardo, 2016). Furthermore, the US road sign program extends worldwide, in Europe (e.g., Spain and Netherlands) and in Asian countries (e.g. China and Malaysia).

[3] There are varied findings from research about using mixed-case or uppercase letters on a sign for the purpose of legibility. Some researchers believe that words with mixed-case letters can improve sign legibility because they provide a varying contour as well as more familiar word shapes (Forbes, Moscowitz, Morgan, & Loutzenheiser, 1951; Garvey, Pietrucha, & Meeker, 1997). However, some researchers believe using uppercase letters also plays an important role in sign legibility, because uppercase letters could enable readers to perceive the importance of the message which can convey an emergency message (Lay, 2004a).

- *British traffic signs*

Fig. 0-5 shows two traffic signs in use in the UK. The British wanted to accompany their signs with written messages, and many of their pictorial traffic sign designs were based on the Geneva protocol of 1949 (Baines, 1999). The British approach to a road sign program has been consistently developed, designed by Jock Kinneir and Margaret Calvert between 1957 to 1963. The Government set up an advisory committee in 1957 to develop signs for the needs of the new high-speed roads. Jock Kinneir the committee's adviser, and his assistant Margaret Calvert were appointed to design motorway direction signs and the motorway alphabet (also called *Transport* typeface) for this specific use.

Figure 0-5. *Traffic sign in Reading (left) and Bicester (right), the United Kingdom. Photographed by the author, 2018.*

By using mixed-case letterform (following American practice) and sans serif alphabets that differed from its predecessor, the motorway alphabet has generated public debate on letterform legibility. The debate led to large-scale legibility experiments conducted by the Road Research Laboratory to investigate whether mixed-case letterform and sans serifs are superior to capitals and serifs (Lund, 2003). However, the experiments focus on only letter design but neglect other influential factors, such as sign colour, weather conditions, illumination, mounting and placement of signs, which resulted in controversial results.

In 1961, Kinneir developed two slightly modified versions of the motorway alphabet for use on the UK's 'all-purpose roads'; named *Transport Medium,* for positive contrast signs and *Transport Heavy*, for negative contrast signs (dark characters on a white background). The prominent characteristics of Kinneir's motorway directional signs are:

> '… no serifs, no boxes around destination name and road number, no barbs on the heads of the arrows that symbolise the road ahead, and, not least, no forced symmetrical or grid-based positioning of destination names … . Although the 'no boxes' feature adhered to an emerging modernist norm in graphic design (meaningful groupings were to be signalled, minimalistically, by spatial relationships alone) … eliminating the boxes around each destination name and road number, while keeping the map-like organisation of the destination signs, allowed for considerably larger lettering on the same sign area.' (Lund, 2003, p. 117)

Since then, the Kinneir Calvert system has been widely applied in the UK, and it is still robust and flexible enough to meet most of the needs of today's traffic (Baines, 1999). This system is taken as reference to similar roads in Greece, Portugal and in Hong Kong.

Project methodology and structure

This research uses different approaches to develop specific questions that arise from the findings of particular stages throughout the research. The research can be divided into two stages.

- An exploratory stage, as will be seen in Chapters 1 to 4, is used to identify the important typographic variables to focus on. This stage is constructed from the investigation of the two secondary research questions (how can the design of CEBTS be analysed; and what are the design challenges of the CEBTS?). It includes a literature review and the current design practice survey of CEBTS. The survey is combined with looking at relevant sign guidelines, visual analysing sign samples, and interviewing practitioners. This stage highlights that although many previous studies have concentrated on the influence of typeface and type size on road sign legibility, there may be a gap in knowledge when it comes to thinking about the optimisation of sign legibility through spatial arrangement of bilingual text. The exploratory stage, thus, sheds light on the main research question: how can sign legibility be improved by the spatial presentation of bilingual location name(s) comprised of Chinese and English?

- An experimental stage presents the core content of this research. It combines three empirical studies that attempt to answer the main research question raised at an exploratory stage. The tested variables are connecting spacing (text vertical distance connects the two scripts to form a bilingual location name), separating spacing (vertical spacing separates different bilingual location names), and text alignment. It also includes reviews of ways of measuring sign legibility to inform the methodology used in the empirical studies. This stage is mainly discussed in Chapters 5 and 6.

Chapter 1 is a literature review that defines some key concepts to provide context in relation to current practices and previous research. It lays a solid foundation for investigating the research question: how can the design of CEBTS be analysed? It links sign requirements to sign design components from the perspectives of information designers, transport engineers, and environmental psychologists. As a result, the sign graphic system (one of the sign design components) is identified as the primary focus of this research. This chapter also reviews bilingual typography studies to link appropriate typographic attributes affecting sign legibility. Furthermore, to prevent potential misunderstandings, concepts such as CEBTS and sign legibility are explained.

Chapter 2 clarifies and restructures the general factors involved in the shaping of a sign graphic system, then a descriptive framework of a sign graphic system is proposed. The proposed framework provides a systematic way to analyse a sign graphic system and is used to explore the current design practice of CEBTS.

Chapters 3 and 4 discuss the survey of the current design practice of CEBTS. With the factors involved in the proposed descriptive framework in mind, the survey intends to address the secondary research question of how CEBTS have been designed so far and what the design challenges are. The survey comprises a review of traffic sign Standards and policies; analysis of samples of the current bilingual traffic signs in China; and interviews with practitioners. The survey documents traffic sign Standards and samples CEBTS in practice, discussed in Chapter 3. It includes six mandatory Standards which deal with traffic signs for all types of routes, and also investigates how the graphic system is constantly being improved and refined in the process of Standard development; these were published between 1999 and 2017 in China. Sign samples include photographs of urban road signs in four Chinese cities : Beijing, Shanghai, Wuxi and Dalian, there is a comparison of the design of traffic signs in these different cities and an exploration of how Standard guidance is applied to the real signs; the majority of the CEBTS samples were photographed between 2017 and 2019, from a moving car. In Chapter 4, five semi-structured interviews with a range of practitioners are presented to reveal the issues raised from the investigation of Standards and samples. The interviewees include experts who have been engaged in compiling and implementing traffic sign Standards, and who work in the design and production of CEBTS.

At this point in the research, the extrinsic attributes of bilingual legends and sign layout are highlighted, and it appears that there is currently insufficient research and specifications in relation to them to support the design practice. The extrinsic attributes in this research refer to character configuration, such as spatial attributes (letter spacing, word spacing, and line spacing), line length, and text alignment based on Twyman's approach (Section 2.2.1). To identify which factors involved in the extrinsic attributes of bilingual legends and sign layout might primarily be focused on, Chapter 5 applies exemplar studies to distinguish the ways that drivers may use the signs and what sign elements may support them in doing so. The findings show that bilingual legends are involved in most driving tasks. Accordingly, the chapter sheds light on the main research question in relation to the impact of extrinsic attributes of bilingual legends on CEBTS legibility. Chapter 5 defines the test variables and informs the methodology applied to the empirical studies by reviewing various ways of measuring sign legibility.

Chapter 6 shows the development of three empirical studies and presents their results and findings. These three studies aim to examine the effects of adjusting the spatial presentation of bilingual location names on CEBTS legibility. The adjustments include changes in connecting spacing, separating spacing, and text alignment. The approach to the studies is a threshold method combined with a search task and accuracy check. A monitor displays a number of CEBTS shown in a 3D graphics rendered video clip of someone driving towards the road sign. Participants make their response immediately once they have identified the target. The response time it takes to look up at a target was recorded, together with the accuracy of the response.

Chapter 7 evaluates the research. It highlights the findings of the empirical studies, which suggest that the spatial presentation of the Chinese/English legend(s) is a significant consideration for CEBTS legibility. The contributions and implications of the experimental findings are also stated, combined with the methodological contribution in testing legibility of bilingual signs. This chapter also shows the findings and contributions of the exploratory stage, and especially discusses the function of the proposed descriptive framework, as well as its potential applicability in a wide range of sign design programs. Suggestions and recommendations for future research include noted limitations (some arising from this study), are also provided.

1/ Context and concepts

This chapter serves to contextualise the research in relation to previous exploration and current practices in order to build solid foundations for the investigation of the research questions. It also considers appropriate vocabulary for subsequent description and analysis. To be sensitive to potential misinterpretations, core concepts, such as CEBTS and sign legibility are explained. Studies in the field of bilingual typography are also reviewed which helps to connect important attributes of a dual-script setting on a sign scenario.

1.1/ Sign programs and traffic signs

A sign program (Calori & Vanden-Eynden, 2015; Gibson, 2009) is a set of signs working together to gain a unified purpose: conveying information to its audiences. Such a program not only requires an appropriate design for a single sign, but consistency and uniformity across a whole set. A sign program comprises a hybrid set that includes iconic, symbolic and semantic components. What ties these components together is sign layout. A sign program weaves informational and visual messages together to guide people to find their way through an environment, thereby assisting the wayfinding process. However, a sign program is not synonymous with wayfinding. Wayfinding is a problem-solving process that describes how people find their way around an environment, whereas a sign program is a wayfinding device that aids the wayfinding process.[4]

Sign programs play an important role in human-built environments and benefit people in their daily lives. Signage can perform a communication role in directing, identifying and informing people; it can also establish a sense of place and reinforce a brand identity in environmental form; more importantly, an effective sign program could contribute a sense of personal well-being, safety and security in a dynamic and often high-stress context, such as airport and hospitals (Calori & Vanden-Eynden, 2015; Gibson, 2009). In transport, especially, traffic signs can be critical to safety. Traffic signs can include not only signs on posts, but also signals, markings and traffic islands and other devices (Department of Transport, 1982). There are also new technologies, such as Variable

[4] For extensive reading regarding wayfinding processes and strategies please see Carpman & Grant, 2002; Jeffrey, 2017; Passini, 1984.

Message Signs where the message varies over time. Traffic signs, according to Lay (2004), ensure the movement of traffic safely, predictably, efficiently and orderly. The ineffective sign has a number of potential costs. Drivers can be late for important occurrences if they do not know where they are or the routes to get their destination; they may also feel stressed and frustrated, which may result in negative physical and psychological effects, therefore could ultimately have an impact on their performance and safety. In the UK, approximately 15% of road intersection accidents and 32% of bridge bashes (NetworkRail, 2012) could be attributed to ineffective traffic signs.

1.1.1/ Chinese-English bilingual traffic sign (CEBTS)

The subject of this research, CEBTS, refers to the traffic signs that provide information and guidance for drivers while driving as the aid to efficient traffic movement and road safety. Thus, drivers are specified users rather than cyclists (considering a bicycle's much lower moving speed than a motorised vehicle) and pedestrians. In addition, CEBTS only refer to the static bilingual text-based traffic signs erecting at the side of, or above, roads rather than Variable Message Signs and symbolic signs.[5]

This research focuses on CEBTS in the Mainland China context. In China, traffic signs can be broadly divided into two categories: expressway signs and signs for urban routes (General Administration of Quality Supervision et al., 2009). The two categories require particular specifications, for example, the type size relating to the speed of an approaching vehicle differs. Therefore, the analysis of expressway signs and urban route signs should be considered separately. Within the scope of this doctoral research, only the traffic signs used on urban routes are analysed and CEBTS only refers to urban route traffic signs in the following discussions, unless otherwise stated. However, the findings of this research may inform the design of expressway signs that have a similar layout with urban route signs.

1.1.2/ Sign requirements and design components

With regard to this research, it is appropriate to understand the basic requirements of traffic signs in a driving context and how it differs for signage for walkers.[6] The act of driving involves many tasks that are performed in parallel. The three major tasks are controlling the vehicle, interacting with other vehicles (following, passing, merging, and such), and navigating by using information devices (Smiley & Dewar, 2015). Researchers

[5] Symbolic signs are important and there is lots of research into these (Garvey & Kuhn, 2004; Horberry et al., 2004; Jacobs, Johnston, & Cole, 1975; Shinar, Dewar, Summala, & Zakowska, 2003), but text-based signs are necessary and widely used too. This research is going to focus on those which aims to investigate how textual information affects sign legibility.

[6] Driving signage generally requires larger messages than pedestrian signage and therefore results in the use of a larger sign size. These scale decisions are affected by the driver's distance from the sign and driving speed (Gibson, 2009).

and policymakers seek to minimise the time drivers devote to signs (navigation) in order to increase the amount of attention paid to the road and vehicle control, thereby helping drivers to proceed safely and efficiently (Jamson, 2004). To achieve that, a traffic sign must be visible, legible, and comprehensible.

Sign visibility refers to a traffic sign that can be seen and is able to attract driver's attention while driving; *sign legibility* denotes how easily a sign's textual or pictorial message can be read; and *sign comprehensibility* describes whether the message can be interpreted correctly to produce the intended action (Garvey & Kuhn, 2004). Accordingly, visibility, legibility and comprehensibility are key design requirements to be considered when thinking about how drivers respond when encountering a traffic sign (detection, reading, understanding and appropriate action).

These requirements are embedded in the design of a sign program. Sign design, according to Calori and Vanden-Eynden (2015), can be divided into three components: the information content system, the graphic system, and the hardware system. The *information content system* deals with the message displayed on the sign and how it is worded; it also consists of sign location issues (a place where a sign should exist). The *graphic system* covers the activities of encoding and displaying the messages presented on the two-dimensional sign surface. The messages include either text or pictorials, that information designers utilise to communicate in a meaningful way. The *hardware system* refers to physical sign objects that include the sign shapes and sizes, sign material, mounting, and lighting techniques. The three design components are interrelated, and each play an important role in composing the design of a whole sign program. The information content system is the bedrock, the raw informational material that is communicated by the graphic system, which in turn is displayed on the hardware system.

- Sign information content system and hardware system contribute to sign visibility

Both the information content system and hardware system contribute to sign visibility. Sign visibility, as mentioned above, requires a sign to be detectable and conspicuous. For example, to be visible, the sign should be located where it is possible for it to be seen by drivers, which is based on their visual field. Matson (1955) suggests that 'a sign should fall within a visual cone of 10° to 12° on the horizontal axis and 5° to 8° on the vertical axis' if a sign is to be noticed (in Garvey and Kuhn 2004, p. 7.7). Lay (2004) states that a sign should be no more than 10° from the driver's line of sight. The reasons for these scales are explained in Section 1.2.1 below.

From the perspective of information design, the information content system dealing with what messages are displayed on the sign associates with the *physical level* (Carliner, 2000) that helps users to find information of interest easily, which is the first level of the information design process.[7] In wayfinding strategy, sign placement (another constituent within the information content system) is dealt with in terms of *decision points*. Decision points are the points along the routes where people need to decide where they are and what the next action should be. Fendley (2009) proposes principles inherent in a wayfinding system for walking in London. One of them is *progressive disclosure* that aims to provide the right information at the right place, and to answer the question of the user within the constraints of the location. Here, 'the right information' and 'the right place' can link the two constituents (wording of sign message and placement of sign) within the information content system together. 'The right information' reflects the decision on what messages will be displayed on a sign and 'the right place' reflects the sign location.

The sign information content system is also associated with the information processing limitations of human beings (section 1.2.2). Many studies suggest that reaction time increases according to the information quantity on both English traffic signs (Bohua, Lishan, & Jian, 2011; Du, Pan, & Guo, 2008; Lyu et al., 2017) and Chinese traffic signs (Liu, 2005; Wang et al., 2015). Therefore, it is important to offer sign messages that users only need at a given location rather than overloading them with too much information.

The sign hardware system can be utilised to increase the chance of traffic signs attracting attention. To meet sign conspicuousness levels, the sign must attract the users' attention. Hughes and Cole (1986) have found that 30% to 50% of drivers' attention is attracted by objects not related to driving; advertising for example. In contrast, only 15% to 20% of attention is given to traffic signs, which is not sufficient to ensure that most traffic signs attract a good proportion of attention. Accordingly, larger sign size, and higher contrast in luminance between the sign and its background are the particular determinants of sign conspicuousness.

- *Sign graphic system contributes to sign legibility and comprehensibility*

In contrast, the sign graphic system contributes to sign legibility and comprehensibility. The ultimate purpose of the graphic system is to assist drivers to read signs, to act on signs if needed, and to guide them through an environment. According to the principles of information design and wayfinding design, the graphic system is associated with the *cognitive level* that helps users to understand information and make use of it; and the *affective level* that relates to motivating users to perform (Carliner, 2000). It is the graphic system that is the essential centrepiece for information. Most information designers agree that the graphic system is one of the key factors affecting sign design success (Craig Berger, 2009; Gibson, 2009). As Petretta (2004) states, 'the graphic logic of message sequence and

[7] Carliner (2000) identified approaches to information design on three levels: physical, cognitive and affective. The physical level relates to helping users to find information of interest easily; the cognitive level relates to helping users to understand information and make use of it; the affective level relates to motivating users to perform.

a layout consistency come into play when the physical placement of the sign reflects the adequate information in the space specific sequence' (p. 19). This research majorly focuses on the sign graphic system, analysing the design of CEBTS by using information design perspectives and approaches.

1.2/ Human factors

The sign requirements and sign design components discussed above have been originated and considered with respect to human capabilities and habits. This section aims to provide perspectives on sign requirements and design components at a behavioural level.

1.2.1/ Visual search

One of the major tasks of a driver is to search and use information (such as traffic signs and landmarks) in order to find their way and arrive at the destination. It highlights the importance of driver's vision in the context of roadway use. As discussed above, the sign should be located appropriately to meet the sign visibility requirement which originates with the limitation of the human visual field. That is because only a small area of the visual field (foveal vision) of the two eyes allows accurate vision (about 2° to 4° of a cone), and the objects seen outside this area (peripheral vision) rapidly fade (Mandelbaum & Sloan, 1947). However, the target can still be detected in peripheral vision and can be shifted to be identified by foveal vision if it is close enough to a human's line of sight (within about 10° to 15°). That is the reason why it is suggested that signs are placed within the driver's line of sight.

In addition, eye movement studies involved in roadway research have revealed that drivers can only distribute their attention to a target (fixations) for very brief periods of time while driving, and increased accident risk is associated with a fixation that is longer than two seconds away from the roadway (Victor & Dozza, 2011). This could explain why researchers seek to minimise the time drivers devote to signs, to improve road safety. Given the limited time (up to two seconds) for reading a guide sign, drivers must rely on familiar patterns and previous experience (or expectations) to assist with driving tasks.

Indeed, many studies suggest that familiarity assists reading signs. Lay (2004) alleges that road users can benefit from the familiar message to recognise sign messages without distinguishing every detail of individual letters. Many other studies have determined that some superiority effect of a typeface is due to the familiarity of the typeface (Sanocki, 1992; Zineddin, Garvey, Carlson, & Pietrucha, 2003). This familiarity can also be created by using lowercase letters whenever possible instead of uppercase letters, because people are used to reading mixed-case documents. That may explain why a mixed-case letterform is suggested for use to form location names on a sign to assist legibility (Forbes et al., 1951; Garvey et al., 1997).

It is also important to meet the expectations of an unfamiliar driver. Drivers rely on their previous experience of the road layout and on road-related patterns, particularly while exploring an unfamiliar environment. As Mahoney (2007) states: 'repeated exposure to, as well as successful experience with, certain roadway configurations creates driver expectancies. These expectancies instill an inclination by drivers to respond to common situations in predictable ways that have been successful' (p. 8). This requires road designers to keep the road environment predictable and keep information sources presented consistently, which will set drivers' expectations for how signs will appear and help them process individual signs more rapidly. Therefore, the inconsistent design of CEBTS potentially breaks the drivers' expectations and as such may increase the time taken for reading signs and ultimately may increase safety risk (see Section 3.3.3 for the discussion of the inconsistent design of CEBTS).

Another factor relating to the human vision's capability is contrast sensitivity. As light levels between an object and its background change, the ability to detect the object changes. In some contexts, such as a smaller object is seen at a lower light level, the increased contrast between the object and its background can improve the legibility of the object (Smiley & Dewar, 2015). The consideration of the sign colour is based on such a principle, and many studies have engaged in the colours used for a sign program (Calori & Vanden-Eynden, 2015; Gibson, 2009; Miller & Lewis, 1999). Often, the colour code of traffic signs is specified in government guidelines or Standards that are required strictly for sign implementors to comply with. Sign colour, in this research, refers to the contrast between the colour of the text and the sign background.

1.2.2/ Processing information

Drivers are very limited in how much they can gather information, and how quickly they can process it. Studies on reading highway signs indicate that it takes drivers between 0.5 to 2 seconds to read and process each sign word (Garvey & Kuhn, 2004). McNees and Messer (1982) provide evidence that 'a cut-off of approximately 4 seconds to read any sign was critical for safe handling of a vehicle along urban freeways' p. 49). The research on sign-reading speed indicates the appropriate amount of information presented on a sign (signs with four to eight words can be comfortably read and comprehended in approximately 4 seconds and signs with one to three words in about 2.5 seconds) and also explains why the overload of information increases the reaction time.

1.2.3/ Individual experience

The design of a traffic sign is further complicated when concerned with meeting the needs of people of diverse ages, especially older drivers. Hulbert, Beers, and Fowler (1979) found significant differences in comprehension according to age. The highest comprehension level is 79% achieved by drivers aged 24 to 50 years old; the medium level is 72% for those over 50 years old; the lowest is 70% for those aged less than 24 years. In a follow-up study, Hulbert et al. (1980) found older drivers (over 50 years) comprehended signs significantly less well than other age groups. That might be because of a greater mental workload resulting from complex driving tasks (overtaking manoeuvres for example) for the older drivers than for the younger drivers (Cantin, Lavallière, Simoneau, & Teasdale, 2009).

Aside from age factors, other individual attributes, such as gender, marital status, educational background, accident involvement, and so forth, may also affect driver performance. Al-Madani (2004) reviews and summarises existing studies on sign legibility in relation to driver individual attributes. Ng and Chan (2008) found that total years with a driving license is another significant attribute that affects driver performance.

1.3/ Legibility

According to the above two sections, the design of traffic signs is preoccupied with the interaction between the physical appearance of graphic displays and the capabilities and limitations of humans. Sign visibility, legibility, and comprehensibility are different concepts, and the main focus of this research, the sign graphic system, is associated with sign legibility and sign comprehensibility. However, in this research, the term legibility will be used as a broad term to cover both sign legibility and comprehensibility. This is because it may be difficult to distinguish between some related concepts that depend on contexts, such as it may not always be possible to make a clear distinction between where legibility stops, and comprehensibility begins. Therefore, Dyson (2019) advocates that the term legibility can be used to cover a broader range of concepts.

Additionally, the term legibility is a more general interpretation that often has overlapping concepts and is used interchangeably with other terms, such as the term readability. Cheetham, Poulton, and Grimbly (1965) believe legibility refers to the recognisability of individual characters and readability refers to the reading of a continuous text. Östberg, Shahnavaz, and Stenberg (1989), Haramundanis (2001), and Watzman (2003) use the term legibility for the intrinsic characteristics (Section 2.2.1) of typeface and readability for the quality of typesetting. Tracy (2003) regards legibility as the clarity of single letters of a typeface, and readability as the visual comfort achieved by the typefaces as a whole. Moreover, some designers use the term readability to indicate pleasure and interest in reading (Kunz, 1998).

Based on these foundations, the term legibility, in this thesis, is used as a broad embracing term to cover 1). typographic presentation that assists drivers to read traffic signs fast, and 2). information comprehension that drivers can understand and use the information to make a correct decision to take action if needed.

1.4/ Bilingual typography

1.4.1/ Macro-and micro-typography

Luna (2018) introduces typography as 'design for reading. It is a set of visual choices designed to make a written message more accessible, more easily transmitted, more significant, or more attractive' (p. 1). The communicative effects of typography are aided by the use of typographic components. Researchers propose frameworks, or toolkits, for a typographic analysis by organising and categorising typographic components. Kunz (1998) organises typographic components to macro- and micro-aesthetic levels. A macro-aesthetic level captures the reader's initial attention, which calls for the design of space, form, composition, colour, the structure, the contrast between the primary elements and the space around them. However, a micro-aesthetic level plays a key role in the quality and expression of a visual composition, and it requires the design of typeface, letterforms and counterforms, spacing between letters, words and lines.

Stöckl (2005) tends to elaborate on the analysis toolkit by proposing four domains of typographic components. They are micro-typography in relation to the use of fonts and individual letters (e.g., typeface, type size, colour of type); mesto-typography in relation to the configuration of typographic elements in lines and text blocks (e.g., word spacing, line spacing, position/direction of lines); macro-typography in relation to the graphic structure of the overall document (e.g., indentations, emphasis, caps and initials); and para-typography in relation to materials, instruments and techniques (e.g., material quality of medium).

Hochuli (2008), however, refines the above categories. Hochuli treats macro-typography as the typographic layout that deals with the format of the printed matter, 'with the size and position of the columns of type and illustrations, with the organisation of the hierarchy of headings, subheadings and captions' (p. 7). Micro-typography, however, is concerned with the individual components, such as letters, words, lines and spacing between them.

Luna's (2004) description and category of typographic components aligns with Hochuli's but is more concise. He claims that the aspects of macro-typography tend to relate to documents and page layout, and micro-typography to what happens within a paragraph or within a line.

Typography is by its nature communication-effective, inseparable from legibility. Legibility research was initially preoccupied with the micro-typography for continuous reading before the 1970s. Afterwards, it has expanded beyond the detail level to look at macro-typography. After World War II, apart from printing, legibility research has become more and more involved with road signs. Accordingly, sign legibility is, to a degree, achieved by controlling the qualities and attributes inherent in typography (Gibson, 2009). The studies in the field of bilingual typography are thus reviewed to help connect important attributes of a dual-script setting to a specific sign scenario. Aligned with the main focus of this research, the term *bilingual* here refers to two languages using different scripts (e.g., Chinese and English), rather than bilingual texts using only one writing system (e.g., English and Welsh), therefore, is used alternatively with the term *dual-script*.

1.4.2/ Harmonised design of bilingual typography

Bigelow and Holmes (1993) coin a concept, *harmonised design,* as an approach for the design of multiple scripts, which is one of the first scholarly studies that deals with two or more scripts. In their view, the concept means 'that the basic weights and alignments of disparate alphabets are regularized and tuned to work together, so that their inessential differences are minimised, but their essential, meaningful differences preserved' (p. 292).

A harmonised design highly depends on different typographic scenarios and applicability of context (Nemeth, 2016; Tam, 2012). Regarding document design, there is a lot of work on presenting bilingual typography in a harmonious way. Nemeth (2016) distinguishes two broad categories of bilingual texts. The first category is called *mixed setting* (Fig. 1-1) in which one script is dominant, and the other script only appears in a complementary role (in a bilingual dictionary, for example). For this category, Nemeth suggests using the non-harmonised design because text categories which have different functions should be visually demarcated; while the potential risk of blurring differences in harmonised design may damage typographic differentiation. The other category is *parallel setting* (Fig. 1-2) where the two scripts are given equal importance (government documents and instruction manuals, for example). A harmonised design is needed for a parallel setting, which is based on aesthetic preference for stylistic homogeneity. But stylistic homogeneity is not a search for homogenisation.

Based on Nemeth's theory, a bilingual sign falls into the parallel setting category because the readers of a sign in which one script that is translated and presented together with another script are considered as being equally important. Their respective languages in typography thus should also be treated as equivalent. However, in China, English location names on CEBTS are often mispresented by putting into a layout solely tailored to Chinese typographic rules (Section 3.3), which violates the principle of a parallel setting. It goes against the harmonised design principle that respects the characteristics of different languages within the cultural framework, at the same time, regularise appropriate typographic attributes to make both scripts working together. Thus, it is important to consider which characteristics of Chinese and English are key to harmony, and which typographic attributes could be utilised to enable both to work together, especially in a sign scenario. To answer these questions, some important Chinese-English typography research is reviewed below.

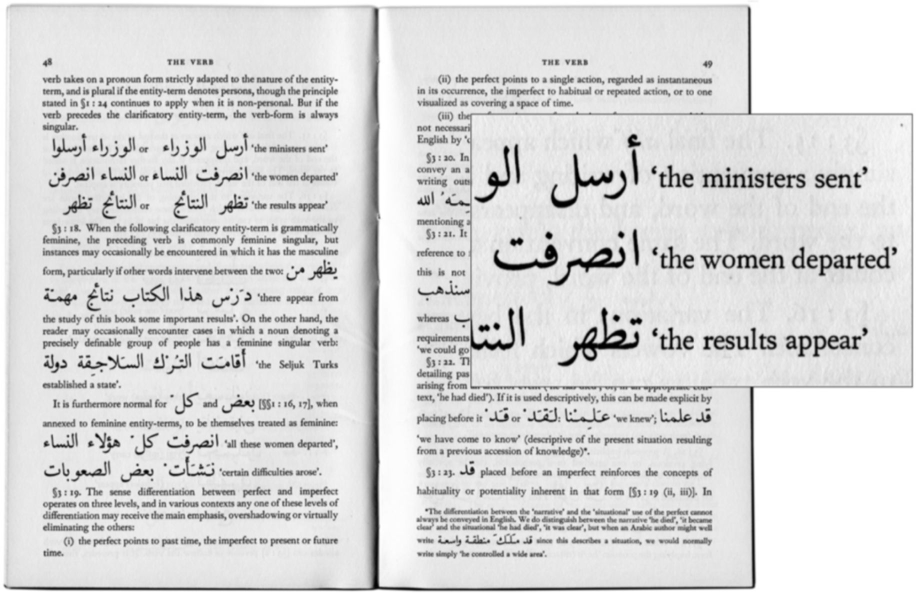


Figure 1-1. *Mix-setting example. Adapted from Digital fonts and reading (p.158) by Mary C. Dyson and Ching Y. Suen, 2016, Singapore: World Scientific Publishing Co. Pte. Ltd. Copyright 2016, World Scientific Publishing Co. Pte. Ltd.*

Figure 1-2. *Parallel setting example. Adapted from Digital Fonts and Reading (p.164) by Mary C. Dyson and Ching Y. Suen, 2016, Singapore: World Scientific Publishing Co. Pte. Ltd. Copyright 2016, World Scientific Publishing Co. Pte. Ltd.*

The Multilingual Typography Research Group[8] led by Ruedi Baur is one of the practical groups interested in Chinese-English typography. Roman Wilhelm was a member of this group who conducted lots of studies on the coexistence of Chinese and Latin characters. He suggests that there are three considerations involved in choosing Chinese and Latin typeface in order to make an optical harmonious match: optical grounds (types with similar characteristics), historic grounds (typefaces applied in a similar historic period or context), and practical grounds (typefaces serve a similar purpose in use). Additionally, Wilhelm believes that the optical centre line and baseline are two crucial visual reference lines for the optical appearance of Chinese and Latin typeface. He thus illustrates the way to bring the two crucial lines together to make equilibrium of the two languages (in terms of neither Chinese nor Latin seems to be bigger) (Fig. 1-3).

Stahl (2010a) also concentrates on Chinese-English typography. He begins by comparing the similarities and differences between Chinese and English scripts. And based on this, Stahl suggests, in a continuous text and for the purpose of homogeneity, adjusting Chinese line spacing 6pt wider than English line spacing when the type size of both scripts is consistent (Fig. 1-4). Such effort can make both Chinese and English columns have an appropriate line spacing, at the same time, they are still aligned to each other (aligning every two lines of Chinese characters and every four lines of Latin letters).

Apart from the Multilingual Typography Research Group and Stahl, Takagi (2012) provides a way to support the communication skills for English typographers by using western typographic terms to describe parts of Chinese characters. Tam (2012) illustrates a comparative descriptive framework to identify which graphic and spatial cues in Chinese and English typography have equivalent attributes and which ones have no equivalents.

However, the findings of the above studies appear difficult to apply to a sign scenario, because they tend to focus on dual scripts in relation to typeface selection or document design. For example, Stahl's work deals with dual scripts in a two-column format (each script occupies one column), therefore may not be appropriate to extend to a dual-script sign in which the two scripts are often arranged vertically on signs and the spatial arrangement of information is also related to indicating particular directions (Fig. 1-5). It appears that none of the research has investigated the influential typographic variables when Chinese and English coexist together on a traffic sign.

[8] The Multilingual Typography Research Group works on the design methods and models for the visualisation of multilingualism. A number of their studies were presented at the ATypI Hong Kong 2012 conference.

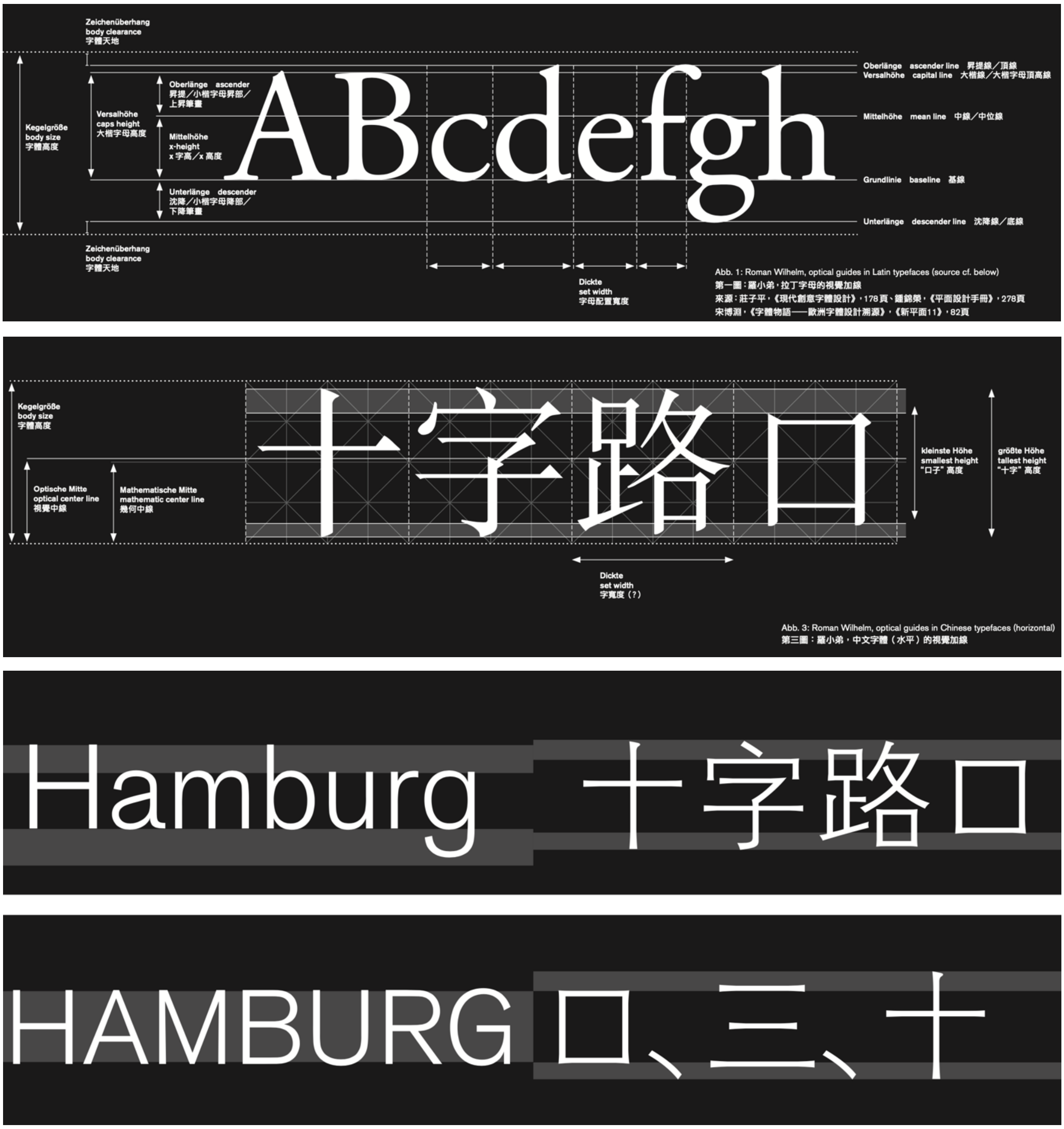


Figure 1-3. *Optical guides in both Latin and Chinese typeface. Latin typefaces crucially stick to the baseline, as well as to the x-height and Chinese typefaces stick to the optical centre line. Based on this, to achieve an optical harmonious match, Roman Wilhelm provides some approaches. 'Typed upper and lower case, Latin characters range between ascender, descender, caps height, x-height and baseline. This provides a dynamic feeling which can be able to match with Chinese characters ranging between '十-height' and '口-height'. Typed upper case, the impression changes to rather static. In many cases, the '口-height' may help adjusting, as well as the '三' character.'*

(Baseline and optical center line, Roman Wilhelm, 2012).

Figure 1-4. *Adjusting line spacing of a Chinese-English two-column texts (above: before adjustment; bottom: after adjustment). Adapted from 'Hanzi of the West, letters of the East', by Christoph Stahl, 2010, p.341. Copyright 2010, Christoph Stahl.*

Figure 1-5*. Bilingual place names are placed vertically on traffic signs in China. Photographed by the author, 2018.*

Looking outside Chinese-English typography, there are relatively few studies which consider harmonised design in the specific multi-script sign scenario. Eid (2009) considers Arabic/English signs and suggests that the differences in the scripts aid the users to locate the text they need quickly. But it is essential that both scripts are designed in harmony and have a balanced layout. To achieve that, it is important to consider:
1. the treatment of space (ensuring enough space to reduce clutter as the result of double information, but also work with space constraints in case causing expensive solution);
2. scripts alignment (placing the English and Arabic vertically as it is read better in relatively shorter messages); and
3. the role of pictorial elements (symbols are bilingual on their own and take an effective role in creating visual groups of messages, which makes perceiving them easier).

Figure 1-6*. Difficult information sequence when sharing a line; Arabic flow (reading direction) runs contrary to English. Adapted from 'Arabic sign design: Right to left and left to right', by Julia Petretta, 2014, Information Design Journal, 21(1). 18-33, Page 28. Copyright 2014, Julia Petretta.*

Petretta (2014) highlights the role of the information sequence in combining Arabic and English together within a sign system (Fig.1-6). With different reading directions and very different character proportions, Petretta believes that staggering the two scripts (rather than typesetting them on the same line) and the grouping of languages offers a clear hierarchy of information. A clear hierarchy of information aids quick-glance comprehension of information clusters.

Although Eid's and Petretta's work offer ideas and ways to analyse multi-script signs, their findings appear difficult to extend to Chinese/English typography, and to CEBTS. This is because Chinese has very different typographic image and design rules that need to be considered specifically. While there appears to be no research into CEBTS from the standpoint of bilingual typography, this brings difficulties to identify the typographic attributes that are essential to design CEBTS.

Nonetheless, existing knowledge on the design of Latin-based monolingual signs (considering a large number of studies on it) could be referred to with a view to locate some general considerations that are likely to be the attributes for looking at CEBTS. The following chapter reviews Latin-based signs in order to identify the key attributes to consider when analysing CEBTS.

2/ A descriptive framework of sign graphic system

The primary intention of this chapter is to identify the typographic attributes involved in the graphic system of a sign program. As the preceding chapter has shown, the existing Chinese/English bilingual typography studies mainly focus on document design which means their findings may not necessarily be extended to a sign program. To identify which typographic attributes could be used to allow both Chinese and English messages to collaborate on a sign program, this chapter refers to the existing knowledge of the design of Latin-based monolingual signs to locate some general typographic attributes that are essential to design CEBTS.

The description of factors involved in the graphic system of Latin-based signs seems to be slightly different for designers and transport engineers. These descriptions have overlapping concerns but may be labelled differently or classified in a different way. To ensure a meaningful and consistent description for this research, it is important to clarify the adopted description of the sign graphic system. Accordingly, a descriptive framework of the sign graphic system is proposed that combines and restructures the perspectives of both designers and transport engineers. The descriptive framework covers the factors embraced in the graphic system of a sign program and these factors are explained separately in the rest of this chapter. In the next chapter, the detailed explanation of each factor is discussed in relation to the CEBTS Standards, and samples of real signs that were photographed in Beijing, Shanghai, Wuxi, and Dalian.

2.1/ Sign content & sign layout

Despite the fact that researchers and practitioners use slightly varied terminology, many of them agree that the sign graphic system has two main components. One is the *two-dimensional graphic elements*, such as textual messages, symbols, and arrows; and the other component relates to how to arrange these pictorial elements into formats. Calori and Vanden-Eynden (2015) use the phrase *visual communication devices* to describe the two-dimensional graphic elements. Mollerup (2013), however, attributes typography, pictograms, and arrows to *sign content*; and colour, sign size, format, grids, and grouping to *sign* *layout*. For simplicity, Mollerup's terminology is adopted and so the shorter term ***sign content*** is used in the proposed framework to denote the two-dimensional graphic elements (or visual communication devices); and the term ***sign layout*** to denote how the sign content is presented into formats.

2.2/ Sign content

Many factors are involved in sign content. From the designer's perspective, there are two groups within sign content: *typographic messages* and *pictorial devices*. Calori and Vanden-Eynden (2015) believe that the typographic messages are the backbone of the sign graphic system because 'most of the informational content of a sign program is conveyed by words rather than pictorial elements' (p. 127). They emphasise the importance of choosing a suitable and legible typeface for a sign program as it is key to the visual appearance of a sign program's graphic system. They further provide suggestions on considering typeface suitability by using serif or sans serif letterforms, each of which has broad stylistic connotations; and considering typeface legibility by typographic treatment, such as case (uppercase or mixed cases) and letter spacing. Calori and Vanden-Eynden also highlight that symbols and arrows are pictorial devices that can replace or be paired with typographic messages to communicate certain information.[9] From the transport engineer's perspective, Lay (2004a) believes that the sign content communicating information, from signs to road users, relies on *legends* (textual messages conveyed by words and numbers) and *pictorial elements* (graphic symbols, arrows, and colours). Since this project concerns traffic signs, the terms specified in the domain of transport appear to be appropriate to categorise sign content. The terms ***legends*** and ***pictorial (and schematic) elements*** are terms selected to group the factors within sign content.

2.2.1/ Legends

The legends are textual messages and the design of textual messages, to a large degree, are an activity of typography (Fig. 2-1). Thus, the factors involved in legends are analysed from a typographic perspective. As discussed in Section 1.4.1, various typographic components work together to contribute to a successful typographic design, and the toolkits for typographic analysis proposed by Kunz (1998), Stöckl (2005), Hochuil (2008), and Luna (2018) are introduced. The toolkits that the above researchers suggested are, however, more relevant to a printed continuous text and may not be appropriate for a sign program. For example, some typographic components within the macro-typography (e.g., headings and indentations) are not applicable to a sign.

[9] Diagrams are another device, but Calori and Vanden-Eynden particularly refer to maps, which are beyond the scope of this project.

Figure 2-1. *Road signs only present legend(s). English legend (left) and Chinese/English bilingual legend (right). Photographed in Beoley, UK and Beijing, China in 2018. Photographed by the author.*

In the proposed descriptive framework, to better organise the typographic components for an analysis of Chinese-English legends, a further tool that could be used is Twyman's (1985) approach of distinguishing between *intrinsic* and *extrinsic* components of verbal graphic languages. According to Twyman, the intrinsic components tend to relate to the character and the system that produces the characters, such as typeface, type size, and type weight; the extrinsic attributes tend to relate to character configuration, such as spatial attributes (letter spacing, word spacing, and line spacing), alignment, and colour. Tywman separates spatial attributes and type characteristics as two aspects, however, Kunz, Hochuli, and Luna combine the two aspects at the micro-typographic level. While Stöckl tends to further subdivide the extrinsic attributes into mesto-typography, macro-typography, and para-typography (Section 1.4.1).

Tywman's approach benefits the analysis of Chinese-English legends in this research. The outcomes of the exploratory stage of this research (Chapters 3 and 4) lead to a focus on spatial attributes rather than type characteristics on which many existing studies have concentrated. Therefore, the intrinsic /extrinsic method benefits by distinguishing and clarifying the typographic focuses. As many typographic components have interaction impacts on a typographic work, a strict category boundary of them is not the purpose of the proposed framework. The purpose is to look for an effective toolkit for a typographic analysis, (as the above researchers did) and in particular for an analysis of a sign program. In summary, in the descriptive framework, the typographic attributes that are vital to a legend are divided into ***intrinsic attributes*** and ***extrinsic attributes*** based on Twyman's method.

2.2.1.1/ Intrinsic attributes

Regarding legend intrinsic attributes, a legible typeface and an appropriate type size are critical. Many typefaces have been developed for traffic sign use, for example the *Highway Gothic* and *Transport* typefaces discussed in the introductory chapter. Apart from designing new typefaces, there are also studies involving the use of the existing legible typeface. Garvey and Kuhn (2004) state that a legible typeface tends to exhibit an appropriate x-height, use mixed-case words, and optimal stroke width-to-height ratio. Miller and Lewis (1999) give more criteria, such as using sans serif typeface or a typeface with very small serifs, being aware of using italic and condensed type styles, and spacing letters consistently. Beier (2016) further suggests that the regular weight of the type (not too heavy or too light) helps achieve a legible typeface.

The criteria for selecting a legible typeface that designers are focused on, in turn, are important factors affecting sign legibility, which could be highlighted and grouped in the intrinsic attributes. Miller and Lewis' terminology can be utilised to cover and summarise these criteria, which include: *type weights* (bold/ regular/ light), *type styles* (regular/ italic/ condensed), *text styles* (uppercase/ mixed case), and *stroke width*. Accordingly, in the descriptive framework, the intrinsic attributes are grouped into ***typeface, type size***, ***type weights***, ***type styles***, ***text styles***, and ***stroke width***.

2.2.1.2/ Extrinsic attributes

Text spacing, such as letter spacing, word spacing, and line spacing, is important to consider for sign legibility (Barker & Fraser, 2004; Gibson, 2009; Watzman, 2003). In line with Twyman's category method of verbal graphic language, text spacing belongs to extrinsic attributes. Another extrinsic attribute Twyman mentioned is *text alignment*, or text ranging (the term used by Barker and Fraser, 2004), which is believed to be one of the most important ways to arrange textual messages. There are three basic alignments: ranging left, ranging right, and centred. Barker and Fraser (2004) recommend using left- or central-alignment on a sign because these are easier to read than right-alignment. *Line length* is another attribute that both designers and transport engineers advocate to control for the purpose of improving sign legibility. Gibson (2009) suggests that, to establish an appropriate type size for a particular sign program, designers should carefully consider what line breaks are necessary and where messages will need to be abbreviated. As transport engineers, Garvey and Kuhn (2004) believe that monolingual English signs with four to eight words could be comfortably read and comprehended. Line length is thus considered in the descriptive framework and is grouped into extrinsic attributes based on Twyman's method. In short, the extrinsic attributes are grouped into ***text spacing***, ***text alignment***, and ***line length*** for the framework.

2.2.2/ Pictorial (and schematic) elements

As discussed at the beginning of this section, the pictorial elements include ***graphic symbols***, ***arrows***, and ***sign colours***. Although colour is also categorised into extrinsic attributes (see Twyman) or into sign layout (see Mollerup) with different perspectives and contexts, it is grouped into the pictorial elements for a sign graphic system in this research. It should be noted that in a sign scenario, the term *colour* refers to the colour contrast between the text and sign background. It does not belong to textual messages (legend), neither does it relate to the way that the sign content is arranged (sign layout). Miller and Lewis (1999) believe that sign legibility can be improved by enhancing sign colour.

2.3. Sign layout

In the proposed descriptive framework, sign layout includes:
1. proportioning and placing pictorial elements according to legends;
2. spacing around and between legends and pictorial elements, which includes
    a. margins;
    b. horizontal spacing between side-by-side sign contents, such as gutters between arrows and textual messages;
    c. vertical spacing between stacked sign contents, such as vertical spacing between arrow and textual messages;
3. alignment of sign contents.

The factors highlighted in the sign layout above, and the method used to group them, are in light of Calori and Vanden-Eynden's (2015) study. They treat sign layout as a tool for sizing and arranging all sign content into formats that determine the appearance of a sign as a whole. They map out the considerations embraced within the sign layout, which embraces:
a. sizing legends for viewing distance;
b. proportioning and placing symbols and arrows according to legends;
c. spacing around and between sign contents, which includes:
    c1. margins;
    c2. horizontal letter and word spacing within lines of legends;
    c3. horizontal spacing between side-by-side sign contents, such as gutters between arrows, symbols, and legends;
    c4. vertical spacing between lines of legends;
    c5. vertical spacing between stacked sign contents, such as spacing between legends and arrows;
    c6. alignment of sign contents. (pp. 165-180)

Among these considerations, a. sizing legends for viewing distance is excluded because it is in relation to *type size* attributes that belong to sign content aspect. The considerations c2. and c4. are excluded since they have overlapping concepts with *text spacing* that is involved in the extrinsic attributes of legends.

2.4. Chapter summary

In summary, a descriptive framework of the sign graphic system is illustrated, which is presented in Figure 2-2. The framework identifies the important factors within the graphic system of a sign program by relabelling and restructuring the different perspectives of designers and transport engineers. Although it is summarised according to the literature on monolingual and Latin-based sign design, it is applicable to traffic signs. This is because the descriptive framework is built on existing knowledge of general sign programs rather than a specific one, which means it covers the most common factors for a range of sign design programs that include traffic road signs.

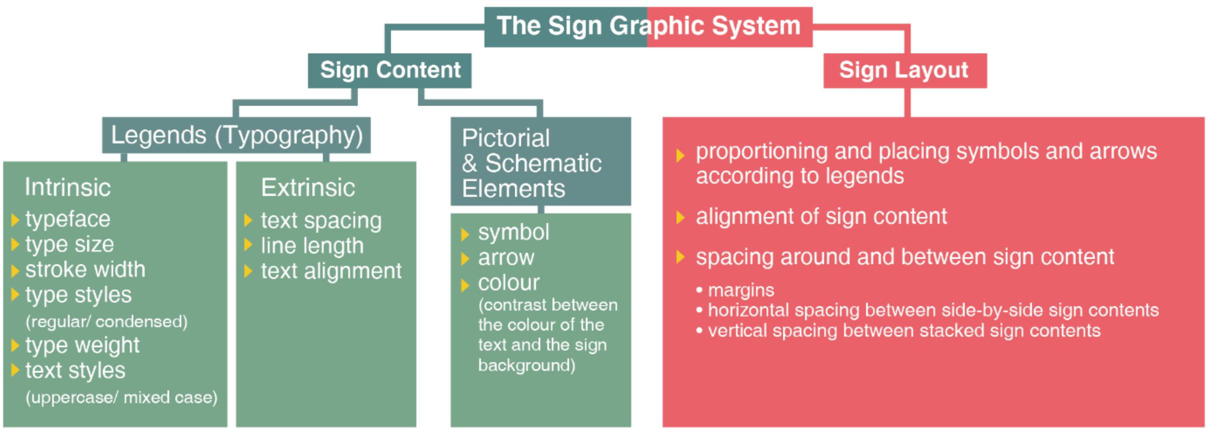


Figure 2-2. *Factors embraced in the graphic system of a traffic sign program. The description framework of the graphic system for a sign program. Illustrated by the author.*

The descriptive framework can also be applied to CEBTS with some special attention. Once considering the graphic system of CEBTS, the identified factors within the framework should be considered in both scripts' conditions. For example, with regard to sign alphabets, the typeface for Chinese characters should also be focused on. Moreover, multiple interactions occur when considering an additional script. For example, regarding text alignment, when looking at the alignment of two lines of English text and two lines of Chinese text, the alignment of two lines of Chinese/English bilingual text should also be considered.

Accordingly, the descriptive framework builds the descriptive and analytical foundation of CEBTS. The factors within the descriptive framework are, in turn, the concerns in the survey of the current CEBTS design, which will be seen in Chapter 3. Chapter 3 also explores how each factor is embraced in the graphic system in relation to the traffic sign legibility based on the existing studies.

3/ Survey of current CEBTS design

The descriptive framework of the sign graphic system proposed in Chapter 2 (Fig. 2-2) has identified the general factors for analysing the graphic system of a sign program. This chapter intends to answer the research question (what are design challenges to the current CEBTS?) through looking at each factor involved in this descriptive framework.

To explore the current design of CEBTS, the relevant Chinese traffic sign Standards are documented and reviewed, in order to find out how the graphic system is constantly being improved and refined, in the process of Standard development. The reviewed Standards comprise of six mandatory Standards that deal with the use of traffic signs for various routes, and they were published in China between 1999 and 2017. The guidelines of the sign graphic system are extracted and analysed in Section 3.1.

In addition, samples of CEBTS are photographed and analysed in order to identify how the sign graphic system is designed and arranged in practice. The sign samples include urban road signs that were photographed in four cities in China: Beijing, Shanghai, Wuxi and Dalian. The majority of the CEBTS samples were photographed from a moving car between 2017 and 2019. The full sampling method introduced in Section 3.2. Section 3.3 is a visual analysis of CEBTS samples which investigates how Standard guidance is applied to real applications, and how sign designers make decisions within Standards, or improvise when a Standard does not cover a specific situation. Section 3.4 summarises the main findings.

3.1/ Review of Chinese traffic sign Standards

This section explores how the guidance of the sign graphic system is embedded in Chinese road sign Standards. By reviewing the Standards, it also helps to ensure the design of the experimental materials is reasonably compliant with the current sign specifications (see Section 6.1.3). Specifically, Section 3.1.1 gives a brief introduction of the six reviewed Standards. In Section 3.1.2, the guidelines relating to each factor within the description framework are extracted from the six Standards and analysed respectively. Section 3.1.3 highlights the key points of the Standard survey.

3.1.1/ Brief introduction of six Chinese traffic sign Standards

Six National Standards for traffic signs have been published since the 1990s to the date of this research. The six Standards are composed for the traffic signs used in different hierarchies of routes.[10] In Figure 3-1, the six Standards are listed in chronological order from a. to f., and are colour coded based on the statute that they are applied to.

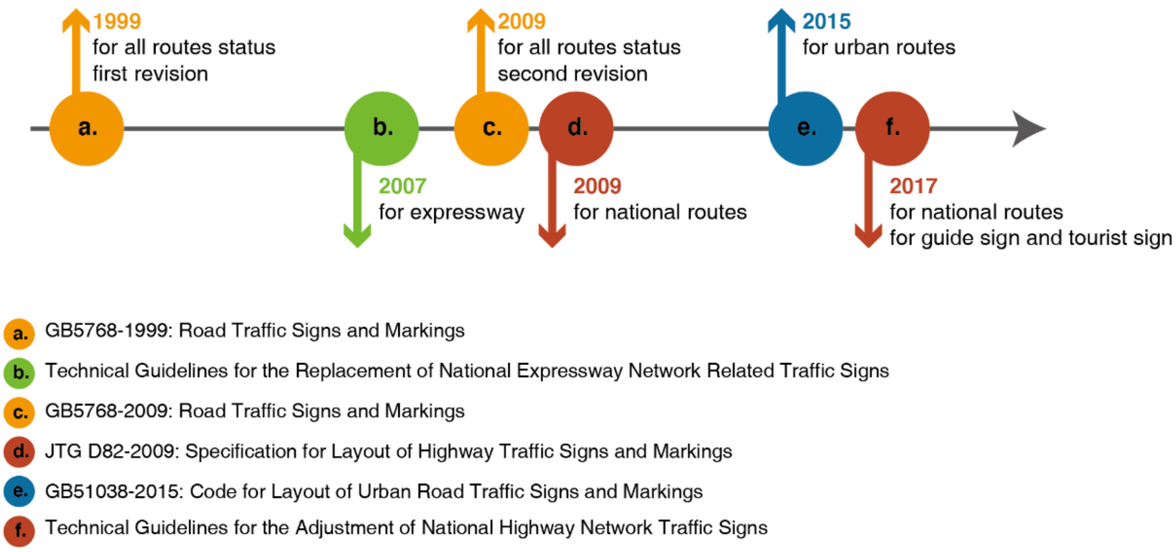


Figure 3-1. *Development timeline of the six Standards and the colour coding relationship among them. Diagram by the author.*

The National Standard that relates to traffic signs was issued in 1986 and was first revised in 1999. The *GB5768-1999 Road Traffic Signs and Markings* was adopted as a mandatory Standard that covered traffic signs used for all hierarchies of routes. This Standard was reviewed and replaced by *GB6768-2009* in 2009. The two Standards are colour coded in yellow in Figure 3-1 (*Standard a.* and *Standard c.* will be used to refer to these two Standards respectively in the following discussion for simplification). The Standards *JTG D82-2009: Specification for Layout of Highway Traffic Signs and Markings* and *Technical Guidelines for the Adjustment of National Highway Network Traffic Signs* were published in 2009 and 2017 respectively, and both are based on and referenced from *Standard c*. These two Standards specify traffic signs used on national routes (coloured in red; *Standard d.* and *Standard f.* will be used respectively for simplification). In 2007, the Standard *Technical Guidelines for the Replacement of National Expressway Network Related Traffic Signs* was published to exclusively guide the design of traffic signs used on the expressways (coloured in green and *Standard b.* will be used for simplification). For the traffic signs used on urban routes, the Standard

[10] Routes in China have two hierarchies. National routes are fast-speed routes that can be subclassified into three levels according to the speed of a vehicle driving on them. They are (speed from fast to slow): expressway, highway, and ordinary highway. The other hierarchy is an urban route that accesses all areas within the city and links to the external routes outside the city. The allowed speed on urban routes is slower than it is on national routes.

GB51038-2015 Code for Layout of Urban Road Traffic Signs and Markings was issued in the year of 2015 (coloured in blue and will use *Standard e.* for simplification).

3.1.2/ Specifications of the sign graphic system

3.1.2.1/ Sign content

Legends – intrinsic attributes

The guidelines relating to a legend's intrinsic attributes within the six Standards are extracted and illustrated in Table 3-1. The detailed discussions of how each intrinsic attribute is specified in the relevant Standard are discussed respectively.

Typefaces

The usage of typefaces in a sign program is one of the key variables that affects sign legibility that has been studied for years. A sign typeface is designed by using laboratory, prototype and in-service field testing to ensure optimum legibility (Lay, 2004a). An appropriate typeface increases the *legibility distance* and therefore drivers could have adequate response time to act (Garvey et al., 1997). Legibility distance is the maximum distance at which the intended message can be read. The legibility distance of a letter would be based primarily on the detail dimension, the stroke length-to-width ratio for example. It also depends on the shape of the word and its familiarity with readers (Garvey & Kuhn, 2004; Lay, 2004a). Many alphabet typefaces are specifically designed for traffic signs, such as *Highway Gothic* and *Transport* (see Introduction Chapter). In regard to Chinese traffic sign typeface, researchers believe that Hei style[11] is highly legible at low resolution (Lu & Tang, 2016) and has advantages for driving tasks when used on a Variable Message Sign (Lai, 2008). Li (2010) also states that Hei style performs best when the vehicle is moving at 100km/h in the daytime, however, Chang Song style (one of Song styles) is more legible than Hei style in the night-time. The features of the four styles of Chinese characters are compared in Figure 3-2.

According to the reviewed Standards, there was no specific typeface designed for Chinese traffic signs when *Standard a.* was issued. It only specifies that Hei style (simplified) should be used on traffic signs but without specifying which Hei typeface. Since there are many Hei typefaces within the Hei style, this ambiguous guideline may lead to various Hei typefaces being applied in practice, thus may cause inconsistency. The specific typeface, *Typeface A*, is proposed in *Standard b*. but only with a script specimen provided in the Standard's appendices. More details are refined in *Standard f.*, which introduces two more typefaces for the use of alphanumeric scripts, *Typeface B* and *C*, and their applicable guidelines on signs (Fig. 3-3). Figure 3-4 compares the old and new typefaces, which provides insights on how the CEBTS typeface has been changed and developed.

[11] Hei style is one of four basic Chinese type styles (Hei, Kai, Song and Li) and is commonly used in headlines and signages. Hei style generally lacks decorations and has strokes of even thickness. Hei style is akin to the sans serif styles of western typography (Lee & Moys, 2016; Lu & Tang, 2016).

Table 3-1. *Guidance of the intrinsic attributes in the six Standards. 'H' refers to the height of one Chinese character; '—' means no changes had been made relative to the above Standard, and '×' means absent from the Standard. Tabulated by the author.*

	Legends/ Intrinsic attributes				
	Typeface	**Type size**	**Stroke width**	**Type styles & Type weight**	**Text styles**
Standard a.	**Chinese scripts:** Hei style (simplified) **Alphanumeric Scripts:** × (letter specimen is provided in the Standard Appendix)	**Chinese scripts:** Height: based on the approaching speed of vehicle Width: equal to the height **Latin scripts:** Capitals: 1/2H Lowercases: 1/3H **Arabic numbers:** Height: H Width: 3/5H	**Chinese scripts:** 1/10H **Latin scripts:** × **Arabic numbers:** 1/6H	×	×
Standard b.	Typeface A	—	—	Use condensed Chinese when the sign has limited space (height and width ratio 1 to 0.75)	Mixed case
Standard c.	×	**Chinese scripts:** — **Latin scripts:** 1/3H to 1/2H **Arabic numbers:** Height: — Width: 1/2H to 4/5H	**Chinese scripts:** 1/14H to 1/10H **Latin scripts:** × **Arabic numbers:** 1/6H to 1/5H	×	—
Standard d.	×	The size guidance of Arabic numbers should be only applied to road number and exit number	—	×	—
Standard e.	×	**Chinese scripts:** — **Latin scripts:** — K (kilometer): 1/2H M (meter): 2/5H	—	×	—
Standard f.	Typeface A Typeface B Typeface C	×	×	Recommend using uncondensed scripts	—

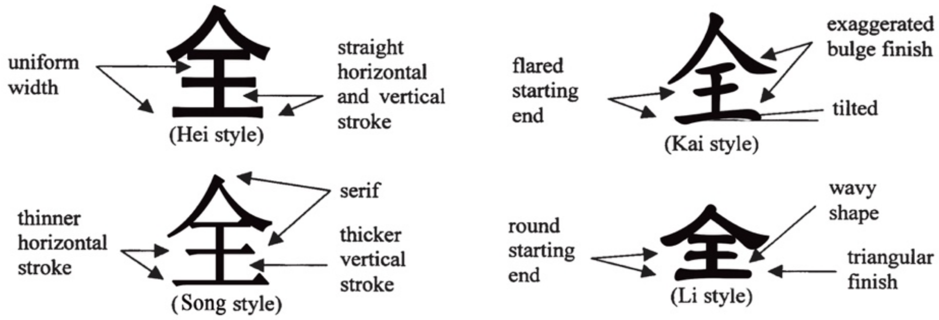


Figure 3-2. *The Hei, Kai, Song (Ming), and Li styles of the Chinese character '全'. Adapted from 'Applying image descriptions to the assessment of legibility in Chinese characters', by C.-F. Chi, D. C. Cai, and M. L. You, 2003, Ergonomics, 46(8), 825-841, Page 831. Copyright 2003, C.-F. Chi, D. C. Cai, and M. L. You.*

	Typeface
巢湖、芜湖、庐江、南	A
S206	B
G329、S226	C

Figure 3-3. *The illustration of applying the three typefaces to a Chinese traffic sign. Typeface B is used for the route number, exit number, and kilometers; Typeface C is used for the route number placed on the route arm; Typeface A is used for the rest of the situations. Extracted from Standard f., 2017, page 11.*

Figure 3-4*. Comparison of the old (left) and new typefaces (right) specified in the Standards. According to the script specimen shown in Standard f, Typeface B and C appear to be the condensed variants of the original Typeface A. Illustrated by the author.*

Type size

Zhang (1993) demonstrates that Chinese characters at 60cm height achieve optimal legibility (compared with 40cm, 50cm, and 70cm) on traffic signs for use on expressways where the vehicle speed is 120km/h. Zhang's findings align with the type size specifications in the Standards which is according to the approaching vehicle speed (Table 3-2).

Table 3-2. *Recommended height of Chinese characters in terms of approaching vehicle speed. This table (translated into English by the author) is extracted from Standard a., page 28.*

Speed (km/h)	100-120	71-99	40-70	<40
Height of Chinese character (cm)	60-70	50-60	40-50	25-30

In all reviewed Standards, 'H' is the basic unit of measurement that refers to the height of one Chinese character and will be used throughout this thesis. The measurement of all elements on the sign rests on a foundation of proportional relationships based on the dimension (H). This method is uniform for all common applications. However, the basic unit of measurement (H) should be more precise when it comes to referring to the height of the body frame of Chinese characters or the height of the surface frame. Both the body frame and surface frame (Fig. 3-5) are relative to the size of Chinese characters (Lu & Tang, 2016). *Body frame* is similar to the concept of body space in the field of Latin typography, which refers to the box that contains each character and small amount of space around the character for attaching it to the adjacent character. Generally, the body frame is fixed in a certain font. The *surface frame*, however, is the actual boundary box of a character which is smaller than the body frame. Surface frames vary from character to character in each font. Thus, the height of the body frame and surface frame are different. The potential ambiguity of H may bring difficulties in deciding the correct size of the legends, as well as the size of pictorial elements that rest on the basic unit in the implementation.

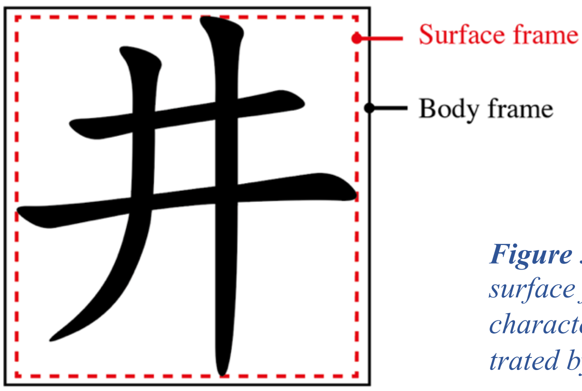


Figure 3-5*. The body frame (black line) and surface frame (red dotted line) of the Chinese character '井' (written in Kai style). Illustrated by the author.*

Regarding the size of Latin letters, in the Standards, it seems inappropriate to measure them by using the height of capitals and lowercases. This is because the height of lowercases with ascenders and descenders varies from one font to another and in some typefaces the capital height is lower than the ascender height. Although the height range of the Latin scripts is pointed out in *Standard c.* (p. 4), it also seems not to make sense because it does not specify what this range refers to, initial capital or x-height. For Latin letters used on signs, Meeker (2010) suggests measuring the letter by using the size of the initial capital letter of a location name. The UK traffic sign Standard, however, specifies the size of an alphabet in terms of its x-height (Department of Transport, Scottish Development Department, & Welsh Office, 2013).

In this research, to prevent ambiguity for the design of the experiment materials (Chapter 6), H is specified as the height of the body frame of one Chinese character. The size of Latin letters is measured by the size of the initial capital letter and rests on the dimension of H.

Stroke width

For the purpose of sign legibility, Lay (2004a) states that a stroke with a length-to-width ratio of between five to ten achieves optimal legibility, with a preference of about six. Soar (1955) examines the stroke width in numeral visibility. 12 combinations of four height-width proportions and three stroke widths are tested, and Soar found that stroke width is not a significant factor of numeral legibility. But there is a combination, a height-width ratio of 10:7.5 and a stroke width to height ratio of 1:10, that is the most legible for all numerals.

The stroke width of Chinese characters also plays an important role in their legibility (Dobres et al., 2016; Liu et al., 2016), though Zhang's (1993) finding is not consistent with this. Zhang investigates the effects of three levels of stroke width, 0.8:10, 1:10, 1.2:10 (the ratio of the stroke width to the character height) on traffic sign legibility. The findings show that there are no significant differences between the three levels of sign legibility. However, the stroke width cannot be considered in isolation because there appears to be an interaction between typeface, stroke width, and script width on visual acuity (Garvey, Zineddin, & Pietrucha, 2001). Thus, the stroke width and script width are, normally, already built into a designed typeface by typographers for best legibility. Accordingly, the reviewed Standard guidance specifies a stroke width that may be inappropriate because it may lead to wrong decisions for sign makers who are without professional typographic knowledge. This probably explains why stroke width guidance is replaced by using a specific typeface in *Standard f. Standard d.* emphasises the sizes of Arabic numbers used on route numbers and exit numbers: height (H), width (1/2H to 4/5H), and stroke width (1/6H to 1/5H). However, this guidance is removed in *Standard f.*, *Typeface B* is proposed for the Arabic numbers used on route and exit numbers.

Type weight and type styles

The type weights (bold/regular/light) and type styles (regular/italic/condensed) are two further intrinsic attributes involved in the sign graphic system. However, there are limited guidelines in relation to them in the six Standards. In *Standard b.*, the condensed Chinese characters with a height-width ratio of 1:0.75 are adopted when there is limited sign space. However, using uncondensed Chinese and Latin scripts is recommended in *Standard f.*

Text style (uppercase/mixed case)

This text style attribute is only applicable to Latin letters. Mixed cases provide a varying contour as well as more familiar word shapes, so that is sometimes considered more legible than only using uppercase letters (Forbes et al., 1951; Garvey et al., 1997). In contrast, Lay (2004a) believes that using uppercase letters can improve sign legibility because they could help road users perceive the importance of the message. According to the reviewed Standards, mixed case is suggested for Chinese traffic signs.

Legends – extrinsic attributes

Table 3-3. *The guidelines of extrinsic attributes in the six Standards. '×' means absent from the Standard. Tabulated by the author.*

Standard	Legends/Extrinsic attributes				
	Text spacing			**Line length**	**Text alignment**
	Letter space	Word space	Line space		
a.	×	Above 1/10H	1/3H	×	×
b.	×	×	×	×	×
c.	×	×	1/5H to 1/3H	×	×
d.	×	×	×	×	×
e.	×	×	×	×	×
f.	×	×	×	×	Left- or central- aligned

Text spacing

Barker and Fraser (2004) state that text spacing, including letter spacing, word spacing and line spacing, can be arranged to assist in sign legibility. Regarding typesetting in English, the letter spacing is considered to affect sign legibility (Solomon, 1956). Lay (2004) proposes that the appropriate letter spacing, about 0.3 times capital letter height, achieves better legibility. Tejero, Insa, and Roca (2018) also provide evidence which supports the case that drivers can benefit from increasing the default inter-letter spacing of words. Garvey and Kuhn (2004) assert that the line spacing of 75% of the capital letter height appears optimal for legibility. However, there has been little research into the effect of word spacing on sign legibility, which may be due to location names generally being combined by a few words and arranged vertically on a sign. Letter spacing and line spacing may, therefore, become the main concerns. Nevertheless, in the western typography field, word spacing that is either too tight or too loose influences performance in reading continuous documents (Highsmith, 2012).

Figure 3-6*. A Chinese character '霸' in Kai style. '霸' is composed of three radicals: '雨', '革', and '月'. The overlapping area coloured in red indicates the internal word patterns of this character. '霸' on the right hand of the figure is not adjusted and located next to each other. The characters can seem separated and the connection between three radicals is lost, which causes difficulties for Chinese character recognition. That is because the internal word patterns are destroyed. Illustrated by the author.*

Very little research has considered the effect of text spacing of Chinese text settings on traffic signs as a variable of interest. Letter spacing and word spacing do not apply in the same way in Chinese as they do for Latin typesetting (Lee & Moys, 2016). In English, one or several individual letters combine a semantic unit, this creates various words' widths and shapes. However, in the field of Chinese typography, the internal word patterns provide more cues for recognition rather than the shape and letter or word spacing (Fig. 3-6), and each Chinese character is a semantic unit, which yields the same width in a line or block of text. To prevent potential misinterpretation, the term *unit spacing* is used in this research to refer to the distance between two semantic units in the Chinese sense. Hsu and Huang (2000) demonstrate that unit spacing (Hsu and Huang use word spacing in their study) may reduce misinterpretation and enhance reading performance while reading Chinese continuous text. In Chinese proofreading performance, Chan et al. (2014) state that the increased line spacing resulted in longer reading time. However, the above studies concern the impact of text spacing on wide column texts and the findings may not necessarily be applicable to sign programs.

In the reviewed Standards, the guidance relating to bilingual text spacing is ambiguous. For example, in *Standard a.* (p. 28), the word spacing specified as over 1/10H does not identify whether it is for Chinese or English scripts. The line spacing is set to 1/3H, or a range of 1/5H to 1/3H (*Standard c.* p. 4), with no indication of whether it is for two lines of monolingual text or two lines of bilingual text.

Text alignment

One of the most important ways of controlling layout is through the alignment of text (Barker & Fraser, 2004). There are two basic alignments used on alphabet signage: left- and central-alignment (Barker & Fraser, 2004). Barker and Fraser also suggest that the text should be ranged according to the direction of the arrow. These two alignments are also suggested in the reviewed Standard (*Standard f.* p. 11). However, there is a lack of clear specification that could inform the selection of the alignments in the Standard.

- Pictorial & schematic elements

The pictorial and schematic elements here refer to symbols, arrows, and sign colour (the contrast between the colour of the text and the sign background) in line with the proposed descriptive framework. According to the Standards, the orientation-direction patch (Fig. 3-7) and route arm (Fig. 3-8) are the two most frequently used symbols on CEBTS. The orientation-direction patch indicates the north, west, east, and south on signs. The diagram provided in *Standard c.* informs the shape and size of the orientation-direction patch (Fig. 3-7).

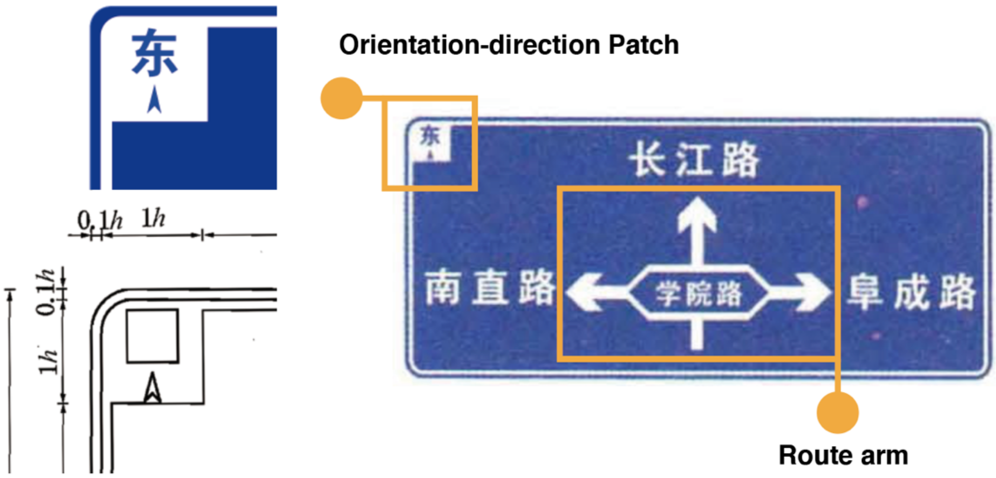


Figure 3-7. *The orientation-direction patch and route arm on a Standard example. The example is extracted from Standard e., 2015, page 259. The diagram is extracted from Standard c., 2009, page 122.*

The route arm can indicate more than one direction, which is a necessary and distinctive symbol on map-like signs (see sign category, Table 3-5, Section 3.2.3). Different shapes of the route arm are illustrated in *Standard e.* (Fig. 3-8. a). The new updated appearance of the route arm is specified in *Standard f.* (Fig. 3-8. b).

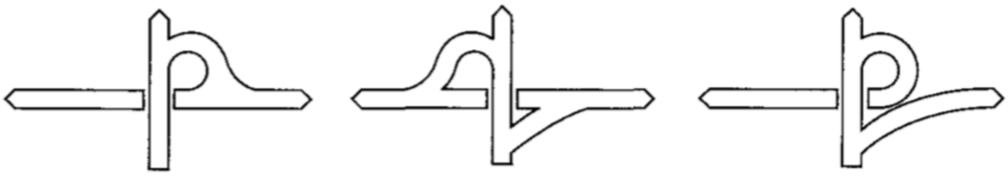
Arrows are one of the most useful pictorial elements in a sign program, but Barker and Fraser (2004) believe that they are more misused than any other pictorial element. In the reviewed Standards, there are guidelines provided in relation to the shape and size of an arrow and how these may be inclined to suit the direction being indicated.

According to the Standards, the basic principle of colour coding of signs used for different hierarchies of routes is summarised as follows:

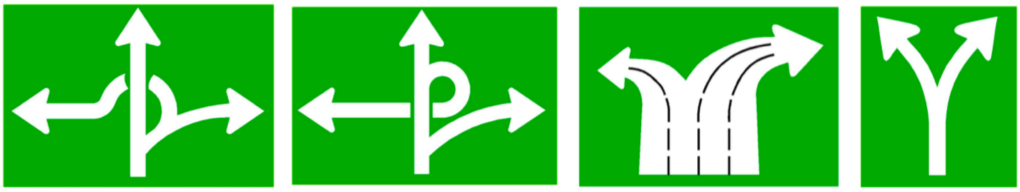
- urban routes — white sign content on a blue background;

- national routes (expressways) — white sign content on a green background;
- tourist attractions — white sign content on a brown background.

As with the colour coding principle in the Standards, all CEBTS use positive contrast applications with white sign content on a dark background.



(a) route arm illustrated in Standard e.



(b) route arm illustrated in Standard f.

Figure 3-8. *Illustrations of route arm in Standard e., 2015, page 30, and Standard f., 2017, page 115.*

3.1.2.2/ Sign layout

Sign legibility depends as much on the use of space as the typeface. Meeker et al. (2006, 2010) consider sign layout as it relates to the mathematical relationship between graphic elements on a sign (e.g., the mathematical relationship of the legend to the border, border size, and line spacing and the mathematical relationship of the graphics to the panel) and define the proportions for key dimensions, including figure and margin.

Sign layout guidance, compared with sign content guidance, is less comprehensive in the reviewed Standards. Particularly, these limited guidelines hardly cover practical applications because most of them are monolingual plans rather than bilingual ones. In relation to proportioning and placing legends according to pictorial elements, some guidelines include unnecessary flexibility. For instance, *Standard d.* specifies that 'the place names should be placed next to route arm, but they can also be located above or beneath the route arm' (p. 29). It would be better if this guidance was extended to be more precise for placement instruction, because the current guidelines could lead to inconsistent decisions. Further, this guidance does not specify the distance between the place names and the route arm, nor their spatial relationship with other surrounding elements. Imprecision can also be seen in another guideline that describes how the orientation-direction patch should be placed at the top left corner of the sign, but can also be placed at the right top corner *in some cases* (*Standard d.*, p. 42). *Standard e.* specifies *some cases* refers to instances when the sign is mounted on the left-hand side of the road. However, this guidance also suggests that the patch can be placed at the bottom left- or right-hand corner of a sign *in some cases*, but without specifying in which cases.

Diagrams included in the Standards provide helpful guidance for sign designers. For example, Figure 3-9 provides key sizes in terms of their proportional relationship according to H. But all diagrams only contain a Chinese legend without an English one. However, most of the signs are in a bilingual form in practice. The diagrams therefore are limited in their application because they cannot cover the practical issues that sign designers may need to consider for bilingual signs.

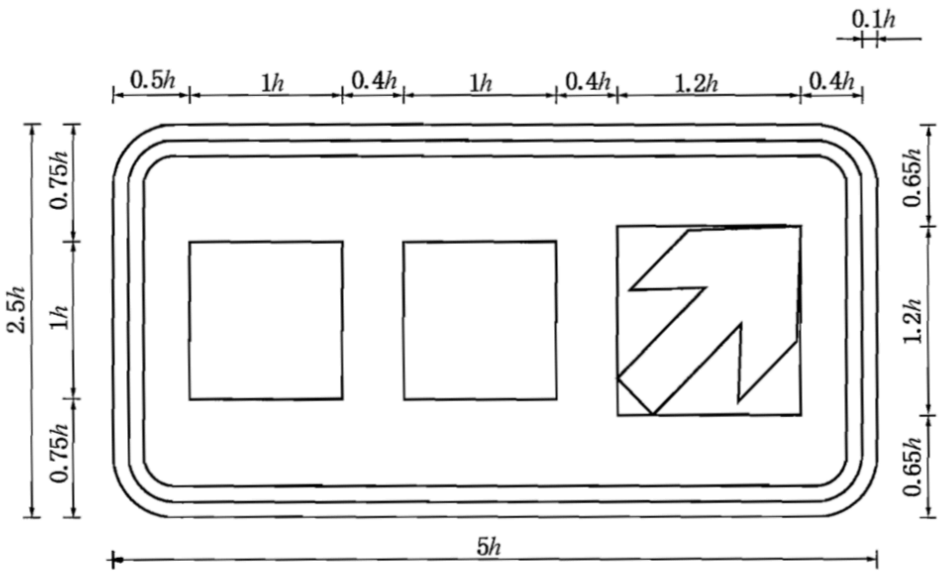


***Figure 3-9.** The diagram provided in the Standard to inform the size settings of a one-direction sign. Extracted from Standard c., 2009, page 132.*

3.1.3/ Summary

According to the analysis above, there are many guidelines relating to sign content, but limited guidelines relate to sign layout. Regarding sign content guidelines, the review of the Standards shows that the intrinsic attributes are gradually being refined and improved along with the general development of Standards. The sign typeface, including both Chinese and alphamerical scripts, has been designed and set in *Standard f*, which is a significant improvement. However, the Standards have not articulated precise and appropriate guidelines that could fully support the implementation in practice. For example, the imprecise guidance of type size and inappropriate guidance of stroke width. The imprecision and inappropriateness are also found in guidelines relating to the extrinsic attributes. The guidelines of pictorial and schematic elements are difficult and inconvenient to retrieve because they are dispersed in different chapters throughout the Standards. Some act as annotations and some are shown in the appendix, such as the guidance of orientation-direction patch. In the reviewed Standards, there has been unnecessary flexibility lent to sign layout guidelines (e.g., the use of the phrase *in some cases*). This brings potential difficulties in the decision-making process for designers. In addition, the findings show that most sign layout guidelines are monolingual plans, so they are limited in their applications. To explore how the reviewed Standard guidelines are translated through to the implementation stage, the following section shows the collection of CEBTS samples (Section 3.2) and conducts a visual analysis of these (Section 3.3).

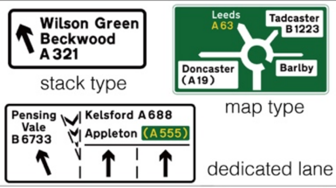
3.2/ CEBTS samples collection and reclassification

To identify how the sign graphic system is applied to implementation, the research next moves to look at real CEBTS in practice. The sign samples are thus photographed and collated for a visual analysis (Section 3.3). This section presents the method used to collect samples and the way of categorising them properly to ensure the samples collected can be used as the representative signs for the visual analysis. Specifically, Section 3.2.1 looks at the details of sign categories from the Standards, which intends to identify the target sign category that needs to be focused on for sample collection. Section 3.2.2 describes the method used to collect samples. Section 3.2.3 reclassifies the collected samples in terms of their layout as a foundation for the visual analysis.

3.2.1/ Sign category in Standards

In China, traffic signs are classified into six categories (Table 3-4) according to *Standard a.* There are many ways to classify traffic signs and different countries use different categories. Taking the UK for example, traffic signs are divided into three main groups apart from carriageway markings and temporary signs (Department of Transport, 1982). Table 3-4 makes a comparison between the six sign categories in China and the three categories in the UK.

Table 3-4. *Traffic sign categories in China and the United Kingdom.*

China: Example	China: Categories		UK: Categories		UK: Example
		Warning sign	Warning sign		
		Prohibitory sign	Regulatory sign		
		Mandatory sign			
	*Urban Routes	Guide sign	Informatory sign	Advance direction sign	 stack type; map type; dedicated lane
	Express-way			Direction sign	 flag type; rectangular type
		Tourist sign		Route confirmatory sign	
				Gantry mounted sign	
		Road construction sign		Motorway sign	

This table was derived from Standard a., and the English translations of categories are referenced from the appendix of Standard a. In the UK, mandatory signs and prohibitory signs belong to one category, that of regulatory signs, which refer to the signs that give notice of requirements, prohibitions or restrictions. Guide signs, Tourist signs and Road construction signs are classified as informatory signs which give road users information about the route and about places and facilities of particular value or interest.

Although the sign examples of urban routes provided in the Standard is monolingual (highlighted with an asterisk), the actuality of signs in practices are in a Chinese-English bilingual format.

Tabulated by the author.

As noted in Chapter 1, the monolingual signs (Road construction sign), symbol signs without text (Warning sign, Prohibitory sign, and Mandatory sign) and expressway signs are beyond the scope of this research. The bilingual Guide sign and Tourist sign used on urban routes in a driving context have been selected to analyse.

3.2.2/ Sampling method

After identifying the target sign categories (Guide and Tourist signs for urban routes use), the next step is to collect appropriate samples from the field of various signs within the two categories. Due to the huge quantity of signage in both categories it is only practical to gather a selection from each in an attempt to understand the larger whole. Therefore, the samples are collected from four cities in China. Beijing as the capital of China and Shanghai as one of the most developed cities in China are selected as target cities. Wuxi and Dalian are chosen to showcase eastern and northern China respectively. The signs within the target categories that are chosen in these four cities generally represent the design of CEBTS in the rest of the country. More than one city is considered in order to compare the design practice in different cities and to observe the consistency level across the country.

Figure 3-10. *Tourist sign photographed from the ground (pedestrian zone), causing the extreme angle of the subject (sign) in the photo. Photographed by the author in Dalian, 2018.*

The sign samples were collected by taking photographs in the four cities between 2017 and 2018. Most of the sign samples were photographed from a moving car. That is because, firstly, the target samples are used by drivers and naturally located in the driver's line of sight. The samples photographed from a pedestrian's view caused the subject (sign) to be at an extreme angle in the photo (see Fig. 3-10 as an example). The acute angle from the ground causes difficulties in observing the sign. Secondly, it is dangerous to photograph samples while walking or driving. Nevertheless, photography from a moving car has brought an inevitable limitation of the poor quality of some photos. The quantity of the samples in some categories is influenced because the poor-quality photos have to be abandoned. However, this shortfall can be made up by searching for supplementary sign images through online search engines (e.g. Google, Baidu: image.baidu.com.). The keywords used are 'Beijing (or Shanghai, Dalian, Wuxi) road sign' and '北京(或者上海,大连,无锡)道路标识' while searching. The total sample (143) comprises 136 Guide signs and seven Tourist signs.

3.2.3/ Sample reclassification

The collected samples are broadly representative of the typical signs of CEBTS. From the review of the six Standards and the preliminary observation of the collected samples, it is evident that the categories of CEBTS in the Standard documents do not correspond to the actuality of signs in practice. Hence, the representatives are selected from the photographed samples as these reveal the actual physical format of CEBTS.

The Guide and Tourist signs, in *Standard c.*, are divided into subgroups based on sign functions. For each subgroup, the Standard also provides sign examples (*Standard c.* p. 69-108). Like the category method used in most road Standards, sign designers also categorise signs in relation to functions. Mollerup (2013) categorises signs into three groups: identification signs, explanation signs, and instruction signs. Signs are divided into four groups in the book of *Wayfinding, Effective Wayfinding and Signing Systems, Guidance for Healthcare Facilities* (Estates NHS, 2005): locational or identity signs, directional signs, directory signs and other signs. However, these category methods used in road Standards and by researchers are insufficient to be used for the visual analysis for the purpose of this research. Because this research considers how to improve sign legibility by planning and shaping the graphic system on the sign, an alternative way to categorise the Guide and Tourist signs that is based on how the graphic system is presented on the sign is needed, rather than being based on sign functions.

Some important key phrases in terms of sign presentation could be used to assist the reclassification of Guide and Tourist signs, the phrases *map-like* and *stack-like* for example. The intersection direction signs are normally placed before and after the intersection. Lay (2004a) names such signs 'diagrammatic signs' because they are *map-like* and locate the intersection and directions based on the position of the town name on a diagram. In the UK *Traffic signs manual*, such signs are called *map-type signs* when it comes to the design of signs (Department of Transport, 2013). The phrase *stack sign* is used by Lay (2004) to describe the sign which 'has destinations in a vertical list (or stack) and directions represented by a small adjacent arrow' (p.45). Nevertheless, the UK *Traffic sign manual* uses the phrase *stack-type signs* to refer to such signs.

According to the above phrases and the layout features of the samples, the sign layout of the 136 samples photographed in the four cities can be split into five broad categories. The key layout features of each group are summarised in Table 3-5 and the examples of each group are given in Figure 3-11. The five categories of Guide sign samples are (the collection quantity goes from high to low): map-like sign (79), one-direction sign (35), stack-like sign (15), multi-column sign (4) and locational sign (3).

a. Map-like sign

b. One-direction sign

c. Stack-like sign

d. Multi-column sign

e. Locational sign examples in *Standard c.* (left) and in the field (right)

f. Tourist signs

Figure 3-11. *Five categories of Guide signs (a to e) and Tourist sign samples (f). a to e were photographed in Dalian and f was photographed in Shanghai by the author, 2018.*

Table 3-5. *Reclassification of Guide and Tourist sign samples and layout features for each group. Illustrated by the author.*

Groups	Layout Features & Classification basis
Map-like sign	- The position of the place name is flexible, and it is affected by the geographical direction of the destination ahead. - The route arm is an essential and unique symbol. - An orientation-direction patch placed on signs (the placement is not fixed). - Indicating more than one direction.
Stack-like sign	- Able to indicate directions, distance and, sometimes, indicates both together. - The basic unit is a single panel, which consists of destinations with an arrow (or kilometers) to indicate one direction (or the distance). Several single panels are listed from top to bottom and are separated by a horizontal divider.
One-direction sign	- A direction only panel with an inclined arrow used. - The position of the place name and arrow is not fixed.
Multiple column sign	- Indicating several directions with more than one arrow. - Often uses a vertical divider to separate directions. - Sometimes includes distance information and the orientation patch.
Locational sign	- A place name only panel. - The place name can be written vertically sometimes.

The five sign categories can also cover Tourist sign samples. In most sign samples, tourist information is shown as a location name that is displayed on a patch with a white border and brown background on a Guide sign, rather than an individual sign. For example, *Xinghai Park* in a multi-column sign (d.) in Figure 3-11. As an individual sign (f. in Fig. 3-11), Tourist signs have a brown background with white text, an arrow or an icon of the tourist attraction. However, the sign layout is similar to the one-direction and stack-like sign. Therefore, the proposed five categories could be applied to both Guide sign and Tourist sign.

The nomination of the groups is referenced by the key terms that are introduced above, such as ‘map-like’ and ‘stack-like’. The term ‘multi-column’ is used based on the layout features of the group, because the samples within this group have information in columns using a vertical divider to separate them. The terms ‘one-direction sign’ and ‘locational sign’, however, are selected to nominate the groups according to their functions.

Because of the quantity of samples, together with preliminary observation while collecting, more map-like and one-direction samples were collected, which may indicate that the design of these two groups of signs is widely applied and more practical. In contrast, fewer multi-column samples were found from both streets and online searches (only found in Dalian). This may indicate that such sign layout is a specific format used in Dalian rather than the general one that is commonly used in the implementation. In addition, the guidance relating to multi-column signs is absent from the reviewed Standards, which shows a gap between the Standards and the practice. The gap can also be reflected by the different designs of locational signs in the Standards and in practice (e. in Fig. 3-11).

3.3/ Visual analysis of CEBTS samples

This research next considers how the graphic system is arranged on the samples within the categories. According to the reclassification of the samples and with the descriptive framework of the sign graphic system in mind, the visual analysis of the samples is analysed on two aspects: sign content (Section 3.3.1) and sign layout (Section 3.3.2). Each attribute within sign content and sign layout is analysed respectively, together with the potential causes of the implementation. Section 3.3.3 describes findings gained from the visual analysis that are beyond the scope of the descriptive framework, but all the findings indicate that the current design of the collected samples has many inconsistencies.

3.3.1/ Sign content

3.3.1.1/ Legends

Four map-like samples collected from four cities are selected and compared in Figure 3-12. From the four samples, it can be observed that the inconsistencies across the cities' signage are reflected in both intrinsic and extrinsic typographic attributes. As the samples below show, the design of the legends does not strictly follow the guidance in the Standards.

Figure 3-12. *Four map-like samples photographed in four cities in China between 2017 and 2018. Photographed by the author.*

- *Intrinsic attributes*

Although the new typefaces (*Typeface A, B* and *C*) have been designed and set to the Standards, they seem not to be widely applied in practice. Taking four samples of the four cities for example, only the Dalian sample uses the new typeface but the rest of the three cities still use the Hei style (but in various Hei typefaces) (see Fig. 3-12). That may be because of economic concerns, the old typeface may only be replaced when the sign needs to be renewed. The samples shown in Figure 3-12 were photographed in 2017 and 2018 when the new typefaces had just been refined in *Standard f.*, which may explain why the new typeface had not been widely applied to samples. The four map-like sign samples also show that the type size of both Chinese and Latin scripts varies, especially the size of Latin letters, which presents a conspicuous difference between the samples. For example, the Latin letters show a much larger size in the Shanghai sample than in the Wuxi sample. Additionally, the Latin texts presented in the samples are printed in different text styles. The uppercase is used in the Wuxi sample, but the mixed case is used in the other examples.

Figure 3-13. *The strokes width, type style, and type weight used on map-like samples. Photographed in Dalian (top) and Wuxi (bottom) by the author in 2017.*

Figure 3-13 presents how stroke width, type styles, and type weight are used on the collected map-like samples. As Figure 3-13 shows, Latin letters are stretched into slender shapes which alter reading patterns and diminish legibility. It seems that this is an attempt to vary letter width alongside matched Chinese place names and justified alignment. For example, the abbreviation 'Rd.' (for Road) (Fig. 3-13 top) presents different width forms. Only the English place name 'Gao'erji Rd.' among the five place names is presented in a regular type style. Regarding Chinese place names, the type style also varies even on a single sign. For example, in Figure 3-13 (bottom), the Chinese place name '南湖大道' is condensed in what may have been an intentional effort to achieve the same line length as the Chinese place name above it '兴源路'.

- *Extrinsic attributes*

Figure 3-14. *The text spacing of Latin texts used on stack-like sign samples of Dalian in 2017. Photographed by the author.*

The use of text spacing for Latin texts on collected samples is often inappropriate. As shown in Figure 3-14 (top), too little letter spacing and too loose word spacing have been applied, resulting in difficulties in recognising individual letters and separating the words into unconnected elements. In addition, the line spacing is inconsistent. In Figure 3-14, the vertical distance between Chinese and English legend is wider on the bottom sample than on the top one. The sign designers may try to achieve a tabular presentation (or justified alignment) by adjusting the letter and word spacing of English text in order to achieve equivalent line length with the Chinese text. However, such an effort impairs the legibility of the English text on a sign. Lai (2015) reports that most foreigners in China find English translations on signs helpful, but it would be better to space them appropriately instead of bunching them together.

Figure 3-15. *Inherent letter spacing in a Hei typeface. Compared with the word 'Beijing' typed in Helvetica (right), when the word 'Beijing' is typed in Hei style (left) the built-in letter spacing between i, j, i looks so loose that it is difficult to recognise the word. Drawn by the author.*

The inappropriate use of text spacing of the English legend may be because, first, the new recommended typeface has not been widely applied, and the old compulsory Hei style does not have matched and well-designed alphanumeric characters (Fig. 3-15). Secondly, Chinese and English are very different writing systems with significant theoretical and practical differences in typography design. As an outcome, while the new typeface has been used in some samples, sign designers who lack Latin typographic knowledge might easily incorrectly adjust the space size and use it inappropriately.

Regarding the text spacing setting for Chinese texts, in Figure 3-14, all the Chinese place names have been designed with an equivalent line length by increasing the *unit spacing* (the horizontal distance between two semantic units in the Chinese sense) and unit spacing varies according to the number of characters in a line. This may also be an effort to achieve a tabular presentation. For Chinese drivers, this may improve reading speed since the exaggerated unit spacing makes the place name more conspicuous than others, as shown in the first-line place name in Figure 3-14 (top) for example. The tabular presentation may aid Chinese drivers in interpreting messages because they are familiar with the traditional Chinese justified typesetting, and familiarity is a vital factor benefiting reading speed (Garvey et al., 2001; Lay, 2004a). But this presentation needs to be measured and determined in terms of experimental studies.

From the above samples, it shows that justified typesetting appears to be used more frequently than the two recommended alignments that are specified in the Standards (central-aligned or left-aligned). The monospaced nature of Chinese characters encourages justified typesetting (Tam, 2012), which has led to justified typesetting becoming the most common alignment in Chinese composition. It is considered more efficient, more refined, and legible. Therefore, familiarity and custom may lead to attempts to use a justified alignment beside the two recommended alignments in the Standards. That could also explain why sign designers have the preference for a tabular presentation. However, as discussed, justified alignment is achieved by varying character width and text spacing which impairs the sign legibility.

Figure 3-16. *The Latin texts are central-aligned with their corresponding Chinese texts, but the two bilingual place names are left-aligned. Dalian samples photographed by the author in 2018.*

From the samples, it seems the left-aligned setting is rarely used. The Latin text is always centrally aligned with the Chinese text to form a bilingual legend, while the left-aligned setting is only found to be used to align bilingual legends (Fig. 3-16).

3.3.1.2/ Pictorial & Schematic Elements

Figure 3-17. *Repeated from Figure 3-12 for ease of reference. Four map-like signs photographed by the author in four Chinese cities in 2018.*

In the map-like samples collected from four cities in Figure 3-17, the size of the orientation-direction patch placed at the top left corner varies among the four cities. Larger patch size is used in Beijing and Wuxi samples. In the other two cities, fewer elements are presented within the patch (one Chinese orientation word with a pointer). In addition, the pointer is located beneath the Chinese orientation word in the Beijing, Wuxi and Dalian samples, but it is placed at the bottom left of the orientation word in the Shanghai sample. According to the illustration in *Standard e.* (Fig. 3-7), the Dalian sample presents the patch in a way that complies with Standard example. The use of the ambiguous phrase *in some cases* in *Standard e.* (Section 3.1.2.2) may explain the inconsistent use of the orientation-direction patch.

The route arm is located at the horizontal centre of the four map-like samples, but the one applied to the Beijing sample shows a different appearance. In the Shanghai, Wuxi and Dalian samples, where two route arms join, there is a route name placed in a rectangle with a chevron at the beginning and end. Nevertheless, in the Dalian sample, the route name is located on a white background which is different from Wuxi and Shanghai. The length of the route arm also varies between the signage for the four cities, both the vertical and horizontal route arms are much longer in the Shanghai sample for example. According to all the collected samples, the style of route arm most widely in use is the one applied in the Shanghai and Wuxi samples. But there are no illustrations in the

Standards that relate to the design of this style of route arm. The different shapes and styles of route arm applied to the samples may be due to various shapes and styles provided in the Standards (Fig. 3-8) and none of the Standards specified the use of them.

Figure 3-18. *Different use of arrows in shape, size, and location. A Beijing sample (above) and a Shanghai sample (bottom). Photographed by the author in 2018.*

Arrows, in most samples, are uniform in appearance following the ISO 7001[12] recommendation. An arrow should have ends that are parallel to the main stem and are not cut off at 90° (Barker & Fraser, 2004). But this appearance sometimes shows different shapes and sizes in the samples. For example, in the Beijing samples in Figure 3-18, the arrow presented in the one-direction sign on the left-hand side is sturdy with a short main stem, but the one presented on the right-hand side is slender with a long main stem. In addition, arrows are also inconsistent in their placement. The arrows, which all indicate 'ahead' in Figure 3-18, is located on the right-hand side of the legend(s) in the Beijing samples and located on the left-hand side of the legend(s) in the Shanghai sample.

[12] ISO 7001 ("public information symbols") is a standard published by the International Organization for Standardization that defines a set of pictograms and symbols for public information. The latest version, ISO 7001:2007, was published in November 2007. Retrieved from: https://en.wikipedia.org/wiki/ISO_7001

According to the collected samples, it can be observed that the colour (the contrast between the colour of the text and the sign background) complies with the Standard guidance and maintains a certain level of consistency. All samples use white text on a dark (blue or brown) background.

3.3.2/ Sign layout

In information design and graphic design, a grid is used to create visual order and ensures the elements are consistently organised across the whole system (Elam, 2007). The grid is a strong organisational device, providing unity across a series of pages (or screens) and the page (or screen) elements themselves, while at the same time allowing for a vast number of variations (Kunz, 1998). Although the grid is an important component of layout design for print or screen, it can be applied to sign design because sign programs are also concerned with achieving consistency across a whole system and the signs themselves. To systematically evaluate the sign layout of the collected samples, this section analyses how the CEBTS layout is aligned by virtue of grid theory.

In Figure 3-19, two one-direction samples that both indicate the direction 'straight ahead', and both including two place names within the direction, are compared. The orange lines are included to illustrate stopping (or starting) points, or the where the edges for the legends and arrows should be placed. The orange lines are drawn following the principles of flowlines in grid theory that break the space into horizontal bands (Samara, 2017). The flowlines and vertical lines (red lines) form empty regions (or spaces) between the edges of the elements, and regions (or margins) between sign edges and the elements.

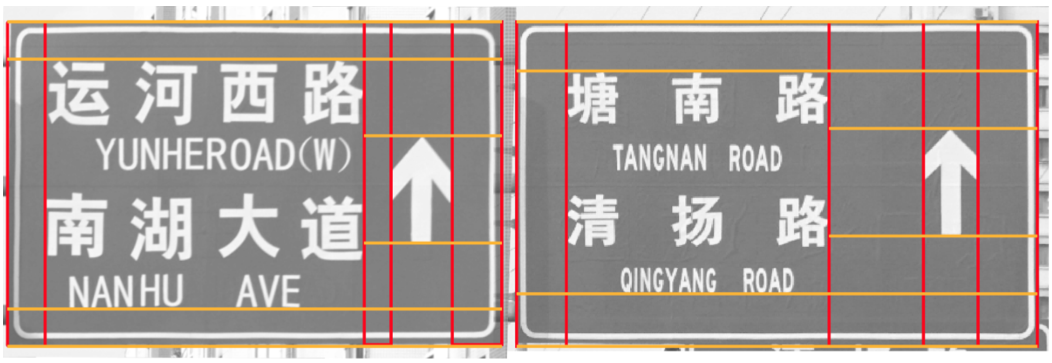


Figure 3-19. *Grid for two one-direction samples. Both samples were collected in Wuxi in 2017. Photographed and illustrated by the author.*

The size of empty regions shown in the two samples highlights that the grid skeleton used for each is very different. The layout of the two samples is a professional design convention rather than the Standard guidelines that designers are supposed to follow. However, it is essential to use the same grid skeleton on every sign to keep consistency across the same categories (have *similarity* from the perspective of Gestalt theory, Section 7.4.1, p. 149). This, therefore, would meet drivers' expectations of how signs should appear and help them process individual signs more rapidly (see Section 1.2.1 for the discussion of sign consistency).

3.3.3/ Inconsistency

The visual analysis of the collected samples reveals the low level of consistency in the CEBTS design and its implementation. Consistency is one of the crucial factors affecting legibility of signs (Berger, 2009; Gibson, 2009; McLendon & Blackistone, 1982; Smitshuijzen, 2007; Uebele, 2007). As discussed in Section 1.2.1, sign consistency refers to meeting driver expectations in order to help road users interpret sign information. In wayfinding theory, Chung (2008) discusses that people may feel confused about whether they are walking through the same district or have crossed into a different district in the wayfinding process if there is disunity in the visual look of signs. Poorly maintained signs may be difficult to interpret and may lead to drivers' ignoring their messages (Lay, 2004a).

Figure 3-20. *The inconsistent use of abbreviation strategies of Latin words (e.g., the word 'expressway'), and the design of a patch (with/without a white border). Photographed by the author in Dalian, 2018.*

Apart from the inconsistent design of the graphic system of CEBTS, the inconsistency can further be identified in the abbreviation strategies of Latin words. For example, in Figure 3-20, both samples were collected in the same city, Dalian, but the full word *Expressway* is used in the right-hand sample, and its abbreviation *Exp.* is used in the left-hand sample. Although abbreviations used on a sign may increase the possibility of incorrect sign interpretation, they are one of the ways to deal with sign size limitations (Garvey & Kuhn, 2004). Huchingson and Dudek (1983) develop two abbreviation methods for highway signs: using only the first syllable for words having nine letters or more; using the key consonants for five- to seven-letter words. The Standard, *English Translation of Public Signs, Part 1: Road Signs* (Municipal Bureau of Quality and Technical Supervision Beijing, 2006), provides lists of 'acceptable' abbreviations for traffic signs. According to this Standard, a dot should not follow the abbreviation Rd, and the word Expressway should be shown in its abbreviation as *Expwy*. Therefore, it is clear that the abbreviations in practice are not in agreement with the guidance in the Standard. The inconsistencies may be because, first, the broad and insufficient guidance cannot cover the situations in practice and therefore, may leave room for freedom of interpretation by individuals. Secondly, ambiguous wording may result in misinterpretation and misuse of the guidance. Thirdly, sign designers do not follow the visual guidance strictly for some unknown reasons.

However, the use of sans serif letterforms in the samples is consistent. Additionally, sans serif letterforms may be more visually matched with Hei style since Hei is akin to the sans serif styles of western typography (Section 3.1.2.1). Therefore, to a degree, consistent use of sans serif on samples improves the sign effectiveness.

3.4/ Chapter summary

This chapter serves to discover the challenges that the CEBTS designers face by looking at how the graphic system of CEBTS is involved in Standard specifications and in real applications. Although the quantity of the reviewed Standards and the collected samples is not comprehensive, it is sufficient to identify the complexity of specifications and signs currently in use.

According to the review of the Standards, generally, the Standard guidelines for the sign graphic system are gradually improving (e.g., the proposed typeface for both Chinese and Latin scripts and the recommendation of using an uncondensed typeface) but are making slow progress. The precise and sufficient specifications for the design of CEBTS have not yet been formulated. The majority of guidelines concern sign content design, while some sign content guidelines are still insufficiently explicit and effective. In particular, very little guidance can be found to support sign layout design and what there is seems limited in its application. Furthermore, there is currently no guidance to support sign makers in arranging the two scripts on the same sign.

With a visual analysis of real CEBTS's samples, noticeable ambiguities and inconsistencies can be observed. Current design practice suggests that there is no ability to arrange bilingual texts in a way that is coherent and legible. The design of the English text has been based on Chinese typography knowledge, seemingly overlooking that these are different language systems and that Latin letters have their own inherent typographical principles. It potentially violates the principle underlying a harmonised design (Section 1.4).

This insufficient and imprecise visual guidance may result in inconsistent and inappropriate design in practice; the implementation does not seem to be strictly carried out according to the Standards. That may be because sign designers misinterpret and misuse the guidance, or, to meet the demands of individual contexts, sign designers make full use of their initiatives. But these initiatives do not appear to maintain any level of consistency.

The current status of visual guidance and practices also shows that the awareness of the important role of arranging two scripts together that are coherent and legible on a sign is low across the whole country. When Chinese and English scripts coexist but are not designed adequately and appropriately, they will appear to be fighting each other and mislead not only the readers relying on English legends, but also disturb Chinese readers when searching for a target location name (Yang et al., 2020). More importantly, traffic signs are associated with traffic safety and driving performance. Research indicates that reading times typically increase – by up to 15% – for the bilingual signs (Latin-based) compared with their equivalent monolingual versions (Lesage, 1981; Rutley, 1972). Because increased reading times result in drivers having their attention diverted from the task of driving safety along the road for periods, then with this consideration, bilingual traffic signs should be an optimum way to convey information without degrading driving performance. There have not been studies investigating how to design the graphic system of CEBTS to enable the dual-script information communicated in an effective way to improve driving performance, which presents an interesting research question that this project attempts to investigate.

Apart from the above findings, the review of the Standards (Fig. 3-1) and real sign samples is an important step to inform the ecological validity of the design of test materials for the empirical studies (Section 6.1.3). The survey of the Standards and samples, furthermore, raises questions in relation to the CEBTS design process, such as:
- are decisions made about the sign graphic system in the Standards based on experimental research and user experience?
- does sign legibility come into play when arranging bilingual legends on CEBTS?
- who takes responsibility for implementing sign design?
- what challenges or difficulties do Standard makers meet in composing the visual guidance, and what do sign designers meet in implementing signs?

To answer the above questions, a series of interviews with experts are conducted and are discussed in the next chapter.

4/ Challenges for the current design of CEBTS — Practitioner Interviews

The survey of the Chinese traffic sign Standards and the real sign samples discussed in Chapter 3 reveals the current design of CEBTS and presents potential challenges that regulators and sign designers are facing. This chapter reports and analyses a series of five practitioner interviews in order to explore the CEBTS design process from different perspectives with a view to contextualise the issues observed in Chapter 3. This interview study, as a supplementary study of the CEBTS current design survey, is important because it not only contextualises the survey, but explores issues that are difficult to articulate or explain through visual analysis of the sign samples.

The interviewees include an expert engaged in compiling sign Standards and a public official responsible for the production, implementation, and maintenance of road traffic signs. They provide information in relation to the decisions made for the visual guidance in the Standards, the design process of CEBTS, and the organisations involved in the design process. In addition, a designer who designed the specific typeface currently recommended for new traffic signs and a Chinese character designer are interviewed. They share their methods and experiences of designing bilingual scripts, especially for use in road signs. A traffic police officer is also included in this series of interviews and gives his working perspective on the current bilingual signs. The interviewees are diverse in their professional roles. While the number of participants in this part of the research is relatively small, their answers represent their professional opinions, and the insights gained from their opinions are important to investigate the secondary research question: what are design challenges of CEBTS?

In the following discussions, Section 4.1 gives the rationales for conducting practitioner interviews and 4.2 describes the recruitment method and the structure of the interviews. Section 4.3 analyses and discusses the findings gained from the interviews.

4.1/ Rationales of practitioner interviews

The review of the Standard guidance and sign samples raises questions in relation to the design process of CEBTS. These not only constitute the motivations for this chapter, but also form the basis of the interview questions. In addition, the interview questions given below are intended to identify answers to the secondary research question, what are the design challenges of CEBTS? The interview questions are summarised below.

> 1. What organisations are responsible for the design, production, and implementation of the signs? How do these organisations carry out their roles and collaborate?

The Standards and sign samples provide the design guidance and the final presentation respectively; however, the stages of design are invisible which can be the critical cue for CEBTS design. Insights into the stages of design might be gathered through exploration of the organisations that are responsible for the design, production, and implementation of the signs, how these organisations carry out their roles, and how they cooperate. The uncovering of the CEBTS design process could help to discover the invisible challenges, such as what currently constrains design, in order to make recommendations for design solutions to the CEBTS graphic system.

> 2. How are decisions made about the graphic system of CEBTS in the Standards, and are the decisions based on experimental studies and user needs?

The Standards include some guidelines for the sign graphic system, such as typeface and stroke width, but there are only a few references and explanations of the considerations and basis for setting those guidelines. Insights into the rules and foundations of setting up those guidelines and the lack of guidance compensated for in practice may help to discover the factors of the graphic system that are focused on in this research. These may also help identify potential reasons for the current inconsistent implementation.

> 3. How is the Latin text added to the CEBTS in implementation and is sign legibility considered when bilingual texts are presented together on traffic signs?

Since there is limited guidance concerning how to present Latin texts on CEBTS in the Standards, the response to the above question could provide significant clues for the design of bilingual typography on a sign program.

> 4. Why do the Standards remain essentially unchanged in relation to the refinement of the sign graphic system? Is this because Standard makers neglect the important role of the sign graphic system design in traffic safety? Alternatively, could it be because the challenges or difficulties are met in compiling visual guidance?

As traffic networks are upgraded through physical elements such as lane width or rumble strips, sign design should be given the same thorough review to make the traffic signs safe

(Meeker et al., 2010). The review of the sign Standards found that the traffic sign Standards in China are being developed and improved continuously, but the sign design guidance is updated comparatively slowly. Accounting for these considerations may help to discover the barriers and difficulties of designing CEBTS.

4.2/ Interviewee recruitment and interview structure

4.2.1/ Recruitment of interviewees

The first step in this interview process is to identify the appropriate interviewees. The people or organisations who have been involved in compiling or implementing road Standards and in designing or producing CEBTS, or in other relevant fields are considered. Therefore, of the initial selection, one of the regulators (Interviewee *Regulator*) of the reviewed Standard (*Technical Guidelines for the Replacement of National Expressway Network Related Traffic Signs*) and a designer (Interviewee *Designer*) who designed the specific typeface currently recommended for new bilingual signs were approached.

Through a snowball sampling technique (Browne, 2005), two further participants were introduced by the existing interviewees and were invited to take part. One of these participants was familiar with the implementation process of traffic signs in Dalian of China and so was able to provide information on the issues of traffic sign implementation (Interviewee *Implementor*). The other introduced participant was included because he is a typographer who may have been willing to share his methods and experiences in designing bilingual scripts (Interviewee *Typographer*). Additionally, a traffic police officer was invited (Interviewee *Police*). Other than *Regulator* and *Designer*, a perspective from a traffic police officer could provide triangulating opinions for the questions under investigation. For example, a traffic police officer may provide data on the number of traffic accidents caused by difficulty reading traffic signs, which may reflect the relationship between sign design and traffic safety.

The recruitment reasons for each interviewee and their primary field of work, together with the questions that might be relevant to their professional experience, are listed in Table 4-1 below.

Table 4-1. *The primary field of work of interviewees, select motivations and questions they could answer. Tabulated by the author.*

Interviewee and role	Responsibilities	Recruitment reason	Question answered
Interviewee Regulator Vice President of the Beijing Highway Survey and Design Institute.	Engage in road traffic safety and transportation engineering; responsible for compiling traffic road sign Standards, providing evaluation and consulting.	Could primarily give responses to the issues of traffic sign Standards compilation, which includes: - decisions made on visual guidance in the Standards; - barriers and challenges in CEBTS design.	2 & 3 & 4
Interviewee Implementor Working in the Traffic Facilities Management Office, the Traffic Police Detachment of Dalian Municipal Public Security Bureau.	Responsible for road traffic planning that includes the design, production, implementation, and maintenance of road traffic signs.	Could primarily give responses to the issues of traffic sign design and implementation, which includes: - design process and method of CEBTS; - considerations and approaches of adding English text on CEBTS.	1 & 3
Interviewee Designer Founder of Huawen font library; Chairman of Beijing Huawen Century Advertising Co., Ltd.; Deputy director and professor of the China Central Academy of Fine Arts (was).	Designed the special typeface for traffic signs use.	Could primarily give responses to: - the issues of the design process of the specific traffic typeface. - the experiences and methods of presenting Chinese and Latin scripts together on a sign; - the considerations and approaches to designing bilingual typography.	2 & 3
Interviewee Typographer Associate professor in the School of Design, Jiangnan University.	Devoted to the creative practice of Chinese character design and visual communication design.	Could primarily give responses to the issues of personal feelings, perceptions, and opinions of the current design of CEBTS in China.	1 & 3
Interviewee Police Traffic police officer in Dalian.	Traffic accident scene measurement.		

4.2.2/ Interview structure

To explore the answers to the questions presented in Section 4.1, the interviews were structured into three parts as follows. A detailed listing of questions based on the designed interview structure was prepared for each participant before the interviews (Appendix I).

a. Information concerning the participants' occupations.

In this part, the participants were asked to talk about their job roles in relation to traffic sign design and how they carried out their responsibilities in the specific field. The main purpose of this part was to elicit the background information of the participants and lead to the main part of this interview.

b. Eliciting information about the design process and method of CEBTS.
This was the main part of the interview. The questions were designed to revolve around specific issues based on the interviewee's role in traffic sign design. Interview prompts were used to expand upon their responses.

c. The interviewee's reflections about CEBTS design in relation to their professional experience.
Each interviewee was asked to give their perspective on the current CEBTS practices. The interviewee was encouraged to explain why they held certain opinions and how to improve the bilingual traffic sign design from their own point of view.

The interview process was given ethical approval by the University of Reading Ethics Committee. With the interviewees' permission, the interviews were recorded. Notes were also taken during the interviews. Four interviews were held in the participants' offices; one (with *Implementor*) was conducted by mobile phone and a phone recording function was used. All the interviews were conducted in Chinese. Personal details were anonymised in all the transcripts.

4.3 / Analysis and Findings

The recorded interviews were transcribed and analysed. Because the interview questions were designed according to the interview structure, the interviewees' responses are organised and summarised under the following themes:
– the organisations involved in CEBTS design (responses to interview part a);
– the visual decisions or considerations made in the production of CEBTS (responses to interview part b)
– the experts' overall perspectives on current practice (responses to interview part c).

Therefore, the transcribed interviewees' responses that fit into these themes were extracted and analysed. Unexpected responses out of the theme scope were beyond the considerations of this interview and thus were excluded from the analysis.[13] Since the interviewees are diverse in their professional roles, they may not have been able to provide

[13] The interviewee *Designer* mentioned that, with the development of automatic driving, it is the right time to consider how road sign functions in relation to new technologies. In the age of big data, it is also important to utilise both static and digital devices to communicate information in a meaningful way. The question of how to make both static and digital devices work together could be a new research topic. *Designer* also provided a topic example: an investigation into the cooperation of road signs and GPS navigation.

definitive answers to each theme. But they could provide a way of identifying shared views that might be relevant to consider in this research. Thus, the findings for each theme are summarised according to the general opinion of five participants rather than individual perspectives.

4.3.1/ Organisations involved in CEBTS design

Many organisations are involved in the traffic sign specification and design process, from national to local level (the roles of the contributing organisations are illustrated in Figure 4-1 below). At national level, the National Standardisation Administration of China (translation of 中国国家标准化管理委员会) is the main body responsible for composing traffic sign Standards and proposing basic and general regulations that need to be complied within the implementation. The Ministry of Transport (translation of 交通运输部) is responsible for providing guidance of road signs used on expressways, and the Public Security Bureau of Ministry of Transport (translation of 交通运输部公安局) is responsible for providing guidance of road sign designs used on urban routes. Both organisations compile guidelines based on National Standards.

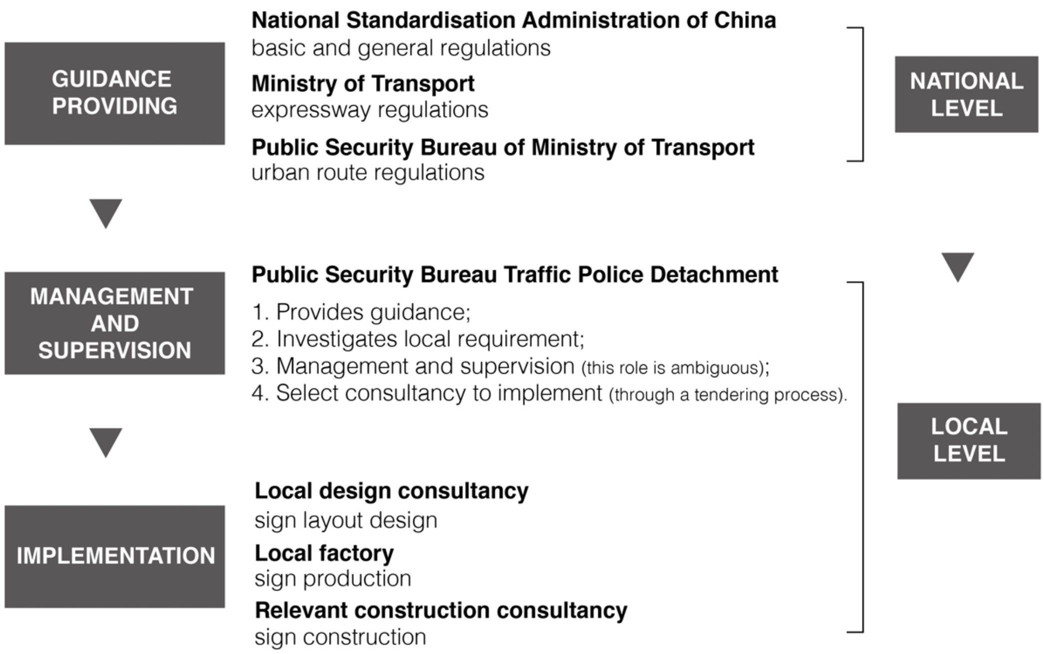


Figure 4-1. *Organisations involved in the traffic sign design process and their roles. Illustrated by the author.*

At a local level, the Public Security Bureau Traffic Police Detachment (公安局交通警察支队) provides guidelines that are based not only on National Standards, but also on regional specific road networks and users' needs. According to *Implementor*, operating at the local level, the procedure includes:

1. study the National Standards;

2. investigate local specific requirements, such as users' needs and the problems that the sign is intended to deal with;
3. propose advice on amendments or updates to the guidelines;
4. report the planned updates to the National Development and Reform Commission (translation of 国家发展和改革委员会);
5. get plan approval and funding for tendering appropriate consultancies to prepare signs.

'The Ministry of Transport also monitors practice and may update guidelines in response. As part of this process, consultation with drivers is used as part of investigating and evaluating user needs in practice. Then the Ministry of Transport may propose new guidelines or update existing guidelines based on investigation and evaluation results.' (*Regulator*)

Regarding the specific design work, it is handed over to local design consultancies that are appointed through a tendering process. According to *Implementor*, a regular public bidding process is managed by the local Public Security Bureau Traffic Police Detachment to identify the design, production, and construction consultancies which may be able to carry out the implementation roles. The consultancies, however, have to follow the implementation plans of the Detachment. Every year, a maintenance fund is established to maintain and manage the existing traffic signs on the routes.

However, as there is no fixed body of design consultancies, this has become one of the hidden reasons that causes inconsistency in this type of design across the country. Even though the design consultancies are guided by the Standards, as well as by the local Public Security Bureau Traffic Police Detachment, the amount of latitude open to the consultancies seems to be too broad. Additionally, it appears to be difficult for design consultancies in different regions to assist in executing the same role, and the visual guidance in the Standards is too general, so there are likely to be different interpretations across regions or even within one city.

'There is no specific institute responsible for it [the design of traffic signs] currently in China; the extent to which the role of our Detachment [the Public Security Bureau Traffic Police Detachment in Dalian] plays in the design process is ambiguous as well, because there is no certain guidance provided in any relevant regulations.' (*Implementor*)

'Each design consultancy differs in the region, with the non-detailed and limited visual guidelines provided in the National Standards, design consultancies take full use of their initiative which causes inconsistency in traffic sign appearance around the country.' (*Police*)

Another point about inconsistency across organisations is differences in the comprehension of the Standards. As *Implementor* mentioned in the interview, the layout design of traffic signs is relatively free and subjective. In Dalian, for example, two different organisations play the same role in the traffic sign implementation process because of the district division. However, even though they use the same Standards and there is often communication between organisations, the interpretation of the Standards is still different.

Implementor also pointed out that even if they have met the guidance provided in the Standards, this may not fit into the needs raised in practice. For example, the expressway route number patches (Fig. 4-2) show four white Chinese characters '国家高速' (marked in a red rectangle) presented on a red-green background patch and follow the Standard requirements (both typeface and type size meet the requirements), but these characters can hardly be read in practice.

Figure 4-2. *Standard guidelines fail to meet practical needs. The design of the four white Chinese characters '国家高速' (marked in a red rectangle) meet the Standard specifications, but they can hardly be read in practice because of the small type size. This photo supports Implementor's opinion that the guidance, sometimes, cannot meet practice needs. Photographed by the author, Dalian, 2018.*

Furthermore, *Implementor* believed that Prohibition signs and Warning signs (Table 3-4 in Section 3.2.1) are widely applied in practice and are more compliant with the Standard guidelines. However, the guidelines of Guide signs provided in Standards often cannot cover the specific situations in which they should be used. When this is the case, the local Public Security Bureau Traffic Police Detachment provide provisional rules for the design consultancies. The formulation of these provisional rules is based on similar existing sign design and other related Standards. The priority is to keep a uniform design in line with the existing signs.

Regulator introduced a discussion about the production process of the traffic signs, which is undertaken by a local factory. Traditionally, signs are updated by printing a new reflective film to completely replace an existing one. However, with new technology, film and panel are now produced as one unit, so that in some cases (due to cost) signs are partially updated rather than replaced completely. This leads to only 'important information' (the phrase *Regulator* used), such as route number, having a compulsory update. However, the guidance of the sign graphic system is often taken as a recommendation rather than compulsory. This leads to the design of most traffic signs in practice not being updated along with the Standard guidance.

> 'Concerning economic and environmental issues, it is not possible to replace the signs that are based on updated Standards across the country and thoroughly. Some important information, such as route name and mileage information, is required to be updated urgently and mandatory, but the visual factors are dependent.' (*Regulator*)

In summary, the main organisations involved in the design process of CEBTS can be divided into two types. The relevant governmental departments, such as the Ministry of Transport, are the management organisations that are responsible for providing guidance, discovering and evaluating the current signage barriers, and supervising the implementation process. The other type has the role of the implementation process; this is conducted locally by consultancies and under the supervision of the local government. The implementation process includes the design, production and construction of the signs.

As the interviews above show, the potential reasons that may cause ineffective design of CEBTS include:
- the instability (no fixed responsible body) of the implementing process conducted by local design consultancies caused different interpretation of the guidance.
- the effectiveness of the supervision varies, according to where the sign is designed and how it is produced.
- the guidance cannot cover many specific practical issues.
- the Government is not aware of the significant role of the sign graphic system in traffic safety.

4.3.2/ The graphic system considerations in CEBTS design process

4.3.2.1/ How visual guidance was decided upon in the Standards

Regarding the question about the decision-making process for the sign graphic system in the Standards, *Regulator* explained that most decisions such as the height of Chinese characters and the width of strokes, are based on experimental research, to ensure the legibility of signs.

The first determined guidance in relation to the sign graphic system was the height of Chinese characters, which was based on the approaching speed of vehicles. The height was established by experimental research led by the Institute of Psychology, Chinese Academy of Science (1986 and 1989). In 2009, the recommended height was reconfirmed, and the width of strokes was established in driver simulation studies by the Ministry of Communications. Condensed typefaces are widely used in practice on signs because they save sign space. However, after practical application for many years, the condensed typeface, condensed Latin scripts especially, had been found to affect the legibility of signs. Thus, in 2014, after a study conducted by the Highway Institute to establish the width ratio of the Chinese characters, use of uncondensed type was encouraged in the Standard, though a condensed Chinese character with a ratio of 1 to 0.75 can still be used when space is limited.

> 'We still receive many objections when working with the Guidelines [the Standard of *Technical Guidelines for the Adjustment of National Highway Network Traffic Signs*]. Those that oppose using uncondensed Latin letters argue that this rule will increase the size of the sign panel, which will cause changes in sign construction. This will be inconvenient in terms of production and implementation, and will, of course, raise costs.' (*Regulator*)

According to the visual analysis of sign samples discussed in Chapter 3, practice varies in the use of text spacing and, in some cases, text spacing is excessive. This has an impact on the legibility of CEBTS. The unit spacing (horizontal spacing between Chinese characters) is specified as 1/10H in the Standard. However, *Regulator* said that he is not aware of any relevant research that investigated the effects of unit spacing on CEBTS legibility. To *Regulator*'s knowledge, the unit spacing of Chinese characters may not be a primary factor that affects sign legibility.

> 'In my experience, the spacing between characters can influence the interpretation of meaning, to some extent, but not very seriously.' (*Regulator*).

In terms of the guidance in relation to Latin scripts and Arabic numerals in the Standards, the primary approach is a reference to the road typeface used in Japan, the United Kingdom, and the United States (Fig. 4-3).

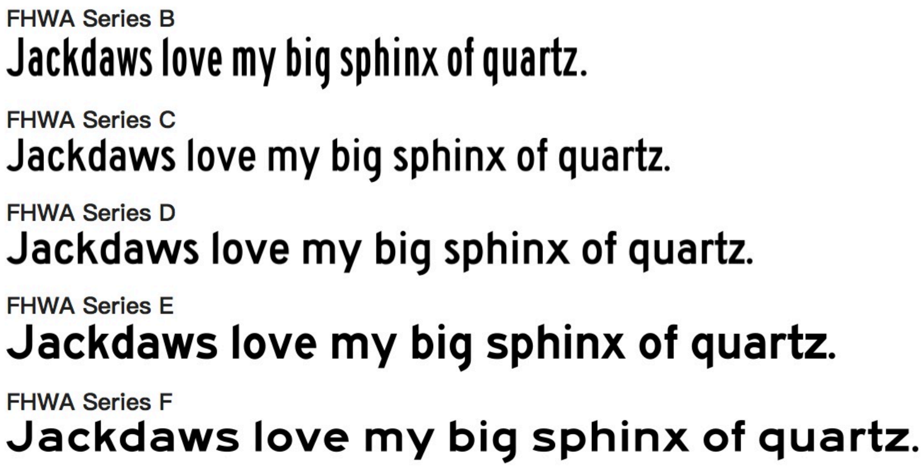


Figure 4-3. *FHWA series typefaces (Highway Gothic, Atanamir, 2020).*

According to *Regulator*, the type size guidance of Latin scripts, when it was first set on road signs, was adopted according to the size set on Japanese/English traffic signs in Japan.[14] It was based on the proportional relationship between Latin and Japanese scripts on the sign, but the type size of Latin scripts was increased afterwards based on the Chinese context. Appendix D in the National Standard GB5768 (1999) provided the typeface specimen for Latin scripts that were designed by taking reference from the typeface *Transport* (used on UK road signs). Then a new typeface was designed based on the FHWA (Fig. 4-3) series typeface (also known as *Highway Gothic*, used on road signs in the US).

The FHWA series consists of six font group: 'A' (the narrowest), 'B', 'C', 'E', 'E(M)' (a modified version of 'E' with wider strokes) and 'F' (the widest). The series originally included only uppercase letters, with the exception of 'E(M)', which was used on larger expressway and freeway guide signs (Fig. 4-3). As *Regulator* explained, the font series E(M) was first adopted, subsequently, in order to avoid using condensed letters and, at the same time, guarantee a fixed panel size, font series B and C were adopted.

While legend specifications are based on precedent, the reference that can aid in compiling visual guidance in relation to pictorial elements is minimal. *Designer* mentioned that due to the short development period of China's transportation network, there is still a lack of relevant research, and some guidelines lack rigour. Many issues and refined guidance need further study. However, the study of pictorial elements is developing; *Regulator* described that the relevant guidance on arrows in the Standards resulted from the findings of an experimental study that was conducted in collaboration with the China Academy of Art.[15]

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[14] I have been unable to find further evidence to back up this statement.
[15] I have been unable to find further evidence to back up this statement.

When asked why limited visual guidance can support the presentation of Latin scripts on a sign, and why most of the Standard examples are monolingual signs rather than in a bilingual format, *Regulator* explained that there has been a vigorous debate among relevant experts on whether English translation should be added to traffic signs in China. The debate has not yet gained consensus. Some experts advocate for the use of bilingual traffic signs because they provide foreigners a positive first impression and make them feel welcome. In addition, as more foreigners are living in China, a sign program should and must provide the information that they need. However, some experts hold different views. They think the majority of sign users in China are still Chinese and most foreigners who use signs can read Chinese. Furthermore, the addition of English increases the complexity of the signs, as *Police* mentioned:

> 'Actually, I pay very little attention to the English translation on signs. Sometimes I think it affects my reading of Chinese information. However, adding English to traffic signs is a good thing from my point of view. It makes it convenient for the traffic police to explain road information to foreigners. As the number of foreign drivers in Dalian increases, bilingual traffic signs will play a more important role.'

The outcome of the debate is far from straightforward, thus *Regulator*, as one of the specification makers, has to find a compromise:

> 'Because of the difficulties of obtaining a uniform opinion, in the National Standard, we removed the English layout illustrations, and we pointed out that each region can add English translation as required instead of it being mandatory. However, the signs for expressway use should be in a bilingual format in order to solve the problem of an increasing number of foreigners coming to China for business negotiations and travels.' (*Regulator*)

4.3.2.2/ How the specific signage typeface was designed

In 2007, the Standard, *Technical Guidelines for the Replacement of National Expressway Network Related Traffic Signs,* was published, proposing, for the first time, a specific typeface for traffic sign use. *Designer* and his team designed this typeface (called *Huawen Gao Biao Hei*). In his interview, *Designer*, explained his methods.

Designer designed alphabetic letters and Chinese characters separately. The design of alphabetic letters was carried out first, and as mentioned above, was based on the FHWA series fonts, specified in the American MUTCD and SHS. Then the Chinese characters were designed, based on the characteristics of the finished Latin letters. Figure 4-4 makes a comparison between the old typeface (above) and the new one (bottom) used on CEBTS in Dalian, China.

Figure 4-4. *The typeface Hei (above) and the new typeface Huawen Gao Biao Hei (bottom) on CEBTS. Photographed by the author in Dalian, 2018. .*

Designer explained that his team chose an existing Chinese typeface, *Huawen Da Hei*, as the basis for the design of Chinese characters, because they believed that *Huawen Da Hei* has similar typographic features to the finished Latin typeface. They designed 6000 Chinese characters that were to be specifically used on traffic signs, naming the derived typeface *Huawen Gao Biao Hei*.

Figure 4-5. *The design process of the new road sign typeface: Huawen Gao Biao Hei. The process is based on the descriptions from the interviewee Designer. Illustrated by the author.*

When asked how he made the two scripts work together, *Designer* described that there were no relevant references or specifications for how to add English text to traffic signs when he was appointed to work on the project. He was upset because the design of CEBTS has yet to form a systematic theoretical system and design method. But *Designer* emphasised two aspects that need to be considered when designing Chinese and English bilingual texts. The first consideration is type size. *Designer* said that

> 'A larger size of Latin letters should be selected to achieve a similar type size with Chinese characters in visual, because the Chinese characters appear larger than letters in visual.'

That could be explained by the fact that characters with more strokes should generally appear larger than characters with fewer strokes (Lu & Tang, 2016).

The second consideration is stroke width. *Designer* described that the most critical attribute he was concerned with when designing *Huawen Gao Biao Hei* was stroke width.[16] Strokes are the basic unit of Chinese characters and the number of strokes for each Chinese character varies from one to approximately thirty.[17] Based on *The Table of High-frequency Used Chinese Characters* (translation of 现代汉语常用字表) (1988), the characters with strokes from 4 to 13 are the ones that are most frequently used. In comparison, English letters have fewer strokes which leads to more counter space (the fully or partly enclosed white space inside a letter). Much of the time this results in Chinese characters appearing heavier (or blacker) than English letters when the two scripts coexist. Therefore, to make the two scripts harmonise visually, the stroke width can be adjusted to achieve the similar counter space.

4.3.2.3/ Experts' overall perspectives on current CEBTS practice

Each interviewee was asked for their perspective on the current CEBTS practices in China, and most of their responses were negative. Four interviewees thought that the design was inconsistent and inefficient, resulting from deficient visual guidance and a non-performing implementation process. *Typographer*, on the other hand, believed that the Government should give designers more freedom to play a role in sign design because the guidelines are difficult to fit into all the requirements that arise in each particular context.

Regulator and *Implementor* identified the inconsistency in the design of traffic signs across the country. As the guidance writer, *Regulator* believed that misunderstanding and misuse in the implementation process is one of the reasons for the lack of unity in practice. *Regulator* also felt that the Standard guidance is not carried out strictly which may be as a result of the local government interpreting the guidance according to their specific needs. On the other hand, as the guidance expert, *Implementor* thought the deficient and incomplete visual guidance in the Standards caused different interpretations. Note the contrast between *Regulator*'s perspective that local governments apply too much interpretation to National Standards and *Implementor* believed that National Standards are unable to accommodate local issues and needs.

[16] Note the term 'type density' instead of 'stroke width' which *Designer* used in the interview. The meaning of the phrase type density that he used is different from the one in Latin typography. Through dialogue with him, I inferred that stroke width is more appropriate to what he really wanted to express. The type density here refers to the total area taken up by the strokes in one Chinese typeface area. It is determined by the width of strokes. The width of strokes is positively related to the density of Chinese characters. To avoid confusion with the density in Latin perspective, stroke width has been used in the rest of this account.

[17] According to the Chinese Language Research Institute (2006), the most complex Chinese character is 龘 (dá) with 32 strokes.

Designer and *Police* were also dissatisfied with the current design of CEBTS. *Police*, from his perspective, held a view that most traffic signs have lost their function and gave these reasons as follows:
1. The public are not informed in time about the changes in the design of signs, so the meaning of new or updated signs is unclear to them.
2. Although the Government announces the new Standards, the public may not be aware of such announcements because the new Standards appear on the official Government website without forewarning.
3. Insufficient maintenance has caused many traffic signs to be obscured by trees. The damaged and old traffic signs are not replaced or updated in time.

> 'Bilingual traffic signs are difficult for me to read and understand. From my working experiences, instead of reading information on the signs, most drivers mainly rely on the familiarity of the road, and their driving behaviour is mainly restricted by a speed camera. In other words, most of the traffic signs perform practically no function.' (*Police*)

Designer believed that the Government neglects the important role of design in traffic safety. He also put forward his individual views on the current CEBTS design barriers. Linguistics, sign layout, and English text were three main aspects he mentioned. He believed the ambiguous, sometimes incorrect, English translations, and the abbreviation method applied to the road signs, are reasons for the ineffective sign layout. Better abbreviation may be one of the breakthroughs that could be used to solve the issue caused by the longer English line length (English text, much of the time, is longer than the Chinese text to express the same semantics). As described in Chapter 3, sign makers have attempted to achieve equivalent line length with Chinese and English texts by adjusting text spacing but neglect the need to restrict adjustment of text spacing when it might compromise legibility. There has been no appropriate method to compensate for this effect yet.

Additionally, *Designer* pointed out that there have been few research attempts to investigate sign layout for a Chinese-English bilingual format, and that guidance is absent in the Standards. There are even fewer guidelines to help with the arrangement of English texts on a sign. *Designer* mentioned that, to his knowledge, Stahl's thesis (2010b) may be one of few studies that provides an approach for arranging the two scripts. However, Stahl's study concerns a horizontal bilingual text (see Section 1.4) which could not be applied to CEBTS appropriately as the two lines of bilingual texts are arranged vertically (with the Chinese text always above of the English text). *Designer* believed that alignment also has a consequence for vertical bilingual text, which has been overlooked by sign makers.

Typographer believed that it is complicated to achieve consistent design on traffic signs nationwide as there are differences across cities and regions, such as the regional economic gaps and the differences in the supply of public services between urban and rural areas. In addition, attempts at standardisation and uniformity are affected by cultural issues. There are 56 ethnic minorities within China, and it is not clear if they all identify with, or prioritise, the need for consistency and standardisation. *Typographer* doubted that more refined and detailed Standards would make traffic sign design better. Too much detail might fail because it might restrict designers' performance. He claimed that designers' performance had a significant impact on traffic sign design but acknowledged that few designers were involved in the Standard formulation, nor played a leading role during the design process.

4.3.3/ Discussion of findings

Triangulating opinions of individuals with different professional roles contextualises the CEBTS design process. The interviews have revealed some challenges and barriers that are difficult to articulate under the review of Standards and visual analysis of sign samples. The interviews have also identified what the concerns of the designers are in relation to the parameters within which they must work. Furthermore, the findings of the interviews provide insights to help answer the research question; what are the design challenges of CEBTS?

As a result of the interviews, it is evident that there are organisational issues which contribute to the ineffective design of CEBTS. Regarding the sign implementation process, there is a lack of a specific and fixed governing body to maintain standards in the implementation process, and the coordination between various organisations and consultancies involved is deficient. This may exacerbate the impact of misusing and misunderstanding the guidance. In addition, the compliance with, and enforcement of, the Standards, is still relatively low and weak. This means that the final presentation of CEBTS is, much of the time, determined by the local design and construction consultancies. Regarding the sign maintenance process, no apparent working group and no clear management of tasks leads to a series of problems, such as renewing and replacing outdated signs which could cause the signs to lose their functions. The various organisations involved in the CEBTS program indicate that a better solution is not an effort that one person or one institute can take on alone, a better solution needs enhanced coordination and cooperation in every organisation and in every process.

The interviews have also revealed that the Government may overlook the significant role of the sign graphic system in traffic safety. The balance between saving sign space or adding English translation has triggered a debate and has caused the Standards to only supply monolingual illustrations. It may indicate the lack of awareness of the fact that signs are designed to meet the needs of all potential users. There is evidence showing that there are many English readers who rely on English translations to guide their way in China

(Lai, 2015), therefore, the two scripts should be given equal importance on a sign (Nemeth, 2016).

Another finding shows that the visual guidance for CEBTS does not sufficiently consider how the two scripts might work together in ways that are coherent, but still sufficiently attuned to the different requirements for making different script systems legible and work in reasonably equivalent ways. In addition, sign layout is another critical challenge for which there currently are not sufficient guidelines or research to guide relevant local government and consultancies to make the decisions.

The interviews present overall negative perspectives on the current CEBTS practice. All the interviewees believe that the current design is inefficient due to either guidance and implementation issues, or insufficient research. Therefore, the critique of the status quo argued in the preceding chapters is shared by all relevant professionals.

This study aims to fill the gap in the current research. As the findings of the interviews suggest, the extrinsic typographic attributes and the layout of CEBTS are particularly important attributes that should be focused on. As presented in the next chapter, this research moves to identify which factors (within the legends' extrinsic attributes, and sign layout) might influence sign legibility and should primarily be focused on for experimental studies. In such a way, the test variables for the experimental studies could be identified.

5/ Empirical variables and methodology

Through the survey of the current design of CEBTS discussed in the preceding chapters, this research has identified that *extrinsic attributes of bilingual legends* and *sign layout* are critical challenges for which there is currently insufficient research and guidance to support design practices. This chapter begins to consider empirically testing whether the extrinsic attributes of bilingual legends and sign layout are important variables affecting CEBTS legibility.

It is necessary to first identify which factors within the extrinsic attributes and sign layout might influence sign legibility, and which should primarily be focused on. According to the proposed sign graphic system descriptive framework (Chapter 2), there are many factors involved in both legend extrinsic attributes and sign layout, and it is impractical to test them all. The first half of this chapter, thus, aims to identify appropriate variables to test (Section 5.1). It also covers the definition of the identified variables in the specific Chinese-English context (Section 5.2). The second half of the chapter reviews existing studies on ways of measuring sign legibility, to serve as a reference and foundation for formulating the empirical methodology, in order to examine the effects of the identified variables on CEBTS legibility (Section 5.3 and 5.4).

5.1/ Exemplars: identify empirical variables

Drivers rely on traffic signs to find their way, and signs should deliver information in a way that a driver can read, understand, and act quickly if necessary. Therefore, an approach to identifying the link between legend extrinsic attributes, sign layout, and sign legibility would be best dealt with by considering a driver's needs (i.e., in which way drivers use CEBTS when they are reading signs) and sign graphic system (Section 1.1.2). The sign elements, or a layout, supporting the sign graphic system that are required across different users' needs may be important to look at. These generalisable elements, or a layout, will be focused on in the next experimental stage.

The users of CEBTS vary by language ability because, on bilingual traffic signs, they need assistance from the information written in their tongue. Yang et al. (2020) compare the effectiveness of CEBTS (on highways) for drivers with different language backgrounds. They identify three groups: Chinese drivers, bilingual drivers who can read both Chinese and English, and foreign drivers who cannot read Chinese and only rely on English information. The use cases literature provides a clue on how to bridge the needs of different groups of drivers with the sign graphic system. A use case is a helpful tool in software engineering and interface design to identify the visible requirements of a system being developed, and connect it with different users' goals (Cockburn, 1997; Ivar, Magnus, Patrik, & Gunnar, 1992). [18] Therefore, it can be a tool to assist in the analysis of the visible requirements from both the users' point of view and the system's point of view.

Although use cases are more relevant to interactions and the signages considered in this research are static and do not react along with driver's actions, the principle underlying use cases could still be utilised to help define how drivers use CEBTS (driver needs) and the outwardly visible requirements of a sign. To prevent misunderstanding, the term *exemplar* is used instead of use cases. Accordingly, in this research, the term exemplar connects drivers and CEBTS in terms of how drivers may use the system; it represents a range of experiences that drivers might have when they are reading CEBTS.

Wang et al. (2015) use the Kano theory[19] to identify driver needs of sign information presented on Chinese urban road guide signs. The analysis of Wang et al. suggests that direction information, current position information, and distance information (shown in order of the display priority), are the critical elements of information required on traffic signs. The prioritisation of information on traffic signs is linked to the way that drivers use signs. Based on the study by Wang et al., four possible exemplars have been identified and listed below.

Direction exemplar: Am I going in the right direction or what direction should I take? It relates to direction information.

Location exemplar: Did I arrive? It relates to current position information.

Distance exemplar: How far do I need to go? It relates to distance information.

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[18] Although the definitions of use cases differ among researchers (Rumbaugh, Jacobson, & Booch, 1999; Schneider & Winters, 2001; Wirfs-Brock, 1993), there appears to be agreement that the actor, system and action (or interaction) all play significant roles in use case study. The actor is anything (can be a person, a system of any kind) that interfaces with the system under discussion and is always external to the system. However, Constantine (2001) argues that user interface design is not usability engineering, only human users interact with the system in user interface design. The actor has some goals requiring the assistance of the system. The system refers to the system being developed and has a set of responsibilities so that it can meet the actor's goals. An action, as Cockburn (1997) describes, triggers an interaction that an actor calls upon the responsibilities of the system. In other words, an action connects the actor's goal with the system's responsibility. From this perspective, use cases gather possible actions between the system and actors, and the actions bridge the actor's goals with the system's responsibilities.

[19] Kano theory is a tool used predominantly by industrial designers to define the features of products that will deliver customer satisfaction (Sauerwein, Bailom, Matzler, & Hinterhuber, 1996; Xu et al., 2009).

Additional information exemplar: What else do I need to know on my way to my destination? It relates to the additional information a driver may need to know on the way to their destination. For example, the regulatory information is added to a map-like sign (Fig. 5-1) to denote 'no left turn'. This exemplar is proposed by observing the collected sign samples but, based on research by Wang et al. (2015), it is not the critical information required by drivers.

Figure 5-1. A 'no left turn' regulatory sign is presented on a map-like sign as additional information. Photographed by the author in Dalian, 2018.

Table 5-1. Five categories with the exemplars that drivers might have when they are reading that category of signs. Tabulated by the author.

Sign categories	Sign functions	Exemplars
Map-like sign	To inform (or forewarn) about the geometric layout of the intersection, the route number or the name of roads, the cardinal and geographical direction, and the distance of the intersection (rare) ahead.	Direction Distance Location Additional information
Stack-like sign	To inform the direction or distance of the road and the cardinal direction (rare) ahead.	Direction Distance
One-direction sign	To indicate only one direction ahead To indicate the distance to that one direction (rare).	Direction Distance
Multiple column sign	To inform the direction of the roads ahead.	Direction
Locational sign	To inform the current location and indicate cardinal direction (rare).	Location

The analysis of exemplars is through the consideration of sets of signs which should be applicable across a range of sign categories. In Chapter 3, five broad sign categories of photographed samples were identified based on sign layout. The exemplars were considered within the five categories. Table 5-1 links the categories with the exemplars that drivers might have when they are reading that category of sign based on the sign functions. It also shows that the four captured exemplars can cover the most common ways that drivers may use the signs within the categories. Then, the main sign elements that might support drivers to complete the exemplars are extracted and summarised in Table 5-2.

Table 5-2. *Main sign elements that might support drivers to complete the exemplars. Tabulated by the author.*

Direction Exemplar	**Am I going in the right direction or what direction should I take?**
Involved elements	*The bilingual legends* and the symbol used to indicate location names and directions are two important elements of a sign to assist a driver to complete this exemplar.
Location Exemplar	**Did I arrive?**
Involved elements	Drivers need a place name to confirm their location. Thus, *the bilingual legends* help a driver to find out where he/she is.
Distance Exemplar	**How far do I need to go?**
Involved elements	Location names and kilometers are needed and thus *the bilingual legends* and the numeral (ends with the Latin scripts KM) are involved to complete this exemplar.
Additional Information Exemplar	
	As photographed samples show, regulatory information is one of the most common additional information on a sign within the categories. More commonly, however, additional information is a separate sign placed next to the main sign (Fig. 5-2).

Figure 5-2. *A 'no left turn' regulatory sign is displayed as a separate sign next to a map-like sign. Photographed by the author in Dalian, 2018.*

As shown in Table 5-2, bilingual legends contain essential information which is included in all captured exemplars, except the additional information exemplar. The bilingual legend on CEBTS combines a Chinese location name with an English translation which forms a bilingual legend to assist all three groups of drivers (Chinese drivers, bilingual drivers, and foreign drivers). The bilingual legends are likely to be the main source of information affecting drivers when performing the exemplars. Although the numeral (e.g., distance information), arrow (e.g., direction information), and regulatory symbols are also important information, they are pictorial and multilingual themselves and thus can be deciphered by all groups of drivers (Gibson, 2009).

The sign layout (Section 2.3) that relates to arranging bilingual legends and other pictorial elements into specific formats might also be an important factor in completing the exemplars. Additionally, there may be an interaction effect between the design of bilingual legends and sign layout on sign legibility. However, the sign layout and the interaction effect are beyond the concerns of the empirical studies, because of the limited research time. In addition, too many variables could bring difficulties in designing experiments and data analysis. It is reasonable to confirm the spatial arrangement within the bilingual legend(s) and then to consider sign layout and their interaction effect. Thus, the sign layout of the stimuli will be controlled and be kept consistent throughout the empirical studies (Chapter 6) in order to identify clear effects for spatial arrangement within the legend(s).

5.2/ Define empirical variables

The above section has established that the extrinsic attributes of bilingual legends are the primary concerns and are identified as the variables for the empirical studies. The extrinsic attributes of legends include text spacing, text length, and text alignment. However, these attributes (or terms) need to be redefined and refined for the purpose of the experiments. That is because, firstly, these attributes (or terms) may be defined differently in Chinese and English contexts, which may lead to misunderstandings for readers with different language backgrounds. Secondly, since the extrinsic attributes are considered for bilingual legends, new terms may arise and need to be defined. Finally, as the review of the Chinese Standards in Chapter 3 revealed, the relative guidelines and terminology are ambiguous and thus may not be able to be used directly. Therefore, this section clarifies and defines the extrinsic attributes for the next experimental stage.

5.2.1/ Connecting spacing & separating spacing

Text spacing, in the field of typography, includes letter spacing, word spacing, and line spacing (Barker & Fraser, 2004). In both Chinese and English contexts, there is ample research to support decisions about text spacing, however, less clarity in current guidance or research to support how to space two lines of text in different scripts.

In Latin typography, the term line spacing, or leading, is used to describe the spacing of two lines of Latin text. Specifically, it is the vertical distance between baselines of two lines of type (Highsmith, 2012). In Chinese typography, the line spacing refers to the vertical distance from the bottom line of characters to the next bottom line (baike.baidu.com/item/行距, accessed December 2020). In turn, the line spacing can also be measured by the top line of two lines of Chinese texts, while both the bottom and top line are relative to the body frame of Chinese characters, i.e., referring to the box that contains each character and a small amount of space around the character for attaching to the adjacent character, rather than the surface frame (see differences between the body frame and the surface frame in Chapter 3, p. 43). Figure 5-3 illustrates the line spacing in both English and Chinese contexts.

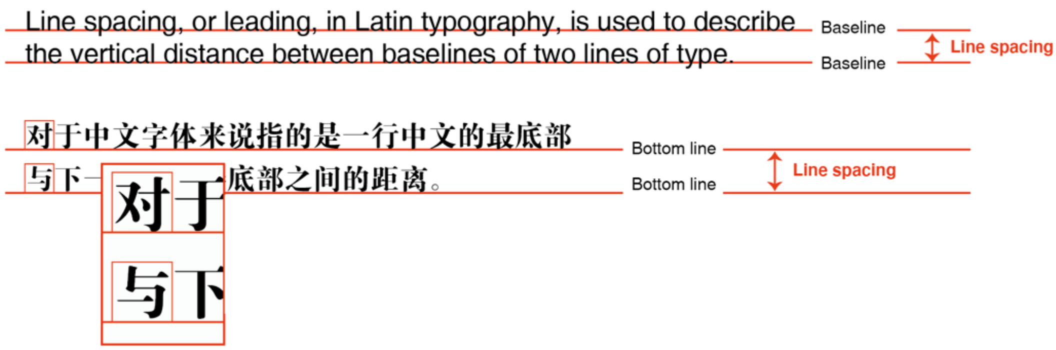


***Figure 5-3**. The line spacing in both English and Chinese context. In a Chinese context, the bottom line is relative to the body frame. Drawn by the author.*

When Chinese and English are combined into two lines of bilingual text, an issue of defining the line spacing arises. On CEBTS, as a single sign can display one or multiple bilingual location name(s) when arranged vertically, line spacing can have two different meanings. One is the vertical spacing between the two languages that is used to *connect* the Chinese location name to its corresponding English translation in order to form a bilingual location name. The other one is the vertical distance that *separates* different bilingual location names. The importance of these connecting and separating design principles can be explained by Gestalt psychology which is an important conceptual tool in information design (Frascara, 2015). Gestalt psychology is based on the way the brain perceives and arranges objects (Coates, 2014). One of the well-known principles of Gestalt psychology is proximity, that is, how 'we perceive objects that are close together as belonging to the same group' (Golombisky & Hagen, 2013, p. 58). The proximity brings together objects that are closer to one another than from others, and it also separates objects that are far apart and seem unrelated. This is a fundamental principle for line spacing. In a context where Chinese and English are placed vertically, the distance between the two lines determines the limits of a bilingual unit, and it also separates one bilingual unit from the other. This research is driven by determining the appropriate vertical distance that the participants tend to connect a bilingual legend and to separate bilingual legends on a sign.

Accordingly, the terms *connecting spacing* and *separating spacing* are adopted to refer to the two meanings respectively. The term line spacing is avoided to prevent potential ambiguity and misunderstanding. To specify connecting spacing and separating spacing, some principal line terms in typography are utilised. As Figure 5-4 illustrates, connecting spacing is the distance from the *bottom line* of the Chinese location name to the *x-height line* of the English location name. As the dominant Chinese location name is always set above its English translation on CEBTS, the bottom line of Chinese characters, rather than the top line, is used in describing the connecting spacing. *x-height*, in Latin typography, refers to the height of the lowercase x in a given typeface and it provides a way of describing the general proportions of any typeface. Because proportions vary from typeface to typeface, the x-height line is used to specify the connecting spacing rather than using the baseline. For the same reason, the separating spacing is specified as the distance from the *baseline*, rather than the x-height line, of the above English location name to the *top line* of the below Chinese location name.

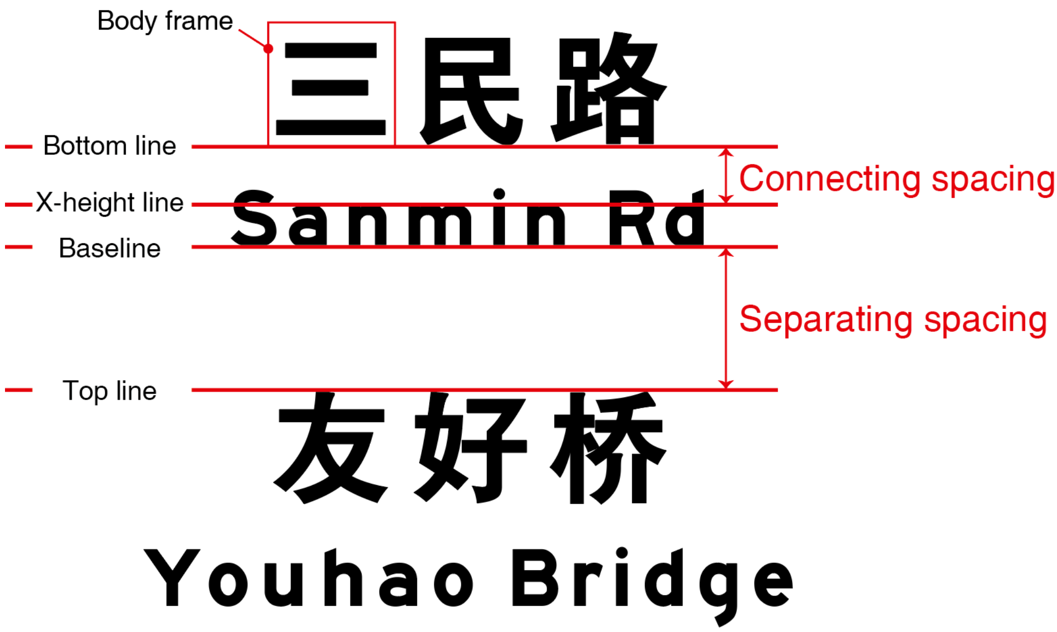


***Figure 5-4**. Connecting spacing between Chinese and English text and separating spacing of two bilingual place names. Connecting spacing is 'line spacing' between the two languages and separating spacing is 'line spacing' that separates two different place names. Drawn by the author.*

5.2.2/ Line length

In both Chinese and Latin typography, line length refers to the width of a line of type. In a sign program, the line length refers to the width of a location name. Generally, a location name is composed of a few words which combine the very short width of a line. Many studies have investigated the influence of line length on legibility (normally for continued reading composed of long sentences) (Chan et al., 2014; Highsmith, 2012; Luna, 2018), it appears that relatively few studies have evaluated if changing the width of a very short line has an impact on legibility. While the fact is that real world signs present different location names that are various in line length. It is important to account for location names of different lengths and build them into the experiments, so that the materials can be reasonably representative of real signs and have ecological validity. Accordingly, in the experimental stage, various lengths of bilingual location names are tested to find out if they affect sign legibility. In addition, line length is tested to consider if it has an interaction effect with connecting and separating spacing on sign legibility.

5.2.3/ Text alignment

Location names are often vertically placed on a sign (Fig. 5-5). Therefore, the term text alignment in the experiments only refers to vertical alignment where bilingual texts are lined up with Chinese above English. It is possible that the bilingual location names may be placed on the same line, but it is beyond the consideration of this research because this only happens occasionally.

Figure 5-5*. Bilingual road signs with location names placed vertically. Photographed by the author in Wuxi, 2018.*

For two lines of monolingual location names, left and central are the two basic alignments used on alphabet signage (Barker & Fraser, 2004). These two alignments are also suggested when arranging the bilingual location names on CEBTS in the reviewed Chinese traffic sign Standards. Since it is possible and often the case that more than one bilingual location name is present on a single sign, the alignment of bilingual location names on a CEBTS in the following discussions includes two aspects of meanings: 1). the way that English translation is aligned to the Chinese text of a bilingual location name, and 2). the way the bilingual location names are aligned to each other.

In summary, connecting spacing, separating spacing, line length, and text alignment are extrinsic attributes that are examined in the experimental stage.

5.3/ Ways to measure sign legibility

The above sections have confirmed and defined the primary variables for the experimental stage. In this section, various ways to measure traffic sign legibility are reviewed to inform the methodology used in the experiments.

5.3.1/ Categories of operational methods in legibility research

An operational definition describes what is measured in the study. The variety of operational definitions of legibility describe the methods, techniques or procedures used for measuring legibility. An overview of the wide variety of operational methods applied to legibility research in the 1970s can be found in Foster (1980) and Zachrisson (1965) and described in more detail whilst discussing the relationship between the methods in Salcedo et al. (1972).

Lund (1999) provides a useful way to classify operational methods applied to legibility research. He believes that most methods are experimental performance studies that can be categorised according to reading materials that observers are engaged in. Regarding continuous text, measuring the speed of reading (by accounting for time or amount of reading) is often employed combined with comprehension tests. Eye movement is an approach based on several automatic unconscious eye movements during reading (saccades, fixations, regressions, and return sweeps) to indicate the legibility of the reading material. Useful overviews and discussions on eye movement studies can be found in Venezky (1984), in Tinker (1963) and in Morrison and Inhoff (1981). Another operational method for a continuous text is blink rate to measure fatigue. Regarding non-continuous text and typographic extrinsic attributes, the search task measuring legibility by counting the time that it takes to search for the target is often applied (Chan et al., 2014; Gould & Grischkowsky, 1986). Concerning individual letters or symbols, time-threshold and distance-threshold are the most frequently used methods employed by researchers (Section 5.3.2). By the time-threshold method, participants are asked to identify the test material that is exposed to them for a limited period, and the time taken for identification is recorded. By the distance-threshold method, it starts with the test material that is too far away to identify and is then moved closer until the participant can identify the material.

Dyson (2019) provides another way to categorise operational methods. The category is based on what behaviour or physical responses are measured. The threshold method (including both time-threshold and distance-threshold) is one of the techniques to measure behaviour. It measures the first point at which the observer can detect and identify the letter or word. Speed and accuracy measures, sometimes combined with recall or comprehension tasks, are other techniques to gauge behaviour. However, eye movements and blink rate belong to physiological measures.

5.3.2/ Threshold method

Although Lund and Dyson use slightly different ways to categorise operational methods, both agree that the threshold method, especially distance-threshold, is appropriate for testing sign legibility among operational methods.

> 'Variable distance … has found application primarily in investigation into the legibility of individual letters and symbols, and more obviously, road signs. The method is certainly applicable for display purpose situations, such as road signs and instrument panels.' (Lund, 1999, p. 29)

> 'A more general method of measuring distance thresholds, which is still in use, is simply to find out how far away something can still be recognised by staring at a great distance and gradually moving the material closer to the participant … The method is appropriate for testing signs or other material that would normally be read at a distance but is also applied in other contexts.' (Dyson, 2019, p. 46)

Many published studies are assessed by the threshold method on the measurement of traffic sign legibility, which suggests the practical and effectiveness of this method. In addition, most of these studies combine the threshold method with other operational methods, e.g., the speed and accuracy method and the search task method.

Gálvez et al. (2016) apply a distance-threshold method in conjunction with speed and accuracy methods to investigate if the new highway typeface (*RutaCL*) outperforms the previous one (*MOP*). The participant moves at an established speed towards a traffic sign. The time that is taken to read the sign is recorded, as well as the accuracy of the responses. Dobres et al. (2017) also compare the legibility difference between the two signage typefaces (*Highway Gothic* and *Clearview*) but use a time-threshold combined with accurate measurement. The stimulus duration is adjusted according to the response accuracy of the participant. They determine which typeface is more legible by the legibility thresholds (more legible typeface has a lower legibility threshold that requires less time to read at the targeted accuracy level). Tejero et al. (2018) apply a distance-threshold together with a search task and the accuracy check to determine whether increasing the letter spacing can benefit drivers reading traffic signs. In their study, the place names on traffic signs are gradually enlarged until the participant is able to identify them. Additionally, the participants are asked to search for a target place name and their response accuracy is analysed as a criterion for legibility.[20]

5.3.3/ Other methods

As introduced in Section 5.3.1, testing eye movement is an approach used for measuring legibility. Research into eye movements while participants are driving on actual roads was conducted by Shinar et al. (1980) and Zwahlen (1981) to evaluate traffic sign legibility. The manual video-tape transcription method (Lansdown, 1996) and fully computerised data analysis are technologies for processing eye movements. However, this method is not always useful due to drivers using peripheral vision to obtain information. Additionally, the eye movement method is an expensive process because of the expenditure of labour costs for video-tape transcription (Lansdown, 2004).

Another method used specifically for measuring the legibility of traffic signs is called verbal protocols (Bainbridge, 1979), or naming method (Summala & Naatanen, 1974); researchers sit in the vehicle with the driver who is asked to name (out loud) traffic signs on a moment-to-moment basis. However, this method suffers from low ecological validity as generally drivers do not name every sign they see whilst driving (Castro, Horberry, & Tornay, 2004).

The accident rate is another way to assess traffic sign legibility. '… it is sometimes possible (for instance, at accident black spots) to install new signs and measure their effects on accident rates. By comparing these data with before-accident rate, it is possible to assess the effectiveness of the sign' (Castro et al., 2004, p. 53). However, this method is time-consuming for collecting data which is inappropriate for limited-time studies.

Subjective preference studies are a non-experimental method of asking readers for opinions. The ways of collecting subjective judgements include asking participants to rank or rate materials or making comparisons of pairs.[21] However, subjective opinion alone cannot determine the sign legibility.

5.4/ Identify an empirical methodology

The above reviewed ways of measuring sign legibility inform the methodology applied to the empirical studies in this research. The empirical studies intend to examine the effects of the identified variables on CEBTS legibility.

A threshold method measures the first point at which an observer can detect and identify a target. It has been named in many studies and it is a practical and effective method for testing sign legibility among operational methods. And so, a threshold method is selected as the primary method applied to the following empirical studies. Additionally, a search

[20] Extensive studies using a threshold measure, and a threshold measure combined with other methods are available elsewhere (Berger, 1956; Cole, 1982; Garvey et al., 2001).

[21] See Dyson, 2019, p. 53 for an extensive reading on subjective preference studies.

task is designed to ask participants to search for a bilingual place name among a set of names, which intends to simulate the activity that drivers looking for a destination on a sign encountered along the route. Apart from the time participants take to look up at a target, the response accuracy is checked as a supplementary parameter to look at their performance. It is because measures that integrate response time and accuracy are useful when speed and accuracy rely on common processes and when the effects of speed and error rate show differences in the same direction (Bruyer & Brysbaert, 2011; Draheim, Hicks, & Engle, 2016). In the empirical studies of this research, when the response time process is increased, by instructions (Chapter 6, in Study A), or the presence of a response deadline (Chapter 6, in Study B and C), responding becomes more error prone (Vandierendonck, 2017). In such a situation, the tested variations (connecting/separating spacing, line length, and text alignment) may have different effects on response speed and accuracy. Therefore, it is important to measure accuracy alongside speed in order to be able to identify whether the slow (or fast) response time is the result of an attempt to be precise (or compromising accuracy). Furthermore, obtaining information from road signs in a timely and accurate manner are both critical while driving; it is important to look at both, in order to provide a better summary of findings that is speed-accuracy balanced.

In summary, a threshold method combined with a search task and the accuracy check is identified as the method to be applied in the empirical studies. The full discussion of how this method is applied to the empirical studies is explained in the next chapter.

6/ Experiments

This chapter presents three empirical studies designed to test whether and how the identified variables (Section 5.1, 5.2), **connecting spacing**, **separating spacing**, and **text alignment**, affect CEBTS legibility. The findings of the three empirical studies suggest that the spatial arrangement of the two languages/scripts is a significant consideration for CEBTS legibility. To improve legibility, the connecting/separating spacing can be utilised to group/distinguish dual-script information, and the text alignment should be according to sign complexity.

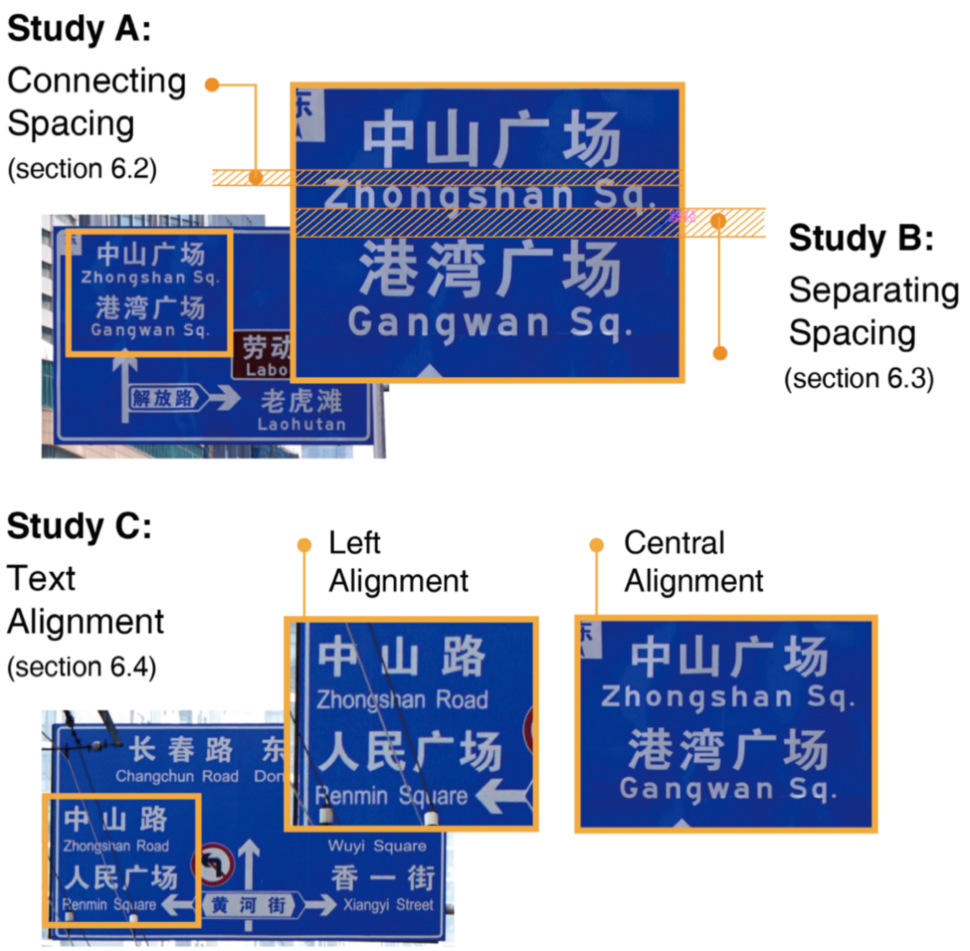


__Figure 6-1__. The main tested variables in each study and illustrated on the photographed sign samples. Illustrated by the author and the samples were photographed by the author, Dalian, 2018.

The first study (Study A) investigates if adjustments to connecting spacing, the vertical spacing that *connects* the Chinese location name and its English translation within a bilingual location name, affect CEBTS legibility. The second study (Study B) examines whether separating spacing, the vertical spacing used to *separate* bilingual place names, has an impact on CEBTS legibility. The final study (Study C) intends to evaluate whether the two alignments of the bilingual location names that are suggested in the Standards, central- or left-aligned, influence CEBTS legibility and whether their effects are different. Figure 6-1 illustrates the main variables investigated in each study.

The three studies utilise the same methodology but incorporate different subject samples and stimulus materials. Section 6.1 introduces the methodology applied to all studies, and the three empirical studies are described in detail in Sections 6.2 to 6.4. Section 6.5 concludes the findings.

6.1/ Study design

According to the review of current research and operational methods used for measuring sign legibility in Section 5.3, a threshold method combined with a search task and accuracy check is found practical and effective in sign legibility measurement and thus, is applied to all three studies. This section presents participant recruitment, how the identified method is applied to the studies, the design of materials, and the setup of equipment.

6.1.1/ Participant recruitment

Participation was voluntary. All three studies (including the pilots built into Study A and B) were conducted in compliance with the University's research ethics procedures and all participants gave their consent. In all three studies, the participants were students and staff recruited from the University of Reading and met the following screening requirements:

a. Have normal or corrected vision, because eyesight has a significant impact on participant reading performance (Section 1.2.1).

b. Do not read Chinese and use English as the first or second language.
As mentioned in Chapter 5, the users of CEBTS vary by language ability and they can be divided into three groups: Chinese drivers, bilingual drivers, and drivers without Chinese reading ability. In the presented studies, only participants who cannot read Chinese and only rely on the English information took part. That is because, on CEBTS, the very different appearances of the two languages, as well as the much larger type size of the Chinese text, aid Chinese and bilingual drivers to locate the Chinese information faster (Eid, 2009; Yang et al., 2020). This meant that the findings could be influenced by participants' language ability. Therefore, this screening question was used to prevent this potential effect.

In addition, driving experience and age factor also have an impact on reading road signs (Cantin et al., 2009; Kline & Fuchs, 1993; Ng & Chan, 2008), therefore, in Study A, the participants were asked to indicate their age range and if they have driving experience. These data are collected (age groups, driver, or non-driver) but some of them were not used as the main variables, because the low number of participants for some of these criteria meant that the findings might not be generalisable. The point was to see if these data could be influential factors. In contrast, in Study B and C, additional screening criteria were introduced to the recruitment to minimise the influence of these potential confounds on the results (Section 6.3.2).

6.1.2/ Method

In the three studies, participants are shown a series of video clips. All video clips are 3D graphics rendered and displayed on a monitor. The stimuli simulate the view a driver would have on a road in which they are driving towards a road sign (with bilingual legends and arrows indicating directions) at a consistent speed. Thus, the signs will appear gradually enlarged on the display until the participants are able to identify them and enter a response.

A threshold method measures the first point at which an observer can detect and identify a target (Dyson, 2019). Accordingly, participants are asked to identify what direction they might take by viewing a series of video stimuli and making an immediate response when they have identified each target. The time they take to look up a target together with the accuracy of the response are analysed as an indication of the relative legibility of the different conditions.

Figure 6-2 extracts the main aspects of each study, including the independent and dependent variables, demographic data, and the used experimental method.

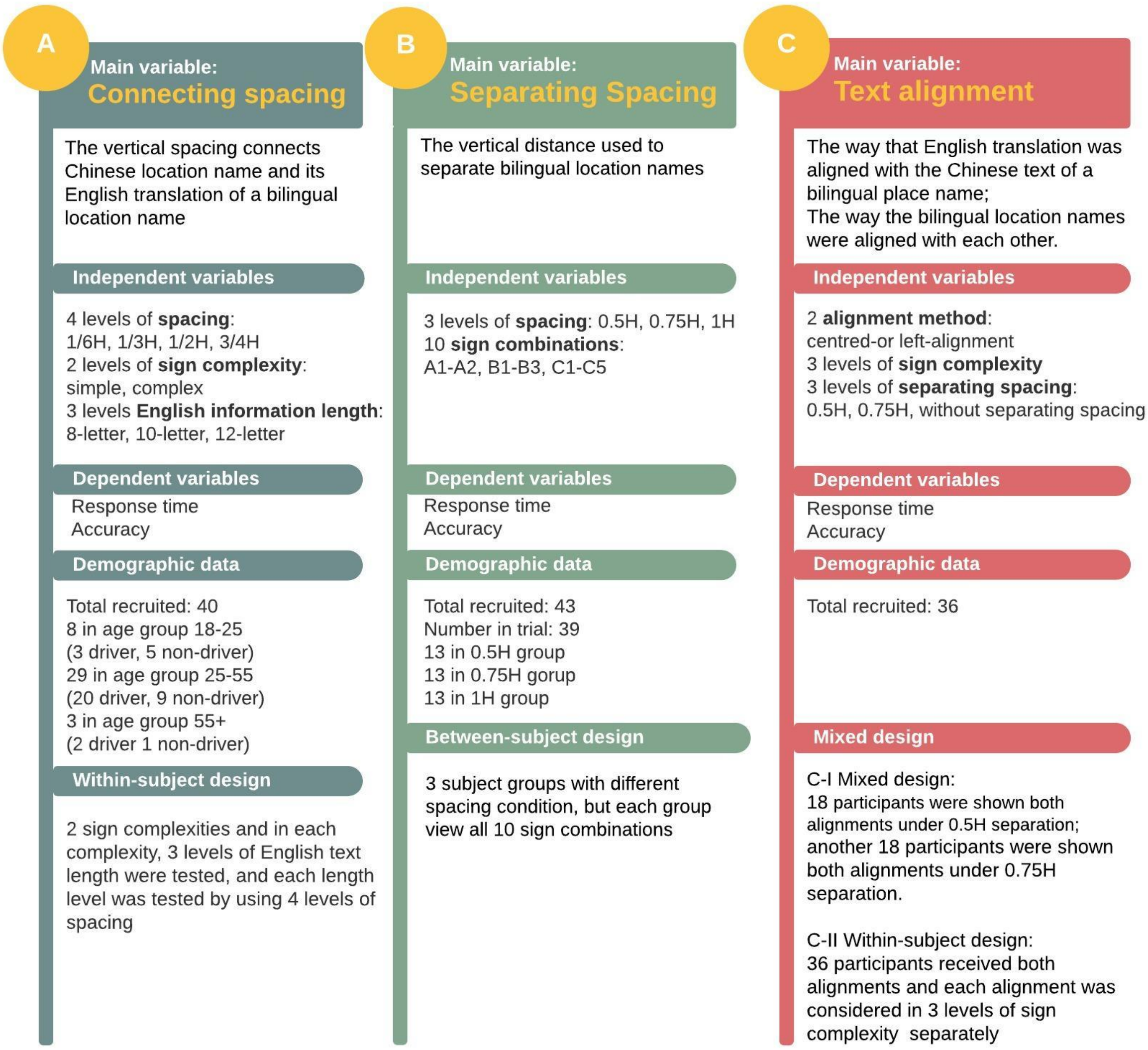


Figure 6-2. Relationship among studies and the main aspects of each study including the tested variables, used experimental method, and demographic data. Illustrated by the author.

In the three studies, the participants are cued by the researcher when the task is ready. The importance of how quickly to respond is emphasised by the researcher to the participants before the study. This emphasis aims to prevent participants from prioritising the accuracy rather than the speed since the response time is the crucial indicator to look at sign legibility in a threshold method. Using the display described in Section 6.1.4, participants are shown several short video clips. For each one, they are asked to answer a question in the form of 'what direction should be taken to destination xxx?'. The participants are asked to read out the question, aimed to help them to carefully read the destination and reduce the temptation to skim through the words. After that, a computer keyboard (specifically using the SPACE key) allows the participant to self-pace when they are ready to engage with watching the clip. The participants need to find the answer by reading the sign they see in the video. When the participants have identified the direction, they are able to make their response by pressing the directions on the keyboard, which also stops the video and causes the screen to go to the feedback screen. The feedback screen indicates the speed and accuracy of the response as an incentive for participants to do the next task. The participants repeat the same procedure until all stimuli have been displayed.

Before Studies A and B, a small pilot test was conducted to identify and adjust for any problems with the main studies. Study A pilot recruited six participants and took ten minutes per participant. Six participants viewed clips that covered all the stimuli (24 clips in total). In Study B, the pilot session recruited six participants, each receiving trials that covered all combinations and levels of separating spacing (ten in total). Each participant took around five minutes to complete the pilot. The findings of the pilot for Study A informed the decisions made for equipment setting that are discussed in Section 6.1.4.

In addition, in Study A, the participants were not given the emphasis of responding as fast as possible prior the study and they were not shown a feedback screen at the end of each video clip. These elements were introduced to Studies B and C to improve the research design, following evaluation of potential limitations of Study A (Section 6.2.5).

The intention of Study B pilot is informed by the limitations of Study A. To prevent participants from trying to respond more slowly because they are trying to be accurate, or vice versa, the duration of clips should be limited. Thus, Study B pilot is mainly used to confirm the exposure duration. Based on the average response time of six participants to the ten combination trials, each clip is displayed in the main study for up to seven seconds with presentation terminating before the full seven seconds, once the participant responded. To facilitate comparison across studies, these adjustments made in Studies A and B are maintained in Study C.

6.1.3/ Materials

It is important to ensure the materials have ecological validity. Therefore, to make the video clips as realistic as possible, all video stimuli are developed to realistically simulate the actual driving experiences in China. In each clip, the car is driven on the right side of the road, having the steering wheel on the left side that is parallel with the right-hand traffic in China. The lane width is 3.5m and the posted speed limit is 40 km/h that is in line with the rules of road in China. The height of the visual horizon in the clips is set to 1.2 meters above the lane based on the actual average height of a person sitting in a car (Capaldo, 2012). The location, size, height, and construction of CEBTS shown in the clips, follow the Standards (as informed by the Chapter 3 review of Chinese traffic sign Standards). Two versions of video clips are developed for testing to match the two most common sign-mounting methods in China, overhead signs and shoulder-mounted signs (informed by the analysis of the real sign samples in Chapter 3) (Fig. 6-3).

Figure 6-3. *Screenshots of video clip developed for overhead sign (top) and shoulder-mounted sign (bottom). The clips were developed for Study A by the author and two collaborators: Zhiqiang Bian and Qingquan Guan.*

Additionally, the CEBTS showed in all video stimuli are designed in accordance with the related regulations (General Administration of Quality Supervision et al., 2009; Ministry of Housing and Urban-Rural Development of the PRC, 2015) to match the road signs that users would be reading in China. It covers typeface and size specifications, graphic elements guidance such as arrows and borders, as well as the spatial value such as the distance between text and pictorial elements used on the CEBTS.

In addition to ensuring the materials have ecological validity, it is important that the materials can be sufficiently controlled so that all tested variants can be compared under equivalent conditions. Accordingly, all video clips are 3D graphics rendered in Lumion and the CEBTS shown in the clips are drawn in Adobe Illustrator 2019, rather than using real signs and actual driving videos.

The above settings prevent easy guessing and minimise any effects caused by familiarity. The bilingual information shown on CEBTS is carefully designed to exclude the place names that are commonly used in practice (Appendix III). That is because many studies suggest that familiarity assists in reading signs (Lay, 2004a; Sanocki, 1992; Zineddin et al., 2003). And so, the Chinese place names are formed with characters that are randomly combined, and they have no semantic meaning. The characters are selected from the *Basic Vocabulary Table of Modern Chinese Characters* and are within the high-frequency category of usage (The State Language Commission, 1989). All English location names are translations of the Chinese ones based on the relevant translation rules (*Standardization administration of China & Inspection and Quarantine of the People's Republic of China*, 2017) (Appendix III). In Studies A and B, the way that bilingual texts should be aligned has not yet been tested. Typically, according to the signs observed in Chapter 3, alignment is central, though this may not be optimal for legibility, therefore, all the bilingual information used in these two studies is centrally aligned on CEBTS. The text alignment is the variable explored in Study C.

Furthermore, there are no passing vehicles, lane changes and slowdowns in the video clips, so as not to distract participants from reading the sign. All contextual parameters are kept consistent.

6.1.4/ Equipment and site

A 75 inch monitor at a resolution of 1280×1024 pixels was used to display video clips. A personal laptop ran E-Prime 2.0 software that controlled the timing, presented the stimuli, and recorded the data on a spreadsheet.

The findings of the pilot for Study A informed the decisions made for the equipment settings. Some adjustments were made after the pilot of Study A that were based on asking participants' feelings and suggestions after they engaged in the pilot. Based on their composite opinions, the changes made are listed below:

1. Instrumentation. Before showing the clips, an instrument slide (written in black text on a white background) was displayed to inform the participants of what they would be shown in the test and how they could participate. According to the suggestions from the

pilot participants, the instrument type size was increased to ensure participants can see clearly from a distance.
2. Keyboard. Changed the position of the arrows on the keyboard from the right bottom to the centre of the keyboard.
3. Viewing distance. Participants were seated 1.6m away from the monitor and it was indicated by most participants as a comfortable distance.
4. Height of the monitor. The monitor was set 1m above the floor and most participants felt comfortable at this height.

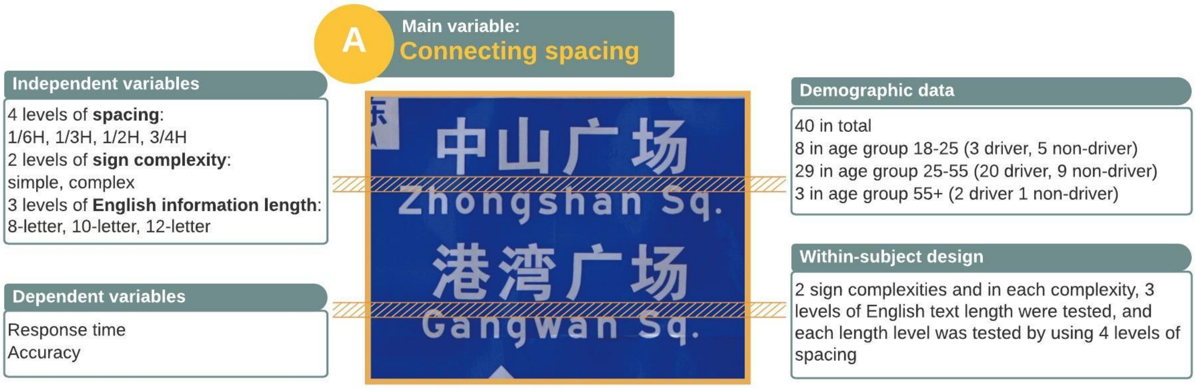
In line with the adjustments made after Study A pilot, during the main studies the participants sat behind a 0.8m high table which was 1.6m away from the monitor. An adjustable chair was provided for the participants' comfort throughout the test. A computer keyboard, adjusted to provide directional arrows for participants to respond, was provided on the table. Figure 6-4 shows a participant doing the study, using the equipment involved in the experiment.

Figure 6-4. *A Participant doing Study A. Photographed by the author in 2019.*

It was not feasible to use the same room for all three experiments, but it was possible to keep the room consistent within each study. The studies were designed in a way to make sure that the viewing height and the distance from the monitor were consistent regardless of which site was used. Therefore, all participants within one study used the same room, though rooms are changed between studies, the viewing height and the distance from the materials are controlled.

Study C took place during a restricted period of movement due to COVID-19, thus COVID protocols were observed during the study. The safety issues for participants and researchers were observed. All items that the participants would touch during the task (including desk, chair, pen, consent form and keyboard) were sterilised before each participant became involved in it. Each participant and the researcher were required to wear a mask throughout the whole test. Hand sanitiser was provided for each participant to use before and after their task. The door of the room was kept open throughout the whole study to maintain the air flow (although it had been kept closed in studies A and B to avoid possible interruptions or distractions).

6.2/ Study A: connecting spacing



Study A, as the above Figure illustrates, is designed to test if adjustments to connecting spacing, the vertical spacing used to connect a Chinese location name and its English translation within a bilingual legend, affect sign legibility. It also looks at sign complexity and length of English information to investigate the effects of the connecting spacing according to these two factors.

6.2.1/ Defining test variables

6.2.1.1/ Four levels of connecting spacing

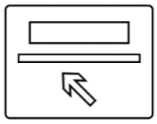
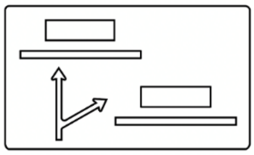
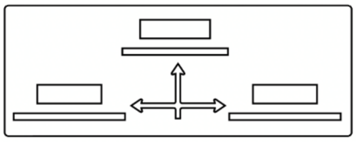
As discussed in the preceding chapters, the definition of 'line spacing' is inexplicit in the reviewed Standards, which causes difficulties in determining the levels of connecting spacing to be tested based on the relevant Standard guidance. Accordingly, the appropriate levels of connecting spacing are identified by looking at the photographed CEBTS samples. Three levels, the closest (1/6H), medium (1/2H) and the widest space (3/4H) are frequently used in the samples. 1/3H is the recommended 'line spacing' in the reviewed Standards (see Chapter 3, though the concept of this line spacing is ambiguous), and thus is added as an additional connecting spacing level which may establish a metric for this study. In total, there are four levels of connecting spacing evaluated in Study A.

6.2.1.2/ Two levels of sign complexity

It is important to consider the complexity of signs to ensure the findings have good application to a range of signs in practice. In addition, it is also valuable to examine whether any effects of the connecting spacing may change along with the sign complexity. Sign complexity here refers to the sign's graphic and informational complexity (whereas the amount and variation in information is what leads to graphic content). In terms of the five categories summarised in Chapter 3 (Fig. 3-11 and Table 3-5), they can be grouped simply into three levels: simple (one-direction and locational signs), medium (stack-like and multiple column signs), and complex signs (map-like signs).

However, the medium complexity is treated as an exception in the three studies, and only simple and complex signs are focused on. That is because both stack-like and multiple column signs have special layout features, e.g., including horizontal dividers, which may have an interaction influence with the test variables. In addition, considering the use frequency of these two categories is low in practice (as the observation of the collected sign samples in Chapter 3), these two sign categories are excluded for analysis. Locational signs are also beyond consideration because they cannot indicate directions and, during the experiments, participants need to identify directions to respond.

Table 6-1. *Two levels of sign complexity. The simple sign indicates one direction; the complex signs indicate two and three directions. Tabulated by the author.*

Simple: **One-direction sign**	one direction		
Complex: **Map-like sign**	two directions		
	three directions		

In summary, two levels of sign complexity, simple (except locational signs) and complex, are tested at the stage of Study A. Based on the collected sign samples, the two complexities can be presented in terms of the numbers of the directions, which are shown in Table 6-1. The two levels can cover a range of signs within one-direction and map-like sign categories.

6.2.1.3/ Length of English information

As discussed in Section 5.2.2, to represent the fact that location names in the real world vary in length, in Study A, the English location names on the stimuli are set into three levels: 8 letters, 10 letters, and 12 letters. It also aims to identify if there is an interaction between the connecting spacing and the length of English information on CEBTS.

In summary, a within-subject design is used. Study A is evaluated under two sign complexities (simple and complex). In each complexity, three levels (8 letters, 10 letters, and 12 letters) of English text length are tested, and each length level is tested by using four levels of connecting spacing (1/6H, 1/3H, 1/2H, and 3/4H). In total, there are 24 (2×3×4) combinations and each combination is presented four times in a different random order for each participant, resulting in a total of 96 stimuli to be presented to each participant.

6.2.2/ Demographic data

The main session, in total, recruited 40 participants and took around 40 minutes per participant, including short breaks in the session (the pilot session recruited six participants, and each took 10 minutes to complete the task). In the main study, each participant first completed a practice consisting of five trials, followed by a series of 96 experimental trials presented in random order. The practice trials were necessary to help participants become familiar with the equipment and procedure so that (a) they felt comfortable and could raise any queries if they needed to and (b) to ensure that the data for the first few stimuli shown was not affected by a lack of familiarity. The number of participants recruited for each age group and its distribution between the participants with and without driving experience is listed in Table 6-2.

Table 6-2. *The number of participants recruited for each age and the distribution of the drivers and non-drivers.*

18-25 years old		**25-55 years old**		**Above 55 years old**	
Driver	Non-driver	Driver	Non-driver	Driver	Non-driver
3	5	20	9	2	1

6.2.3/ Result

6.2.3.1/ General overview of results

In this section, the overall findings and the comparison among the three age groups are provided. In addition, the analysis considers drivers and non-drivers separately because driving status may have an impact on performance (Section 1.2.3). The detailed statistical analysis to support the findings here is provided in Appendix II. However, the data of those individuals that are in the group of 25-55 years old is selected for analysis in depth in Section 6.2.3.2. This is because a larger number of participants were recruited in this group compared with the number of participants in the younger and older age groups, which is not sufficient to make generalisable claims.

Table 6-3. *Mean response times (in seconds) of 40 participants across different levels of sign complexity, length of English information, and connecting spacing.*

DRIVER												
	8-letter				**10-letter**				**12-letter**			
	18-25	**25-55**	**55+**	**All ages**	**18-25**	**25-55**	**55+**	**All ages**	**18-25**	**25-55**	**55+**	**All ages**
Simple sign												
1/6H	3.305	3.824	4.832	3.842	2.152	3.352	4.222	3.260	2.823	3.917	4.605	3.841
1/3H	2.874	4.372	4.754	4.222	2.095	3.133	3.683	3.052	2.610	3.723	4.679	3.666
1/2H	3.030	3.773	4.361	3.371	2.040	3.118	3.084	2.986	2.328	3.410	4.056	3.332
3/4H	2.773	3.809	3.952	3.696	2.249	3.150	3.684	3.084	2.077	3.104	3.549	3.016
All space	2.996	3.944	4.475		2.134	3.188	3.668		2.460	3.539	4.222	
Complex sign												
1/6H	3.267	4.764	6.122	4.693	2.891	3.743	4.983	3.740	2.861	3.549	4.116	3.512
1/3H	2.931	3.695	4.158	3.640	2.699	2.919	4.002	2.980	3.485	4.814	5.248	4.689
1/2H	3.237	3.778	4.061	3.735	2.246	3.099	3.372	3.019	2.050	2.700	3.522	2.688
3/4H	2.387	3.482	4.208	3.365	2.249	3.966	4.392	3.794	2.459	2.727	3.590	2.764
All space	2.956	3.930	4.637		2.521	3.432	4.187		2.714	3.448	4.119	

NON-DRIVER												
	8-letter				**10-letter**				**12-letter**			
	18-25	**25-55**	**55+**	**All ages**	**18-25**	**25-55**	**55+**	**All ages**	**18-25**	**25-55**	**55+**	**All ages**
Simple sign												
1/6H	3.841	4.431	5.106	4.279	3.057	3.565	4.447	3.454	3.791	4.307	6.166	4.259
1/3H	3.814	4.874	4.714	4.510	2.978	3.841	4.189	3.576	3.525	4.447	4.791	4.163
1/2H	3.807	4.204	5.490	4.157	2.807	3.586	4.489	3.386	3.025	3.935	5.340	3.725
3/4H	3.499	4.204	5.114	4.029	2.912	4.047	4.332	3.688	3.077	3.750	3.881	3.534
All space	3.740	4.428	5.106		2.939	3.760	4.346		3.355	4.110	5.045	
Complex sign												
1/6H	4.356	5.018	5.947	4.859	3.570	4.423	3.647	4.087	3.817	4.565	4.342	4.301
1/3H	3.833	4.130	4.931	4.084	3.073	3.944	3.563	3.628	4.328	5.090	6.036	4.899
1/2H	3.357	4.264	5.196	4.024	3.069	3.869	5.423	3.759	2.800	3.644	4.222	3.401
3/4H	3.213	4.095	5.508	3.895	3.871	4.424	5.584	4.317	2.945	3.675	4.118	3.461
All space	3.690	4.377	5.396		3.396	4.165	4.554		3.473	4.244	4.680	

Table 6-3 lists the mean response times of 40 participants across different levels of sign complexity, length of English information, and connecting spacing. This table also shows the mean response times of the participants with and without driving experience in all three age groups.

According to the mean response times across all four spacing levels (shaded in grey in Table 6-3), the line graph (Fig. 6-5), compares the response speed between the three age groups. The graph reflects that the speed of the participants in the younger group (18-25 years old) was faster than the other two age groups regardless of changes in the levels of sign complexity, length of English information, and driving status. The participants aged between 25 to 55 years old took less time to identify stimuli than those aged above 55 years old. In addition, drivers' mean response times (mean: 3.473s) were generally faster than non-drivers' (mean: 4.157s), and participants in both driving status tended to respond faster when reading simple signs than complex signs. This finding could demonstrate that age and driving status affect sign legibility which is in line with the statement of Hulbert et al. (1980) and Ng and Chan (2008) (Section 1.2.3).

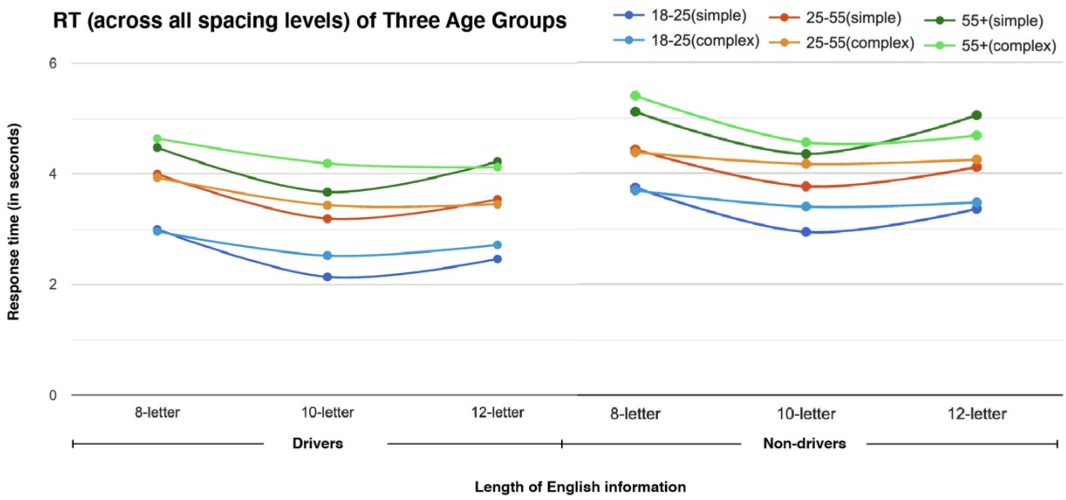


Figure 6-5. *The line graph shows the response time of the three age groups across all connecting spacing levels.*

Regarding participants with driving experience, in the age from 18 to 25 group, the changing of connecting spacing does not elicit a significant mean difference in response time in participants, under all levels of sign complexities and length of English text (Appendix II). However, the results of a three-way repeated analysis of variance (ANOVA) show that the adjustments to connecting spacing have an impact on reading speed in participants aged between 25 and 55 years old, and the 1/2H spacing performs well across all length levels and sign complexities (section 6.2.3.2). Regarding the age over 55 group, both 1/2H and 3/4H spacing appear able to achieve faster response times than the other two tighter connections. Specifically, in a simple sign condition, 3/4H performs at the fastest reading speed when signs include 8 and 12 letters (mean: 3.952s, 3.549s respectively) and the 1/2H connection works best when signs include 10 letters (mean: 3.084s). In a complex sign condition, however, 1/2H spacing achieves the fastest response in all three length levels of English information.

Regarding participants without driving experience, an ANOVA test shows that, in the two younger age groups (18-25 and 25-55), there is a significant two-way interaction between the length of English information and the connecting spacing levels on complex signs, but not on simple signs. In a complex sign condition, the different levels of connecting spacing elicit a significant mean difference in response time when the length of English text includes 8 letters and 12 letters, but not for the length of 10 letters. Post hoc analysis with a Bonferroni adjustment reveals that, in both age groups, there is no significant mean difference in the response time among the four spacing levels on complex signs including 8 letters. However, on a complex sign including 12 letters, the different spacing levels elicit a significant mean difference and the two age groups show differences. In the age 18-25 group, the reading speed is significantly faster by using the 1/2H and 3/4H spacing than using the 1/3H spacing. However, there is no significant difference between applying 1/2H and 3/4H. In the age 25-55 group, the participants' response time was significantly increased by using 1/6H, 1/2H, and 3/4H connecting spacing than using 1/3H, but the difference between 1/6H, 1/2H, and 3/4H is not significant in reading speed. Regarding the age over 55 group, from the Table 6-3, 1/3H connection appears to have achieved faster response times than the other three spacing levels on both sign complexities containing shorter English information (8 and 10 letters), however, 3/4H has the fastest reading speed when signs include 12 letters in both sign complexities.

Because all stimuli are repeated four times for each participant, the accuracy of 40 participants is analysed by classifying the data into non-error and error groups. Non-error group means that the participant responded correctly all four times, and the error group includes the data of the participants who provided at least one wrong answer. The purpose of the empirical studies in this research is to look at the tested variables' effects on sign legibility and whether they can enable participants to respond quickly while remaining correct (see definition of legibility in Section 1.3, and the reasons of measure both speed and accuracy in Section 5.4). The purpose of the empirical studies is, thus, not to look at the effects of variables on error rate, but to look at the results that are speed-accuracy balanced. Therefore, the categories of non-error and error groups can aid in determining whether there are such results achieved by adjusting variables.

The accuracy of response for three age groups is (from younger to older group), respectively, 84.4%, 85.9% and 86.1%. For the participants with driving experience, the accuracy of their response is 85.5%, which is 3.1% lower than the accuracy of the participants without driving experience. 1/2H connecting spacing achieves the highest accuracy (90.8%), followed by 1/6H (86.1%), 1/3H (82.5%), and 3/4H (82.1%).

The sections that follow go into greater detail about the analysis of the specific age group, 25-55 years old (see rationales in the first paragraph of Section 6.2.3.1). The effects of connecting spacing, sign complexity, and length of English information on identifying the stimuli in this age group are evaluated in driver and non-driver conditions separately. Then the results of both the conditions are compared to find out if there is a correlation between the driver and the non-driver group.

6.2.3.2/ Driver condition: response time

In the age group of 25 to 55, 20 participants indicated that they have driving experience. Table 6-4 lists the mean and standard deviation (SD) of these 20 participants' response times for each combination.

Table 6-4. *[Driver condition] Mean and SD of the response times (in seconds) for four levels of connecting spacing across three levels of English text length on both simple and complex signs.*

	Length		1/6H	1/3H	1/2H	3/4H
Simple sign	8 letters	Mean	3.824	4.372	3.773	3.809
		SD	1.237	1.308	0.890	1.236
	10 letters	Mean	3.352	3.133	3.118	3.150
		SD	1.235	0.998	1.196	1.095
	12 letters	Mean	3.917	3.723	3.410	3.104
		SD	1.395	1.077	1.108	1.044
Complex sign	8 letters	Mean	4.764	3.695	3.778	3.482
		SD	1.481	0.887	1.289	1.164
	10 letters	Mean	3.743	2.919	3.099	3.966
		SD	1.138	0.956	1.306	1.446
	12 letters	Mean	3.549	4.814	2.700	2.727
		SD	0.994	1.505	0.913	0.852

A three-way repeated measure ANOVA is conducted to determine the effects of sign complexity, line length of English information, and connecting spacing on time taken to identify the bilingual legends. Four outliers are detected that are more than 1.5 box-lengths from the edge of the box in a boxplot (Fig. 6-6). Inspection of their values does not reveal them to be extreme and they are kept in the analysis. The response time is approximately normally distributed ($p > .05$) except for two combinations (simple sign contains 8 English letters with 1/2H connecting spacing, $p = .028$ and complex sign contains 12 English letters with 3/4H connecting spacing, $p = .032$), as assessed by Shapiro-Wilk's test of normality. The original data has been kept for analysis because there are no meaningful differences changed in statistical conclusions by running three-way repeated ANOVA on the transformed and non-transformed data. There was homogeneity of variances, as assessed by Levene's test for equality of variances, $\chi^2(2) = 23.646$, $p = .266$.

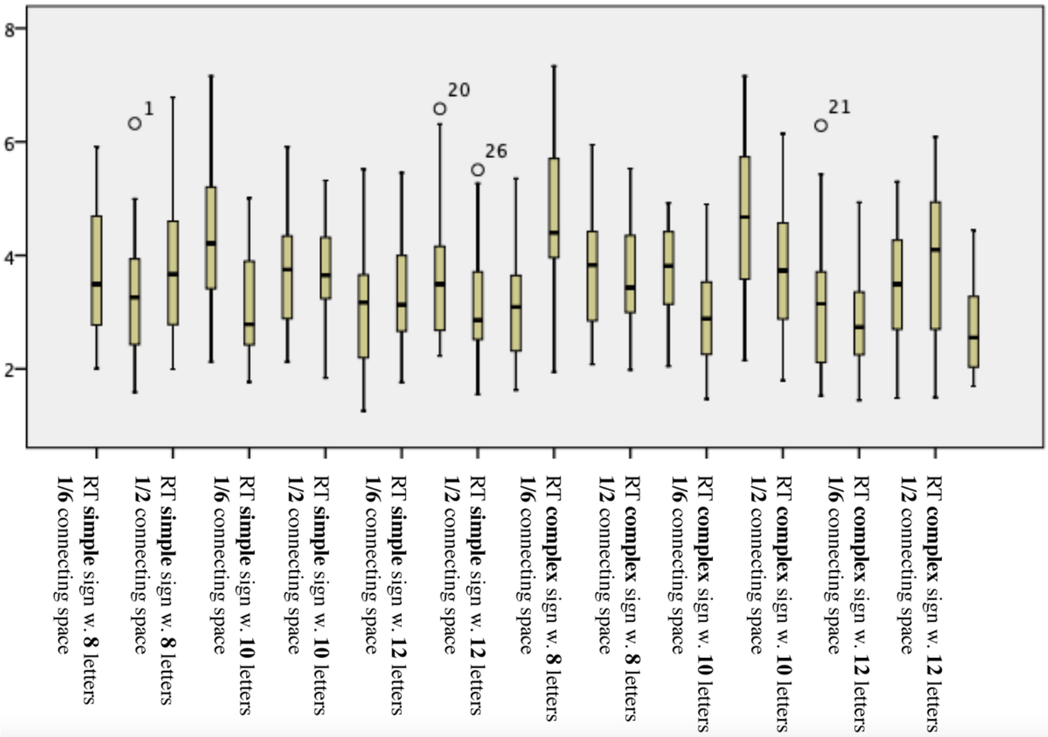


Figure 6-6. Boxplot of 20 participants with driving experience response times for each combination. There were four outliers, and they were all kept in the analysis.

The results show that there is a statistically significant three-way interaction between the three variables, $F(6, 114) = 15.451$, $p < .001$. There is also a significant two-way interaction between the line length and connecting spacing in both simple signs, $F(6, 114) = 2.977$, $p = .01$ and complex signs, $F(3.862, 73.376) = 26.343$, $p < .0005$, $\varepsilon = .644$. In a simple sign condition, the different levels of connecting spacing elicit a significant mean difference in response times when the length of English text includes 12 letters, $F(2.048, 38.907) = 8.924$, $p = .001$, $\varepsilon = .683$, but neither for the length of 8 letters, $F(3, 57) = 2.750$ $p = .051$, nor for the 10 letters, $F(3, 57) = 1.149$, $p = .337$. However, in a complex sign condition, the four levels of connecting spacing under all three levels of English text length have a significant mean difference in reading speed:
8 letters: $F(3, 57) = 18.3$, $p < .001$;
10 letters: $F(3, 57) = 12.166$, $p < .001$;
12 letters: $F(1.476, 38.907) = 51.847$, $p = .001$, $\varepsilon = .492$.

Post hoc analysis with a Bonferroni adjustment reveals that, in a simple sign condition with the English place name including 12 letters, the reading speed is significantly faster by using the 3/4H connecting spacing than using the 1/6H and 1/3H spacing levels. The difference between 3/4H and 1/2H is not significant. In a complex sign condition with the English place name including 8 letters, there is no significant mean difference in the response time between 1/3H, 1/2H, and 3/4H. However, all the three spacing levels achieve a significantly faster response time than using the 1/6H spacing. In regard to the combination of a complex sign including 10 Latin letters, the participants' response time is significantly decreased by using 1/3H and 1/2H connecting spacing than using the other two spacing levels, but the difference between 1/3H and 1/2H is insignificant in reading speed. Under the 12-letter line length, although the difference between the 1/2H and 3/4H connections is insignificant, both spacing levels cause a significant faster reading time than the other two levels. Table 6-5 presents the pairwise comparison between variables for the pairs that have a significant mean difference in reading speed.

Table 6-5. *Pairwise comparisons between connecting spacing levels under both simple and complex sign conditions with the three levels of line length. Only the significant mean differences are presented.*

<table>
<tr><th></th><th></th><th>Space A</th><th>Space B</th><th>Mean Difference</th><th>95% Confidence Interval for difference[b]</th><th>Sig.[b]</th></tr>
<tr><td rowspan="2">Simple Sign</td><td rowspan="2">12 letters</td><td>1/6H</td><td>3/4H</td><td>0.813s</td><td>95% CI [0.239, 1.387]</td><td>p=0.003</td></tr>
<tr><td>1/3H</td><td>3/4H</td><td>0.620s</td><td>95% CI [0.270, 0.968]</td><td>p<0.001</td></tr>
<tr><td rowspan="11">Complex sign</td><td rowspan="3">8 letters</td><td rowspan="3">1/6H</td><td>1/3H</td><td>1.069s</td><td>95% CI [0.433, 1.704]</td><td>p=0.001</td></tr>
<tr><td>1/2H</td><td>0.986s</td><td>95% CI [0.444, 1.528]</td><td>p<0.001</td></tr>
<tr><td>3/4H</td><td>1.336s</td><td>95% CI [0.746, 1.927]</td><td>p<0.001</td></tr>
<tr><td rowspan="3">10 letters</td><td>1/6H</td><td>1/3H</td><td>0.823s</td><td>95% CI [0.398, 1.248]</td><td>p<0.001</td></tr>
<tr><td>1/3H</td><td>3/4H</td><td>1.047s</td><td>95% CI [0.420, 1.673]</td><td>p=0.001</td></tr>
<tr><td>1/2H</td><td>3/4H</td><td>0.867s</td><td>95% CI [0.205, 1.529]</td><td>p=0.006</td></tr>
<tr><td rowspan="5">12 letters</td><td rowspan="3">1/6H</td><td>1/3H</td><td>1.265s</td><td>95% CI [0.478, 2.052]</td><td>p=0.001</td></tr>
<tr><td>1/2H</td><td>0.849s</td><td>95% CI [0.543, 1.155]</td><td>p<0.001</td></tr>
<tr><td>3/4H</td><td>0.822s</td><td>95% CI [0.461, 1.183]</td><td>p<0.001</td></tr>
<tr><td rowspan="2">1/3H</td><td>1/2H</td><td>2.114s</td><td>95% CI [1.430, 2.798]</td><td>p<0.001</td></tr>
<tr><td>3/4H</td><td>2.087s</td><td>95% CI [1.317, 2.857]</td><td>p<0.001</td></tr>
</table>

The b in difference [b] and Sig.[b] refers to the adjustment for multiple comparisons: Bonferroni.

6.2.3.3/ Non-driver condition: response time

Nine participants indicated that they do not have driving experience and their data is used to examine the effects of the three variables on the response time. Table 6-6 lists the mean and SD of the participants' response times for each combination. A three-way repeated measure ANOVA is used. There is one extreme outlier and nine outliers, and they are all provided by two participants (No. 5 and 7) as shown in the Boxplot (Fig. 6-7), which indicates that the general response times of the two participants are notably higher than the others. Accordingly, the data of these two participants has been removed. After that, the Boxplot test is repeated and three outliers are presented, which are included in the analysis since the findings are not found to be affected by comparing the result with and without the outliers. The response time is normally distributed ($p > .05$) as assessed by Shapiro-Wilk's test of normality. There is homogeneity of variances, as assessed by Levene's test for equality of variances, $\chi2(2) = 34.096$, $p = .067$.

Table 6-6. *[Non-driver condition] Mean and SD of the response times (in seconds) for four levels of connecting spacing across three levels of English text length on both simple and complex signs.*

	Length		1/6H	1/3H	1/2H	3/4H
Simple sign	8 letters	Mean	3.608	4.133	3.502	3.441
		SD	0.937	1.047	0.772	1.233
	10 letters	Mean	2.952	3.286	3.006	3.333
		SD	0.790	0.927	0.781	0.927
	12 letters	Mean	3.540	3.612	3.148	2.998
		SD	1.112	0.906	0.677	0.700
Complex sign	8 letters	Mean	4.328	3.626	3.676	3.579
		SD	0.988	0.962	0.734	1.021
	10 letters	Mean	3.595	3.319	3.082	3.715
		SD	0.774	0.862	0.758	1.348
	12 letters	Mean	3.768	4.353	3.062	2.883
		SD	0.917	0.945	0.720	0.918

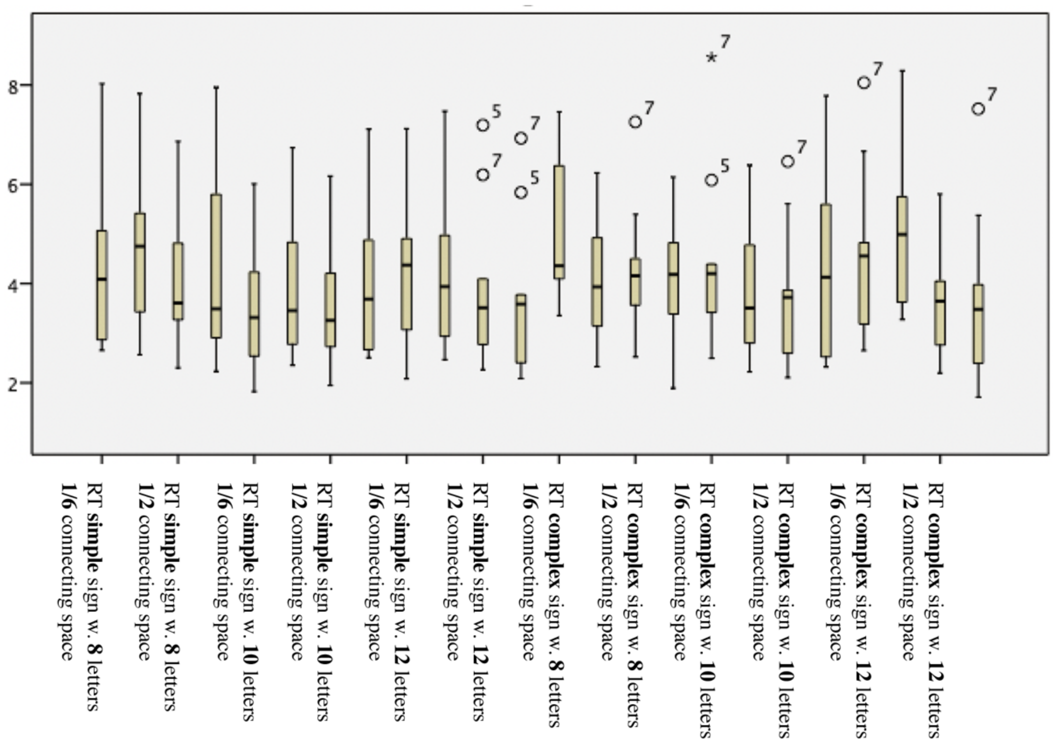


Figure 6-7. *Boxplot of nine participants without driving experience response times for each combination. There was one extreme outlier (with a mark *) and nine outliers (with a mark °) and they were all provided by two participants (No. 5 and 7).*

The results show that there is a statistically significant three-way interaction between the three variables, $F(6, 36) = 3.752$, $p = .005$. There is also a significant two-way interaction between the line length and connecting spacing on a complex sign, $F(2.282, 13.694) =$

6.310, $p = .010$, ε = .380, but not on a simple sign, $F(2.644, 15.867) = 1.526$, $p = .247$, ε = .441. In a complex sign condition, the different levels of connecting spacing elicit a significant mean difference in response times when the length of English text includes 8 letters, $F(3, 18) = 3.690$, $p = .031$, and 12 letters, $F(3, 18) = 15.025$, $p < 0.001$, but not for the length of 10 letters, $F(1.323, 7.937) = 2.670$, $p = .138$, ε = .441.

Post hoc analysis with a Bonferroni adjustment reveals that, in a complex sign condition with the English place name including 8 letters, there is no significant mean difference in the response time among the four levels of connecting spacing. With the English information containing 12 letters, the participants' response time is significantly decreased by using the 1/6H (M = 3.768s, *SD* = .917), 1/2H (M = 3.062s, SD = .720), and 3/4H (M = 2.883s, *SD* = .918) connections than using the 1/3H (M = 4.353s, *SD* = .945), but the difference between 1/6H, 1/2H, and 3/4H is not significant in reading speed.

6.2.3.4/ Accuracy

Accuracy data is classified into two groups: the non-error group that refers to 100% accuracy and the error group (the rationales are provided on p. 111). The non-error group occupies 86.04% and 85.65% for the driver and non-driver groups respectively. Generalised estimating equations (GEE) are used to examine if sign complexity, English text length, and connecting spacing have an impact on the accuracy of reading signs. The result shows the sign complexity, $p = .792$, English text length, $p = .326$, and connecting spacing, $p = .508$ have no significant impact on the accuracy. Additionally, the result of GEE shows that there is no significant difference in accuracy between drivers and non-drivers, $p = .948$.

It is also important to consider if participants tried to respond slowly because they were aiming to be accurate (or vice versa). It is difficult to look at a continuous dependent variable together with a categorical dependent variable simultaneously (in terms of no statistical method has been found). Accordingly, based on the average response time, the data is classified into the fast-response group (above average) and the slow-response group (below average) in order to compare the accuracy of the two groups. In such a way, it may be able to look at the relationship between speed and accuracy. Accordingly, a Mann-Whitney U test is used to determine if there are differences in accuracy scores between the fast-and slow-response groups. The distributions of the accuracy scores for the two groups are similar, as assessed by visual inspection. The median accuracy score is not significantly different between the two groups, U = 113416, z = -.172, $p = .864$, which indicates that there is no significant difference between the fast-response and slow-response group in terms of accuracy. In other words, this finding may suggest that the participants who responded slower did not allow themselves to be more accurate than those who responded faster. Accordingly, it could be assumed that, in this study, participants did not strive to respond slowly in order to improve their accuracy (or vice versa).

6.2.4/ Discussion

The purpose of Study A is to investigate whether changing the connecting spacing affects CEBTS legibility. If it has an impact, to identify how large the connecting spacing should be to improve the legibility, and whether the connecting spacing changes along with the sign complexity and the line length of English place names.

6.2.4.1/ Response time

- 1/2H connecting spacing performs well regardless of sign complexity and the length of English legend

In the driver group, the connecting spacing affects how quickly participants identify bilingual location names on CEBTS, and this effect interacts with the sign complexity and length of English location names. Specifically, the four levels of connecting spacing do not have a significant impact on the legibility of simple signs, especially for the simple signs that only contain shorter English place names (8 and 10 letters). However, when the English place name is longer (12 letters), the wider connecting spacing (1/2H and 3/4H) achieves a faster response time than the tighter spacing levels (1/6H and 1/3H). Although the difference between the two wider spacing is not significant, 3/4H response time leads to a more significant difference from the two tighter spacing conditions than 1/2H spacing. It may indicate that, on a simple sign that only indicates one direction, the longer the English information (compared with 8 and 10 letters), the wider the connecting spacing (3/4H) might slow down the response time. This result aligns with Hochuli's (2008) and Highsmith's (2012) statements that the longer the line, the more line spacing it needs (in continuous reading) for comfortable reading.

Table 6-7. *The connecting spacing achieves significant fast response times (marked *) in both simple and complex signs with three levels of English text length in the driver group. The highlighted grey column shows that the 1/2H level performs well across all length levels in the complex signs, and it also works well in simple signs containing 12 Latin letters.*

Simple sign	**1/6H**	**1/3H**	**1/2H**	**3/4H**
8 letters	No significant difference			
10 letters	No significant difference			
12 letters			*	*
Complex sign	**1/6H**	**1/3H**	**1/2H**	**3/4H**
8 letters		*	*	*
10 letters		*	*	
12 letters			*	*

The different levels of connecting spacing affect the legibility of complex signs significantly. The connecting spacing 1/3H,1/2 H, and 3/4H do not have a significant difference between each other. But all achieve faster reading speed than the tightest spacing (1/6H) in a combination of complex signs containing 8 English letters; both 1/3H and 1/2H perform faster response times than other two spacing on complex signs having 10 English letters; for complex signs including 12 English letters, both 1/2H and 3/4H work better than the others. Table 6-7 illustrates the connecting spacing that achieves faster response times in both simple and complex signs under three levels of English text length.

Table 6-7 shows that the 1/2H connecting spacing (shaded in grey) performs well across all length levels of complex signs. In addition, it also works well on simple signs that contains a longer English translation (12 letters). This result may suggest that using the connecting spacing of ½ height of one Chinese character could improve the reading speed of CEBTS regardless of sign complexity and the line length of an English location name.

- Changing connecting spacing may affect reading speed in the non-driver group in complex signs with longer English information

Regarding the non-driver group, the results show that changing the levels of connecting spacing has little effect on the time spent on reading simple signs with all three length levels of English information. In complex signs, the effect is also not significant when the sign contains shorter English information (8 and 10 letters). However, when the English place name gets longer (12 letters), 1/6H, 1/2H and 3/4H connections achieve faster reading times than 1/3H. Table 6-8 illustrates the connecting spacing that achieves faster response times under three length levels of English information in the non-driver group.

Table 6-8. *The connecting spacing achieves significant fast response times (marked *) in both simple and complex signs with three length levels of English information in the non-driver group.*

Simple sign	**1/6H**	**1/3H**	**1/2H**	**3/4H**
8 letters	No significant difference			
10 letters				
12 letters				
Complex sign	**1/6H**	**1/3H**	**1/2H**	**3/4H**
8 letters	No significant difference			
10 letters				
12 letters	*		*	*

The results may indicate that changing connecting spacing affects the reading speed of complex signs with longer English information. While it is a surprising result that 1/6H results in faster reading speed performance than 1/3H on complex signs with 12-letter English information, this may reflect the small amount of data used for the analysis, or the possibility that some particular location names are more difficult to recognise than others (Appendix III). The small amount of data may also have an influence on other results, such as the four levels of spacing do not have a significant impact on non-drivers, but they do appear to have a greater influence on drivers. The difference between the two groups in reading the materials may demonstrate the finding that driving experience is a predictor of sign comprehensibility (Ng & Chan, 2008). But the difference may also be due to the small number of data points in the non-driver group. However, comparing the results of both driver and non-driver groups, it is evident that the connecting spacing has an impact on the time taken to identify CEBTS.

6.2.4.2/ Response time versus accuracy

The results also show that the majority of participants answer correctly, and the tested variables have no impact on accuracy in both driver and non-driver groups. Additionally, a Mann-Whitney U test compares the median accuracy score between the fast-response group and the slow-response group, and it shows that there are no significant differences between the fast-response and slow-response group in terms of accuracy. This finding may indicate that, in this study, though the accuracy is high, the participants may not sacrifice their speed to enhance it.

6.2.5/ Adaptations

There are some considerations raised from Study A that are highlighted below:

1. The total number of the stimuli (24) and the repetition (four times) of each stimulus that participants engaged in Study A appear to have caused visual fatigue from the observation by the researcher during the study. Visual fatigue may lead to difficulties in concentrating attention on the stimuli which would have an impact on participants' responses. Furthermore, the increasing number of video clips might cause E-prime (software) to become stuck and the HDMI connection to become unstable on occasion.

2. It is important to ensure participants prioritise speed rather than accuracy while they are doing the study. That is because speed is the paramount factor of a threshold method that indicates the sign legibility, while the accuracy check is only the supplement way to look at the results. However, in Study A, it is difficult to determine if participants tried to respond more slowly because they were trying to be accurate (or vice versa), although there is a statistical analysis to examine the correlation between speed and accuracy (as Section 6.2.3.4 did).

3. The results are considered with three independent variables and two dependent variables under three age groups in both participants with and without driving experience. Many variables, conditions, and combinations are considered and compared, which has brought difficulties to the analysis.

Adaptations are made to Study B and C to address the above limitations (Section 6.3.2).

6.3 / Study B: separating spacing[22]

Study B aims to determine whether the separating spacing, the vertical spacing used to separate bilingual place names, has an impact on sign legibility and, if it has an impact, explore how large the space between bilingual place names should be.

Study B adopts the same method as Study A in measuring sign legibility by displaying the stimuli on a monitor. The apparatus and procedures of Study B are established in Study A (Section 6.1). Study B also builds upon the findings from Study A that show that the recommended connecting spacing for both simple and complex CEBTS is 1/2H. Therefore, in Study B, the connecting spacing is set at half Chinese character height and kept consistent. In addition, since in Study A the impact of connecting spacing is different along with sign complexity, it seems appropriate to examine whether the impact of separating spacing also varies with sign complexity. Sign complexity is taken into account, which is also aimed at enabling the findings to have a good application across the identified sign categories (one-direction and map-like sign categories).

Separating spacing is required only on signs with two or more place names arranged vertically. The number of place names relates to the amount of information, which is particularly important to consider, as many studies suggest that reaction time increases according to the information quantity in both English (Bohua et al., 2011; Du et al., 2008; Lyu et al., 2017) and Chinese traffic signs (Liu, 2005; Wang et al., 2015; Yang et al., 2020). Thus, it seems appropriate to also determine whether the impact of separating spacing varies according to the total number of place names on a sign (*total number* will be used for simplicity from here on).

[22] See 'Effects of text space of Chinese-English bilingual traffic sign on driver reading performance' *Displays* 67 (2021).

Additionally, on a sign that indicates two or three directions, it is also important to determine the number of place names per direction (*direction number* will be used from here on) as this number can vary. This creates different combinations of total place names across two or three directions (Fig. 6-8). Thus, if the separating spacing has an impact on driver performance, it would be better to know whether this impact can vary with a different arrangement of place names and directions.

Figure 6-8. *Three map-like signs with various total number of place names. The three signs all indicate three directions but presenting three (left), four (middle) and five (right) place names with different number of name(s) per direction. Photographed by the author in Shanghai (left and middle) and Dalian (right), 2018.*

In summary, the intentions of Study B are to examine:
1. whether separating spacing has an impact on sign legibility;
2. if it has an impact, to recommend how large the separating spacing should be;
3. whether the separating spacing changes according to sign complexity, the *total number*, and the distribution of the *direction number*.

6.3.1/ Defining test variables

6.3.1.1/ Determining combination possibilities

Sign complexity, the *total number*, and the *direction number* are interrelated and cannot be considered in isolation. There are many different combination possibilities in practice (Fig. 6-8) so it seems appropriate to map out all the possibilities in order to determine how many exposures each participant should view.

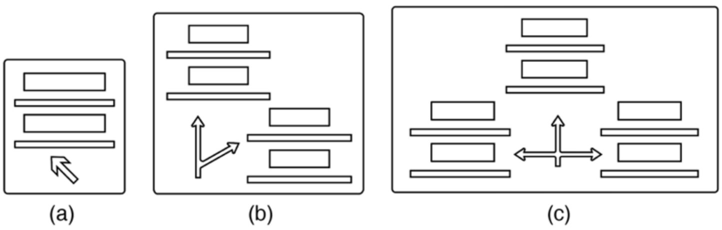


Figure 6-9. *Three levels of sign complexity. (a) one-direction sign; (b) two-direction sign; (c) three-direction sign. Drawn by the author.*

Sign complexity in Study A has two levels, simple and complex. In Study B, more specifically, it is grouped into three levels in terms of the number of directions shown (Fig. 6-9).

In Table 6-9, all variations of the *total number* under the three levels of sign complexity are summarised.

Table 6-9. *The variations of total place name number under three levels of sign complexity. Tabulated by the author.*

Sign complexity	Max total no.	Min total no.	Variations tested
(a)	3 (4 is rarely use)	1	2, 3
(b)	4	2	3, 4
(c)	6	3	4, 5, 6

The total number of place names was determined by observing photographed sign samples and the relevant specifications in published Standards.

On a one-direction sign, there seems to be no guidelines in the relevant Standards providing the maximum number of place names on it. Instead, collected sign photographs are observed and they indicate that the maximum number commonly used is three names (Fig. 6-10). Thus, two variations (two and three names) are evaluated.

Figure 6-10. *A one-direction sign with three place names. Photographed by the author in Dalian, 2018.*

According to the Standard *GB 51038-2015 Code for layout of urban road traffic signs and markings* (2015), on a two-direction or three-direction sign, the maximum number of place names for any one of the directions is two, and six in a single direction traffic sign. Accordingly, the maximum *total number* on a two-direction sign is four (two directions × two place names), and the maximum *total number* on a three-direction sign is six (three directions × two place names). Excluding the minimum *total number* (because the separating spacing only exists when there are at least two place names per direction), the variations considered are three and four place names for a two-direction sign, and four, five, and six place names for a three-direction sign.

Once the variations in the *total number* on the sign are confirmed, the next step is to consider the *direction number*. Figure 6-11 and Table 6-10 illustrate all ten combination possibilities of the *total number* and *direction number* across three sign complexities. The term 'combination' will refer to an association that joins sign complexity, the *total number* and *direction number*.

As Table 6-10 and Figure 6-11 show, combinations B1, B2, B3, C1, and C4 have two similar versions that only differ in the number of place names within the right or left direction. Since the two versions are symmetrical figures, the findings might work on both. To streamline the experimental design (too many multiple factors in turn will elevate the complexity for the statistical analysis), only the version with two place names in the right-hand direction is tested.

Table 6-10. *All combinations of the total number of place names and the distribution of place names per direction across three sign complexities. Tabulated by the author.*

Combination	Number of directions (Sign complexity)	Total number	Direction number		
			Left	up	right
A1	1	2	all place names within one direction		
A2	1	3			
B1	2	3	×	2	1
			1	2	×
B2	2	3	×	1	2
			2	1	×
B3	2	4	×	2	2
			2	2	×
C1	3	4	2	1	1
			1	1	2
C2	3	4	1	2	1
C3	3	5	2	1	2
C4	3	5	2	2	1
			1	2	2
C5	3	6	2	2	2

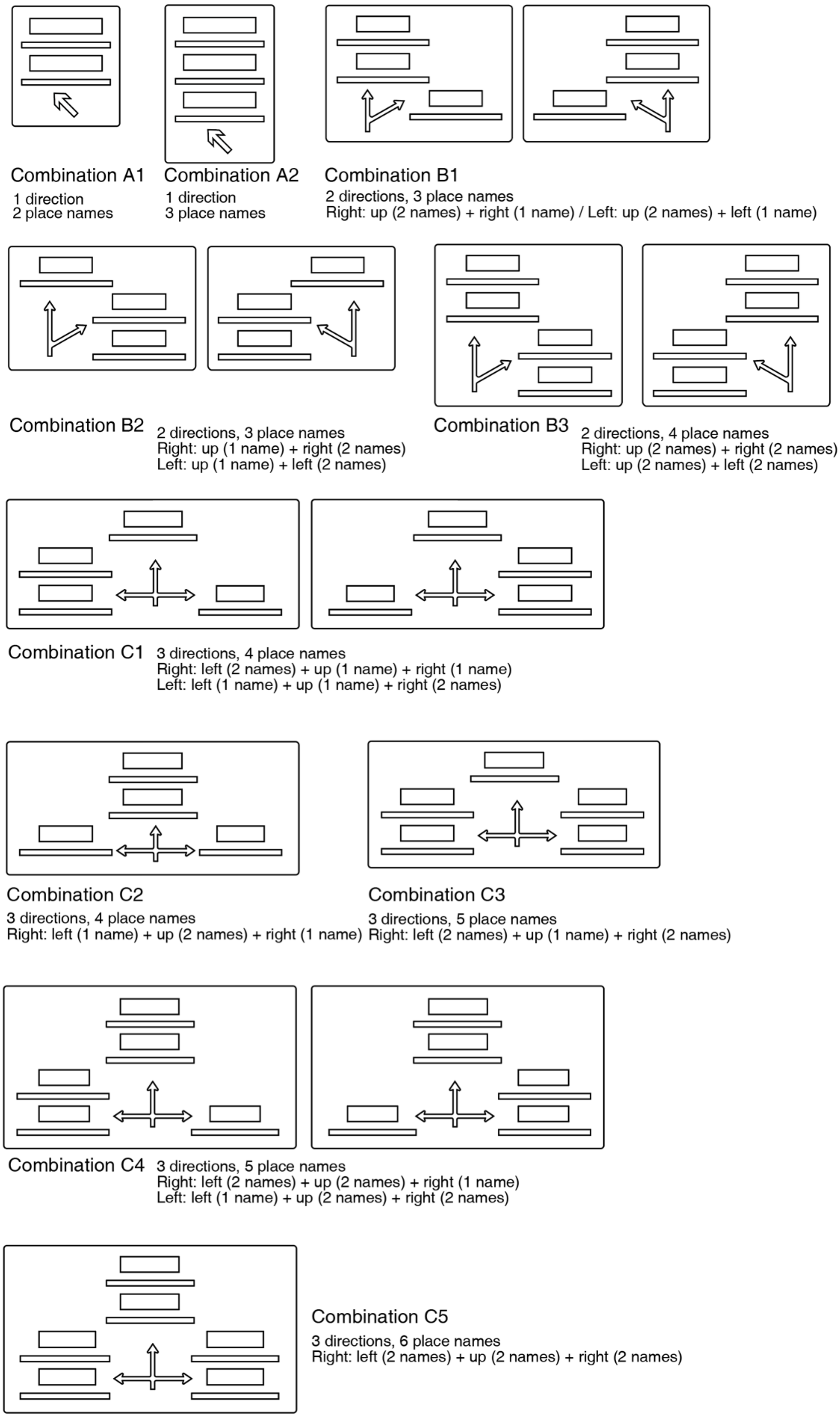


Figure 6-11. *Mapping out all possible combinations of total number and direction number across three sign complexities and excluding the simplest combinations, as per Table 6-10. Drawn by the author.*

6.3.1.2/ Selecting separating spacing levels

Separating spacing, as introduced above, is the vertical space used to separate two bilingual place names within one direction. This is to distinguish it from *directional spacing* that refers to the vertical space between two place names that signals different directions (highlighted in Fig. 6-12). As it is uncertain if there is an interaction between the separating spacing and the directional spacing, the directional spacing is the same as the separating spacing used in all stimuli in order to isolate findings that may be affected by this factor.

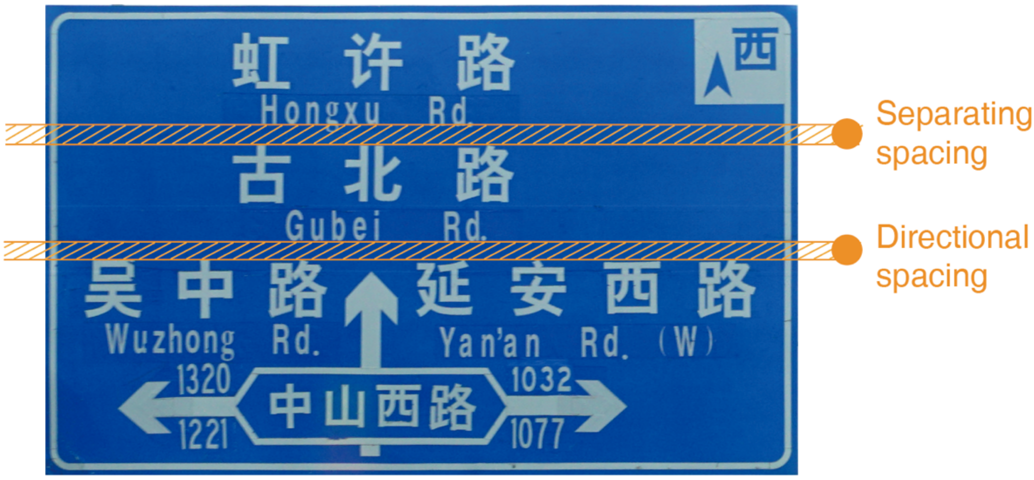


Figure 6-12. *Separating spacing and directional spacing on a three-direction sign. Illustrated by the author. Photographed by author, Shanghai,2018.*

According to Gibson's suggestion for monolingual English signs, on a sign where texts are in a narrow column, 'two-line names are tightly line spaced while the spaces between names are just generous enough to differentiate entries …' (2009, p. 83). In this case, the separating spacing should be set larger than the connecting spacing to differentiate bilingual place names. Because Study A informs a recommendation of connecting spacing of half the height of the Chinese characters, this is selected as the tightest separating spacing to test. According to the samples collected, most separating spacing used on signs is in the range from 0.5H to 1H. Then, the middle-value of 0.75H is also selected to be evaluated. In summary, three levels of separating spacing are tested: 0.5H, 0.75H and 1H.

6.3.2/ Adjustments

As per the remarks highlighted at the end of Study A (Section 6.2.5), some relevant adjustments are made in this study that are listed below.

Firstly, the number of stimuli is reduced in Study B (five practice trials followed by ten experimental trials in the main study) to prevent potential visual fatigue. This also helps to minimise technical issues caused by displaying a large number of stimuli.

Secondly, in Study B, the duration of the video clips is limited to prevent participants from prioritising accuracy over speed. In this case, Study B applies the principles that underlie a time-threshold method. As introduced in Chapter 5, a time-threshold method requires participants to identify test material that is exposed to them for a limited period, and the time taken for identification is analysed as the criterion of sign legibility. Additionally, clearer instruction about the importance of how quickly to respond is emphasised by the researcher to the participants before the study. At the end of each video, participants were also given feedback (time they used and response accuracy) (Fig. 6-13).

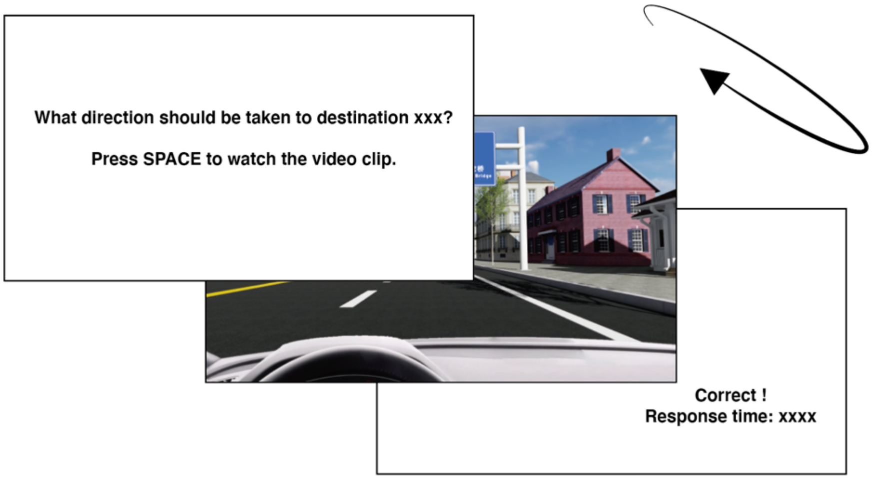


Figure 6-13. *The procedure of Study B. From a question screen, the participants are shown several short video clips. The participants need to find the answer by reading sign(s) they see in the video and press the keyboard that caused the screen to go to the feedback screen. Illustrated by the author.*

In Study A, many variables are tested in many conditions which complicates the analysis. The length of English information at three levels is one of the independent variables in Study A and the results show that it has an interaction effect with connecting spacing. To simplify the analysis of Study B, at the same time, to enable clear comparisons to be made across the findings from Study A and B, in contrast, only one of the levels of length is evaluated (12 letters) and is kept consistent in Study B. This also helps to isolate findings that may possibly be influenced by an interaction effect between the separating spacing and the length of English information.

In Study A, three age groups are considered, and each reaction is analysed in participants with and without driving experience. However, in Study B, only the participants with driving experience and aged between 25 and 55 are recruited to simplify the study analysis. But most importantly, it may not make much sense to recruit all three age ranges and both drivers and non-drivers in Study B. Although a comparison analysis between ages and driving experience is given in Study A, it may not be able to provide a strong claim of the findings because of the small samples in the younger and older age groups, as well as the small samples in the non-driver group. That is also the reason why, in Study A, only the responses for age group 25 to 55 are analysed in depth and a full discussion is given. Hence, to make a clear comparison between studies, and a strong claim of findings between studies, two additional screening questions are added in the recruitment process in Study B, they are: a. age between 25 and 55 years old; and b. with driving experience.

6.3.3/ Demographic data

39 participants who met the age requirements were recruited into the main study (the pilot session recruited six participants, each receiving ten trials that covered all combinations and levels of separating spacing). The main study took around ten minutes per participant. Each participant first completed five practice trials, followed by the ten experimental trials presented in random order.

A between-subject factorial design was prepared. 39 participants were systematically allocated to three groups, each with 13 participants. Each group received a different 'separating spacing condition':
- 0.5H group: participants viewed all signs with 0.5H separation;
- 0.75H group: participants viewed signs with 0.75H separation;
- 1H group: participants viewed signs with 1H separation.

6.3.4/ Result

6.3.4.1/ Separating spacing and response time

The mean response times for the 0.5H group, 0.75H group and 1H group are 5.026s (SE = .083), 4.934s (SE = .084) and 5.366s (SE = .084) respectively. A two-way ANOVA is used to examine the effects of separating spacing and combination on the time taken in reading CEBTS. There is a main effect of separating spacing $F(2, 335)= 7.312$, $p = .001$, partial η2 = .042. There is no significant interaction effect between the separating spacing and combinations on the time taken to read signs, $F(18, 335) = .539$, $p = .938$, partial η2 = .028.

Table 6-11. *Pairwise Comparisons. The differences in mean response times (in seconds) between separating spacing levels.*

Pairwise comparison				
		MD	**Sig.**[b]	**95% CI**
1H	0.5H	.340	.013	.055, .624
	0.75H	.431	.001	.145, .718
0.5H	0.75H	.092	1.000	-.192, .375

The mean difference is significant at the .05 level. b. Adjustment for multiple comparisons: Bonferroni.

All pairwise comparisons are conducted for 95% confidence intervals and *p*-values are Bonferroni-adjusted (Table 6-11). The Sig. column indicates significant differences in response time between 1H and 0.5H separating spacing, and between 1H and 0.75H separating spacing. While there is no significant difference between 0.5H and 0.75H.

6.3.4.2/ Separating spacing and accuracy

The accuracy of response for the 0.5H, 0.75H and 1H groups is, respectively, 81.3%, 87.7% and 84.4%. A chi-square test of homogeneity is used between separating spacing groups and the accuracy of response. All expected cell counts are greater than five (one of the assumptions that needs to be met to conduct a chi-square test). There are no significant differences in the percentage of accuracy in three separating-space groups, $p = .384$.

6.3.4.3/ Combinations and response time

An analysis of the main effect for combination is performed using a two-way ANOVA, which indicates that the combination affects the speed of response to traffic signs significantly, $F(9, 335) = 6.956$, $p < .001$, partial $\eta 2 = .157$.

The findings presented in Section 6.3.4.2 show that there is no interaction between separating spacing and combination on response time, which may suggest that, for an analysis of sign combinations, combining all data collected from three spacing groups for a larger sample size and greater reliability is reasonable. However, the main focus of this study is to look at the effects of separating spacing, and the mere analysis of combinations seems to deviate from the research purpose. The following sections, thus, look at sign combinations along with the spacing levels. Given that both 0.5H and 0.75H separating spacing result in a significantly faster response time than 1 H, the response times on the data of those individuals that received 0.5H and 0.75H separating spacing exposures are extracted for analysis.

- Distribution of the number of legends per direction

The difference in response to the spatial distribution of the *direction number* is compared when the sign complexity, and the *total number,* are held constant. Accordingly, the response time data of the three pairs of combinations, B1 and B2, C1 and C2, as well as C3 and C4, are extracted to be compared respectively (Fig. 6-14, Table 6-12). The analysis excludes A1 and A2 because these two combinations are one-direction signs where all place names are within one direction. A paired-samples t-test and a Wilcoxon signed-rank test are conducted. The mean response times for the three pairs under both the 0.5H and 0.75H separations are listed in Table 6-12. In both separation conditions, there is no significant difference between:
B1 and B2 (0.5H: $p = .207$, 0.75H: $p = .330$);
C1 and C2 (0.5H: $p = .530$, 0.75H: $p = .880$);
C3 and C4 (0.5H: $p = .434$, 0.75H: $p = .157$).

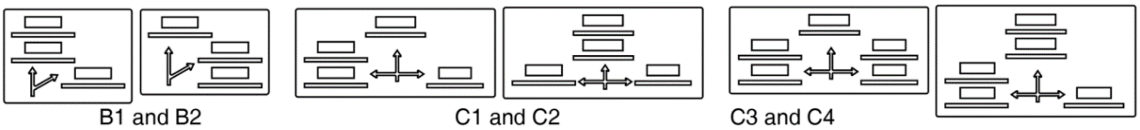


Figure 6-14. *Three pairs of combinations. The two combinations in each pair include same total number of place names and under same sign complexity. But the distribution of the place name number per direction is different. Drawn by the author.*

Table 6-12. *The mean response times (in seconds) for the three pairs of combinations (B1/B2, C1/C2, C3/C4) under 0.5H and 0.75H separations.*

0.5H								
	M	**SE**		**M**	**SE**		**M**	**SE**
B1	4.522	.262	C1	4.603	.255	C3	5.474	.238
B2	4.835	.259	C2	4.690	.261	C4	5.182	.203
0.75H								
	M	**SE**		**M**	**SE**		**M**	**SE**
B1	4.376	.339	C1	4.367	.288	C3	4.884	.398
B2	4.888	.413	C2	4.318	.398	C4	5.540	.228

- Total number of place name

The difference in response times to the total number of place names is compared when the sign complexity is held consistent. One-direction signs are excluded because three one-direction signs were displayed simultaneously in the study which meant that the total number that the participants received was more than the other two complexities (6 in A1 and 9 in A2) (Fig. 6-15).

Figure 6-15. *Screenshot of the video clip showing three one-direction signs, and each sign includes three place names that resulted in nine place names were shown simultaneously.*

In the two-direction sign condition (combination B), the mean and SD of response time for the number variations of place names, under both 0.5H and 0.75H separation levels, are listed in Table 6-13. A one-way repeated ANOVA shows that the changes in the *total*

number do not elicit significant differences in the two separation levels, and Table 6-14 presents the pairwise comparison among factors:
0.5H: $F(2, 24) = 1.366$, $p = .274$ partial $\eta^2 = .102$;
0.75H: $F(2, 18) = .896$, $p = .426$ partial $\eta^2 = .091$.

Table 6-13. *Mean and SD of response times (in seconds) for total place name numbers in two-direction signs under 0.5h and 0.75h separating spacing levels.*

TWO-DIRECTION SIGN			
0.5H		**M**	**SD**
3 place names	B1	4.522	.094
4 place names	B2	4.835	.934
	B3	4.706	1.030
0.75H		**M**	**SD**
3 place names	B1	4.376	1.015
4 place names	B2	4.888	1.513
	B3	4.922	.763

Table 6-14. *Pairwise comparison for total place name number in two-direction signs under 0.5H and 0.75H separations.*

0.5H		**MD**	**Sig.b**	**95% CI**
B1 (3 names)	B2 (4 names)	-.312	.620	-.962, .338
	B3 (4 names)	-.183	.494	-.528, .161
B2 (4 names)	B3 (4 names)	.129	1.000	-.414, .672
0.75H		**MD**	**Sig.b**	**95% CI**
B1 (3 names)	B2 (4 names)	-.512	1.000	-2.178, 1.154
	B3 (4 names)	-.545	.647	-1.746, .655
B2 (4 names)	B3 (4 names)	-.034	1.000	-1.112, 1.045

The mean difference is significant at the .05 level. The b in Sig.b refers to the adjustment for multiple comparisons: Bonferroni.

In the three-direction sign condition (combination C), four place names (C1 and C2), five place names (C3 and C4) and six place names (C5) are compared among each other to determine whether there is a significant mean difference in response time. As described above, there is no difference in response time between the combination C1 and C2, also between C3 and C4. Accordingly, to help minimise potential contradictions, the mean response time of C1 and C2, as well as C3 and C4, is calculated to represent the response times of four place names and five place names separately. Then the means and SD of response times under both 0.5H and 0.75H separating spacing levels are listed in Table 6-

15. A one-way repeated ANOVA shows that the total number affected the time taken to respond:
0.5H: $F(2, 20) = 5.091$, $p = .016$, partial η2 = .337;
0.75H: $F(2, 24) = 3.846$, $p = .036$, partial $\eta^2 = .243$.

Table 6-15. *Mean and SD of response times (in seconds) for the total number of place names on three-direction signs under 0.5H and 0.75H separating spacing levels.*

THREE-DIRECTION SIGN			
0.5H		**M**	**SD**
4 names	C1C2 (mean)	4.447	.498
5 names	C3C4 (mean)	5.301	.458
6 names	C5	5.180	1.052
0.75H		**M**	**SD**
4 names	C1C2 (mean)	4.461	1.108
5 names	C3C4 (mean)	5.106	.801
6 names	C5	5.085	.816

Post hoc analysis with a Bonferroni adjustment reveals that, in 0.5H separation condition, response time significantly increases from four to five place names, but not from four to six place names, and there is no significant difference in response time between five and six place names. However, in the 0.75H separation condition, the pairwise comparison does not show a significant difference among the *total number* variations. Table 6-16 presents the pairwise comparison among factors in the three-direction sign under 0.5H and 0.75H separation conditions.

Table 6-16. *Pairwise comparison under 0.5H and 0.75H separating spacing levels of three-direction signs.*

0.5H		**MD**	**Sig.b**	**95% CI**
4 names	5 names	-.855	.006	-1.451, -.258
	6 names	-.733	.093	-1.572, .106
5 names	6 names	.121	1.000	.121, .351
0.75H		**MD**	**Sig.b**	**95% CI**
4 names	5 names	-.646	.157	-1.479, .188
	6 names	-.624	.096	-1.340, .092
5 names	6 names	.022	1.000	-.622, .665

Based on estimated marginal means. The mean difference is significant at the .05 level.
The b in sig.b refers to the adjustment for multiple comparisons: Bonferroni.

6.3.4.4/ Combinations and accuracy

The difference in accuracy is compared when the sign complexity is held consistent. The analysis also excludes one-direction signs because, in this condition, three one-direction signs are displayed simultaneously in one exposure so that the participants read more place names at the same time (maximum nine place names simultaneously) (Fig. 6.12) than they read in two-or three-direction sign conditions (maximum six place names). This difference in the *total number* might affect the response accuracy.

For two-direction signs with 0.5H separating spacing, the accuracy of response for combination B1, B2 and B3 is, respectively, 99.3%, 100% and 100%. It is 100%, 98.7% and 98.5%, respectively, in the condition of 0.75H separating spacing. Cochran's Q test (Cochran, 1950) shows that, for both 0.5H and 0.75H separations, there are no significant differences among the three combinations in accuracy rate,
0.5H: $\chi2(2) = 2.000$, $p = .368$;
0.75H: $\chi2(2) = 1.000$, $p = .607$.

For three-direction signs with 0.5H separating spacing, the accuracy of response for combination C1, C2, C3, C4 and C5 is, respectively, 90%, 100%, 75%, 75% and 57.9%. It is 100%, 98.2%, 96.4%, 98.1% and 92.7%, respectively, in the condition of 0.75H separation. Cochran's Q test shows that combinations with 0.5H separating spacing appear to elicit significant differences in accuracy, $\chi2(2) = 11.152$, $p = .025$, and the pairwise comparison indicates that the accuracy is significantly reduced from 100% (C2) to 57.9% (C5), $p = .018$. However, combinations with 0.75H separating spacing have no significant impact on the accuracy, $\chi2(2) = 5.000$, $p = .287$.

6.3.5/ Discussion

6.3.5.1/ Selection of separating spacing

The results show that the separating spacing affects the speed in reading CEBTS and this effect appears not to vary according to combination (combination refers to a combination of sign complexity, the total number on a sign, and direction number). Compared to the highest separating space (1 H), both the lowest (0.5H) and medium (0.75H) separating spacing result in faster response time. Although the difference between the lowest and medium spacing is not significant, the medium response time appears to be faster and has a higher accuracy than the 0.5H separation. This result agrees with Gibson's (2009) suggestion that the space that combines two related items should be less than the space that separates them from other items. The results can be explained by the Gestalt psychology of proximity that brings together objects that are closer to one another than from others and separates objects that are far apart and seem unrelated (Section 5.2.1). The tighter vertical spacing (0.5H and 0.75H compared with 1H separating spacing) needed for two lines of Chinese/English legends could be explained by the fact that Chinese characters are formed within a square box without ascenders and descenders, and also without diacritical marks or vowel signs above and below characters. This saves the vertical space that should be added in Latin contexts to prevent the crowding caused by ascending and descending characters, and any accent marks (Black, 1990).

6.3.5.2/ Sign combination

The main concern of this study is to determine whether the separating spacing, rather than combination, affects legibility of CEBTS. Although the results show that the impact of separating spacing appears not to be linked to the combination, it is still important to consider how sign combinations affect the speed and accuracy in driver reading performance which may warrant further consideration for future studies. However, sign combination is looked at along with the separating spacing of 0.5H and 0.75H because the mere analysis of sign combination deviates from the purpose of this study.

The analysis of the combinations shows that, when sign complexity and the total number of place names is held consistent, in both 0.5H and 0.75H separation conditions, the spatial distribution of the place name per direction appears not to affect the speed in reading two-and three-direction signs.

The difference in response time to the total number of place names is compared when the sign complexity is held consistent. The result shows increased response times according to an increase in the number of place names, though some differences are not significant. This result is in agreement with previous research suggesting that the reaction time increases with the information quantity on traffic signs (Bohua et al., 2011; Du et al., 2008; Liu, 2005; Lyu et al., 2017; Wang et al., 2015).

For a two-direction sign, the results also show that, in both 0.5H and 0.75H separating spacing conditions, the variations of total place name number (approximately six to eight Latin words) appear not to elicit significant differences in both response of time and accuracy. This result is consistent with the sign-reading speed research for monolingual English signs indicating that signs with four to eight words could be comfortably read and comprehended (Garvey & Kuhn, 2004).

The results also show that, in the three-direction sign with 0.5H separating spacing conditions, the variation of the total place name number appears to affect the response time significantly, but it does not show significantly when applied to 0.75H separating spacing. Six place names achieve a faster response time than five place names. This is a surprising result that contradicts the expected trend, that is, the increased quantity of information can increase response time (Bohua et al., 2011; Du et al., 2008; Lyu et al., 2017). It may reflect the small number of data points or the difficulties in the recognition/pronunciation of the particular location names (Appendix III). Regarding accuracy rate, in a three-direction sign with 0.5H separating spacing, the accuracy rate is significantly reduced from four place names to six. But this difference is not significant when applies 0.75H separating spacing. Additionally, the mean accuracy rate of a three-direction sign with 0.75H separating spacing is 97.08%, which is higher than that with 0.5H separating spacing (79.58%).

In summary, the results may indicate that, in contrast with 0.5H, 0.75H is a generalisable separating spacing that may be able to show a good performance, in both response time and accuracy, regardless of the changes in the total place name number.

6.4/ Study C: text alignment

According to the review of the Chinese traffic sign Standards in Chapter 3, two alignments are suggested, central- or left-alignment, to arrange the bilingual location names on CEBTS. However, there is a lack of clear specifications that could inform the use of the alignments. By observing the collected sign samples, central-alignment is used frequently in practice, however, left-alignment is rarely used (Section 3.3.1.1). Study C, accordingly, aims to evaluate whether there is a difference between the two alignments of the bilingual location names, central- or left-aligned, in the legibility of CEBTS. If differences are found, it will also consider which one could improve participants' ability to identify bilingual place names.

The alignment of bilingual location names on CEBTS in this study includes: 1). the way that the English translation is aligned with the Chinese text of a bilingual place name, and 2). the way the bilingual location names are aligned with each other.

Figure 6-16. *The main tested variables in Study C-I (top) and C-II (bottom). The variables are depicted in the photographed sign samples, with the exception of the one indicating the left-alignment in Study C-II. Because the one-direction sign using left-alignment is absent in the sample collection, the test material used here. This figure is illustrated by the author and the samples are photographed by the author.*

Study C is made up of Study C-I and Study C-II (Fig. 6-16). Study C-I aims to investigate whether the difference between the two alignments may relate to the levels of separating spacing. In Study B, the results show that both the lowest (0.5H) and medium (0.75H) separating spacing resulted in faster response times than the highest (1H) separation, but the difference between the medium and the lowest separation is not significant. This raises the question of whether the medium and lowest separations might obtain a significant difference by changing the alignment of the location names. Therefore, Study C-I examines the differences in the effect of the two alignments under both 0.5H and 0.75H separating spacing. Study C-II aims to explore whether the two alignments may cause a significant difference in response speed and accuracy without the impact of separating spacing (Fig. 6-16). Separating spacing is required on signs with two or more place names arranged vertically and there are signs in use that only include one location name without separating spacing.

Study C builds upon the method and findings from studies A and B, it includes:
1. Taking sign complexity into account. Based on two previous studies, sign complexity is shown to affect CEBTS legibility. Accordingly, in this study, the two alignments are compared with sign complexity conditions. To align the evaluated levels in Study B, the same levels of sign complexity are tested in Study C: one-direction, two-direction, and three-direction signs.

2. Using 1/2H connecting spacing. The results of Study A recommend that the connecting spacing of a half Chinese character height, compared to the greater and smaller connection, could be used as a generalisable spacing across sign complexities for the purpose of improving response speed. This result informs the stimuli design in Study B that uses 1/2H connecting spacing through the whole study to help participants to respond faster, at the same time, to enable the findings to be unaffected by the influence of connecting spacing. For the same purpose, in this study, the connecting spacing is also set at half Chinese character height and kept consistent in both Study C-I and C-II.

3. Applying the English location name with 12 letters to the stimuli and keeping it consistent. This setting is aligned with Study B and the reason is given in Section 6.3.2.

4. Confirming the total number of place names presented on the stimuli (five bilingual place names in total on a single sign). The results of Study B show that, on a two-direction sign, in both 0.5H and 0.75H separating spacing conditions, the total number of bilingual place names does not affect response time and accuracy in identifying CEBTS. However, the total number of place names affects the reading performance on a three-direction sign. To isolate the findings that may be impacted by the total number of place names, in the three-direction sign condition, Study C-I is tested when the total number of place names is kept consistent.

5. Restricting the duration of the video clips. Informed by the limitations of Study A (impossible to determine the weight between speed and accuracy) and the identified duration of the clips (seven seconds) in the Study B pilot, in Study C, the duration of the video

clips is designed limited to seven seconds to enable the participants to take speed as the first priority. In addition to this, the procedure of Study C is parallel to Study B that emphasised the importance of how quickly to respond to the participants before the study, and the feedback slide (time they used and the accuracy) is provided at the end of each video clip.

6. Recruiting participants with the same screening questions as are applied in Study B. The questions include: (a) have normal or corrected vision; (b) do not read Chinese and use English as the first or second language; (c) have driving experience; and (d) between the ages 25 to 55 years old.

6.4.1/ Demographic data

36 participants were recruited in total, and they did both Study C-I and C-II; C-I was followed by C-II for all participants. In Study C-I, the participants' tasks were tested in three levels of sign complexity separately. In each condition, the two alignments (central-aligned and left-aligned) and the two levels of separating spacing (0.5H and 0.75H) were tested. Study C-I used a within-subject and between-subject mixed design. All 36 participants viewed both alignment groups: reading stimuli where the location names were central-aligned and also reading stimuli where the location names were left-aligned. The order in which participants received each stimulus was random, with the 36 participants being systematically split into two groups: (a) 18 participants were shown both alignments under 0.5H separation (b) another 18 participants were shown both alignments under 0.75H separation. Each stimulus was presented three times to each participant. In Study C-II, 36 participants performed a cross-over design by receiving six stimuli resulting of two alignments across three levels of sign complexity (2×3). Each stimulus was presented only once to each participant, and the stimuli were displayed in random order.

6.4.2/ Result

6.4.2.1/ Study C-I and response time

Study C-I aims to examine the effect of the two alignments under 0.5H and 0.75H separating spacing. The mean and SD of response times for the central- and left-alignments with both 0.5H and 0.75H separating space under three levels of sign complexity are calculated and listed in Table 6-17.

A two-way mixed ANOVA is conducted to examine the effect of the two alignments with the two separating spacing levels on the participants' reading speed. Outliers are assessed by inspection of a boxplot (Fig. 6-17). One outlier is detected that is more than 1.5 box-lengths from the edge of the box in the one-and three-direction sign conditions, and two outliers are detected in the two-direction sign condition. Inspection of their values does not reveal them to be extreme and they are kept in the analysis. In all three sign complexity conditions, the data is normally distributed, as assessed by Shapiro-Wilk's test of normality ($p > .05$). There is homogeneity of variances ($p > .05$) and covariances ($p > .001$), as assessed by Levene's test of homogeneity of variances and Box's M test (Box, 1949) respectively.

Table 6-17. *Mean and SD of response times (in seconds) for the central- and left-alignments with both 0.5H and 0.75H separating space under three levels of sign complexity. The two alignment methods achieve a significant difference on response time when the three-direction signs using 0.5H separating spacing, which is shaded in grey.*

	One-direction sign		Two-direction sign		Three-direction sign	
	0.5H	**0.75H**	**0.5H**	**0.75H**	**0.5H**	**0.75H**
Central-aligned	M: 5.139 SD: .749	M: 5.049 SD: .794	M: 4.711 SD: .874	M: 4.635 SD: .847	M: 5.433 SD: .592	M: 4.914 SD: .991
Left-aligned	M: 5.234 SD: 1.105	M: 5.482 SD: .912	M: 4.494 SD: .703	M: 4.797 SD: .679	M: 4.984 SD: 1.103	M: 5.281 SD: .764

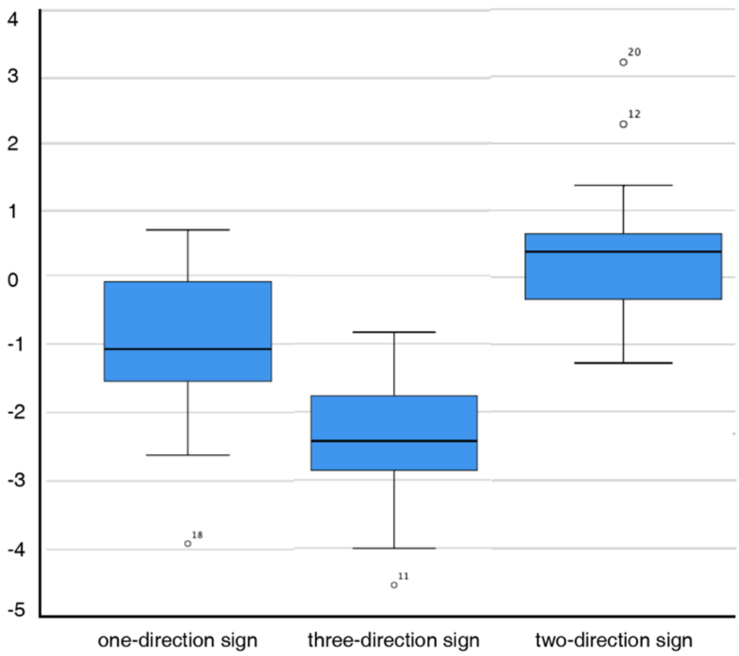


Figure 6-17. *Outliers in three sign complexities shown in a boxplot conducted for a two-way ANOVA examining the effect of the two alignments with the two separating spacing levels on reading speed.*

In both one-and two-direction sign conditions, there is no significant interaction between the separation levels and the two alignments on participants' response times,
one-direction sign condition: $F(1, 30) = .733$, $p = .399$, partial η2 = .024;
two-direction sign condition: $F(1, 34) = 3.103$, $p = .087$, partial η2 = .084.

The main effect analysis shows that there is no significant difference in mean response times between the two alignments regardless of the separating spacing,
one-direction sign condition: $F(1, 30) = 1.789$, $p = .191$, partial η2 = .056;
two-direction sign condition: $F(1, 34) = 0.065$, $p = .800$, partial $\eta^2 = .002$.

In a three-direction sign condition, however, there is a significant interaction between the two independent variables on participants' response time, $F(1, 32) = 7.153$, $p = .012$, partial $\eta^2 = .183$. With 0.5H separation, the speed is significantly faster when the location names are left-aligned than using the central-alignment ($M = .45$, $SE = .19$s, $p = .033$). However, the difference between the two alignments under 0.75H separation is not significant ($M = .37$, $SE = .24$s, $p = .140$) (shaded in Table 6-16).

6.4.2.2 / Study C-I and accuracy

An exact McNemar's test (McNemar, 1947) is run to determine if there is a significant difference in the accuracy between the two alignments for reading CEBTS. Table 6-18 lists the accuracy of the two alignments for each condition. From the Sig. column, it shows that there is a significant difference between the two alignments in accuracy in the three-direction sign condition with 0.5H separating spacing. $P = .039$ (shaded in Table 6-18). With the location names left-aligned, the number of responses in the non-error group has increased to 16 (94.1%), with a concomitant reduction in the number of participants whose responses with errors to 1 (5.9%).

Table 6-18. *Accuracy (without any errors) of two alignments on reading stimuli for each sign combination.*

0.5H Separation			
	Central-aligned	**Left-aligned**	**Exact Sig.**
One-direction sign	83.3%	72.2%	.625
Two-direction sign	88.9%	94.4%	1.000
Three-direction sign	52.9%	94.1%	.039

0.75H Separation			
	Central-aligned	**Left-aligned**	**Exact Sig.**
One-direction sign	76.5%	58.8%	.180
Two-direction sign	83.3%	83.3%	.928
Three-direction sign	77.8%	77.8%	1.000

6.4.2.3 / Study C-II and response time

Study C-II aims to explore whether the two alignments may cause a significant difference in response speed and accuracy when participants reading CEBTS which include only one location name within one direction. It is analysed in terms of the three levels of sign complexity.

Table 6-19. *Mean and SD of response times (in seconds) for the central- and left-alignments under three levels of sign complexity.*

	One-direction sign	Two-direction sign	Three-direction sign
Central-aligned	M: 2.486 SD: .679	M: 1.857 SD: .696	M: 4.910 SD: .890
Left-aligned	M: 3.419 SD: .929	M: 4.150 SD: .982	M: 4.787 SD: .896

The mean and SD of response times for the central- and left-alignments in the three levels of sign complexity are listed in Table 6-19. A paired-samples t-test is used to determine whether there is a significant mean difference between the response time when participants read a central-alignment sign compared to a left-alignment sign. The three levels of sign complexity are tested separately.

In one-and two-direction sign conditions, one outlier is detected that is more than 1.5 box-lengths from the edge of the box in a boxplot. Inspection of their values does not reveal them to be extreme and they are kept in the analysis. There are no outliers as assessed by the boxplot in three-direction sign conditions. The assumption of normality is not violated, as assessed by Shapiro-Wilk's test ($p > .05$).

In both one- and two-direction sign conditions, the participants respond faster when reading the sign where the location names are central-aligned as opposed to the location names are left-aligned. A statistically significant mean increases of .933s in the one-direction sign (95% CI [.594, 1.270], $t(35) = 5.598$, $p < .0005$, $d = 0.93$) and 2.293s in the two-direction sign (95% CI [1.995, 2.590], $t(35) = 15.634$, $p < .0005$, $d = 2.61$) respectively. However, there is no significant mean difference between the two alignments in a three-direction sign condition (95% CI [-.371, .124], $t(32) = -1.013$, $p = .319$).

6.4.2.4/ Study C-II and accuracy

An exact McNemar's test is conducted to determine if there is a significant difference in the accuracy between two alignments when reading CEBTS. Table 6-20 lists the accuracy of the two alignments for each condition, from the Exact Sig. column, it shows that there is no significant difference between the two alignments in each condition.

Table 6-20. *Accuracy (without any errors) of two alignments on reading stimuli in Study C-II.*

	Central-aligned	Left-aligned	Exact Sig.
One-direction sign	94.4%	100%	.500
Two-direction sign	94.4%	83.3%	.180
Three-direction sign	94.4%	97.2%	1.000

6.4.3/ Discussion

Study C evaluates whether there is a difference between the central- and left-alignment of the bilingual location name in the participants' reading performance when encountering a CEBTS. It also evaluates if the difference between the two alignments may relate to the changes in the separating spacing and the sign complexity.

The results show that the participants perform at a faster speed and higher accuracy when shown the left-alignment than the central-alignment in a three-direction sign condition with 0.5H separating-spacing. However, this difference between the two alignments is not significant when using the 0.75H separation. Additionally, in one- and two-direction sign conditions, the two alignments do not achieve a significant difference under both 0.5H and 0.75H separations. It may indicate that either central-alignment or left-alignment could be used for one-and two-direction signs. Although, in a three-direction sign condition, the left-alignment could help the participants to respond faster and with higher accuracy. Nevertheless, using a larger separating spacing (0.75H compared with using 0.5H separation) may reduce the influence that may be caused by using the two different alignments.

However, in one-and two-direction sign conditions, the two different alignments have a strong impact on reading speed in Study C-II. This could imply that the participants respond faster when they are shown the central-alignment than left-alignment, when reading CEBTS which only indicates one place name per direction. However, this difference between the two alignments is not significant under a three-direction sign condition.

The findings of studies C-I and C-II may indicate that, with the influence of the separating spacing, left-alignment could help drivers perform better, although wider separating spacing could be used instead. However, without the influence of the separating spacing, central-alignment may benefit drivers by responding faster, especially when drivers are reading one-and two-direction signs.

6.5/ Discussion of findings

The three studies are designed in sequence. While the method and findings of Study A inform the adjustments in the study design of the following-up Study B, such as simplifying the study variables, selecting the participants with a specific age range, and limiting the duration of the video clips. These improvements are also applied to the subsequent Study C, and the findings of Study B (both 0.5H and 0.75H separating spacing have a faster reading speed and higher accuracy) inform the experimental questions of Study C. Therefore, the text alignment is tested under both separation levels, as well as under conditions without the influence of separating spacing.

The findings of the three studies highlight the effects of connecting spacing, separating spacing, and text alignment on CEBTS legibility. Study A demonstrates that there is an interaction effect between connecting spacing, sign complexity, and the length of English legend on CEBTS legibility. 1/2H connecting spacing means a faster reading time regardless of changes in sign complexity and the length of English legend. However, the adjustment of connecting spacing does not elicit a significant difference in accuracy. In Study B, 0.5H and 0.75H separating spacing increase the reading speed and accuracy, but 0.75H is a generalisable separation that could enable participants to perform well regardless of changes in the total number of place names presented on the stimulus. Study C suggests that the left-alignment achieves faster response times and higher accuracy than the central-alignment when using 0.5H separating spacing on a three-direction sign. However, both alignments could perform well when applied with a 0.75H separation instead. Without the influence of separating spacing, however, central-alignment helps participants to respond faster, especially when they are reading one- and two-direction signs.

These findings demonstrate that the spatial arrangement of the two languages is an important consideration for the legibility of CEBTS. The findings also provide ways of improving the CEBTS legibility by the adjustment of connecting spacing, separating spacing, and text alignment as a mean. The empirical studies could have a further implication on the relevant Standards to provide clear guidance for the presentation of Chinese and English legends; and on sign designers to enhance the awareness of their role in the presentation of the two scripts in sign legibility and strictly follow the design guidance in Standards. The further contributions and implications of the findings are discussed in Sections 7.3 to 7.6, together with the discussion of the methodological contributions of using a monitor to display stimuli.

7/ Conclusions

7.1/ Overview

The motivation for this research comes from considering how bilingual typography in two different scripts relates to sign legibility. It is driven by the wish to optimise sign legibility by manipulating the spatial presentation of Chinese/English bilingual legend(s).

At the core of this research is the main question: **how can sign legibility be improved by the spatial presentation of bilingual location name(s) comprised of Chinese and English?** This question is refined by answering two secondary questions:
a). how can the design of CEBTS be analysed? and
b). what are the design challenges of CEBTS?

To answer the two secondary questions, this research started with literature review and CEBTS design survey that included examination of sign Standards, visual analysis of sign samples and expert interviews. Three empirical studies were conducted to answer the main question. They examined the effects of adjusting the spatial presentation of Chinese/English legends on participants' performance when reading CEBTS, and under which conditions the bilingual legends could enable participants to identify the direction they should take more quickly and accurately. The adjustments included changes in connecting spacing (text vertical distance connects Chinese and English within a bilingual location name), separating spacing (vertical spacing separates different bilingual location names), and text alignment. The findings of the three empirical studies demonstrated that the spatial arrangement of the Chinese/English legend has a significant impact on CEBTS legibility, which is a key consideration for the legibility improvement of bilingual traffic signs.

This concluding chapter considers the contributions and implications of each specific research theme (e.g., literature review, CEBTS design survey, and empirical studies), broadly in the order presented in the thesis but intersects some contents. Together with the overall outcomes, recommendations for future studies and sign design practices are also provided.

7.2 / Relating the research questions to the knowledge gap

This research contributes to seeking out and filling the knowledge gap in both research and practice domains. The main research question is refined by reviewing previous academic studies, as well as by assessing current design practices.

7.2.1 / The gap in academic knowledge

Due to the cross-disciplinary nature of this research, the literature review draws from three fields of study; environmental psychology, transport engineering and information design. There are abundant studies of legibility research (including sign legibility) within each field. Research within environmental psychology has long investigated the cognitive and perceptual processes of sign information and human capabilities and habits in relation to sign legibility. By providing clear findings grounded in empirical studies, environmental psychologists have greatly contributed to developing methodologies for analysing sign effectiveness. Researchers within the field of transport engineering, who have been concerned with roadways and signs, have demonstrated numerous design solutions in relation to the sign hardware system, such as sign shapes and sizes, sign materials, mounting, and lighting techniques, for the purpose of legibility. Nevertheless, they do not always link the sign legibility to the messages presented on the two-dimensional sign surface strongly enough. Information designers, or sign designers, in contrast, have focused on utilising the graphic and typographic attributes to convey sign information legibly. Many of their studies have concentrated on the influence of typefaces, type size, and the shape of pictorial symbols on sign legibility. They have greatly contributed to assisting users to find their way through effective information.

By combining the findings from each field and utilising their strengths, the literature review has identified that there are a considerable number of studies on legibility in general within all three fields, and most of the studies are established in a monolingual context or in a bilingual context using the same scripts. However, the discussions of bilingual signs using two different scripts that are encompassed in all three fields is strikingly absent. This is one of the academic knowledge gaps that this research identifies and addresses.

Another gap in academic knowledge identified by this research, is that in contrast with many studies that have concentrated on the effect of the legend's intrinsic attributes, there is very little research to support appropriate guidelines for optimising sign legibility through the spatial arrangement of legends. Particularly on CEBTS, many studies have suggested increasing the size of the legends to improve sign legibility. This research, on the other hand, deals with the legend's extrinsic attributes in order to benefit sign users, providing a new way to improve CEBTS legibility.

7.2.2/ The gap in practice

Apart from reviewing academic research in the relevant fields, this research also looks at CEBTS design practices. The approaches used in the survey include:
- Reviewing traffic sign Standards, in which six mandatory Standards, published between 1999 and 2017 in China, dealing with traffic signs used for all status of routes, are reviewed.
- Visually analysing sign samples, in which the urban road sign samples from four cities in China, photographed from a moving car between 2017 and 2019, are looked at and analysed.
- Interviews with professional experts, in which five practitioners were asked to give their perspectives and comments on the issues raised by the survey of Standards and samples.

A survey of the Standards demonstrates that sufficiently clear guidance for CEBTS graphic system is absent from the published Standards. Although there are guidelines concerning sign content, they are insufficiently explicit and comprehensive, while little guidance can be found to support sign layout in the reviewed Standards, and there is currently no guidance to support an appropriate way to arrange both Chinese and English that is coherent and legible. The omissions in the published Standards lead to lots of inconsistences and confusions in practice which is observed through analysis of CEBTS samples and articulated in expert interviews.

Therefore, the findings of the survey strongly suggest that the research question is more than simply about a gap in academic knowledge; it also has implications for professional practice and the use of signs in everyday life.

7.3/ The descriptive framework of the sign graphic system as a tool for researchers and designers

The breadth of literature review has also allowed for connections to be made across disciplines. Building on these, a descriptive framework for analysing a sign graphic system (Chapter 2) that researchers and practitioners can operate and utilise is proposed, which is one of the research contributions.

By linking and utilising the strengths which are apparent in the fields of environmental psychology, transport engineering and information design, this research shows a deep understanding of a sign program. Sign requirements (visibility, legibility, and comprehensibility) are connected to sign design components (information content system, graphic system, and hardware system), and both are considered with respect to human capabilities and habits. Accordingly, the sign graphic system has been identified as the component that information designers utilise to communicate in a meaningful way. The descriptive framework is meant to be useful for sign legibility and is developed to encompass significant variables that are involved in the sign graphic system. It is likewise built by combining and restructuring the different perspectives of designers, transport engineers, and psychologists. The framework, therefore, contributes to providing a more holistic way of considering sign programs.

Firstly, the framework is developed specifically for sign programs. Information designers work on the interpretation, ordering and presentation of visual messages that are intended to transmit specific information to social groups, with specific objectives. The information required on a sign program is very different from the information presented on other scenarios (such as on paper and screen), because sign messages are often displayed in a larger size and in a more complex context (be viewed whilst moving and from far away, for example). Also, the effective presentation of sign information often has implications for human wellbeing, in particularly safety. All those bring additional tasks to information designers and other related practitioners. In this case, the framework contributes to clarifying and systematically structuring the factors within a sign graphic system. As a result, it can be used by information designers and practitioners as a tool to think systematically about what factors they are tasked with effectively communicating in the presentation of information in specific signage scenarios.

Secondly, the framework is distinct because it can be adapted to a wide range of sign programs. The descriptive framework is built upon the analysis of general sign programs, rather than a specific one, and so, it could be applied to many contexts, from walking signs to signs used in a fast-moving condition; from internal building signs to external environmental signs. In particular and distinguished from most of the existing knowledge for analysing a monolingual sign program, the framework proposed in this research can be extended to consider multi-script sign programs (as this research did). It can be used as a checklist for both academics and practitioners when launching a new sign program or reviewing a current one.

Finally, the framework contributes to building a frame for analysing signs from the standpoint of legibility. Visibility and legibility (including comprehensibility here) are sign requirements that demand different design components to support them (Section 1.1.2). In some cases, the two requirements and their required design components, as well as their relationship to each other, are overlapping and ambiguous because they often have interaction effects. This might potentially cause confusion when it comes to thinking about what factors can be utilised to achieve legibility, and what can achieve visibility. This framework clarifies the important factors for researchers and practitioners to consider sign programs for a specific legible purpose.

7.4/ Findings and suggestions for the design of dual-script sign programs

7.4.1/ Spatial arrangement of Chinese/English legends for legibility

Three typographic variables in relation to the extrinsic attributes of Chinese/English legends have been tested, connecting spacing, separating spacing, and text alignment. Three empirical studies have been developed to investigate the effects of adjusting the three variables on CEBTS legibility. Using H as a measure for the character height of a Chinese character, the following are the highlighted findings of the three studies:

Connecting spacing

- The connecting spacing, sign complexity, and the length of English legend have an interaction impact on CEBTS legibility.
- 1/2H connecting spacing performs faster response time in participants with driving experience regardless of sign complexity and the line length of English information.
- The adjustment of connecting spacing does not elicit a significant difference in accuracy.

Separating spacing

- Separating spacing affects the response time regardless of sign combinations.
- Both separating spacing and sign combination appear to not have a significant influence on the accuracy rate on reading CEBTS.
- Both 0.5H and 0.75H separations cause significantly faster reading time and higher accuracy than 1H, but 0.75H is a generalisable separation that could help participants perform well regardless of changes in the total number of place names presented on the stimulus.
- In both 0.5H and 0.75H separation conditions, when sign complexity and total number of place names are consistent, the result does not reveal a direct relationship between the spatial distribution of the place names and the response time.
- The increased response times according to the growth in the number of place names, though some differences are not significant when sign complexity is consistent.

Text alignment

-The left-alignment achieves a faster response time and higher accuracy than the central-alignment when using 0.5H separating spacing on a three-direction sign.
- Both left- and central-alignments could have a faster response time and higher accuracy when applied with a 0.75H separation instead.
- Without the influence of separating spacing, however, central-alignment helps participants to respond faster, especially when they are reading one-and two-direction signs.

The results of connecting and separating spacing studies indicate that wider spacing is required to separate different Chinese/English legends than the spacing required to connect the two scripts into a dual-script legend (0.75H separating spacing compared with 0.5H connecting spacing). Regarding text alignment, the findings may suggest that central-alignment works better at improving sign legibility when the signs only present one Chinese/English legend. But the left-alignment appears to work better when many Chinese/English legends are stacked on a sign. Nevertheless, when many Chinese/English legends are presented on a sign, using a wider separating spacing can bring a relatively flexible usage of the alignments.

The results of the three empirical studies show that the spatial arrangement of the Chinese/English legend(s) has a significant influence on the capacity of participants to identify CEBTS, which is an essential factor for CEBTS legibility. Therefore, the findings provide design suggestions for future design practice through the adjustment of the spatial arrangement of Chinese/English legends for a legible purpose (Section 7.4.1), which could have a positive safety outcome. The findings indicate that future Chinese traffic sign Standards should include sufficient and precise specifications for the spatial presentation of Chinese/English legends. In addition, the Standards should be tightened to guarantee that the execution closely matches the specifications, and sign designers should carefully present Chinese/English legends in the implementation process. This research is timely and relevant to the current bilingual context of most Chinese cities. However, the insights of this research may arguably contribute to both research and design practice undertaken in other countries (e.g., Asian and Arabic countries) that use dual-script traffic signs to consider the importance of spatial presentation in sign legibility, therefore, have global impacts.

Furthermore, this research provides a safe, efficient and cost-effective way to test a range of conditions (Section 7.5.2). The results could be used to develop appropriate materials to test in road simulation experiments (where the materials would be shown at actual size and participants might be driving a car). Therefore, this research could inform which variables would be best for researchers to test further through using a fully interactive driving simulator.

7.4.2/ Suggestions for designing dual-script sign programs

Three primary thoughts raised by the findings of this research could be taken as suggestions for a design and research of dual-script sign programs.

1. Utilising vertical spacing to group and separate bilingual information
The vertical spacing between two lines of dual-script messages is a useful tool that researchers and sign makers can utilise to organise information for a legible purpose. It provides clues as to what information belongs to which group. It also helps separate individual information from groups of information. Specifically, on a dual-script sign, it is important to ensure that the vertical spacing can connect both scripts into a bilingual legend

as a whole, to convey the same meaning to their potential users. But this spacing should not be so tight that it increases the risk of clutter due to double information. It is also important to ensure sufficient space to separate the amount of dual-script information into different groups. And the findings of this research suggest that, compared with the vertical spacing used to connect two scripts into a bilingual legend, using a wider spacing to separate different bilingual information can offer more legible information to road users.

The above suggestion can be supported by the grid theory in information design and the Gestalt theory of proximity. Information designers use a grid to organise space to create structure and direct the eye flow. Samara (2017) states that a common way is to divide space based on content: like information is grouped together, disparate information is separated, and Elam (2007) advocates that the line break (and line spacing) is a useful approach to group and separate content. Using vertical spacing to organise dual-script legends based on semantic meaning of bilingual contents, therefore, improves sign structure and guide driver's eye flow, which, as a result, can increase reading speed. Among the various types of Gestalt groupings, proximity groups objects in terms of physical space (Wertheimer, 1950), which serves to bring together objects that are closer from one another than from others (Frascara, 2015). According to this, the vertical spacing on CEBTS serves to connect English legends to their right Chinese legends and separate one Chinese/English legend from another.

2. Selecting alignment in relation to sign complexity
The alignment of two lines of dual-script information on a sign for legibility purposes is conditional. Choosing an appropriate alignment may require taking sign complexity (or the number of directions the sign indicates) into account. Based on the findings of this research, sign makers could consider using central-alignment on a simple sign indicating one direction, or on a two-direction sign with one destination in each direction to aid road users in identifying dual-script information faster. However, using left-alignment on a two- or three-direction sign, particularly when each direction indicates more than one dual-script legend, improves sign legibility. As an alternative, sign designers could also consider increasing the separating spacing between dual-script legends, which may lead to more freedom to use either central- or left-alignment on a complex sign.

Left-alignment works better when many Chinese/English legends are stacked on a sign, which may be because a straight left edge makes it easier for the users to track from one group of information to the next group, and the direction in which that group of information belongs. However, central-alignment is less legible for a body of text made up of multiple lines with a varied starting position for each line, so there is no consistent place to move eyes to. Central-alignment, however, works better on simple signs where the overall amount of text is small, and centred text may contribute to grabbing the attention of the user and therefore improving the legibility. However, the increased separating spacing may enhance the impact of the proximity so that readers are able to locate the information they need faster regardless of the use of text alignment.

3. Keeping consistency (similarity)
Apart from taking advantage of either the vertical spacing or the text alignment to improve sign legibility, it is important to maintain design consistency throughout the program. In other words, the role of the extrinsic attributes in sign legibility will not be played effectively if they are inconsistently designed. Presenting dual-script information consistently makes road signs more predictable and sets drivers' expectations for how signs will appear, allowing them to process individual signs more rapidly. This suggestion derives from the restriction of human capability in visual research (Section 1.2.1). It is also based on the similarity principles of Gestalt Psychology. The similarity refers to grouping based on repetition of features (Wertheimer, 1950) in order to help with arranging the layout's flow which is the key to visual unity (Golombisky & Hagen, 2013). Based on the principle of similarity, it is important to keep repeating the same extrinsic attributes on every sign so that the same grid skeleton will contribute to the consistency.

In summary, the findings show that the extrinsic attributes of a dual-script legend are very important design elements, just like all other sign elements such as messages, arrows, symbols, etc. Though they often go unnoticed, they should be designed intentionally in a very subtle way to emphasise other sign elements of the layout. The appropriate design of the extrinsic attributes is beneficial for drivers because it can give visual cues and guide drivers on a specific path assisted by the sign. It aids the information being communicated in a meaningful way.

7.5/ Research methodological contributions

7.5.1/ CEBTS practice survey

The CEBTS practice survey contributes to cataloguing and arranging the data for the current design of CEBTS into order and, as a result, enables new interpretations.

In this research, by documenting the existing Chinese sign Standards, the guidelines in relation to the sign graphic system are extracted and presented systematically based on the proposed descriptive framework. It is more than a simple list of the guidelines; it structures and groups the guidelines in a systematic way, which not only helps to gather meaningful and in-depth insights into the research questions, but also favours both researchers and practitioners in better understanding the current CEBTS design. The design guidelines in the reviewed Chinese sign Standards are dispersed in different sections and chapters, and some guidelines are provided in the Standard Appendices. This has resulted in inconvenient retrieval and time-consuming to link or compare relevant guidance. Also, there appears to be no studies or other relevant documents that have attempted to catalogue the current design guidance of Chinese traffic signs in a meaningful way to researchers and practitioners. Thereby, this research integrates all design guidance from the current reviewed Standards into one place. For researchers, this way of organising Standard guidance could shorten the research time for future studies, with the purpose of looking at how traffic sign design is incorporated into the Standards and what is included and excluded from the Standards. It can also help practitioners to locate the specific guidance more quickly and easily which will make their decision-making process more effective.

In addition to looking at the existing sign Standards, the visual analysis collected sign samples and expert interviews. Triangulating various qualitative methods to explore the answer to one research question (what the design challenges of CEBTS are) provides a more comprehensive view of CEBTS design practice. To some extent, it alleviates the misleading conclusion that may be caused by researcher bias or a small qualitative research sample. Since the findings gained from each method can be compared with each other, they can then be verified by linking them with other findings. For example, in the survey, the review of sign guidelines shows that there is limited guidance relating to the spatial arrangement of the two languages on CEBTS. This finding, likewise, is observed from the sample analysis. The interviews with the practitioners, as a strong supplement, also highlights the same challenge. Therefore, by applying various research methods, it can be demonstrated that the critique of the status quo argued in this research is presented in practice and shared by relevant professionals.

7.5.2/ Empirical studies

This research uses a mixed methodology that not only includes qualitative research (as mentioned in the above section), but also applies quantitative research. The three empirical studies in this research utilise the experimental quantitative research method that manipulates independent variables to measure their effect on dependent variables.

The simplified laboratory approach to understanding driver performance has often been criticised because it can hardly mimic the real-life complex environment. However, Waller (2007) suggests that testing signs in situ and in real settings 'would be impracticable for several reasons, including the high cost of mounting signs with multiple factors in turn, and the difficulty in obtaining judgements in consistent conditions' (p.3). Although the experimental findings of this research are obtained through participants sitting in a room, reading from a monitor display without the stress of driving, the important thing is that all test variables are compared under equal conditions. It is the comparison that is important to the experiments, not absolute measures.

Nonetheless, ecological validity is important, and the tested variables are sufficiently considered to be relevant to the real-world context. In this research, the material design is informed by both visual analysis of real CEBTS samples and systematic analysis of existing

Standards. For example, the video stimuli and CEBTS shown in the stimuli are controlled in line with the traffic rules in China so that it is able to simulate the actual driving experience in China as much as possible. CEBTS are gradually enlarged in the display and participants are asked to perform a search task. Similarly to when driving, the sign appears to expand as the driver approaches it and drivers need to look for a destination from a sign encountered along the route, and so, the test is able to simulate the navigation activities whilst driving. Additionally, the variables are not selected to test in isolation but the relationships between variables is considered.

Furthermore, CEBTS legibility is tested by using a monitor displaying a 3D graphical scene of the virtual world which is reasonably representative (the video stimuli align with existing Standards and conventions), at the same time, it ensures participants' safety whilst performing the tasks. In a real driving condition, participants must do other tasks in parallel, such as controlling the vehicle and interacting with other vehicles (Smiley & Dewar, 2015) which would bring potential risks. While, in this research, without the stress of driving, participants sit in a quiet room and only need to view video clips and press the keyboard to make responses, which enables their safety.

Using a fully interactive driving simulator (Cantin et al., 2009; Jamson et al., 2005; Tejero et al., 2018; Yang et al., 2020) is another way to test traffic signs in controlled conditions whilst guaranteeing safety. There are existing state-of-the-art facilities in driving simulation centres around the world[23] that can simulate the interaction between driving behaviours and the complex environment. For example, a test could include brake, accelerator pedals, steering, and all manual controls; create realistic sounds of the engine and other noises; provide a view seen through the vehicle's rear-view mirror, and so forth. However, accessing a full integrative driving simulator is an expensive process and there are limited simulation centres that can provide research services. In contrast, the method used in this research is relatively cost-effective and easier to access.

Overall, this research makes a methodological contribution through demonstrating how using a monitor to display stimuli in empirical studies can ensure that variables are sufficiently controlled and compared under equal conditions, and at the same time, to ensure these variables and findings have ecological validity. In addition, the experimental design performs low-risk studies, meanwhile, the method is easier and quicker to apply. There is still a need for testing signs through a fully interactive driving simulator, but this research

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[23] In England: Institute for Transport Studies, University of Leeds (http://www.its.leeds.ac.uk/); Transport Research Laboratory (http://www.trl.co.uk/);
In France: INRETS (http://www.inrets.fr/index.e.html);
In North America: many excellent laboratories, one of which is the University of Michigan Transportation Research Institute (https://umtri.umich.edu/home-page/driving-simulator/);
In Australia: Monash University Accident Research Centre (https://www.monash.edu/muarc).

approach demonstrates that it is efficient to test a range of variables then to identify which combinations might be significant and merit further testing through other methods.

7.6/ Future research

As the empirical studies mainly investigate the impact on the reading behaviour of the participants aged between 25 and 55, the results and findings are measured focusing on this specific group. The differentiation between younger and older individuals is not sufficiently shown in the studies. Therefore, it remains to be determined if the impact of the variables on bilingual sign legibility that is tested in the studies are more or less apparent in younger and older individuals. Additionally, most participants are designers or typographers recruited from the Department of Typography and Graphic Communication. Their expertise may contribute to the recognition of scripts and reduce their response time (Dyson, Tam, Leake, & Kwok, 2016). And so, further studies would be needed to validate the findings in larger participant samples with a variety of professional backgrounds.

The methodology applied to the empirical studies is capable of accommodating further extensions which could improve its performance quality and enable further investigations. Here is a list of future research questions arising from this research:
- What are the impacts of connecting spacing, separating spacing, and text alignment on the legibility of bilingual expressway signs?

- What effect does connecting spacing, separating space, and text alignment have on legibility in other sign categories, e.g., stack-like signs and multiple column signs?

- How does sign layout affects CEBTS legibility?

- How does the spatial presentation of dual-script legends affect dual-script signs' legibility in a pedestrian context (e.g., airports and hospitals)?

In terms of the findings of this research, there are also some recommendations for relevant practitioners and researchers.

- For sign specifications and policymakers:
1. The awareness of the significant role of the sign graphic system in sign legibility and, in turn, to benefit society in general, should be enhanced. Therefore, designers should be able to have a significant role in the guidance formulation process.

2. Although there are small cities using Chinese monolingual traffic signs, it is evident that bilingual traffic signs are used in most metropolises in China. Hence, in the

Standards, both Chinese and English should be given equal importance to meet the needs of all potential users, in other words, the specifications of English legend should be provided explicitly.

3. In the current reviewed Standards, the guidelines in relation to sign graphic system are found to be difficult and inconvenient to retrieve, because they are dispersed throughout different chapters, and some guidance is provided as an annotation and some are shown in the appendix. It could be meaningful to integrate all the current design guidelines into a single design chapter that also includes clear guidance of the way to arrange the two scripts and sign layout. It could bring convenience to sign makers, or designers, to find specific guidance more efficiently, and as a result, may benefit their decision-making in practice.

-For relevant organisations:
1. Currently, the final presentation of CEBTS is, much of the time, determined by the local design and construction consultancies, and these consultancies are selected via tendering process, so they are not fixed. However, a nominated fixed body may need to take responsibility for CEBTS design and implementation of the design to prevent inconsistencies caused by misunderstandings between bodies.

2. The compliance with an enforcement of the Standards should be enhanced in the implementation process.

- For researchers:
1. The research in relation to the design of Chinese/English bilingual signs is at an initial stage and there are many critical challenges that need to be explored and investigated. Relevant researchers should address the literature gap. The evidence provided by the background research could help to promote the development of visual guidance, inform the decision-making of sign makers and designers, and could also help remove other barriers observed in practice.
2. For the current design of CEBTS, sign layout is an urgent issue that researchers could focus on.

This research is mainly analysed from the point of view of an information designer. It demonstrates that the spatial arrangement of two-script legends plays a key role in sign legibility. It shows the importance of separation and grouping of dual-script information in benefiting road users and distinguishes and connects between double information based on proximity. While it is obvious that a better solution should not be a one-person or one-institute endeavour, it does require increased coordination and collaboration among all organisations, individuals, and processes.

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9/ Appendices

I. Expert interview question lists

Question list for Interviewee Regulator.

* Interviewee Regulator is now the Vice President of the Beijing Highway Survey and Design Institute. He mainly focuses on research on road traffic safety and traffic engineering. He also engages in compiling traffic road Standards, as well as providing evaluation and consulting.

Research questions	Questions to Institute
How are decisions and considerations made about visual guidance in the National Standards?	Could you talk through how National Standards were issued and what is your role in this process?
	How do you carry out this role?
	Did you meet any challenges when executing the role, and how did you fix them?
	What are the challenges you face that affect the design of traffic signs?
	In Chapter 4.2, National Standard GB5768 'Sign page layout', how is the decision made about the size (or height) of Chinese characters?
	About the relationship between the size of character and the approaching speed of vehicles, in what way is the data collected and analysed? Is it based on experimental results and how the experiment was conducted?
	The 0.75 times the width of the Chinese character is adopted when the sign surface space is limited according to the Standard. Is this without compromising the legibility of the Chinese characters?
	I noticed that the guidelines for how Latin letters are displayed on signs are limited, and the sign examples provided in the Standard are without English translation but are presented in a bilingual form in practice. Could you explain why?
	The spacing regulations are limited, such as the spacing between characters/letters and graphic elements (arrows, border, compass and so on), and the word spacing, line spacing and so on. Thus, how to fix spacing issues in practice?
	How are users involved in the whole process?

Question list for Interviewee Implementor

* Interviewee Implementor is currently working in the traffic facilities management office, the traffic police detachment of the Dalian Municipal Public Security Bureau. He is responsible for road traffic planning, including the design, production, implementation and maintenance of road traffic signs.

Research questions	**Questions to Institute**
How do the National Standards of traffic signs apply to practice?	To what extent does your job relate to traffic signs?
	What is your department's role in the design of the traffic signs? How does the department carry out this role?
	Are there any organisations assisting in executing the same or similar role? If there is, what are their specific responsibilities?
	Do you need to hand over professional work to other organisations or companies during the lifetime of the project? If it is, what are their specific roles?
	Are there any National or Regional Standards of Traffic Signs provided to guide the work?
	How does your department execute its role whilst undertaking this work?
	How is the decision made if the Standards cannot cover a specific practical situation?
	In what way is it decided whether an improvised design (of the specific practical situation) can work well?
	How is the decision made on whether the traffic signs need changing or updating, and what is the process of updating a traffic sign?
What is the current status of design for traffic signs in Dalian?	Did you meet any challenges when executing your role, and how did you fix them?
	What are the challenges that your department faces that affect the design of traffic signs?
	I noticed that the surface design of one category of traffic signs is different in Dalian than that in the other cities, what are the reasons for this inconsistency?
	Who is responsible for the surface design of traffic signs?
	When and how are decisions made about typographic and graphic elements?
	Is the design of traffic signs based on user experience?
	From your perspective, what is the current situation of traffic signs in Dalian? In what way to improve its application.

Question list for Interviewee Designer

* Interviewee Designer is the founder of HUA WEN font library, the Chairman of Beijing Hua Wen Century Advertising Co., Ltd. He was the deputy director and professor of the China Central Academy of Fine Arts, and the multimedia director of the Beijing Olympic Committee. He and his team designed the special typeface for traffic signs and supported the promulgation of the Standard *Technical Guidelines for the Replacement of National Expressway Network Related Traffic Signs*.

<table>
<tr><th>Research questions</th><th colspan="2">Questions for interviewee</th></tr>
<tr><td rowspan="5">What is the design process used in carrying out the special traffic typeface?</td><td colspan="2">What is your role in the design of the special traffic typeface?</td></tr>
<tr><td colspan="2">What is the motivation for designing a new typeface to replace the previous one? What is the aim of it?</td></tr>
<tr><td colspan="2">How long does it take to complete the design of the new typeface?</td></tr>
<tr><td colspan="2">Do you face challenges when producing a new typeface?</td></tr>
<tr><td colspan="2">How do these challenges affect the design of new typeface, and what are the solutions to these challenges?</td></tr>
<tr><td rowspan="3">What typographic and graphic elements need to be considered when designing a typeface for traffic signs?</td><td colspan="2">What changes or adjustments are made for the new typeface compared with the previous one?</td></tr>
<tr><td colspan="2">What typographic and graphic attributes should be focused on when designing the special traffic typeface? Why?</td></tr>
<tr><td colspan="2">How does the new typeface meet the requirements of legibility?</td></tr>
<tr><td rowspan="4">How to balance the Latin letter with the Chinese typeface?</td><td colspan="2">What typographic and graphic attributes should be considered when designing the Latin letters for traffic signs? Why?</td></tr>
<tr><td rowspan="2">Did you design the Chinese typeface first then design Latin letters, or did you design them at the same time?</td><td>If designed separately, how do you make two languages match each other? Or how do you design Latin letters based on the finished Chinese typeface?</td></tr>
<tr><td>If the designs are carried out simultaneously, how were the Chinese and Latin typefaces produced and what consideration did you looked at first?</td></tr>
<tr><td colspan="2">What are the similarities and differences when designing Chinese typeface and Latin letters? Does this also work on traffic signs?</td></tr>
<tr><td rowspan="2">How does the new typeface work well with the other elements on traffic signs?</td><td colspan="2">In the process of designing a new typeface, do you consider how it matches other elements, arrows and graphic samples for example?</td></tr>
<tr><td colspan="2">How are decisions made about the way the sign surface is presented with new typeface and other elements?</td></tr>
<tr><td rowspan="2">How are users involved in the design process?</td><td colspan="2">How is it confirmed that the new typeface is ready for use?</td></tr>
<tr><td colspan="2">Are the new typeface designed based on user experience?</td></tr>
</table>

Question list for Interviewee Typographer and Interviewee Police.

* Interviewee Typographer is an associate professor in the School of Design, Jiangnan University. He has long devoted himself to the creative practices of Chinese character design, visual communication design. Interviewee Police is a traffic police officer in Dalian.

Research questions	**Questions for interviewee**	
What is the current status of design for traffic signs in China?	Could you introduce your occupation?	
	To what extent does your job relate to traffic signs?	
	From your point of view, do traffic signs give full play to their functions in practice?	
	What causes traffic signs to lose some parts of their functions?	
	Are traffic signs in your city easy for you to read?	
	How do you achieve the legibility of traffic signs from your professional knowledge?	
	Question for Interviewee Typographer: In your opinion, what typographic and graphic elements should be redesigned in order to achieve the legibility requirements of traffic signs?	Question for Interviewee Police: (Ask only if the interview atmosphere is comfortable) According to your working experience, how many cases of traffic accidents that caused by the difficulty in recognise traffic signs have you dealt with?
What is the current status of design for Chinese-English bilingual traffic signs in China?	Have you paid attention to the Latin letters on bilingual traffic signs?	
	Do the Latin letters affect your recognition of traffic signs?	
	What are your feelings or views about Latin letters that are shown on bilingual traffic signs?	
	Question for Interviewee Typographer: In your opinion, how do you balance Latin letters with Chinese characters on traffic signs?	Question for Interviewee Police: According to your working experience, will the Latin letters shown on bilingual traffic signs affect traffic safety?

II. Supplement analysis of Study A (age range18-25)

- Participants with driving experience (3 participants)

A two-way repeated measure ANOVA was conducted to determine the effects of the line length of English information and connecting spacing on time taken to reading the CEBTS in two sign complexities separately. The results showed that, in both simple and complex sign conditions, there was no significant two-way interaction between the two variables:
simple sign condition, $F(6, 12) = 1.353$, $p = .308$;
complex sign condition, $F(6, 6) = 1.558$, $p = .302$.
Additionally, in both sign complexity conditions, the different levels of connecting spacing did not elicit a significant mean difference in response time.

- Participants without driving experience (five participants)

A two-way repeated measure ANOVA was conducted and the results showed that, in simple sign conditions, there was no significant two-way interaction between length of English information and spacing levels, $F(6, 24) = .758$, $p = .610$. However, there was a significant interaction between the two variables in the complex sign condition, $F(6, 24) = 7.337$, $p < .001$.

In a complex sign condition, the different levels of connecting spacing elicited a significant mean difference in response time when the length of English text including 8 letters $F(3, 12) = 10.786$, $p = .001$, and 12 letters, $F(3, 12) = 16.689$, $p < .001$, but not for the length of 10 letters, $F(3, 12) = 2.740$, $p = .090$. Post hoc analysis with a Bonferroni adjustment revealed that, in a complex sign condition with the English place name including 12 letters, a significant mean increase of 1.528s and 1.383s by applying 1/2H connecting spacing (95% CI [.741, 2.343], $p = .005$) and 3/4H connecting spacing (95% CI [.027, 2.741], $p = .047$) than using the 1/3H spacing. However, there was no significant mean difference between 1/2 H and 3/4H (95% CI [-.970, .61], $p = 1.000$).

III. Chinese/English legends used on stimuli

8-letter

凡尚/Fanshang
凤苑/Fengyuan
高眉街/Gaomei St
华竹街/Huazhu St
克西公园/Kexi Park
南美广场/Nanmei Sq
三民路/Sanmin Rd
帖奏广场/Tiezou Sq
吞规街/Tungui St
永田/Yongtian

10-letter

按步桥/Anbu Bridge
财将街/Caijiang St
春帮路/Chunbang Rd
电占广场/Dianzhan Sq
耳丝桥/Ersi Bridge
弓扬艺/Gongyangyi
冠王路/Guanwang Rd
互忘公园/Huwang Park
净念路/Jingnian Rd
令丰街/Lingfeng St
丽杨公园/Liyang Park
马玉桥/Mayu Bridge
青典街/Qingdian St
诗卷门/Shijuan Men
五古桥/Wugu Bridge
五山公园/Wushan Park
勇顺路/Yongshun Rd

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别迟桥/Biechi Bridge
岔纪肠路/Chajichang Rd
长江街 /Changjiang St
丞幺五路/Chengyaowu Rd
尘挖桥/Chenwa Bridge
陈线公园/Chenxian Park
闯找街/Chuangzhao St
出达正街/Chudazheng St
当元行/Dangyuanhang
二兰仲路/Erlanzhong Rd
奉灵公园/Fengling Park
革专刃路/Gezhuanren Rd
共毕园路/Gongbiyuan Rd
关奂公园/Guanhuan Park
官用公园/Guanyong Park
号扎桥/Haozha Bridge
禾昌音街/Hechangyin St
红县园 /Hongxianyuan
环亢公园/Huangkang Park
井闲公园/Jingxian Park
亮皇街/Lianghuang St
隶政音路/Lizhengyin Rd
南麦肖路/Nanmaixiao Rd
让玄公园/Rangxuan Park
伞叉桥/Sancha Bridge
尚因目路/Shangyinmu Rd
圣尝街/Shengchang St
甩兰乎路/Shuaihulan Rd
双小街/Shuangxiao St
思升右路/Sishengyou Rd
丸厂木街/Wanchangmu St
瓦向言路/Waxiangyan Rd
阳土丰街/Yangtufeng St
羊先庙/Yangxianmiao
印光庙/Yinguangmiao
尹尧肖路/Yinyaoxiao Rd
佣贤店/Yongxiandian
友好桥/Youhao Bridge
元希桥/Yuanxi Bridge
枣览桥/Zaolan Bridge
早未馆街/Zaoweiguan St
中匠路/Zhongjiang Rd
终伟四路/Zhongweisi Rd
爪木欢街/Zhuamuhuan St
庄层街/Zhuangceng St