Collecting and Analyzing Stakeholder Feedback for Signing at Complex Interchanges

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FOREWORD

Interchange navigation presents a range of challenges that are different from those associated with driving on continuous roads. For example, interchanges confront the driver with time-sensitive task demands (i.e., forced-paced tasks). More specifically, drivers at unfamiliar interchanges must read the available signage, observe pavement markings, and determine a path through the interchange before they reach the gore point. As an additional source of stress, driver errors at interchanges are often more difficult to correct since drivers transfer to a grade-separated freeway, highway, or roadway which provides limited access points for their return to the original roadway. Clear navigation signage is needed to guide drivers and reduce errors.

Recent Federal Highway Administration research examined challenges that drivers face while navigating complex interchanges, which was important for understanding these problems from the drivers' perspective. The current project extended this line of research by conducting interviews with State engineers and other stakeholders about the practical challenges they encounter related to complex interchanges. These interviews provided information about how stakeholders identify problem interchanges, what types of problems occur, how they can address those problems, and how they deal with unique configurations that are not covered by existing design references. These findings were then used to identify research gaps, which were subsequently prioritized by a larger group of stakeholders. Obtaining this type of feedback is valuable because the stakeholders are the end-users of the findings that will emerge from future research projects. Thus, obtaining feedback directly from stakeholders is an important way to ensure that future research remains calibrated with the information needs of engineers and other practitioners.

Monique R. Evans
Director, Office of Safety
Research and Development

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16. Abstract

The purpose of this project was to identify design constraints related to signing, markings, and geometry for complex interchanges, and then to identify useful topics for future research that will yield findings that can address those design issues. Obtaining this feedback was an important way to ensure that future research remains calibrated with the information needs of engineers and other practitioners.

This project involved conducting phone interviews with 17 State transportation departments, represented by 28 individuals. These interviews provided information about how stakeholders identify problem interchanges, what types of problems occur, how they can address those problems, and how they deal with unique configurations that are not covered by existing design references.

Complex interchanges pose an ongoing challenge to roadway engineers and State transportation department personnel. These interchanges often involve multiple routes that converge or diverge within a short distance, resulting in geometric or signing elements that ultimately cause higher workload for drivers. However, there is no simple definition or single prototype example of a "complex interchange", and a variety of geometric and signing elements can make different interchanges complex and difficult for drivers to navigate. Consequently, the human factors problems that drivers can face at these interchanges also vary greatly, which is reflected in the wide range of research needs identified by stakeholders. They also see value in additional research and design guidance that would address these information gaps.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	$candela/m^2$	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	$candela/m^2$	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AASHTO	American Association of State Highway and Transportation Officials
APL	Arrow-per-Lane
DDI	Diverging Diamond Interchange
FHWA	Federal Highway Administration
HOV	High-Occupancy Vehicle
ITE	Institute of Transportation Engineers
MUTCD	Manual on Uniform Traffic Control Devices
NCHRP	National Cooperative Highway Research Program
SLOSS	Suggested List of Surveillance Study Sites
TRB	Transportation Research Board

CHAPTER 1. INTRODUCTION

BACKGROUND

Recent research in complex interchanges investigated driver expectations and signing at complex interchanges.[1,2] The results from these efforts indicated that complex interchanges pose significant challenges to most drivers, and that many of these problems arise from basic human factors issues related to various aspects of interchanges. For example, one important design issue identified was that the perceptual grouping of information elements on guide signs had clear and systematic effects on how drivers interpret and use sign information, and moreover, that the inappropriate application of perceptual grouping led to incorrect driver assumptions about lane destinations. This is a problem from a sign design perspective because these perceptual factors are a source of "uncontrolled" variability in terms of how drivers respond to guide signs. Fortunately, these basic perceptual factors, in addition to other human factors issues, can be investigated using empirical data collection methods. They also have the potential to lead to useful design guidance for promoting the consistent and effective implementation of good practices related to perceptual elements of guide signs.

One limitation of the work conducted in the driver expectations study is that the research was conducted only from a driver's perspective. This was necessary in order to first establish that the human factors concerns represent real and systematic problems. However, before continuing with additional research into these issues, it is an opportune time to consult with roadway engineers and other stakeholders to identify how they can best be served by new research and design guidance about human factors and complex interchanges. Specifically, it is important to know what their constraints are regarding design options. This is critical information because it is important to focus subsequent research on aspects that can be practically implemented. Furthermore, consulting with the stakeholders, who will be the end-users of the design information that this research will produce, is a useful way to gain an understanding of their design process, issues they must consider, trade-offs they make, etc. This information is also invaluable for identifying research questions that stakeholders will find useful and will be able to apply to their specific design problems. All of these aspects were considered during this project.

PROJECT OBJECTIVES

The objectives of this project were as follows:

- To work with roadway engineers and other stakeholders to identify design constraints applicable to signing for complex interchanges.
- To identify useful topics for future research on complex interchanges that might yield findings that can address the design issues identified by stakeholders.

PROJECT OVERVIEW

This project mainly consisted of two stakeholder activities to gather feedback about complex interchanges.

The first activity was stakeholder interviews. These were conducted to collect qualitative data from stakeholders about the following topics:

- Stakeholders' conception of complex interchanges, and experiences with complex interchanges in their area.

- Human factors issues and driver considerations that stakeholders have had to address at complex interchanges.

- Stakeholders' thoughts about human factors research needs that can be used to identify candidate topics for future research plans.

Following the identification of the research needs, a follow-up survey was also used to gather the opinions of a broader group of stakeholders to prioritize future research topics.

REPORT OVERVIEW

This report provides a description of the methods, results, and conclusions from the stakeholder feedback activities conducted in this project. The body of this report contains the following topic sections:

- **Methods.** This section reviews the methods used to recruit stakeholders, collect their feedback on concepts related to complex interchanges (e.g., signs, markings, roadway geometry, etc.), gather their opinions on the priority level of the different research ideas, and analyze the data.

- **Results.** This section describes the results of both the stakeholder interviews and the follow-up survey.

- **Conclusions.** This section discusses ideas for future research and other conclusions drawn from the results.

- **Appendices**

    - Appendix A: Flyer used for recruitment efforts.
    - Appendix B: Visual presentation of interchange signing examples.
    - Appendix C: Interview guide used during the interviews.
    - Appendix D: Follow-up survey questions.

CHAPTER 2. METHODS

This section of the report describes the methods used to conduct the stakeholder activities and analyze the data.

STAKEHOLDERS

A key element to the success of this project was the participation of stakeholders. The recruitment methods used and general characteristics of those who participated are described below.

Stakeholder Recruitment

The target stakeholders were transportation professionals, primarily roadway designers and engineers, who work for State transportation departments and have responsibilities related to interchange planning, design, and/or maintenance. Stakeholders were recruited using existing contacts from our Federal Highway Administration (FHWA) complex interchange project panel, through networking and recruitment by FHWA contacts, and at two in-person events: a local Washington Institute of Transportation Engineers (ITE) chapter meeting and the Traffic Control Devices Consortium Pooled Fund Study Annual Meeting. The recruitment flyer, provided in appendix A, was prepared and distributed in-person and electronically to provide background information on the project to stakeholders.

Three criteria were used for recruiting stakeholders to participate in the interview process. The first was based on the recommendations of the members of the complex interchange project panel. The project panel has varied experience with aspects of interchange design and is therefore familiar with States or regions that have a number of complex interchanges. The second criterion was to obtain a geographic dispersion of individuals. The goal was to obtain feedback from a distributed group of States or regions to allow us to gain information about any environmental, geographic, or organizational differences across the country. The third criterion was to gather a variety of professional perspectives from individuals with varied backgrounds, including those who have experience with signing, marking, and geometric design. If the initial contact in a State was with an individual who did not have experience with interchanges or who felt another individual in his or her group or department would be more suited for the interview, contact information for this other individual was provided and they were contacted about the project.

For the follow-up survey, the link to the questions was emailed out to the entire original stakeholder contact list, even those who did not respond to the original request for participation. Participants in the interviews were also emailed, if they were not included in the original list. Those who were emailed were invited to forward the link to anyone else within their organization who would be well-suited to respond.

Participating Organizations

Figure 1 illustrates the geographic distribution of stakeholders who were interviewed, participated in the follow-up survey, or both (“dual participant”). Each region indicated as an interview participant took part in a single interview, with the exception of Washington. Two

interviews were conducted with the Washington State Department of Transportation, with two individuals on the first interview and one individual on the second interview. Note that on figure 1, Alaska, Hawaii, and Puerto Rico are shown beneath the contiguous United States.

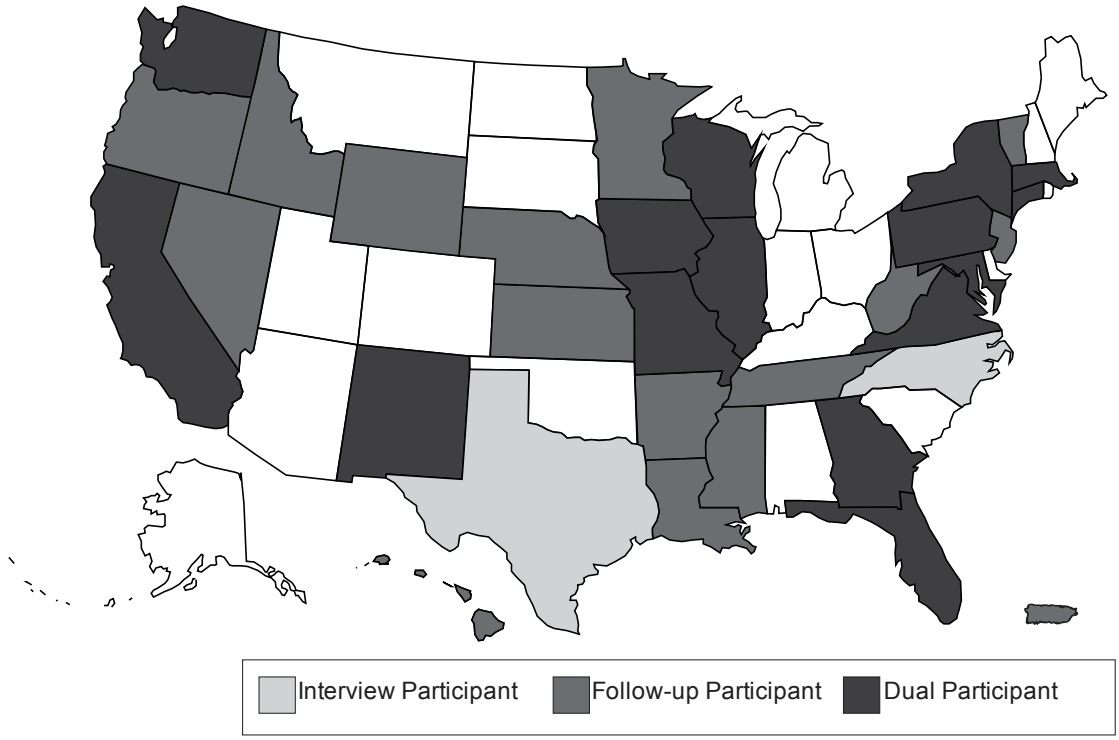

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Figure 1. Illustration. Map of State and regional transportation departments that participated in the interviews, follow-up survey, or both.

Table 1 provides the number of participants on the phone for each interview and the number of participants in the follow-up survey. Each interview involved one to five individuals representing their organization. Interviews were conducted with 17 State transportation departments, representing 28 individuals. The survey was completed by 66 individuals (or groups), from 32 regions, including some individuals from FHWA. Note that the number of individual participants does not necessarily correspond to the number of people whose opinions are represented. Some individuals who participated in the interview did not contribute comments, while some survey responses may include the opinions of multiple individuals within a group.

Table 1. Number of participants in each activity by State/region.

State/Region	Interview	Survey
Arkansas		1
California	1	6
Connecticut	1	1
District of Columbia		1
FHWA*		5
Florida	1	2
Georgia	1	1
Hawaii		1
Idaho		1
Illinois	1	1
Iowa	5	3
Kansas		2
Louisiana		2
Maryland	1	1
Massachusetts	2	2
Minnesota		2
Mississippi		1
Missouri	1	1
Nebraska		1
Nevada		1
New Jersey		2
New Mexico	1	1
New York	3	3
North Carolina	1	
Oregon		3
Pennsylvania	1	2
Puerto Rico		1
Tennessee		2
Texas	1	
Vermont		1
Virginia	1	6
Washington	3	3
West Virginia		1
Wisconsin	3	3
Wyoming		2
Total	28	66

*5 FHWA employees also completed the survey.

Stakeholder Characteristics

Figure 2 is a histogram showing the distribution of years of experience across stakeholders. This figure shows that the full range of years of experience was represented by the participants in each activity. In particular, a significant number of the participants had many years of experience in their technical domain.

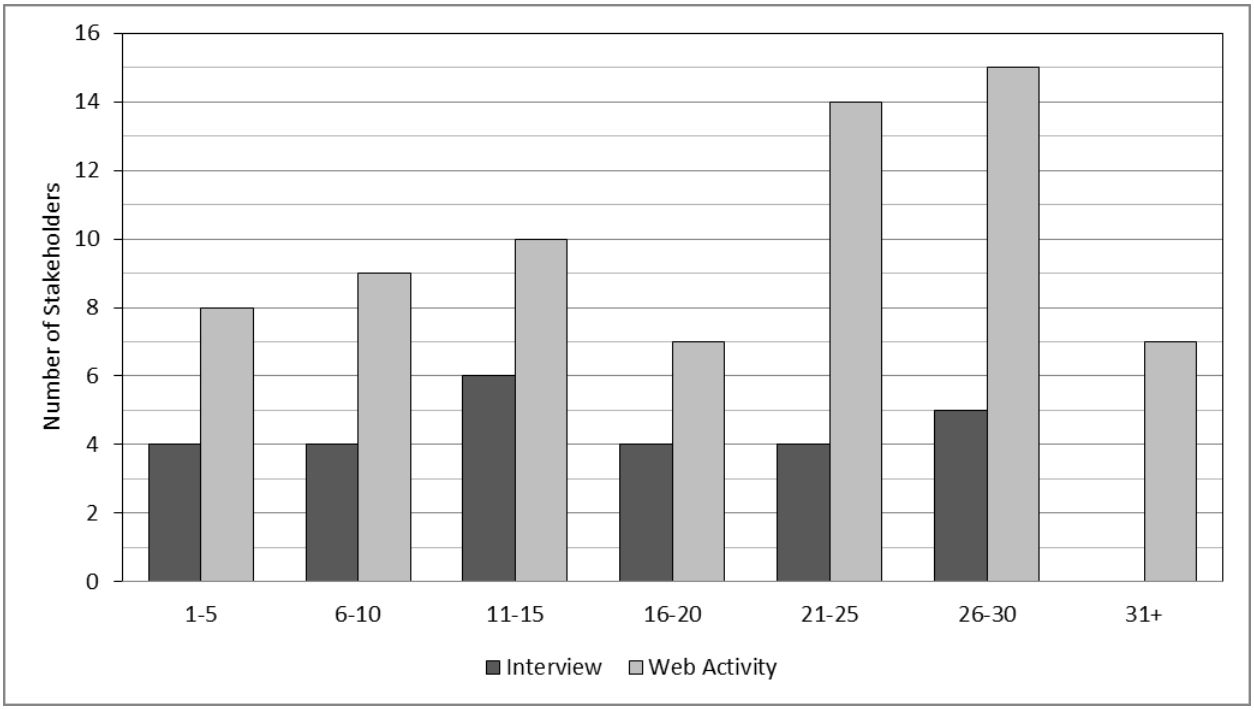

Figure 2. Histogram. Distribution of years of experience across stakeholders.

Stakeholders had experience with the signing, markings, and geometry of interchanges and held jobs at a variety of levels. Table 2 shows the number of stakeholders associated with each combination of job category and primary technical domain. Many participants fell into the Engineer job category. Note that there was substantial overlap between these categories based on the stakeholder descriptions of their job responsibilities, but table 2 provides a high-level overview of the breadth of experience and domain-knowledge of the stakeholders. The table values in brackets represent the interview participants, while the values outside of brackets represent the follow-up survey participants. Since the survey was anonymous, it is unknown if some of the interview participants also completed the survey.

Table 2. Distribution of job category and primary technical domain of stakeholders for the survey and interviews.

Job Category	Example Titles	Signs and Markings	Geometry	Planning and Development	Policy/ Compliance	Safety*
Manager/ Director	Statewide Director of Design; Manager of Signs, Standards and Specification	3	3	3 [1]	2 [5]	0
Project Manager	Project Manager/Designer; Program Manager for Highway Construction Program	1	4	2 [2]	0	1
Engineer	State Traffic Engineer; State Sign & Marking Engineer; Policy and Standards Engineer	17 [9]	12 [1]	7 [6]	5 [3]	10

*The Safety category was not given as an option in the survey response set but was written in by many participants.

Although we originally intended to include consultants in the stakeholder group, many stakeholders said that they rarely use outside consultants for human factors or driver-related questions.

PROCEDURES AND MATERIALS

The phone interview was the primary method used to identify research needs and stakeholder concerns. This approach yielded a large and diverse set of research needs. A follow-up survey was then conducted with a broader group of stakeholders to gather information that could be used to prioritize the initial set of research needs.

Phone Interview Protocol

Interview participants received a handout before the interview via email. This provided them with background information on previous complex interchange projects and a list of topics that would be discussed during the interview.[(2)] Stakeholders were also asked to prepare one or two specific examples of challenges they had previously addressed involving complex interchanges.

Phone interviews were conducted by two researchers, one serving as the interviewer and the other serving as a note-taker. Notes were entered into an electronic version of the interview guide during the interview. All interviews were recorded to allow the notes to be checked afterwards for accuracy. After the notes were verified, the recordings were deleted. The electronic versions of the notes were later compiled by question across interviews, prior to data analysis.

Most interviews lasted 1 h. The interview closely followed the interview guide question sequence and stakeholders were given as much time as they needed to answer each question. As appropriate, follow-up questions were asked to either gain more information about the question topic or to better understand the answer provided.

A presentation provided via web conferencing was used to show examples of complex interchanges to stakeholders (see appendix B). This helped explain different topics such as destination grouping, visual perspective, and information overload, which can affect how drivers interpret the sign information or their understanding of how to complete the movements they want to make. The examples were intended to help the stakeholders come up with examples of their experience with complex interchanges in case they had trouble coming up with examples on their own. In addition to the presentation, there were instances in which the stakeholder shared his/her screen to show the example interchange on a map. If the stakeholder verbally provided the roads that make up the interchange (e.g., I-85N at I-985), this location was entered into Google Earth™ and shared on the web conference to help the stakeholders explain the example, and to help the researchers understand it.

Interview Guide

The interview moderator guide is provided in appendix C. The first set of questions in the interview guide asked about basic stakeholder background information including job title, job responsibilities, number of years in their current position, and how their role fits into the design or analysis processes for interchanges. If multiple individuals participated in the interview, this section was covered for each individual. The purpose was to obtain information about the individual's background and information about their design process to help understand their experience with interchanges.

The second set of questions was asked to gather information about an example of a time in which stakeholders identified and resolved or attempted to resolve issues with complex interchanges. These questions asked them for details about the example, such as how they knew what the problem was, how they tried to fix it, and what design information would have been useful, if it had been available. If the stakeholder had more than one example, the same questions were asked about each example. The purpose of this set of questions was to obtain specific information about interchange issues and relevant background information on stakeholder processes, such as their approaches for fixing issues, monitoring the success of those fixes, and filling information gaps.

The third set of questions asked about their experience with complex interchanges. Specifically, what they think makes certain interchanges more difficult for drivers to navigate, how often they do projects related to complex interchanges, and based on their definition of complex, approximately how many complex interchanges are in their area. The purpose of the third set of questions was to obtain general information on complex interchanges, their perspective on complex interchanges as an issue, and the pervasiveness of these interchanges.

The fourth set of questions asked about how they design for drivers, such as if they make any assumptions about what drivers need or what drivers know, how they identify driver information needs, what design fundamentals they use, and how they go about designing signing or markings for unique interchanges where there is not sufficient guidance in the *Manual on Uniform Traffic Control Devices* (MUTCD) or other sources. The purpose of this set of questions was to get an idea of how the stakeholders think about drivers as users of the interchanges and to help us provide information in future projects from a perspective that they are able to relate to.

The fifth set of questions asked about research needs in the area of interchange design. Specifically, what research would help them resolve interchange design issues, if there is any design information missing, and where the collective knowledge gaps are in the area of interchange design. The purpose of the fifth set of questions was to give stakeholders an opportunity to provide more general feedback regarding research needs.

Follow-up Survey Protocol

The follow-up survey was conducted using a web-based survey tool. The link to the survey was emailed out to the stakeholders, who were invited to distribute the link to others. The survey was comprised of 17 questions, which took approximately 10–15 min to complete.

A copy of the questions that were included in the follow-up survey is provided in appendix D. The main purpose of conducting the follow-up survey was to prioritize the research topics that were identified in the phone interviews. This prioritization is important information to guide the selection and development of the research plans in the following task of this study.

The first set of questions asked about participant background information including their job title category, primary technical domain, years of experience in that domain, and State transportation department or other place of employment. The purpose of this set of questions was to help categorize and look for trends among responses.

The second set of questions asked participants to consider 12 research topic ideas. Each topic was included with a scale to indicate the priority of conducting research on the topic, from "low priority" to "high priority," and also including an option to indicate that the idea was "not a perceived problem." Space was provided to include comments on the topic or ideas for clarifying the topic. Participants were asked to consider each topic independently of the others (i.e., not to worry about balance between high and low priority ratings).

The third and final set of questions asked participants to describe any other general human factors research areas, geometric challenges, etc., that they face that also need research.

DATA ANALYSIS

The data gathered during the stakeholder interviews was aggregated by question for later analysis. Prior to beginning the analysis, the data was sorted by topic. Data was then reviewed for trends across stakeholders and across topics.

The primary data gathered during the follow-up survey was the priority ratings and comments for the research topic ideas. One concern with the ratings was that regions that provided many responses may sway the ratings towards research ideas that would only be useful to their region. Therefore, before the ratings were analyzed, an average rating was calculated for each region that provided responses. Then, one rating per region was used in the analysis. (Upon investigation, however, it does not appear that this method substantially affected the ranking of the research topics.) The ratings given by FHWA were not considered in the ranking of the research topics, since their needs and role in design are different than that of the other stakeholders. All of the comments provided by all of the individuals were considered, including those provided by FHWA.

CHAPTER 3. RESULTS

This section describes the results of the stakeholder activities, and it is divided into three parts. The first part addresses stakeholder experiences with complex interchanges. This includes common characteristics of complex interchanges, which leads to a high-level definition of what stakeholders think constitutes a complex interchange. Also covered in this part is how often stakeholders work on complex interchange projects and the specific human factors challenges that stakeholders encounter at complex interchanges. The second part of the Results section addresses issues that stakeholders consider when they are designing for drivers. Specifically, what assumptions they make about drivers, how they identify problems at complex interchanges, and what design resources or guidance documents that they use regularly. The last part of the Results section summarizes the key research needs related to complex interchanges that were identified by stakeholders in the interviews and survey. This section concludes with a final prioritized list of research needs that was obtained in the survey.

Although the information in this section comes from the interview and follow-up survey, the organization of the sub-sections does not strictly follow the order of the interview questions (see appendix C). The reason for this is that many of the same ideas were reported in different questions, so we extracted the common themes across sections and used them to organize the report sections. Note also that for most questions there is no information provided about how frequently topics were mentioned across stakeholders. Although some topics were mentioned repeatedly, our focus in this report is to capture breadth of topics discussed, since the number of stakeholders interviewed is too small to support quantitative analyses.

One caveat that is important to convey at the outset of the Results section is that the findings presented in this report are based on stakeholder comments only, and not separate analyses or existing research. At multiple points in the discussion of the results, the comments about State-level practices sometimes differ from the current MUTCD recommendations or common practices. This likely reflects several factors, including shortcomings in the awareness/communication of recent guidance and supporting research, the casual nature of the interviews and the fact that stakeholders were not asked to prepare in advance, and that some stakeholders held administrative positions removed from the engineers doing the day-to-day implementation. Nevertheless, the project objective is to present stakeholder views on complex interchange topics, so the findings reported describe their knowledge, opinions, and experiences. Contradictions with the MUTCD or other guidance materials are left as-is. Thus, the findings should not be interpreted as suggesting that the MUTCD or common design practices are flawed or lacking.

STAKEHOLDER EXPERIENCES WITH COMPLEX INTERCHANGES

This section focused on discussing general characteristics of complex interchanges, the pervasiveness of these interchanges, and stakeholders' perspective on complex interchanges as an issue. Questions 6 through 9 of the interview asked stakeholders for this information.

Characteristics of Complex Interchanges

This section of the interview focused on obtaining information about stakeholders' previous experiences in which they were involved in identifying, resolving, or attempting to resolve issues with complex interchanges. Specifically, stakeholders were asked to identify and discuss an example of an interchange that they previously had to deal with that had specific problems involving human factors issues (question 6). Follow-up questions addressed how they determined what the problems were, and various aspects of their efforts to address those problems.

Stakeholders did not have a common definition of what a complex interchange was, and it was more common for them to base their assessment of whether an interchange was complex on specific elements that caused problems for drivers. A list of the characteristics associated with the examples of complex interchanges discussed by the stakeholders is provided in table 3. Additional discussion about these specific driver problems is provided later in this Results section. A trend that emerges from the characteristics listed in table 3 is that complex interchanges often involve multiple routes that converge or diverge within a short distance, resulting in geometric or signing elements that ultimately cause higher workload for drivers in addition to a scenario that departs from drivers' mental models and other expectations.

Table 3. Characteristics of complex interchanges from the stakeholder examples.

Characteristics of Complex Interchanges	Mentions by Stakeholders
System interchanges	6
Multiple/successive option lanes, splits, or exits	5
Short weaving sections	4
Collector-distributor roadways	4
On-ramps and off-ramps for high-occupancy vehicles (HOVs) and managing/signing access	3
Providing a lot of information to drivers	1
Unfamiliar sign/marking elements	1
Lack of lane balance leading to forced merges	1
Unexpected maneuvers/violations of driver expectations	1
Horizontal/vertical alignment of interchange	1

How Often Stakeholders Work on Complex Interchange Projects

Based on their definition of complex interchanges, stakeholders were also asked how often they work on projects related to complex interchanges and how many complex interchanges there are under their jurisdiction. There was a wide range of responses to both of these questions and stakeholders generally found them difficult to answer because they often lacked a clear definition of what interchanges qualify as complex interchanges.

Figure 3 shows how frequently stakeholders were involved in projects that addressed complex interchanges. Note that text descriptors accompany the numeric ranges for each category. This is because not all answers to this question could be unambiguously linked to a specific numeric estimate, and some participants did not have a precise answer. Nevertheless, the overall trend is

still informative. Based on the responses to this question, approximately two-thirds of stakeholders work on projects related to complex interchanges at least once a year.

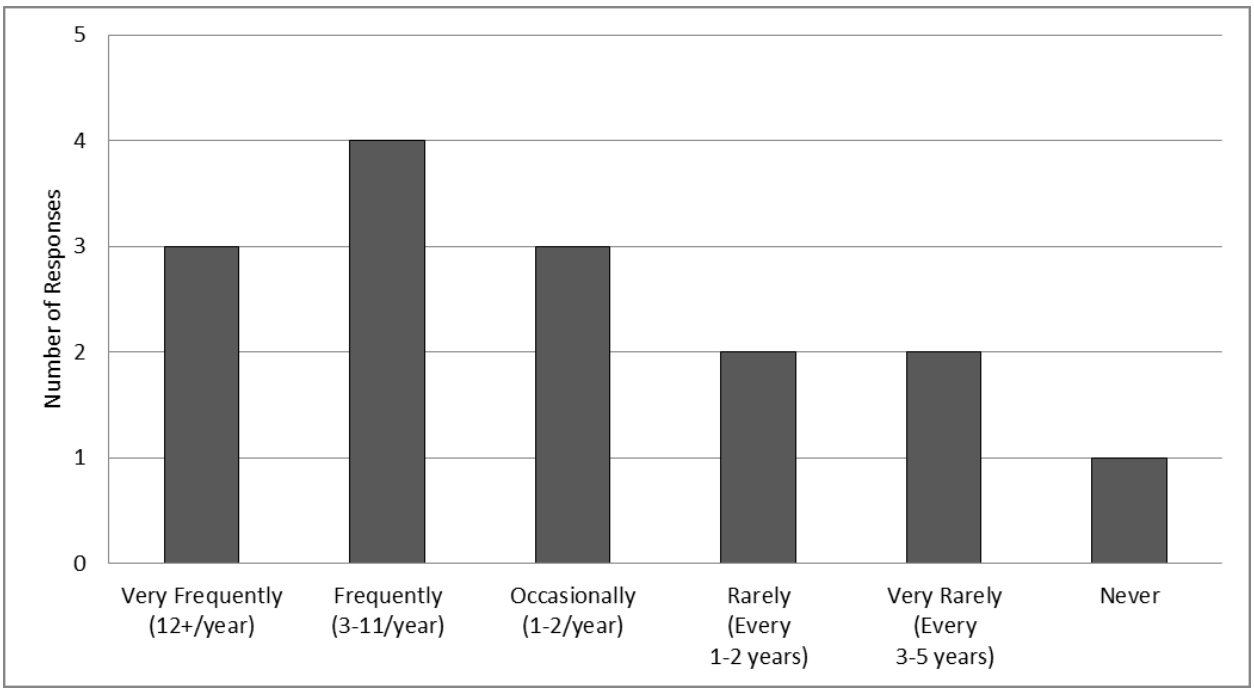

Figure 3. Histogram. Frequency of projects related to complex interchanges per year.

Figure 4 shows the number of complex interchanges in the stakeholders' areas (the same caveat about the numeric range described for figure 3 also applies to this figure). The wide range of responses is most likely due to the fact that some stakeholders interviewed work at the State level and were replying with the number of complex interchanges in the whole State compared to other stakeholders who work at a district level, and were replying with the number of complex interchanges in their district. Most stakeholders said there were several or many complex interchanges in their area.

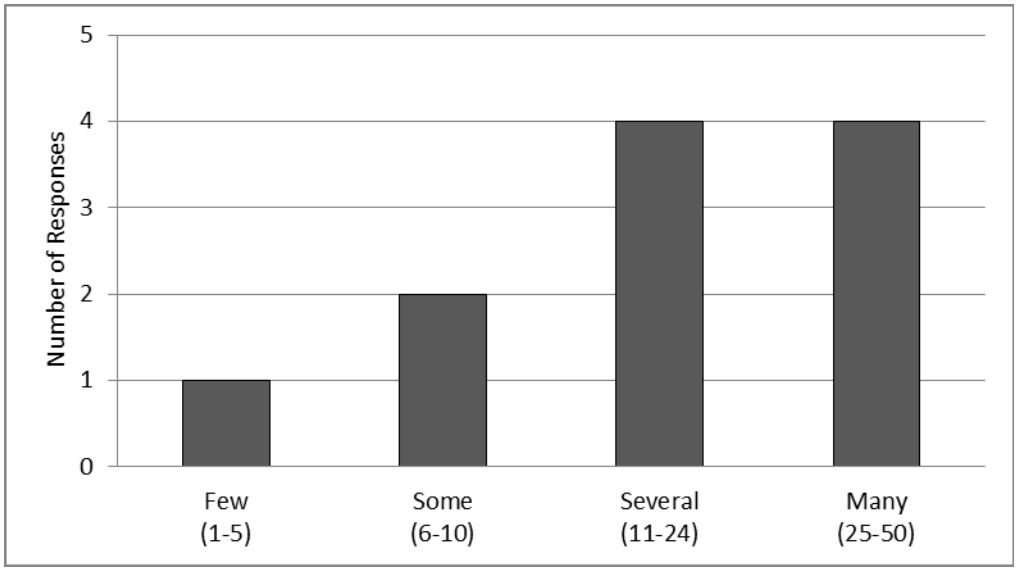

Figure 4. Chart. Number of complex interchanges in stakeholders' areas.

Specific Human Factors Challenges that Stakeholders Encounter at Complex Interchanges

Overall, stakeholders identified a range of human factors challenges that they encounter at complex interchanges. Most of these involved design and implementation issues, but some involved the planning and construction phases. Stakeholders were also asked to discuss previous instances where they had to improve or address a problem at a complex interchange. In the past-project examples, some stakeholders were also able to describe solutions that they developed for specific problems. A list of the most commonly mentioned issues is provided below. The first four topics were cited most frequently, and they are discussed in more detail below the list. Some topic discussions also include information about solutions or alternatives that were implemented, as follows:

- Close spacing of interchanges, routes, or access points.
- Signing lane movements (e.g., signing option lanes).
- Guide sign destination information (e.g., control destinations, pressure to include cities).
- Driver task overload.
- Left/right exit plaques (e.g., the significance of plaque placement).
- Cost-benefit analysis (e.g., justifying roadway improvements).
- Construction (e.g., driver navigation in construction zones).
- Route continuity.
- Diverging diamond interchanges (DDI), (e.g., signing).

- Arrows on signs (e.g., visual perspective, vertical size, requirement to sign through lanes).

- High-occupancy toll/HOV lanes (e.g., communicating complex lane permissions).

- Lane balance.

Close Spacing of Interchanges, Routes, or Access Points:

Concerns related to closely spaced interchanges, routes, or access points were a common problem that stakeholders discussed. These roadway sections were associated with a variety of challenges for drivers (e.g., hurried maneuvers, information overload, etc.), and engineers (e.g., providing sufficient sight distance for signing, deciding what information to provide, etc.). The fundamental problem is that drivers have to make more decisions in a shorter amount of time under these conditions. Moreover, this is compounded by the fact that engineers are also often more constrained in the amount of information that they can present in that limited space. These circumstances lead to a variety of specific challenges, which are described as follows:

- **Short weaving sections**. Several stakeholders described these as a major concern since they were a relatively frequent source of crashes, traffic delays, and driver complaints. Engineers are often faced with too many service interchanges, without much that can be done to reduce the number of them. This means that they cannot meet the minimum spacing requirements in many cases. Some of the specific challenges mentioned by stakeholders were: providing information and signing, having insufficient space to meet sign-spacing requirements as well as providing drivers with enough time to make decisions and change lanes, and dealing with drivers coming on and getting off the roadway at the same section. In general, it is easy to overload drivers with information, and difficult to provide sufficient sight distance in urban areas. Some of the solutions mentioned included: trying to compensate with signing and traffic control, and combining two exits into one (however, the signing for this can be difficult, and one transportation department had changed signs twice since original installation).

- **Collector-distributor roadways.** Stakeholders identified these as a common source of problems at complex interchanges. Some issues discussed included signing for multiple destinations on mainline signing, or guiding drivers through a sequence of movements (e.g., exiting one ramp going to one destination then having to get off on another ramp to get to another destination—which results in a higher number of missed exits). High exit density was also mentioned as being challenging. One example was a ramp from a local roadway coming to a freeway in which the next interchange was so close that by the time drivers merged, there was another exit coming up and not enough distance for signing or for drivers to make a decision about which lane to use, which led to traffic backups. One solution that a transportation department implemented for closely spaced exit ramps was to replace them with braided ramps. This eliminated weaving and merging on the mainline and got traffic off the mainline earlier. Signing was also simplified, since drivers only needed one sign for their off-ramp. Other stakeholders reported that collector-distributor roadways can simplify signing and navigation. Not only are speeds slower, which gives drivers more time to read signs, but drivers typically do not have to

read too many signs on the mainline because the relevant signs are provided on the collector-distributor roadway.

- **Exit-lane splits**. Another specific problem encountered was an exit ramp that subsequently splits into two or more exits, often located where two interstates come together. The general problem is trying to get drivers separated out before the split. If drivers are not in the correct lane, they only have a short distance (e.g., 1,000 ft) to get into the correct lane for their destination.

- **Information overload.** Having many signs in one area can result in information overload for the driver, making it challenging for them to decide which information is pertinent and which is not for navigating the interchange. They also may not be able to read or find the relevant information in the time that they have available. Additionally, sometimes there is political pressure from the local government to sign for attractions, lodging, historical sites, etc., because they receive pressure from their constituents. There is not enough room for every destination to have a sign in urban environments. In more rural areas where there are interchanges every 8–10 mi, it is easier to sign for destinations of interest (attractions, lodging, etc.).

- **Multiple routes that run concurrently.** Similar to the information overload factor, if multiple routes run concurrently, a stakeholder mentioned that it is difficult to get all of the necessary information across to drivers, allowing them to get to their desired destination.

- **Lack of space for advance signing.** If there is not enough right-of-way or if interchanges are spaced closely together, there may not be enough space to post the standard advance signing. Stakeholders expressed that these situations required them to prioritize which advance signs are displayed leading up to the interchange. For example, the close spacing of two interchanges prevents installation of some of the necessary early signing for the second interchange because it cannot be posted until after drivers have passed the first interchange. This configuration not only causes difficulty from a traffic operations standpoint, but also when trying to meet the decision sight distance based on the guidance in the MUTCD.

- **Density of access points.** In a geometry that includes a dense distribution of access points, it is difficult to arrange the signs so that you give enough information to drivers so they know where they need to go, while not overloading them with information.

- **Number of decisions the driver is required to make at the interchange.** An interchange's complexity is increased when drivers have to make many decisions while navigating.

Signing Lane Movements

Problems related to signing permissible lane movements were discussed by several stakeholders, particularly in the context of making decisions about sign design during upgrades to existing interchange signing. In general, stakeholders are looking for effective approaches, but they must also deal with key constraints, such as exit density and implementation costs. Changing a sign

design to include the MUTCD up-arrows is perceived as making it easier for drivers to understand the driving movements, but implementation can be prohibitive because of the arrow size requirements and high cost of providing the requisite support structure. Specific problems encountered by stakeholders include the following:

- A few stakeholders discussed how the height requirements for upward-pointing arrows make for very tall signs that must be mounted on a large and costly sign structure that spans the width of the roadway. A compromise approach taken by one group was to basically "reverse engineer" the sign to conform to the available sign space and sign structure (e.g., determine the maximum parameters that the structure can handle, and then work backwards from the MUTCD to a substandard design that fits within those maximums). Using this approach, they came up with a shorter arrow design, which they tested and implemented. Their objective was to create a design that's as close as possible to the MUTCD, while fitting into the existing infrastructure.

- One stakeholder discussed how diagrammatic signs on approaches to interchanges that have 7–8 lanes can create complex exiting conditions. In those cases, diagrammatic signs tend to cause drivers to stay to the far left or far right sides of the roadway, resulting in less traffic in the middle lanes. This stakeholder's impression is that upward arrows would be easier for drivers to understand, and therefore lead to a more equal traffic distribution.

- One stakeholder discussed the unclear benefits of providing an arrow-per-lane (APL) on a guide sign for every lane on a straight highway, where the through lanes continue visually straight ahead. This comes at a cost in information to drivers because engineers lose the ability to add other advance guide signs to that structure where the through lane arrows are posted.

Stakeholders also discussed specific problems related to providing navigation information for single lanes that serve multiple destinations (e.g., option lanes, exits that split), and for unusual interchange configurations that are not expected by drivers. These include the following:

- **Option lanes.** Many stakeholders mentioned option lanes because it is difficult to convey that drivers can reach two different destinations from the same lane.

- **Exit-lane splits.** Stakeholders mentioned exits that depart from the mainline using a single lane, and then split to serve multiple destinations. It is difficult to direct drivers to the proper lane assignment for the split in the brief time available. If drivers do not anticipate the correct movement, the result can be erratic maneuvers at the split on the exit ramp.

- **Lane drops.** These were also mentioned by stakeholders as a complicating factor. If there is not clear signing indicating that a lane is an exit only lane, drivers may end up exiting the mainline when they did not intend to.

- **Left exits.** Some stakeholders mentioned left exits as always being a problem due to their conflict with driver expectations and their low frequency of occurrence in most areas.

- **Unusual configurations/types of interchanges.** An example provided was using a cloverleaf instead of a diamond interchange. In the case of a cloverleaf interchange, the driver has to select one of two off-ramps going in separate directions. For example, if there is an Exit 33A and an Exit 33B, drivers can become confused about which one they should take to get to their desired destination.

Guide Sign Destination Information

Stakeholders identified problems with the selection of which major destination information to include on signs. This issue can lead to guide signs that are inconsistent with driver navigation expectations, or that are more difficult to comprehend because of the additional information elements. Some of the specific problems that stakeholders reported on this issue include the following:

- Drivers not understanding that the control cities listed on guide signs do not include all of the major cities beyond the city identified on the sign.

- Different considerations apply when selecting an appropriate major destination for a rural or an urban area.

- Pressure to include lower-priority destinations on signs, when doing so would lead to "information overload." This often comes from institutions lobbying to be included on a sign, and it sometimes involves direct intervention from State or local officials.

Driver Task Overload

Stakeholders reported issues with driver task overload. Driver task overload can be the result of short weaving distances, many lane changes, or the lack of advance guide signs. This overload can cause drivers to miss a sign due to its location or to not understand which way to go in order to get to their destination. Some of the specific examples stakeholders provided about this issue include the following:

- One stakeholder discussed how drivers were missing the only sign giving notice of an option/exit only lane going to a major destination because the sign is at the same location in which drivers are merging into six lanes of traffic of a busy highway. Pavement markings were added to assist drivers in getting into the correct lane and to their destination.

- One stakeholder mentioned drivers experiencing confusion about which way to turn to get onto the correct highway due to the large number of route shields presented in one location. This situation can potentially be very confusing for a local driver who is driving through this location for the first time, or for an unfamiliar driver who is not from the area and is trying to get to onto the correct highway and to their destination.

DESIGNING FOR DRIVERS

Stakeholders were asked how they design for drivers and how they incorporate driver needs into their design processes. This included discussion about the design resources that are commonly

used and stakeholders' approaches to solving design problems that are not covered in those design resources.

Assumptions that Stakeholders Make about Drivers

In this section of the interview, we asked whether stakeholders make any assumptions about what drivers need or what drivers know when they are designing a new or retrofit interchange (question 10).

Driver Characteristics

Assumptions that stakeholders reported they made about driver characteristics were as follows:

- Some proportion of the driver population is in the older age group and may require certain allowances (e.g., wider lane markings, increased character heights on signs).
- Some proportion of the driver population does not speak English and may require symbolic information to help them navigate.
- Some proportion of the driver population has difficulty with interchanges because of their lack of overall driving experience, old age, or because they are lost.
- Some proportion of the driver population is from out-of-state or otherwise unfamiliar with the area.

Driver Abilities

Assumptions that stakeholders reported they made about driver abilities were as follows:

- Drivers can follow signs.
- Drivers have the ability to look at a map to help them navigate; otherwise guide signs would likely be insufficient.

Driver Needs

Assumptions that stakeholders reported they made about driver needs were as follows:

- Drivers will perform better at a more conventional interchange configuration (i.e., something that they are familiar with, like a diamond or cloverleaf interchange).
- Drivers may not understand the signs or know how to navigate the first time that they drive through a new or modified interchange. They have to "get used to it" during an adjustment period.
- Drivers would be helped by consistency in signing across the States.
- Drivers need a decision sight distance as recommended by the American Association of State Highway and Transportation Officials (AASHTO).

- Drivers require, as the most important information to be presented, traffic route information, such as: the route names themselves, route shields, major destinations, and cities.

- Drivers may be able to identify some routes by the number and cardinal direction; however, if there is a more common alternate name (e.g., "the turnpike") or a control city, then it is important to present that as well.

- Driver needs are accommodated by the available design standards (e.g., MUTCD, *AASHTO: A Policy on Geometric Design of Highways* ("Green Book"), FHWA documents for design processes), so by creating a compliant interchange design, all drivers should be able to successfully navigate the interchange.

How Stakeholders Identify Problems at Complex Interchanges

As a follow-up to the discussion of issues at interchanges, we asked how stakeholders identify problems involving driver information needs or driver issues at interchanges or other roadway sections (question 11). There are three main categories of ways in which State transportation department representatives identify drivers' issues: crash histories or reports, complaints from the driving public, and observations from trained professionals (e.g., highway patrol, field personnel). These are described in more detail below.

Crash Histories or Reports

Nine stakeholders reported using crash histories, crash trends, or individual crash reports (including the type of crash, location in reference to decision points, verbal information provided to the Highway Patrol) to determine sites where drivers are having issues. One State creates a list called the "Suggested List of Surveillance Study Sites" or the "SLOSS" list every year. This list includes all of the sites where the crash rate is higher than what would normally be expected for that type of roadway. The sites that are high on this list are the first to get fixed. Additionally, if there is an ongoing project, they will check to see if any of the project sites are included on the SLOSS list. If so, they will do a little investigation to see if the crash cause can be easily fixed during the ongoing project.

Complaints from the Driving Public

The most common way that State transportation departments know where there is a problem is when the driving public sends a complaint using email, phone calls, or letters. States generally take complaints very seriously and a State or district representative is certain to follow up with each person. One State described a complaint tracking system that ensures that each complaint is addressed. Another State described how they call each person who complains to find out exactly what that person is talking about. Additionally, they will look on Google Maps™ to find the problem, direction of the approach, etc. This information gets passed down to the individual districts, whose personnel will visit the site to make sure that all of the appropriate signing is present and visible.

Observations from Trained Professionals

There are multiple types of trained professionals who make and report traffic observations, including the following:

- State transportation department representatives who observe traffic to gain clarity on issues and to identify solutions.
- Transportation Management Center operators who are watching camera systems. They identify areas with issues (e.g., where many drivers cross the exit gore) to see if those areas can be remedied.
- Field personnel who either see drivers making unsafe actions or experience a poor design themselves when they drive. Similarly, maintenance workers are out during different times of the day and night, so they view drivers navigating a range of conditions.
- State Highway Patrol officers who notice something unsafe or identify crash patterns and will make suggestions.

Design Resources that Stakeholders Use

There are many design fundamentals for signing and markings that are used by stakeholders (question 12). The resources that were mentioned are as follows:

- *AASHTO "Green Book."*
- *AASHTO Highway Safety Manual*.
- *AASHTO Roadside Design Guide*.
- FHWA documents for design processes.
- MUTCD.
- ITE manuals.
- National Cooperative Highway Research Program (NCHRP) reports.
- *Roundabouts: An Informational Guide, Second Edition. (NCHRP Report 672).*
- State design manuals or other State resources.
- Strategic Highway Research Program projects.
- *Transportation Research Board* (*TRB*) *Highway Capacity Manual*.

To follow up, we asked how transportation department personnel design signing or markings for unique interchanges where there may not be any guidance in the MUTCD or other sources (question 13). The following approaches were mentioned, often in combination with one another:

- Attempt to conform to the MUTCD, while coming up with a plan as best as they can. For example, an expressway sign should be white lettering on a green background. One stakeholder described this as "applying the spirit of the MUTCD," that is, figuring out what the MUTCD would recommend if such guidance was provided.

- Apply their engineering judgment and what they know from their experiences to come up with a solution.

- Contact their MUTCD and FHWA representatives to get their input on the situation.

- Find an example to start from that is the most similar to the current issue.

- Ask their peers in other States and agencies if they have experienced or encountered something similar.

- Reach out to national committees like AASHTO and NCHRP.

One stakeholder added that they would let their FHWA contacts know that guidance is missing and needs to be created for this design situation, to ensure consistency between States.

RESEARCH NEEDS FOR COMPLEX INTERCHANGES

At the end of the interviews (question 14), we asked stakeholders specifically if they had any ideas about research needs that would help them resolve interchange design issues. Below is a description of the most commonly mentioned research needs that were discussed during that portion of the interview. The research needs mentioned by stakeholders fit into several themes, including: signing, roadway geometry, and general design challenges. The "corresponding research summary" sections within each description more succinctly summarize what a research project in that area might examine. These research summary sections are also the exact text that the stakeholders used to assign priority ratings during the follow-up survey.

Signing

Guide sign spacing requirements. The research basis for the 800-ft required spacing between guide signs in interchanges is unknown to some stakeholders. That standard is difficult to maintain for closely spaced exit ramps or interchanges, particularly in urban areas. Additionally, there is a limit in the MUTCD for the amount of information that can be placed on each guide sign. This limit can feel like it compounds the challenge, since engineers are limited on the number of signs per mile and the amount of information that can be presented on each of those signs. This is the topic of a current research study being conducted by FHWA.

Corresponding research summary. This research would examine whether the 800-ft guide sign spacing requirement is necessary in urban environments, where interchanges are closely spaced and there are many destinations to list. More specifically, if the 800-ft distance is not met, what

are the impacts on drivers in terms of information acquisition success, sign reading time, and traffic flow? Since this research is already being performed, this topic is not a priority for new research; however, it is important to follow-up and convey the findings to stakeholders.

Information limit per guide sign. There was an opinion expressed by multiple stakeholders that the MUTCD's limit on the amount of information that can be put on a single guide sign is unrealistic. In some situations, there is a minimum amount of information that needs to be presented to guide drivers to make the appropriate movements, to ensure safe operation of the roadway, and to direct traffic. One stakeholder acknowledged that while it can be a lot of information on a single display, from a driver's perspective they do not have to read and digest all of that information; they focus on what they are looking for. Also, if that information limit was strictly followed, some sign information would be left out and people would complain. In previous focus groups addressing complex interchanges, some drivers agreed that they could scan the signs and ignore irrelevant information; however, many others noted that including too much information on a single sign structure causes problems.[(2)]

Another State had a local university perform some research that examined the maximum number of items of information that could be presented on a guide sign. Guidance was given for situations where there were one, two, or three signs on a single support structure.

Corresponding research summary. This research would examine the limit on units of information for guide signs, particularly in urban areas where there are many destinations to sign for and limited space to hang signs. What are the human factors impacts of including additional guidance information on guide signs in dense areas? Although there is a lot of existing research on this topic in both driving and comparable domains, some stakeholders find the current limit to be unreasonably low. They would like either a clear justification for the limit, or some sort of analysis of the trade-offs of providing more information beyond that limit.

Sign placement in interchanges. One stakeholder mentioned a case regarding an issue with sign placement. He noted that drivers were missing a critical guide sign because it was placed in a location where they were merging from an on-ramp onto the mainline. His solution utilized pavement markings in that location to denote the lane for the primary destination, which was an airport. However, if the situation could be avoided altogether, that would be better. Something like merging onto the highway and then immediately merging or negotiating a merge-weave should be avoided, but sometimes it is challenging to avoid this situation altogether.

It would also be useful to compare exit approaches at interchanges with and without some of the design features like pavement markings, option lane signing, etc., particularly in situations where drivers need to view all of the signs to reach their destination. This stakeholder believes that it would be helpful to have supplemental pavement markings in those areas; however, this would be a good area to study.

Corresponding research summary. This research would gather and present the human factors considerations for implementing pavement markings containing guidance information within complex interchanges. It would examine the driver interpretation of pavement markings and the best placement choices for those markings within different interchange scenarios.

APL sign requirements. At multiple times during different sections of the interview, stakeholders discussed the MUTCD requirement to use APL signing. The new requirement for APL signing is extremely difficult to accommodate because the arrows themselves can be 6 ft high. This sign height requires that a large and costly support structure be installed to mount the signs. This is sometimes cost-prohibitive for States. They are attempting to follow the MUTCD guidance, but often the cost of the sign support limits their ability to do so.

Figure 5 shows an alternate design where the destination names were placed beside the arrows instead of above the arrows, reducing the required sign height.

Original image: ©2013 Google®

Figure 5. Photo. Example of alternate APL destination name layout.[(4)]

Another solution proposed was truncating the upward-pointing arrows, as shown in figure 6.

Source: Missouri Department of Transportation

Figure 6. Photo. Truncated up-arrows on APL guide sign.

It would be helpful for States to have an alternate design option for APL signs, in order to have shorter signs that still provide adequate guidance to drivers. A published laboratory study compares driver comprehension of various signing options, including what is currently recommended by the MUTCD.[(3)]

Corresponding research summary. This research would examine alternate methods for signing APL configurations that would reduce overall sign size requirements, while still communicating the necessary information to drivers. This research would examine sign height reductions and also sign width reductions, such as whether it is beneficial to sign all of the through lanes for the width of the roadway, or whether that space on the sign support could be used to provide other guidance information for upcoming decision points.

Roadway Geometry

Option lanes or shared lanes. In general, it is easier to communicate that a lane serves a single destination rather than multiple destinations. There is a wide range of sign designs, and in particular arrow types, that are used for signing option lanes (e.g., one arrow, two arrows, up-arrows, down-arrows, slanted arrows). Stakeholders expressed some uncertainty regarding what is the best signing method and if the current MUTCD language reflects the results of research and current studies of driver perception. Engineers want to know how drivers understand the signs and what they can do to help drivers understand that the lane is an option lane. Although there is existing research on this topic, and stakeholders are generally aware of the current guidance and research findings, they did not seem confident in applying this knowledge. The benefits of undertaking the effort to comply with the current guidance are unknown.

Additionally, sometimes lanes are used as option lanes in order to satisfy AASHTO's recommendations for lane balance. Although that may help to balance the traffic flow, the

signing becomes more complicated as a result. The stakeholder who discussed this issue noted that he thought that the lane balance guidance from AASHTO should be applied on a case-by-case basis.

Note that the option lanes or shared lanes research need does not have a corresponding research summary section because it was not included in the follow-up survey.

Two-lane flyover ramps. When constructing two-lane flyover ramps, some States are encountering problems with horizontal and vertical alignment. With the concrete barriers that are on the ramp, the construction does not meet the AASHTO horizontal sight distance requirement. As the drivers go around the curve, they cannot see far enough ahead due to the height of the barrier. In order to meet the criteria, the barriers need to be very tall and that is not cost effective or feasible. The solution that has been used, for example for a left-turning curve, is to move the right shoulder to the left side to improve sight lines as drivers are going around the curve. This is a design exception, but it could benefit from more research to see if it is acceptable.

Corresponding research summary. This research would examine vertical and horizontal sight distance requirements for two-lane flyover ramps. Specifically, what are cost-effective and physically feasible ways to meet these requirements, or can these requirements be reasonably violated in some scenarios?

General Design Challenges

Algorithm for justifying the cost of roadway construction projects to drivers. One stakeholder described in detail the calculations that are often undertaken to justify the cost of roadway improvement projects to the general public. In order to justify the cost, they perform calculations to figure out the savings afforded by the completion of the project. Savings based on crash reductions are easier to calculate than savings based on delay reductions, because the data on the cost of fatalities and injuries is widely published. To calculate the savings based on the delay reduction, values for things like the value of gasoline saved, driver time saved, and emission reductions are necessary. Placing a numeric value on driver time and vehicle emissions is difficult, since there is no standard source for these values.

Corresponding research summary. This research would create an algorithm that could be used to justify the cost of roadway construction projects to the public. The algorithm would include standard metrics to quantify and calculate the project's benefits, such as driver time saved, pollution reductions, etc. This research would relate to the MAP-21 Act, with an emphasis on performance-based decisions and management.

Develop additional design examples. One stakeholder noted that he would like to have additional examples available to him regarding how to design or fix a particular interchange scenario. He suggested that a batch of Subject Matter Experts evaluate challenged interchanges around the country to determine how they were designed, how they could have been designed, and how they could be improved. If those proven or suggested design solutions could be made sufficiently generic, then engineers in other States could apply them to their interchanges.

If this research resulted in a reference document, then instead of only having a small number of examples in the MUTCD, engineers would be able to see a much larger number of examples, one

of which may be a better match to the situation that they are facing. If the examples were all vetted by a panel, then State engineers wouldn't need to submit an example to FHWA and wait for a response. These examples could include signing, marking, and geometric solutions, or a subset thereof.

It would also be preferable if this document also contained more written descriptions of the decision criteria. For example, if a decision had to be made between two sign types, which one should be chosen, and why? The current MUTCD often gives multiple options that are satisfactory, without guidance about which option to select. It would be beneficial to have additional guidance explaining why a particular sign type is preferred.

Another stakeholder described a similar need for additional research that would help them know what the outcome would be for designs that do not conform to the MUTCD. For example, some interchanges cannot be designed or altered to look like an MUTCD solution. If that is the case, how will that interchange function? Engineering confidence could be improved in terms of what the outcome would be for a non-standard interchange design.

Corresponding research summary. This research project would find examples of uncommon complex interchange design challenges across the country. Solutions to signing, marking, and geometric problems would be developed by a panel of experts, and the corresponding example solutions shared in a compendium with the engineering community. An additional tool for explaining the solutions could be simulations or visualizations of their design and function.

ADDITIONAL RESEARCH TOPICS

A follow-up survey was conducted to help prioritize a subset of the key research ideas identified in the interviews. The main component of the follow-up activity asked the participants to assign the priority of conducting research on each of 12 research ideas (survey questions 5–16). They were also provided with space to give comments on each research topic. Note that the order of the research topics was randomized between participants to ensure that the presentation order did not affect the results. The list of research needs in the previous section provided the basis for many of the topics that were included in the survey. The others were based on the results of other portions of the interview and are as follows:

- **Control cities on guide signs.** This research would examine driver expectations regarding control cities. Specifically, do drivers understand that the city on the sign is the one with the next major interchange rather than the next major city? Also, what is a good policy for dealing with requests for including non-control cities on guide signs and what are the implications of using a non-control city?

- **DDIs.** This research would examine the best methods for signing and marking DDIs. More specifically, what are the human factors considerations for implementing DDIs? What are effective ways to reduce driver uncertainty about the maneuvers that they have to make?

- **Organization and number of route shields.** This research would investigate how to present effective route shield information. More specifically, for interchanges that contain

a large number of routes, what is the clearest way to present a large number of route shields to drivers? What is the limit on the number of route shields that should be presented on a single guide sign?

- **Signing for collector-distributor roadways.** This research would seek to identify the best methods for signing for multiple destinations off the collector roadway, when drivers first must exit from a single point on the mainline. Specifically, what is the clearest method for guiding drivers through that series of movements (e.g., exiting on one ramp from the mainline, then having to exit on another ramp to get to their destination)?

- **Signing for exit-lane splits.** This research would investigate signing options for exit-lane splits (where one lane that exits from the mainline quickly splits into two exits that serve different destinations). The goal of this research would be to find a way to efficiently separate drivers into the correct exit lane while reducing last-minute lane changes.

PRIORITIZING RESEARCH NEEDS

Table 4 shows the results of the rating of research ideas performed in the follow-up survey. The research topic rows are sorted by ascending rank. As mentioned previously, in order to account for the differing number of participants per region, an average was calculated for each region before averaging by topic across all of the regions. This was done to give all regions equal weighting, regardless of the number of participants from that region. The "Average" column in table 4 was calculated in this way. The "1 or 2 Rank" column shows the absolute number of times that an individual participant rated this research topic as "high priority" or "medium-high priority." The "State Rank" column reflects the order of research topics, as determined by the average rating across States.

Table 4. State/region rating results for complex interchange research ideas.

Research Topic	State Rank	Average*	1 or 2 Rank
APL sign requirements	1	2.18	39
Guide sign spacing requirements	2	2.18	35
Information limit per guide sign	3	2.32	35
Pavement markings	4	2.44	33
Develop additional design examples	5	2.50	28
Signing for exit-lane splits	6	2.60	26
Diverging diamond interchanges	7	2.69	30
Signing for collector-distributor roadways	8	2.78	23
Organization and number of route shields	9	3.31	15
Algorithm for justifying the cost of roadway construction projects to drivers	10	3.34	18
Control cities on guide signs	11	3.54	13
Two-lane flyover ramps	12	3.75	12

*Rating values used in the calculations correspond to the ratings from "High priority" (1) to "Low priority" (5).

CHAPTER 4. CONCLUSIONS

The findings from these stakeholder activities led to several conclusions that address the objectives of the project, plus some additional findings. These findings include the following:

- Stakeholder's conception of and experience with complex interchanges.
- Aspects of complex interchanges that cause problems for drivers.
- Recommendations for future human factors research based on stakeholder information needs.

Each of these conclusions is described below.

STAKEHOLDER'S CONCEPTION OF AND EXPERIENCE WITH COMPLEX INTERCHANGES

Almost all stakeholders had direct experience addressing problems associated with complex interchanges, and approximately two thirds of them have to address problems with these interchanges on a yearly basis. When stakeholders were asked what makes an interchange complex, most did not have a specific definition. Rather, they tended to mention characteristics of interchanges that make navigation more challenging for drivers, even leading to higher crash rates in some instances. The key characteristics of complex interchanges include:

- System interchanges.
- Multiple/successive option lanes, splits, or exits.
- Short weaving sections.
- Collector-distributor roadways.
- On-ramps and off-ramps for HOVs and managing/signing access.
- Providing a lot of information to drivers at one time.
- Unfamiliar sign/marking elements.
- Lack of lane balance leading to forced merges.
- Unexpected maneuvers/violations of driver expectations.
- Horizontal/vertical alignment of interchange.

A trend that emerges from examining these characteristics is that complex interchanges often involve multiple routes that converge or diverge within a short distance, resulting in geometric or signing elements that ultimately cause higher workload for drivers in addition to a scenario that departs from drivers' mental models and other expectations. Requiring drivers to analyze a lot of

information, make many decisions, and execute multiple maneuvers in a short period of time seems to cause problems, especially if those elements are not routine (e.g., unexpected maneuvers, determining where a lane goes, viewing unfamiliar symbols). This finding is consistent with the results obtained in a previous project that that examined this question from the driver's perspective.[2] Moreover, one outcome of that earlier project was the development of a basic task analysis approach for quantifying drivers' perceptual, cognitive, and psycho-motor loads across specific interchange maneuvers. There may be some value to developing that approach into an early-screening tool that can be used by engineers to identify interchange designs that could be overly complex.

ASPECTS OF COMPLEX INTERCHANGES THAT CAUSE PROBLEMS FOR DRIVERS

Stakeholders identified several common interchange elements that seem to routinely cause problems for drivers. These driver problems included: increased crash rates, traffic delays, information overload, missed exits, and complaints from drivers about poor route guidance and insufficient time to make decisions and lane changes. Some of the interchange characteristics that cause the most problems for drivers include the following:

- Closely spaced ramps and interchanges.
- Short weaving sections.
- Collector-distributor roadways.
- Signs for certain lane movements, including option lanes, exit-lane splits, lane drops, and left exits.
- Control destinations on guide signs.
- Signs with many information elements that lead to information overload.

CONSDERATIONS FOR FUTURE HUMAN FACTORS RESEARCH BASED ON STAKEHOLDER INFORMATION NEEDS

A key finding from the interviews is that stakeholders see value in conducting additional research on human factors issues at complex interchanges. In particular, stakeholders reported that they have to deal with problems at complex interchanges on a regular basis, and most of them provided specific examples of human factors challenges that they had to address at a specific complex interchange in the past. A common view among stakeholders is that they have insufficient guidance and supporting design information to identify specific and effective solutions, or suitable design alternatives to address problems at interchanges. On a related note, many stakeholders mentioned at some point during the interview that they have a strong desire to see consistency both within their State and across States. Following the MUTCD ensures some degree of consistency, but stakeholders lack similar reference information that they can use to address the broad range of driver problems they regularly encounter at complex interchanges.

The combination of the stakeholder interviews with the follow-up survey provided a good understanding of the priorities for future complex interchange research. The priority level of a topic was determined by the rank, as shown in table 4. The topics that received the highest priority ratings generally focused on signing requirements and the distribution of guidance information on the roadway. The top-rated research topic was related to APL sign requirements (see table 5). This is perhaps not surprising, given that this topic has received a lot of attention due to recent changes in regulations. Some of the interest may be attributable to those recent changes. There also, however, seems to be a disconnect between what is a desirable design for APL signs and what is seen as feasible from the States' perspective.

Table 5. Highest priority research topics based on stakeholder feedback in the survey.

Priority	Research Topic
1	APL sign requirements
2	Guide sign spacing requirements
3	Information limit per guide sign
4	Pavement markings

The next three highest ranked topics all related to the distribution of information on the roadway, including: guide sign spacing requirements, the information limit per guide sign, and the application of pavement markings that include navigation guidance. These three topics consider three aspects of information layout, particularly in dense areas where a lot of navigation guidance can be presented to drivers at the same time. It may make sense to study these related topics in conjunction with one another, as part of the same research project. Guide sign spacing and the information limit per guide sign both relate to Federal guidance (e.g., MUTCD) that can be difficult to follow in some situations. Pavement markings differ in that there is a sense that they provide a useful approach to providing information to drivers; however, there is less guidance available as to where and how they should be applied. All three of these topics would likely be studied in an urban environment, where there is a high density of exit ramps, interchanges, and/or destinations to sign. The countermeasures found during these studies would be implemented to improve driver navigation by redistributing navigation guidance in areas where the information density is high.

In addition to the research needs listed in table 5, stakeholders also identified a wide range of other issues involving human factors for which they would like to see more research conducted. These topics were also evaluated in the follow-up survey, and they are listed as follows in alphabetical order:

- Algorithm for justifying the cost of roadway construction projects to drivers.
- Control cities on guide signs.
- Develop additional design examples.
- Diverging diamond interchanges.
- Organization and number of route shields.

- Signing for collector-distributor roadways.
- Signing for exit-lane splits.
- Two-lane flyover ramps.

It is clear from the stakeholder feedback described in this report that complex interchanges pose an ongoing challenge to roadway engineers and State transportation department personnel. Previous projects have begun to identify human factors issues that can lead to driver stress and errors when navigating these interchanges. However, there is no simple definition or single prototype example of a "complex interchange," and a variety of geometric and signing elements can make different interchanges complex and difficult for drivers to navigate. Consequently, the human factors problems that drivers can face at these interchanges also vary greatly; this is reflected in the wide range of research needs identified by the stakeholders. It is also clear from the interviews and survey that stakeholders have many unmet information needs and other questions related to complex interchanges. They also see value in additional research and corresponding design guidance that would address these information gaps.

APPENDIX A. STAKEHOLDER RECRUITMENT FLYER

Collecting and Analyzing Stakeholder Feedback for Signing at Complex Interchanges

Stakeholders Needed

U.S. Department of Transportation
Federal Highway Administration

Recent FHWA-sponsored research indicates that complex interchanges pose significant challenges to many drivers. An important design issue identified in this research is that the perceptual grouping of elements on guide signs (e.g., layout, spacing) has clear and systematic effects on how drivers interpret and use sign information. Research into these and other perceptual factors that affect driver behavior should eventually lead to design guidance for promoting consistent and effective best practices.

Battelle – FHWA's contractor for this project – is starting a follow-on project with the objective of consulting roadway engineers and other stakeholders to identify how these individuals can best be served by new research and design guidance about guide signs, markings, and roadway geometry. Specifically, it is important to understand engineers' constraints related to developing and implementing different design alternatives at complex interchanges. This is critical information because it is essential to focus subsequent research on aspects that can be implemented in a practical way. Furthermore, consulting with the stakeholders, who will be the end-users of the design information that this research will produce, is a useful way to gain an understanding of their design process, issues they must consider, trade-offs they make, etc. This information is also invaluable for identifying research questions that stakeholders find useful and which solutions could apply to their specific design problems.

A key element of the success of this research is the participation of sign design stakeholders in discussions related to complex interchanges. We are looking for stakeholders who are:

1) Involved in any aspect of interchange sign, marking, or geometric design/planning, and
2) Willing to participate in one-on-one phone interviews.

These phone interviews will take approximately one hour and will involve a discussion of complex interchanges, design processes for interchanges, specific driver issues, and other related topics.

If you have an interest in participating in this study, or would like to receive further information, please contact:

Monica Lichty, M.S.E.
Center for Human Performance and Safety
Battelle Seattle Research Center
lichtym@battelle.org
206-528-3292

Jim Shurbutt, Ph.D.
Office of Safety R&D
Federal Highway Administration
jim.shurbutt@dot.gov
202-493-3420

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Figure 7. Screen Capture. Stakeholder recruitment flyer.

APPENDIX B. VISUAL PRESENTATION OF INTERCHANGE EXAMPLES

These examples of complex interchanges were presented to participants during some of the interviews.

Figure 8. Photo. Example of information overload on a sign structure.

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Figure 9. Photo. Example of confusing destination grouping caused by perceptual cues from sign elements.

Figure 10. Photo. Example of skewed visual perspective causing difficulty in matching arrows to lanes.

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Figure 11. Photo. Example of mismatch between direction of arrows on signs and perceived roadway direction.

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Figure 12. Photo. Example of skewed roadway perspective and difficult arrow alignment.

Figure 13. Photo. Example of perceived misalignment between down arrows and lanes.

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Figure 14. Photo. Example of difficult-to-see lane lines on a diagrammatic sign.

Figure 15. Photo. Example signing for a mixed system-service interchange.

APPENDIX C. INTERVIEW MODERATOR GUIDE

The following text is the interview guide from the stakeholder interviews. All of the main questions are those that are numbered. The sub-questions (i.e., those noted with a letter) were optional, and only asked if there was time and if they were useful for obtaining follow-up responses.

Interview Introduction

- Thank you for taking the time to talk with us today.
- Did you have a chance to look over the handout we sent you ahead of the interview?
- The purpose of these interviews is to have discussions that lead to input on future research directions for complex interchange research.
- All of the information you provide will be reported in an anonymous and aggregated manner. The contact information you provide will only be used to follow-up if there are any questions regarding your responses.
- We would like to make an audio recording of this interview to allow us to check our notes to make sure that we have accurately recorded what was said. After we verify our notes, the recording will be deleted. Is it ok with you if we record this interview?
- If there are any questions you don't feel comfortable answering, please let me know and we can skip them.
- The interview should last about 1 hour. Do you have any questions before we get started?

Interview Scope

- In a previous project related to complex interchanges, we found that in complex interchange configurations, some of which did not even appear complex at first glance, drivers had difficulty understanding how to complete the movements that they wanted to make.
- We also found that there were consistent patterns in how drivers interpreted the sign information, interchange markings, and geometry, and this interpretation affected how well drivers understood what to do.
- Based on these previous findings, more research could be conducted to learn about how these design elements shape driver expectations, and therefore, their success in navigating the interchange.
- The purpose of these interviews is to have discussions that lead to input on future research directions for complex interchange research.
- The output of these interviews will help to inform research plans for FHWA.

- We are focused on issues that exist from the driver's perspective (e.g., issues like inconsistent destination information rather than too many exits per mile).

- We are also focused on conducting research that will provide guidance to the technical process of designing and implementing interchange designs.

Section 1: Background Information

1. What is your official job title?

2. In a few sentences, what are your day-to-day responsibilities?

3. How long have you been in your current position?

4. How does your role fit into the design or analysis processes for interchanges?

5. Do you use outside consultants for human factors- or driver-related questions?

Section 2: Examples/Prior Experience with Complex Interchanges

Were you able to prepare a couple of examples regarding times where you identified and resolved (or attempted to resolve) issues with complex interchanges? If so, please tell us about the examples that you selected.

6. For the example that you selected:

    a. What was the problem?

    b. How did you know what the problem was (driver-based approach or crash-based approach)?

    c. What did you try to do to fix it?

    d. How well did that work?

    e. How did you know whether it worked or not?

    f. What design information (if any) would it have been nice to have, but wasn't available?

    g. Was there any missing information specifically related to drivers or human factors?

    h. How many other similar or different complex interchange projects have you completed?

    i. When finding these examples, what types of interchanges did you look at?

Section 3: Complex Interchanges in General

7. In your experience, what factors make certain interchanges more difficult for drivers to navigate?

    a. What factors contribute to the complexity of an interchange, from the driver's perspective?

8. How often do you do projects that relate to complex interchanges?

9. Based on your definition of interchange complexity, how many complex interchanges are in your area?

Section 4: Designing for Drivers

10. Do you make any assumptions about drivers, driver needs, or what drivers know when you design?

11. How do you identify driver information needs or driver issues at interchanges or other roadway sections?

12. What design fundamentals for signing and markings do you use?

13. How do you design signing or markings for unique interchanges where there may not be guidance in the MUTCD or other sources?

Section 5: General Feedback Regarding Research Needs

14. Generally, what research would help you resolve interchange design issues?

    a. What design information is missing?

    b. Where are the collective knowledge gaps?

    c. What conditions and challenges are you currently or frequently dealing with?

APPENDIX D. FOLLOW-UP SURVEY QUESTIONS

Complex Interchanges Stakeholder Follow-up

Complex Interchange Research Issues

Thank you for taking the time to answer these questions. This activity is being conducted as part of a research project for the FHWA that involves talking to state and local transportation professionals about design issues related to complex interchanges. In the first part of this project, we conducted interviews with roadway designers, engineers, and other stakeholders to discuss complex interchanges and ideas for new research examining driver behavior in complex interchanges, especially with those involved in the signing and marking of interchanges. The goal of this current activity is to collect feedback from designers and engineers, before developing plans for future research.

If you have any questions about this research project, please contact Monica Lichty using the information provided below.

lichtym@battelle.org
(206) 528-3292

Page 1

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Figure 16. Form. Follow-up survey page 1.

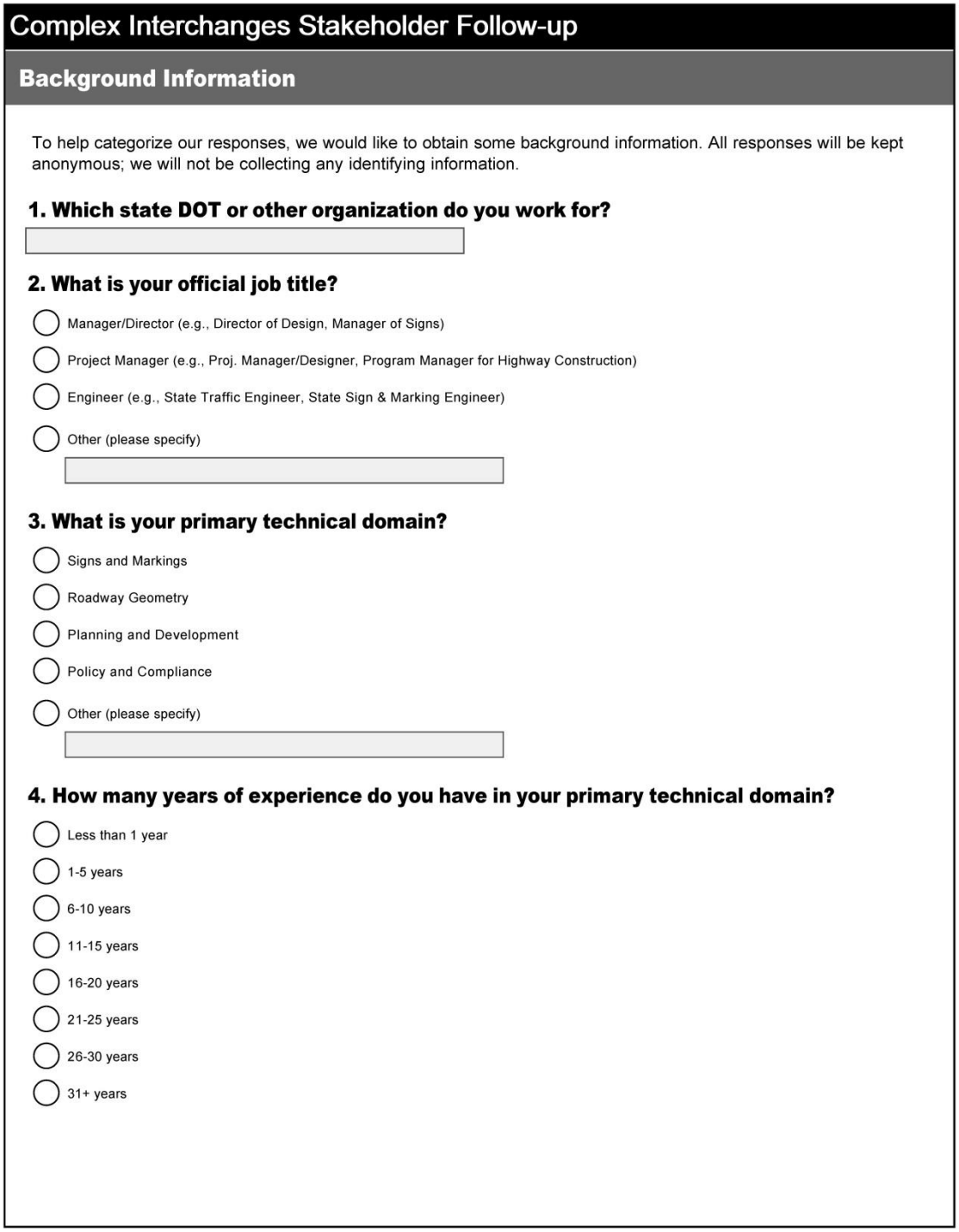

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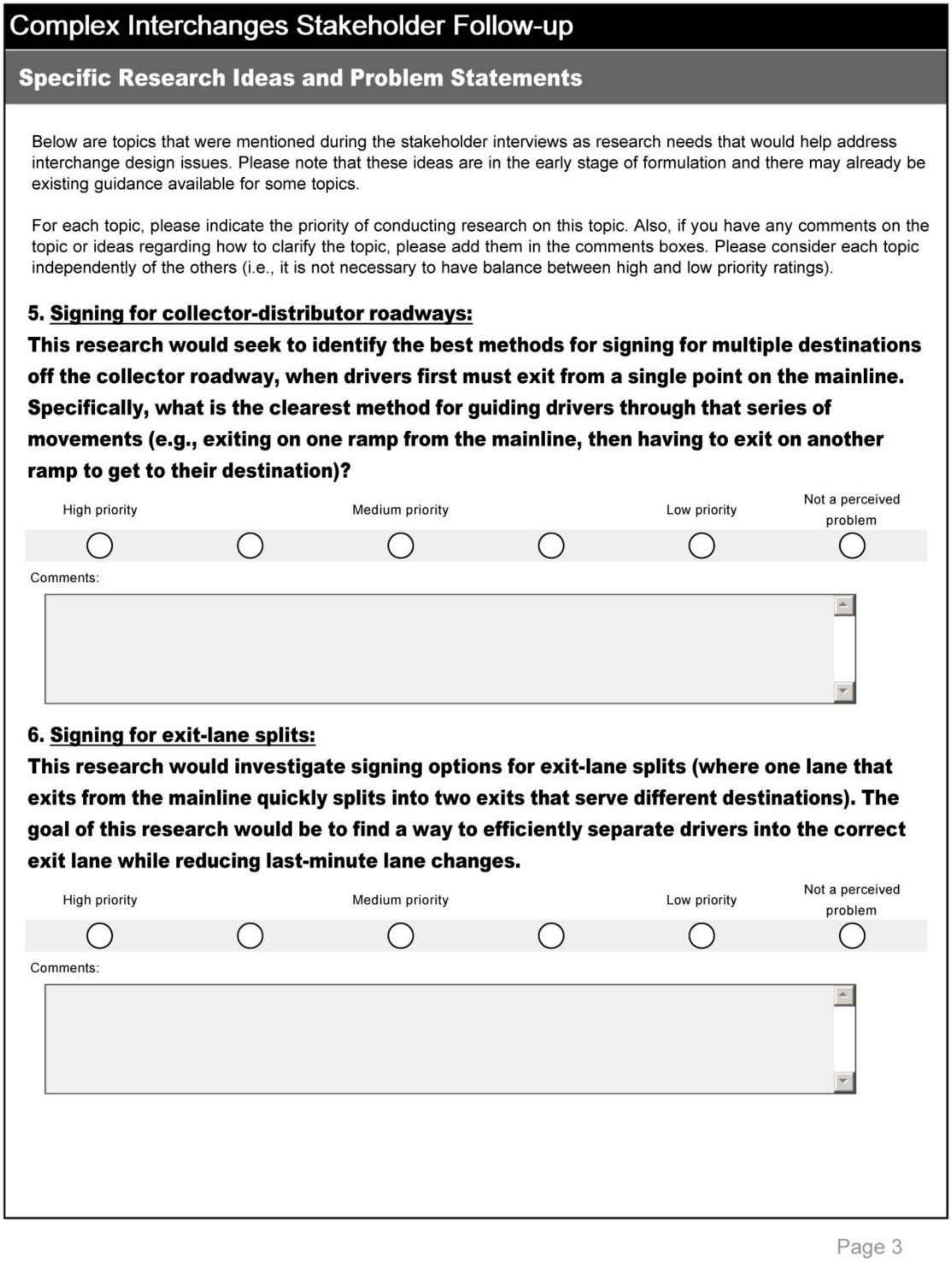
Figure 17. Form. Follow-up survey page 2.



Complex Interchanges Stakeholder Follow-up

Specific Research Ideas and Problem Statements

Below are topics that were mentioned during the stakeholder interviews as research needs that would help address interchange design issues. Please note that these ideas are in the early stage of formulation and there may already be existing guidance available for some topics.

For each topic, please indicate the priority of conducting research on this topic. Also, if you have any comments on the topic or ideas regarding how to clarify the topic, please add them in the comments boxes. Please consider each topic independently of the others (i.e., it is not necessary to have balance between high and low priority ratings).

5. Signing for collector-distributor roadways:

This research would seek to identify the best methods for signing for multiple destinations off the collector roadway, when drivers first must exit from a single point on the mainline. Specifically, what is the clearest method for guiding drivers through that series of movements (e.g., exiting on one ramp from the mainline, then having to exit on another ramp to get to their destination)?

High priority | Medium priority | Low priority | Not a perceived problem

Comments:

6. Signing for exit-lane splits:

This research would investigate signing options for exit-lane splits (where one lane that exits from the mainline quickly splits into two exits that serve different destinations). The goal of this research would be to find a way to efficiently separate drivers into the correct exit lane while reducing last-minute lane changes.

High priority | Medium priority | Low priority | Not a perceived problem

Comments:

Page 3

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Figure 18. Form. Follow-up survey page 3.

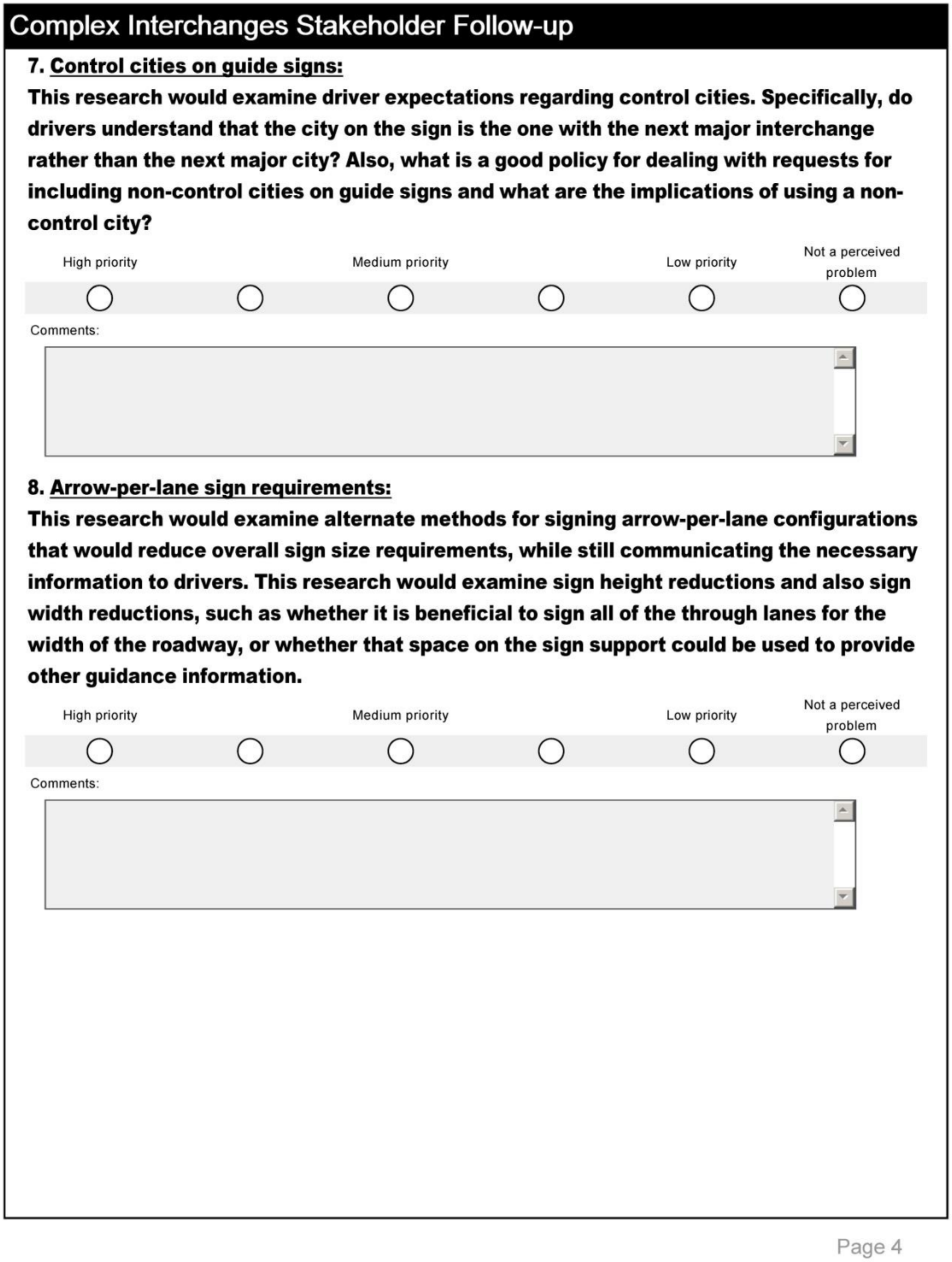

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Figure 19. Form. Follow-up survey page 4.

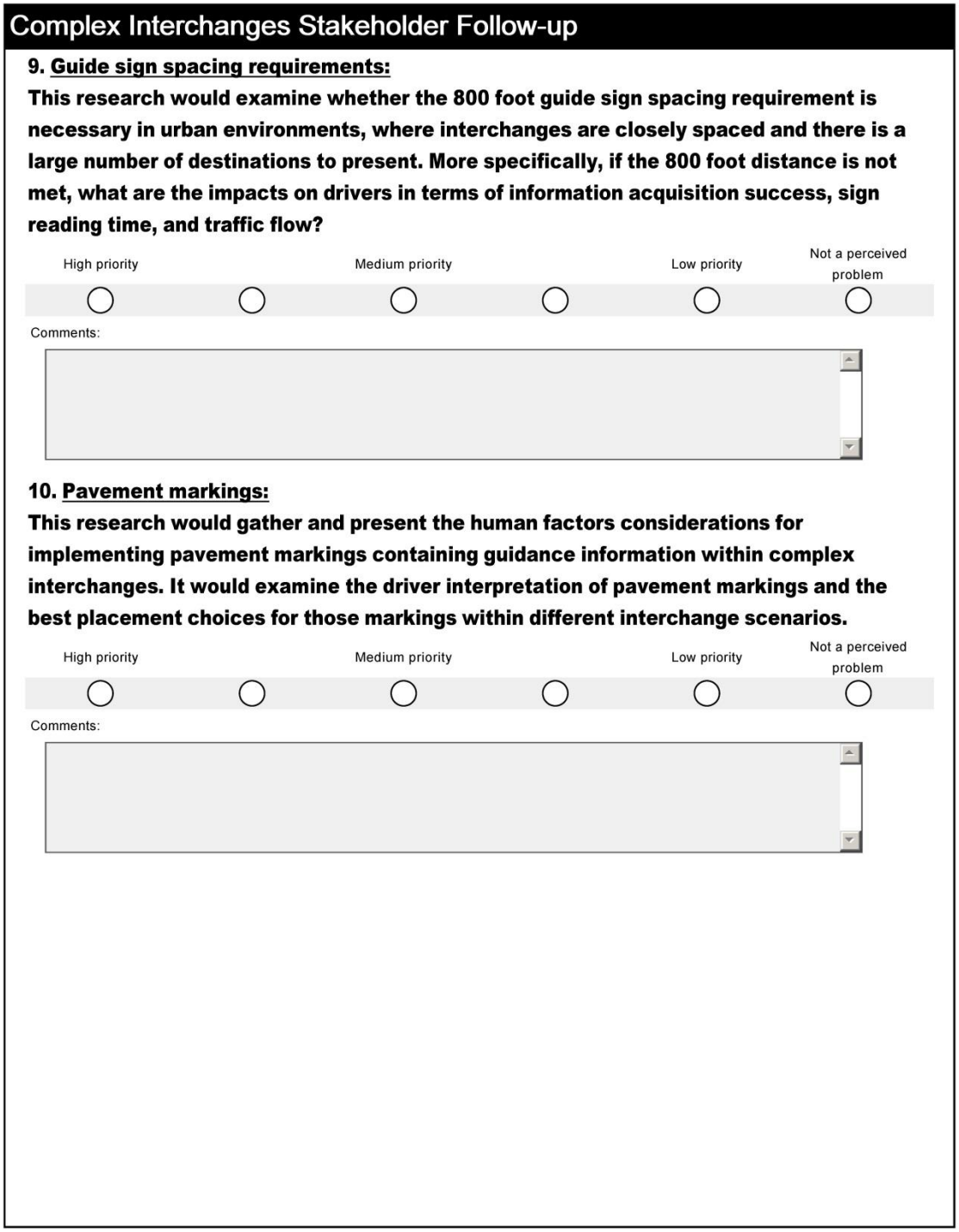

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Figure 20. Form. Follow-up survey page 5.

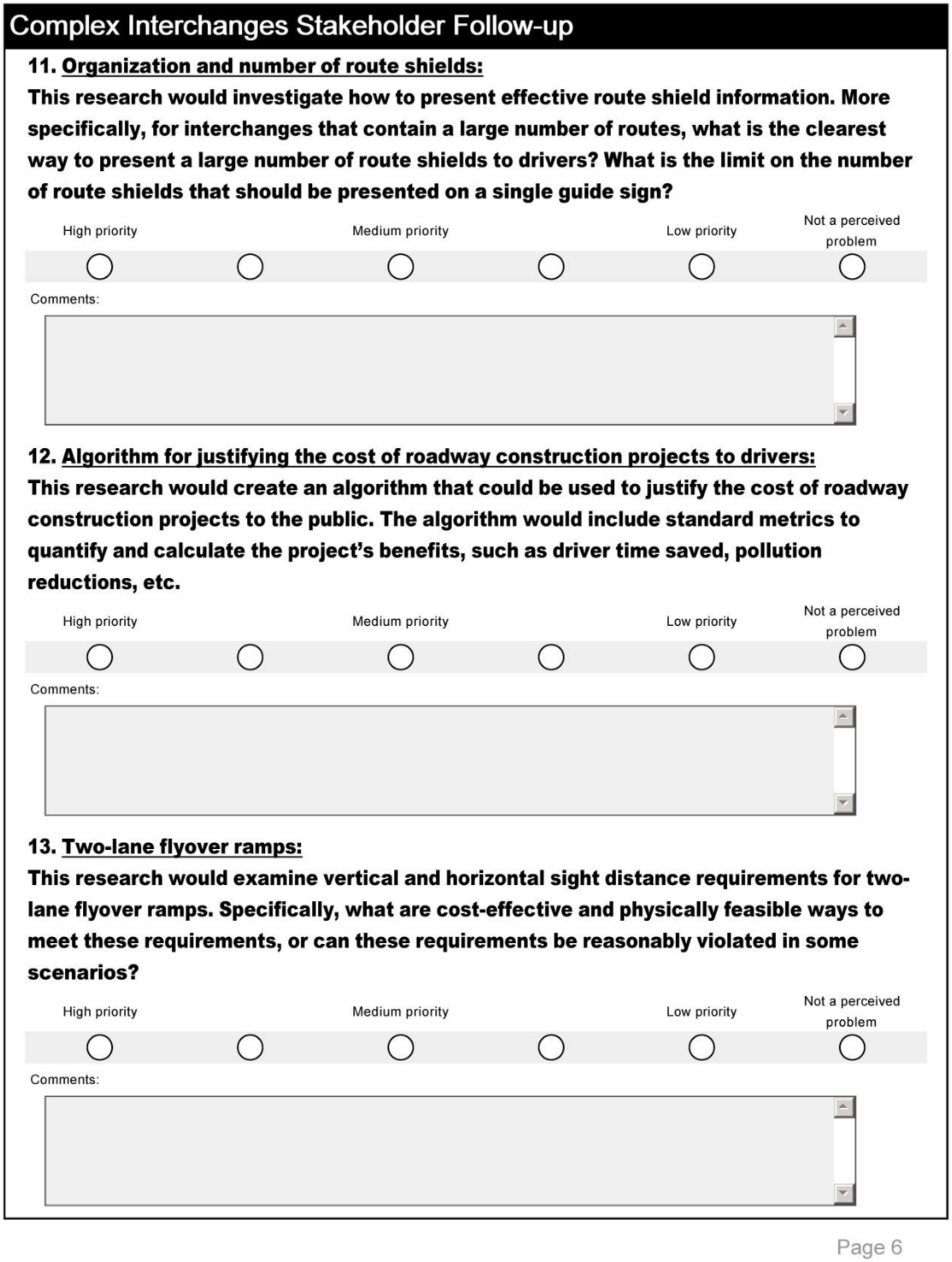

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Figure 21. Form. Follow-up survey page 6.

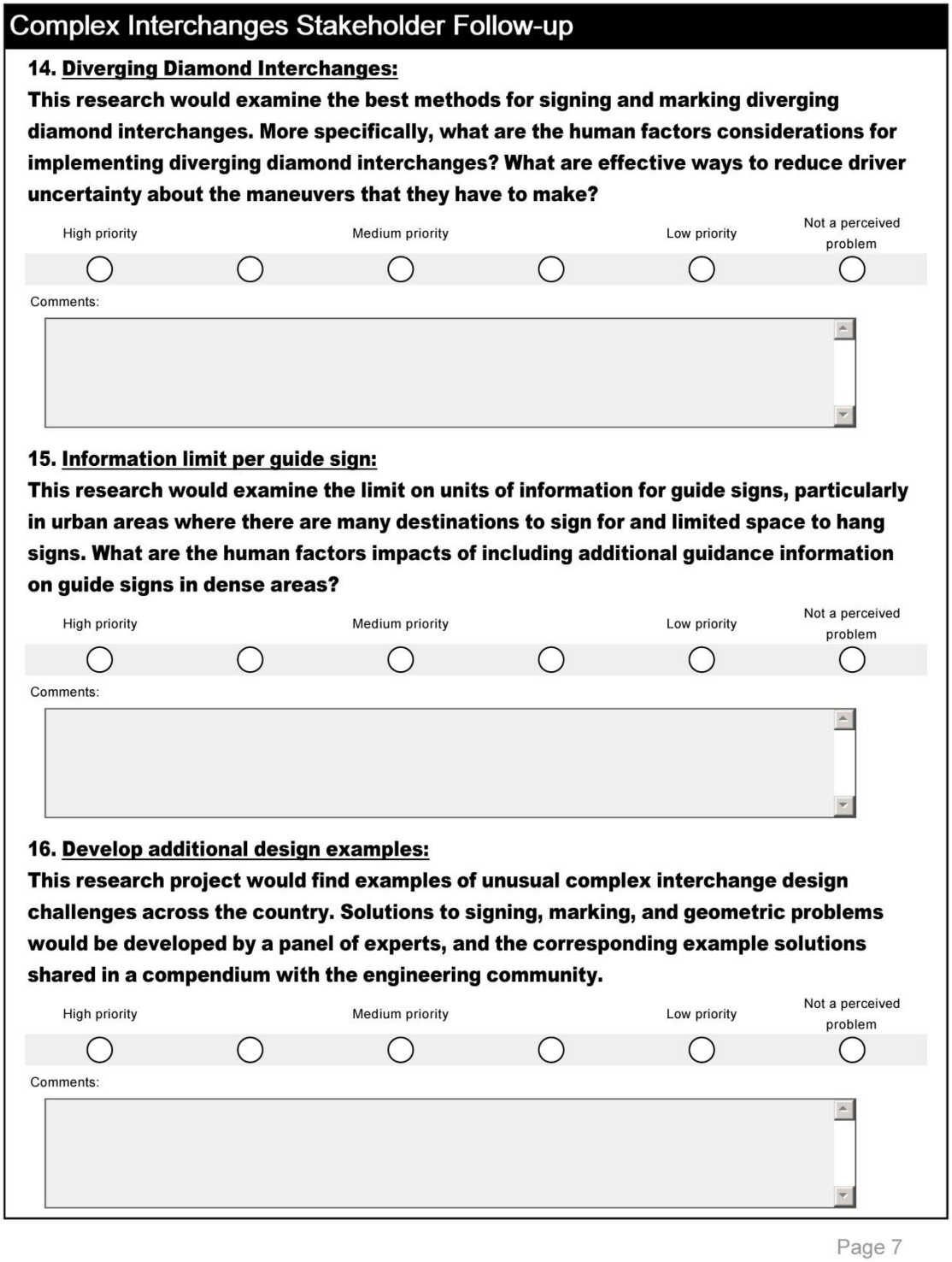

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Figure 22. Form. Follow-up survey page 7.

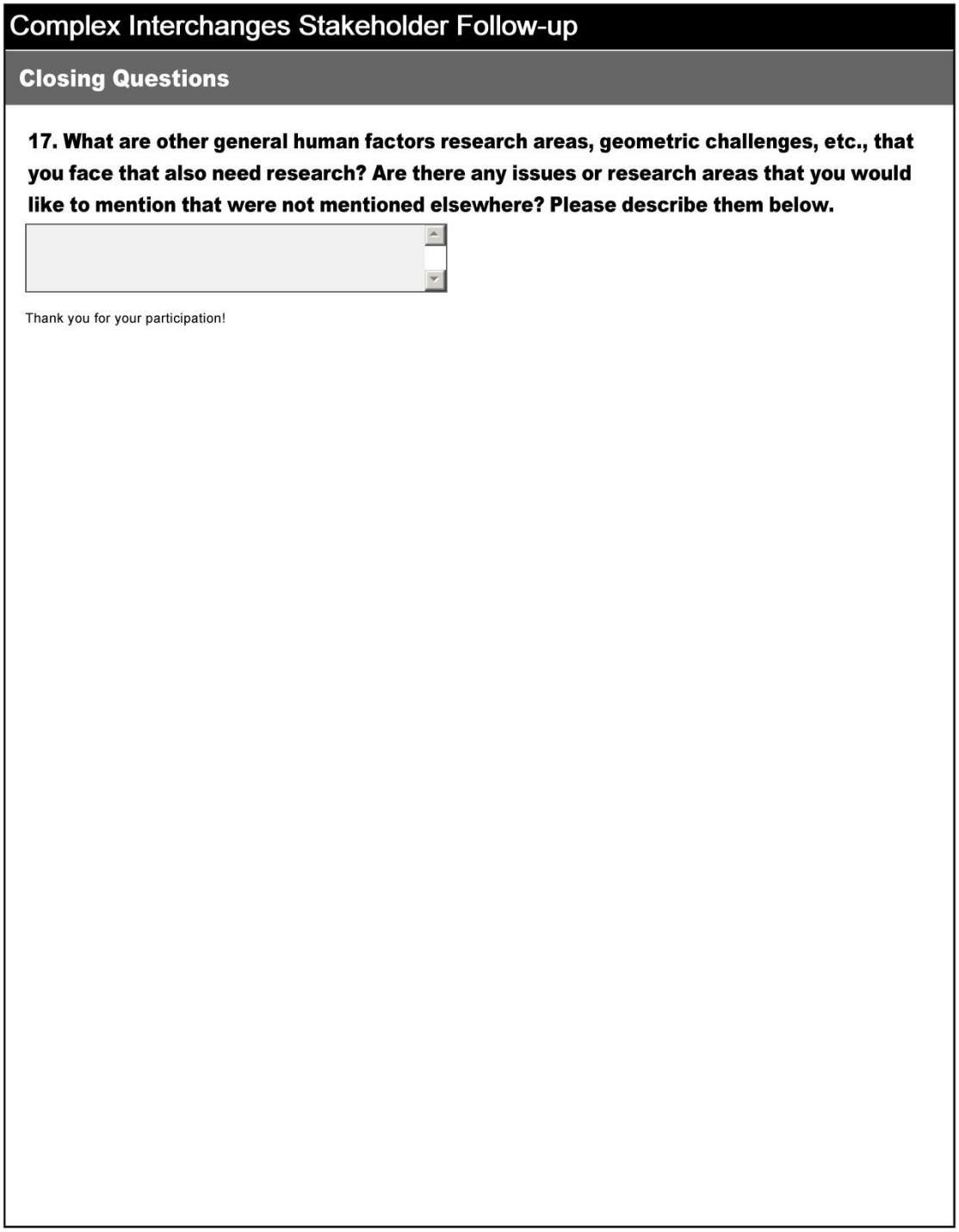

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Figure 23. Form. Follow-up survey page 8.

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