Identifying the Links Between Mental Frameworks, Context Features, and Driver Attention in Complete Streets Environments

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IDENTIFYING THE LINKS BETWEEN MENTAL FRAMEWORKS, CONTEXT FEATURES, AND DRIVER ATTENTION IN COMPLETE STREETS ENVIRONMENTS

by

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ABSTRACT

Complete street systems integrate a wide range of users in the same space, with unequal risks and responsibilities. This makes driver attention a critical factor in assuring the safety of vulnerable users. The Conditioned Anticipation of People psychological model of driver attention proposes that drivers reflexively reengage their metacognitive processes when they anticipate visually interacting with the human face or form due to the neurological priority that the brain places on human recognition. To test this model, an eye-tracking tabulation was generated from the SHRP2 Naturalistic Driving Study that measured midsegment percent of time on-task and multitasking behavior for 200 sites in Tampa, Florida and Seattle, Washington. This attention data was statistically analyzed for the impacts of a wide range of context variables using single variable ANOVA and various multivariate models such as ordered probit fractional split and ordered probit models. Context features with a strong correlation to vulnerable user presence that support driver’s visual recognition of that presence were also strongly correlated with driver attention. Features like corridor width, block length, doorway density, and sense of enclosure had the largest impact. Features that did not have an impact on the potential visual connection with street users, like lane width, right of way width, onstreet parking, functional classification, or Walkscore had no impact on driver attention or weak effect sizes, despite strong correlations with vulnerable user presence. Crash history was evaluated in conjunction with the variables most sensitive to driver attention with mixed results. Many of the features that increase the potential for drivers to see and interact with people also contribute to increases in vehicle to vehicle conflicts. A decrease in crash rate with increasing sidewalk width implies that the CAP effect can have some impact on crashes. Implications for complete streets and community design are discussed.
Keywords: complete streets, driver psychology, speed, attention, caution, naturalistic driving, driving schema
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# TABLE OF CONTENTS

LIST OF FIGURES ....................................................................................................................... ix

LIST OF TABLES ........................................................................................................................... x

CHAPTER 1: INTRODUCTION ....................................................................................................1
  Background .............................................................................................................................1
  Motivation for The Study ........................................................................................................5
  Objective of the Dissertation ...................................................................................................8
  Outline of the Dissertation ......................................................................................................9

CHAPTER 2: LITERATURE REVIEW .......................................................................................11
  Street Design Parameters ......................................................................................................11
  Near-road Parameters ..........................................................................................................14
  Mental Schema or System Level Categories ........................................................................15
  Summary ...............................................................................................................................22

CHAPTER 3: PSYCHOLOGICAL MODELS OF ATTENTION IN URBAN SPACES ...........24
  Background ...........................................................................................................................24
  Attention in an Urban Setting ...............................................................................................26
  The Conditioned Anticipation of People (CAP) Model ........................................................31

CHAPTER 4: DATA .....................................................................................................................36
  Naturalistic Driving Data ......................................................................................................36
  The Attention Tabulation .....................................................................................................36
LIST OF FIGURES

FIGURE 2.2: MDS Scaling Solution for Picture Sort of 34 Road Photos ........................................18
FIGURE 2.3: FDOT Context Classification Categories ................................................................19
FIGURE 2.4: Contextual Independent Variables .........................................................................23
FIGURE 4.2: Study Areas and Sites ..........................................................................................38
FIGURE 4.3: Corridor Width Measurements .............................................................................39
FIGURE 6.1: CAP Based Urban Context Limits .......................................................................72
LIST OF TABLES

TABLE 3.1: Historical Summary of the Theory of Driving............................................. 25
TABLE 3.2: Speed/Distance/Time Interaction................................................................. 33
TABLE 4.1: Primary Context Feature Measurements...................................................... 41
TABLE 5.1: Repeated Measures ANOVA for Attention and Vulnerable User Presence 44
TABLE 5.2: Mixed Ordered Probit (MOP) Fractional Split Time On-task Model........... 50
TABLE 5.3: Corridor Width Model Comparison, Time On-task.................................. 51
TABLE 5.4: On-task Driving Ratio Elasticities ............................................................... 53
TABLE 5.5: Ordered Probit Model for Multitasking...................................................... 55
TABLE 5.6: Corridor Width Comparison, Multitasking.................................................. 57
TABLE 5.7: Elasticities for Multitasking Level............................................................... 57
TABLE 5.8: Significance Comparison of Context Features on Attention ....................... 62
TABLE 5.9: Negative Binomial Models for Crash Rates and Context Features .......... 64
CHAPTER 1: INTRODUCTION

Road: A wide way leading from one place to another.
Street: A public road in a city, town, or village, typically with houses and buildings on one or both sides.
-Oxford English Dictionary

Background

Multimodal environments are a safety paradox: those that are most at risk in the environment have the least control over that risk and those that are least at risk are often the least aware of the risks they pose to others. As population around the world transitions to urban settings, exposure for pedestrians and bicyclists to this unbalanced risk profile is dramatically increasing and with it, incidents and fatalities are on the rise (Aevaz, 2019). Although much has been written about self-explaining roads (Charlton et al., 2010; Gitelman, Pesahov, Carmel, & Bekhor, 2016; Porter, Donnell, & Mason, 2012) and context sensitive design (California Department of, 2005; Cesme, Dock, Westrom, Lee, & Barrios, 2017; Stamatiadis, Kirk, Jasper, & Wright, 2017), there are precious few studies that can comprehensively provide design guidance for discouraging the behavioral antecedents of collisions, particularly in naturalistic settings. Fitzpatrick and her colleagues have examined how driver speed selection is impacted by a wide range of variables including lane width, posted speed, access density, functional classification, shoulder width, number of lanes, parking types, median type, roadside development, clear zones, pedestrian, activity, median type, signal spacing, and roadway alignment (K. Fitzpatrick, Carlson, Brewer, & Wooldridge, 2001; K. Fitzpatrick et al., 2019; K. Fitzpatrick, Miaou, Brewer, Carlson, & Wooldridge, 2005). Lane width has been reliably correlated to speed, but the impacts and effect

1 Portions of this chapter have been previously submitted for publication. See Appendix B for citations.
sizes have been equally consistently low (C. D. Fitzpatrick, Samuel, & Knodler, 2016; Godley, Triggs, & Fildes, 2004; Isebrands, Newsome, & Sullivan, 2015). Speed appears to be “low-hanging fruit” from a behavioral standpoint. It is easy and non-invasive to measure and has a direct impact on the driver’s ability to perceive vulnerable users and the intensity of any resulting crash. However, vehicle speed remains an externally visible outcome of internal driver states like attention and caution. Because attention is a precursor to both speed and caution, understanding it could result in more dramatic safety impacts than addressing these downstream states alone.

Transportation engineering tends toward a reductionist approach, analyzing each individual component of a roadway system with great precision in controlled settings. Urban design, a sub-specialty of landscape architecture, relies on centuries of city design to create livable “places” but is only beginning to explore measurable, repeatable scientific analysis that could illuminate the design features that mitigate this risk inequity (Lejano, Ballesteros Jr, & Tallod, 2012; Warren, 2009). Understanding the design features and critical components within the built environment that can adequately shape driver behavior before incidents occur is one of the critical questions of our era. It requires a combination of both approaches, as well as the input of a third discipline: human factors psychology.

To address safety considerations in terms of driver behavior, there are three major domains across which this behavior can be assessed: attention, speed, and caution. Speed is a directly observable behavior that is readily measured both in the field and in a simulator, but is ultimately a consequential result of multiple factors including attention, caution, and motivation. Speed can be measured in natural settings, and the availability of speed data from Bluetooth measurement has widely expanded the availability of segment level speed information. However, without corresponding attention and caution data, speed data alone fails to provide a complete picture of
driving behavior in urban settings. It is possible to measure visual attention and caution with some consistency within a simulator environment by measuring eye movements and acceleration or lane-keeping behaviors. This is far more difficult to measure in the field. In addition, driving behavior in the real world has several major features that are difficult to capture in a short-term simulator-based experiment, like motivation, distraction, and automaticity.

In contrast to simulation data, naturalistic driving data is collected over an extended period—often a year or more. This extended exposure minimizes the behavioral changes that occur due to the observation process and provides a wide range of trip motivations, time pressures, and contextual interactions as well as normal physical reactions that emerge in a three-dimensional environment, unexempted from any of the physical laws, their input, or their consequences. Because multiple traversals are measured across most segments in a region, a statistically valid sample of readings can be collected and analyzed for the contexts that are to be studied. Behaviors that correspond to specific test conditions can be isolated from the main data sample with little difficulty.

In this analysis, we will focus on visual attention as a leading indicator for pedestrian safety. Although driver attention has multiple dimensions beyond merely visual attention, as Wickens’ Multiple Resource Theory (2008) attests,2 vulnerable users tend to be less predictable than other hazards in the driving environment, making it critical that drivers maintain visual attention at a high level in urban spaces. Mind-wandering (Burdett, Charlton, & Starkey, 2019) and vigilance (Eisert et al., 2016) are common behavioral issues within driving and reflect the very

---

2 In essence, Wickens’ theory states that tasks that use the similar dimensions of cognitive resources simultaneously (i.e. two visual tasks or two logical tasks) require more attention and time to process than those that use different dimensions or modalities (i.e. a combination of a visual monitoring task and a logical/cognitive task).
conditions that pose significant risks to vulnerable users. There is evidence that people “satisfice” their attentional resources to the driving task, providing only the sufficient attention to successfully perform the task (Lewis-Evans & Rothengatter, 2009) with excessive boredom states recognized as quite uncomfortable to the driver (Steinberger, Moeller, & Schroeter, 2016). The ability of a driving context to elicit levels of attention commensurate with the (externalized) risks to vulnerable users may be difficult to measure within a simulation due to the lack of trip-based motivation, real-world distractions, local experience, and mind-wandering patterns that do not occur at the same rates in a simulator. However, within a naturalistic study that includes eye-tracking, visual attention can be measured with high fidelity within the constraints of the real world.

Over the last two decades, the complete streets movement has attempted to expand the focus of transportation design beyond the passenger vehicle so that a wide range of mode choices are available for mobility (Hui, Saxe, Roorda, Hess, & Miller, 2018). This is critical for equitably supporting a wide range of users, some of whom cannot afford or use a car. Although some in transportation design and planning have attempted to look at complete networks (McCann, 2013), the vast majority of the focus has been on attempting to provide a wide range of modal support within a single cross section. Few have been willing to address the additional risks posed by incorporating high speed, high inertia vehicles in the same space as low speed, vulnerable users, but it is clear that this poses direct risks that result in higher incident rates (MacLeod, Sanders, Griffin, Cooper, & Ragland, 2018). It may be easy to pass increased crash rates off as a transitional issue, but there remains serious questions about the circumstances in which complete streets conversions can ultimately become safe and productive uses of public resources.

For complete streets conversions to be successful and safe, the design and context factors that directly improve driver awareness must be clearly identified and quantified. Once these
factors are understood, the street designer can adjust these variables to craft an environment that clearly communicates to the driver what behavior is expected in ways that are more effective than mere signage, which is frequently disregarded or not seen at all (Fisher, 1992). There is anecdotal evidence that this task is not out of the range of a designer’s capacity, though it may involve variables that are not familiar to roadway engineers or require strategies that are beyond the scope of the right-of-way. Within the planning realm, urban designers have shown a remarkable ability to craft environments that result in significant changes to operations and behavior based on an intuitive understanding of urban interaction. This understanding comes from hundreds of years of social observation and data-derived theories of social behavior. This study is intended to bridge the gap between this intuitive understanding and the evidence-based practice required within engineering.

**Motivation for The Study**

In my transportation planning and engineering practice, I have often been called upon to perform traffic calming studies in residential areas. As I read through the literature, analysis, and implementation of a myriad of gadgets, designs, and tools, I was struck by the lack of verifiable, evidence-based research to document the success or failure of these strategies. During the same time, the concept of “Complete Streets” became a hot topic with the hope that planners and engineers could increase our person through-put by adding more efficient modes than the personal automobile to congested urban areas.

Safety engineers and roadway designers continually express frustration at the speed and disinterest drivers demonstrate as they navigated multimodal environments with vulnerable pedestrians and bicyclists located only inches away from their bumpers. They look for street designs that encouraged or enforced sensible speeds that were safer for a wider mix of vehicles
and users, but standards for designing to encourage a specific speed do not exist or at least are not in common use. Although urban designers have extensive experience regarding how to accomplish this goal, the social and intuitive nature of their supporting data leaves roadway engineers with questions about the safety and efficacy of the strategies that planners propose at the street-level or intersection-level scale where crashes occur. The lack of fine-grained data was no real challenge for planners because their primary data source is usually public opinion gathered through rigorous and open public involvement campaigns. However, without empirical data at the resolution of the street, the standards engineers must follow cannot be written. Engineers are bound by law and ethical considerations to follow the accepted standards unless they have good evidence to support a different path. One recent discussion on the ITE board brings this into clear focus as some engineers advocate for context sensitive tweaks, deviations, or additions to standard MUTCD designs while others argue that it is not worth risking a lawsuit or one’s professional licensure to experiment, even if the intentions and are good and the “engineering judgment” can be supported.

The design of roadways (facilities with the express purpose of moving people and goods quickly) is dominated by the laws of physics. Design parameters like roadway curvature, superelevation, and stopping sight distance are generated based on the physical laws that govern rapidly moving bodies with human physiological and psychological factors considered as inputs that reflect the characteristics of the population. To protect drivers from the consequences of moving faster than our bodies are naturally designed to move, roadway facilities are designed so that our sensory systems can give us ample time to react before a catastrophic physical consequence occurs. However, a second layer of protective control comes from the driver’s
discomfort and the accompanying expectation of physical harm that may result from risky behavior. Physical laws have no mercy for the reckless.

In contrast, in low-speed environments where land access is the priority, the primary risks occur due to interactions between fast-moving large inertia bodies and slower, low inertia bodies. Before the advent of the car, interpersonal interactions governed behavior based on the inherent social dynamics of face-to-face contact. Risky behavior was socially controlled through interpersonal dynamics and jurisdictional regulations. Today, within the typical urban street in the US, interactions occur between partners with unequal power. The design of the roadway exerts minimal physical control on the driver or his vehicle and interpersonal social cues are rarely exchanged or enforced between driver and pedestrian. Since physical laws rarely pose a serious impediment to driver behavior in these low-speed contexts, the management of this power imbalance must be addressed through the social and psychological domains. However, the current criteria for street design is still largely based on physical laws and accommodation for worst-case scenarios (i.e. stopping sight distance, clearance intervals, largest vehicle, clear zones), rather than the psychological management of driver behavior and attention. Design criteria that accommodate behavior that may be risky to the driver is appropriate and necessary in environments where vehicles are the only population. Design features that accommodate risky vehicular behavior in mixed mode environments amplify the risk to low-speed modes by increasing the likelihood of that risky behavior. For instance, a wide street accommodates and therefore tacitly encourages a faster vehicle flow, which increases the risk of fatal harm to a pedestrian or bicyclists.

Since my childhood, I have worked closely with occupational therapists, teachers, and psychologists as they shaped the thinking and behavior of their clients and students. One major principle they use is that if you can change the way people think, then their behavior changes
automatically, and if you can do it without their knowledge, they will not fight the attempt. Tasks that are frustrating become an invigorating challenge when reframed as a game or hobby. Mindsets from a person’s previous experience can be conscripted to help them understand the unfamiliar. Mental frameworks, or schema, like well-rehearsed scripts, govern our behavior in novel situations. More critically, we learn from experience which lays the foundation for unconscious patterns of habitual behavior that do not even rise to the level of conscious schemata. Thus, if we can understand how these frameworks and habits are cued by the environment, we can shape people’s understanding of the world and change their behavior, permanently, seamlessly, and without their conscious recognition or opposition.

**Objective of the Dissertation**

From the literature review, it is evident that there are several contextual features that could have an impact on driver speed and awareness and methods exist for discovering the mental frameworks that underlie speed selection and attentiveness.

Initially, the objective was to isolate the specific contextual features that cue drivers to use the higher level of visual attention that is required in an urban environment. However, in the process of the research, the objective shifted to understanding the principles that govern urban driving attention. *If we understand why drivers pay attention, the features that are necessary to elicit that attention will become obvious, and the implications of our design can objectively and subjectively evaluated based on a clearly understood set of principles.*

It is hoped that the principles within this dissertation will be subsequently used to evaluate urban design standards and formulate recommendations for roadway design and land development codes in urban complete streets settings. More importantly, it is hoped that this work will shift the way engineers perceive urban and non-urban spaces, providing them with the conceptual understanding needed to make independent judgements in the absence of robust data. This
understanding can also be used to manage community expectations regarding the behavior they can expect from the environment they have created.

Outline of the Dissertation

The remainder of the research proposal is divided into three chapters which shows how each chapter positions the current research effort within the larger context of the safety literature.

Chapter 2 provides a brief review of previous relevant research regarding how specific contextual features impact driver behavior. Historically, research regarding how context impacts driver behavior has approached the problem from the directions: roadway design, near-road features, and mental schema. This chapter discusses how a higher level approach looking at the mental frameworks drivers use to decode an environment is likely to result in better outcomes than a granular, feature-specific approach. A preliminary list of features that can be used to understand driver thinking and behavior is identified and discussed. Chapter 3 describes the Conditioned Anticipation of People (CAP) model. This model uses human limitations and reflexive abilities to explain why drivers attend more strongly to contexts where they anticipate seeing the human form and face. It describes how speed, reaction time, and visual ability generate the physical scale of the effect in terms of the envelope of space around a moving vehicle. This model will be tested using the statistical and econometric behavioral models identified in Chapter 5. Chapter 4 describes the data that was collected and analyzed. A detailed tabulation of driver attention from the SHRP 02 Naturalistic Driving Study at Virginia Tech was collected and used eye-tracking information to document time on-task, multitasking, and vulnerable user presence at 200 sites in Seattle and Tampa. This was paired with extensive physical measurements, tabulations of contextual features, and crash history in the built environment around each site. Chapter 5 provides a description of the analysis, their results, and a discussion of how these results relate to driver
attention and the CAP model. First, attention and vulnerable user presence are analyzed using a series of single variable one-way ANOVA analyses to identify and confirm the nuances of the CAP model. Then a series of multivariate probit analyses were performed to identify how major contextual features interact to shape driver attention. Finally, a negative binomial analysis was used to identify how the CAP model impacts overall crash patterns. Chapter 6 summarizes the overall framework of the CAP model, its implications, and the limitations of this study. Essentially, people will pay attention at a higher level when they expect people to be nearby. Narrow corridors with lots of human activity will generate attention commensurate with the risk to vulnerable users. Wide corridors and high levels of buffering move people out of the driver’s working field of view, eliminating the reflexive increases in attention that their presence generates. However, this higher level of attention is demanding to the driver, which impacts the distances they are willing to traverse in these contexts and may prematurely induce fatigue and lapses in judgement if exposure extends beyond driver’s limitations, an area ripe for additional research. This has significant implications for urban form and scale.
CHAPTER 2: LITERATURE REVIEW³

Based on a review of the applicable research, there have been three successive approaches to impacting driver behavior in complete streets environments: modify the street design, adjust the near-road context, and identify the mental schemas (categories) that drivers use to govern their behavior and adjust the environment accordingly.

Street Design Parameters

The first approach to modify driver behavior was to shape the features within the roadway cross-section and the first target behavior was speed, resulting in a wide array of speed-based research and minimal research regarding features that impact driver attention. The design features that were most likely to impact vehicle speed and safety were best summarized in a 2009 TRB National Conference session that discussed speed limit credibility (Aarts, van Nes, Wegman, Van Schagen, & Louwerse, 2009) using the information shown in Table 2.1:

<table>
<thead>
<tr>
<th>Road design and layout characteristics</th>
<th>Decelerator</th>
<th>Accelerator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pedestrian facility</td>
<td>pedestrians mix with other traffic</td>
<td>pedestrians prohibited</td>
</tr>
<tr>
<td>Bicyclist facility</td>
<td>cyclists mix with other traffic</td>
<td>cyclists prohibited</td>
</tr>
<tr>
<td>Parking facility</td>
<td>parking on the roadway</td>
<td>parking prohibited</td>
</tr>
<tr>
<td>Number of lanes</td>
<td>one carriageway</td>
<td>several lanes per driving direction with hard separator</td>
</tr>
<tr>
<td>Junctions</td>
<td>junctions at grade without priority indication</td>
<td>grade separated junctions</td>
</tr>
<tr>
<td>Straight stretches</td>
<td>short straight stretches</td>
<td>long straight stretches</td>
</tr>
<tr>
<td>Physical speed limiters</td>
<td>physical speed limiters</td>
<td>no physical speed limiters</td>
</tr>
<tr>
<td>Road/lane width</td>
<td>small roads/lanes</td>
<td>wide roads/lanes</td>
</tr>
<tr>
<td>Road surfacing</td>
<td>uneven surfacing</td>
<td>even surfacing</td>
</tr>
<tr>
<td>Density of road environment</td>
<td>dense vegetation or built-up area</td>
<td>sparse vegetation or built-up area</td>
</tr>
</tbody>
</table>

³ Portions of this chapter/section have been submitted for publication. See Appendix B for citations.
Several of these factors are likely to have a stronger impact on complete streets applications than others. Adding features like bike lanes or sidewalks may increase driver awareness, but without users on these facilities the extra space they provide can have the opposite effect. For instance, the addition of a minimal bike lane to a roadway system is likely to do more harm than good because bikers will not use it and drivers will come to see the additional width as an excuse to drive faster and pay less attention (Isebrands et al., 2015). In the past, bike lanes could be as narrow as 3 foot in width. The 7-foot width of FDOT’s new buffered bike lane standard has the potential to reverse this trend but it is too early to judge its effects.

A statistically significant but weak correlation was identified between lane width and 85th percentile speed across a wide range of speeds (p=0.0012, R^2=0.27) (K. Fitzpatrick et al., 2001). Several studies identified increased accident rates, particularly with regard to sideswipe and rear-end accidents as lane widths decrease (Rista et al., 2018) (Rahman et al., 2018). However, the lower speeds identified in narrower lane widths are likely to reduce the severity of the accidents, particularly when multimodal conflicts are a concern.

This narrower cross section need not interfere with through-put. For example, SE 149th Street in Bellview, Washington is a 4-lane street with a built-up median that carries 41,000 vehicles per day using 10-foot lanes with an impressive safety record (Burden, 2001). There is good reason from a perceptual standpoint to anticipate significant speed and attentiveness benefits when lanes are narrow. Based on studies of visual attention and physical orientation, it has been postulated that lane-keeping is maintained by the ambient (peripheral) vision field, rather than foveal (focal) vision processes (Shinar, 2008). Shinar’s experiments showed that for experienced drivers, lane keeping can easily be maintained as long as the ambient vision field includes the roadway. The roadway edge is almost never the subject of the experienced driver’s direct focus and thus requires
little, if any, cognitive effort. Since this orientation function is continually operating in the mental background while the ambient field of vision includes the orienting images, visual deviations from the driving environment seem acceptable to the driver as long as the vehicle remains within a reasonable margin within the lane. These deviations can include what are often considered distractions from the driving task, but may also include standard safe driving practices like looking in the rear or side mirrors. A wide lane allows a much wider margin for acceptable lane-keeping and therefore may allow for longer distraction events. When the lane is narrow, this margin of acceptable lane-keeping is less and therefore the driver has two choices: attend closely or drive slowly in order to maintain the same amount of attention drift. The original concept of a design speed was tied to studies from the 1930’s using a ball-bank indicator (see Figure 1) on horizontal curves to measure driver comfort (Moyer & Berry, 1941). In low-speed environments, turning radii must be very small to exceed this type of acceleration-based criteria. However, roadway curvature may also reduce speed due to driver uncertainty based on the available sight distance. It may be possible to directly correlate sight distance to driver speed choice over a wide range of speeds. Sight distance may also impact drivers in terms of intersection or driveway spacing.

![Ball Bank Indicator](image)

**Figure 2.1: Ball Bank Indicator** ("Ball Bank Indicator,")

Other cross section elements may have a measurable impact on driver speed and attentiveness in a non-parametric manner (absence vs. presence). As Table 2.1 shows, medians often increase driver speed due to decreased risk of conflicts from oncoming vehicles, however
the type of median may make a difference in both safety and speed. Small landscaped medians that act as chokers provide pedestrian refuges and reduce speeds (Hallmark et al., 2008), while large landscaped medians without pedestrian refuges often have the opposite effect (K. Fitzpatrick et al., 2005). Occupied bike lanes tend to decrease traffic speed (Jilla, 1974), while habitually unoccupied ones have less conclusive results. Onstreet parking has been shown to have a direct impact on speed in urban environments and must be considered in any cross-sectional study (Marshall, Garrick, & Hansen, 2008). Pavement texture can also increase attentiveness and decrease speed, and is often used in locations where conflicts are expected. Drawbacks to this treatment include concerns about noise and maintenance (Kuemmel, Jaeckel, Satanovsky, Shober, & Dobersek, 1996). A study in China showed that parallelogram markings that visually narrowed the lane width approaching crosswalks had a measurable impact on both speed and safety (Guo, Liu, Liang, & Wang, 2016). Other visual ‘tricks’ may be candidates for reducing speed and increasing attentiveness (Manser & Hancock, 2007), but care should be exercised to assure that the impact of the mitigation is likely to be permanent based on genuine perceptual impacts rather than mere novelty—the traffic equivalent of a placebo treatment. Intersection geometry also plays a part in drivers’ speed choices. Large scale intersections that are difficult to cross are less likely to include conflicting users like pedestrians or bicyclists and therefore may elicit higher traversing speeds.

**Near-road Parameters**

As the impacts of the cross-section elements have come into focus, many have begun to look up from the cross-section to the context around the roadway to find features that would impact driver behavior. Connection spacing and density were the first to be identified as having a direct impact on speed due to the risk of conflicts with other vehicles and are easy to measure due to the availability of satellite imaging. Scanning the environment for conflicting vehicles in the presence
of visual clutter adds to the cognitive workload (Zeitlin, 1995) and therefore is likely to precipitate slower speeds to compensate. Intersection or driveway spacing may also be confounded by the land uses that are accessing the corridor. Dense intersection spacing that is due to a traditional grid neighborhood and its developed properties is likely to have a very different impact on driver behavior than dense driveway spacing in a suburban corridor. The first decreases driver speed and increases attentiveness. The impacts of the second are likely to include high speed variability, low pedestrian/bicycle interaction, and overall unsafe behavior.

The presence and proximity of sidewalks and vegetation may also have a direct impact on drivers, although the literature shows some inconsistency. A recent study performed in Denver, CO showed a significant negative correlation between the presence of street trees and accident rates (Marshall et al., 2008) turning 50 years of transportation practice about clear zones on its head. A 60% tree canopy coverage translated into a 66% decrease in accident risk. Other simulator studies have shown no impact on speed or attentiveness in roadway corridors with trees placed 6 feet from the roadway and only minor impacts in speed with the addition of roadside barricades (Bella, 2013). Of course, the incorporation of trees and other vegetation into the built environment has manifold benefits, some of which may produce secondary outcomes that impact driver behavior. For instance, the inclusion of street trees over the sidewalk not only provides a visual and physical barrier between drivers and pedestrians, but also makes walking more pleasant, which increases the frequency of pedestrian activity. This increased activity may have traffic impacts on its own.

**Mental Schema or System Level Categories**

A different approach to this issue is to decode the mental categories (schema) that people use to understand their environmental context in order to guide their behavior. This could be a reflection of the higher-level categorizations that roadway designers use, like hierarchy or context
classification, but it is more likely to be based on the driver’s neurological characteristics or previous exposure to driving settings and events. An experienced driver employs a set of behaviors based on automatic cognition: thinking patterns that are “implicit, unverbalized, rapid and automatic” (d'Andrade, 1995). This automatic cognition is governed by schemata, which DiMaggio defines as “knowledge structures that represent objects or events and provide default assumptions about their characteristics, relationships, and entailments under conditions of incomplete information.” Schemata reflect an underlying mental categorization that is triggered or recognized based on contextual cues. Once a specific schema is appropriately cued, then any unfamiliar aspect or event can be processed in light of the over-arching categorization which affords the person an appropriate set of reactions or understandings. These schemata may or may not be consciously understood by the driver. There is also evidence that whereas behavioral choices are generally clear and immediately recognizable when queried in the immediate moment, memory for those choices decays quickly and the driver remains unaware of the myriad of choices that were made in the moment during the trip (Richards & Charlton, 2020).

In several recent studies in New Zealand (Samuel G Charlton & Nicola J Starkey, 2017; S. G. Charlton & N. J. Starkey, 2017), the psychological concept of cognitive schema was used to understand the mental representations drivers use to understand their environment and guide their behavior. Participants were given 34 pictures of familiar rural roadways and asked to ‘sort them into piles so that their behavior would be the same for all the roads in one pile and different to the roads in other piles.’ They could make as many piles as they wanted. On average, the participants sorted the pictures into just under 5 piles (range: 2-9 piles) with simple descriptions for each pile. A similarity matrix was used to calculate a multidimensional scaling solution. Figure 2.2 from the report depicts the psychological ‘distance’ between the 34 road scenes based on how often they
were grouped together by the participants. A hierarchical clustering analysis resulted in six, non-overlapping road categories. Each of these scenarios elicited unique driving behavior consistent with the categorization. This research may explain why no one geometric variable shows a strong correlation with driver behavior. Driving contexts are comprehended as a whole rather than as a sum of the individual components. Approaching context from a schematic perspective may help address many of the less quantifiable implications of streetscape context. If the driving characteristics underlying these mental models can be understood, schema definitions can guide design categories and public relations efforts toward safer multimodal environments.

Several environmental variables are likely to underlie these cognitive schemata and should be considered when constructing experiments to understand drivers’ attitudes. A multivariate model looking at geometric conditions identified intersection density and shoulder width as strong predictors of speed while vertical and horizontal deviations had a smaller impact (Gitelman et al., 2016). In a different study, successful implementation of Self-Explaining Roads on residential and collector streets used restricted forward visibility and clear delineation of pedestrian, bicycle and roadway elements with travel lane width reduction (Charlton et al., 2010) to elicit better speed compliance and awareness.

It remains to be seen whether hierarchical distinctions like arterial, collector, or local street should sit above individual contextual schema or should be considered a part of an overarching driver schemata. Clearly, both these hierarchical distinctions and the adjacent land uses have a significant impact on the mental models that drivers use to guide their behavior. One approach that may resolve this issue is the ‘Link and Place’ framework developed in the UK (Jones, Marshall, & Boujenko, 2008). Since a specific roadway can fulfill both link and place functions, they are categorized independently on the same numeric scales. Link-ness is categorized by
transportation professionals while place value is categorized by urban or land use planners. This set of categorizations may provide valuable assistance in categorizing suburban environments and subsequently planning for the appropriate design solutions. The recognition that a complete street may, in fact, have strong link characteristics and weak place characteristics like the typical collector ‘tube’ that runs between walled subdivisions allows communities the freedom to recognize these locations as a connection (road) rather than attempting to artificially generate a ‘place.’
The FDOT Context Classification is an attempt to delineate, in bulk, different contexts throughout the typical built environment. Figure 2.3 shows the FDOT Context Classification Categories (Context Classification, 2017).

![FIGURE 2.3: FDOT Context Classification Categories](Context Classification, 2017)

The classification contains 8 categories that range from C-1 (Natural) to C-6 (Urban Core). It is not prescriptive but descriptive in terms of the built environment categories that have been generated over the last century and could be considered the major mental categories defined within Urban Design. Four of the classifications reflect areas where mixed mode travel should be common (C2T, C4, C5, and C6) while the remaining four are areas where an automobile-centric design pattern predominates (C1, C2, C3R, C3C). Rural Towns (C2T) appear out of place in the classification scheme, but are typical of pre-WWII construction patterns and are typically urban in character and multimodal by design. It is important to note that facilities for multiple mode travel will exist in each of the contexts, but the investment toward supporting active travel modes is expected to be less in car-centric areas. As a result, requests for extensive multimodal improvements in those areas are likely to be discouraged because they encourage walking and biking in areas where drivers may be less sensitive to their presence. The environmental features
mentioned within the context classification scheme are tabulated in a matrix (Table 2.2) from the FDOT Classification document, along with a description of how they would manifest in each context. The features included in this matrix that can easily be tabulated for this analysis include the following:

- Land Use (Single family residential, multifamily residential, commercial)
- Building height (stories)
- Building placement (feet to edge of pavement)
- Building height to open width ratio (building height/face to face building distance)
- Parking location (onstreet, driveway, lot in front, lot in back, structured parking)
- Doorway spacing (spacing of functional doorways along the block face)
- Corridor width
- Block length (feet)
- Walkscore

The exploration of the mental constructs that underlie driver behavior also brings up the issue of change over time. Most changes to the development patterns in an area occur gradually, allowing for less recognition of the changing character of the area. This may result in drivers using a mental framework to decode an area that is consistent with their past experience rather than the current development pattern. This is likely the cause for most NIMBY reactions to tipping-point projects. Identifying how drivers change their perspective on an environment is critical for transitioning to safer urban spaces.

Complete streets reconstructions often cause a sudden change to the area that may jar local drivers into recognizing a new context and rapidly adjusting their behavior, particularly if the implementation has strong community recognition and support. Coupled with an understanding of the features that make a critical difference in driver behavior, these changes may result in permanent, positive behavioral change.
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<tr>
<td>C1-Natural</td>
<td>Lands preserved in a natural or wilderness condition, including lands unsuit for settlement due to natural conditions.</td>
<td>Conservation Land, Open Space, or Park</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
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<td>C2-Rural</td>
<td>Sparsely settled lands, may include agricultural land, grassland, woodland, and wetlands.</td>
<td>Agricultural or Single-Family Residential</td>
<td>1 to 2</td>
<td>Detached buildings with no consistent pattern of setbacks</td>
<td>No</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>&lt;1</td>
<td>N/A</td>
</tr>
<tr>
<td>C2T-Rural Town</td>
<td>Small concentrations of developed areas immediately surrounded by rural and natural areas; includes many historic towns.</td>
<td>Retail, Office, Multi-Family Residential, Institutional, or Industrial</td>
<td>1 to 2</td>
<td>Both detached and attached buildings with no or shallow (&lt;10°) or medium (10° to 24°) setbacks</td>
<td>Yes</td>
<td>Mostly on side or rear occasionally in front</td>
<td>&lt;100</td>
<td>&lt;3,000</td>
<td>&lt;500</td>
<td>4</td>
<td>&gt;0.25</td>
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<td>C3R-Suburban Residential</td>
<td>Mostly residential uses within large blocks and a disconnected or sparse roadway network.</td>
<td>Single-Family or Multi-Family Residential</td>
<td>1 to 3, with some 3</td>
<td>Detached buildings with medium to large (10° to 24°) setbacks</td>
<td>No</td>
<td>Mostly in front, occasionally on side or rear</td>
<td>&lt;100</td>
<td>N/A</td>
<td>N/A</td>
<td>1 to 8</td>
<td>N/A</td>
</tr>
<tr>
<td>C3C-Suburban Commercial</td>
<td>Mostly non-residential uses with large building footprints and large parking lots within large blocks and a disconnected or sparse roadway network.</td>
<td>Retail, Office, Multi-Family Residential, Institutional, or Industrial</td>
<td>1 (retail area), and 1 to 4 (office uses)</td>
<td>Detached buildings with medium to large (10° to 24°) setbacks on all sides</td>
<td>No</td>
<td>Mostly in front, occasionally in rear, or side</td>
<td>&lt;100</td>
<td>&gt;3,000</td>
<td>&gt;600</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>C4-Urban General</td>
<td>Mix of uses set within small blocks with a well-connected roadway network. May extend long distances. The roadway network usually connects to residential neighborhoods immediately along the corridor or behind the uses fronting the roadway.</td>
<td>Single-Family or Multi-Family Residential, Institutional, Neighborhood Scale Retail, or Office</td>
<td>1 to 3, with some taller buildings</td>
<td>Detached buildings with medium to large (10° to 24°) setbacks on all sides</td>
<td>Yes</td>
<td>Mostly on side or rear occasionally in front</td>
<td>&lt;100</td>
<td>&lt;3,000</td>
<td>&lt;500</td>
<td>4</td>
<td>N/A</td>
</tr>
<tr>
<td>C5-Urban Center</td>
<td>Mix of uses set within small blocks with a well-connected roadway network. Typically concentrated around a few blocks and identified as part of a civic or economic center of a community, town, or city.</td>
<td>Retail, Office, Multi-Family Residential, Institutional, or Light Industrial</td>
<td>1 to 5, with some taller buildings</td>
<td>Detached buildings with no, shallow (&lt;10°) or medium (10° to 24°) setbacks</td>
<td>Yes</td>
<td>Mostly on side or rear occasionally in front, or in shared off-site parking facilities</td>
<td>&lt;100</td>
<td>&lt;2,500</td>
<td>&lt;500</td>
<td>4</td>
<td>&lt;0.75</td>
</tr>
<tr>
<td>C6-Urban Core</td>
<td>Areas with the highest densities and building heights, and within FDOT classified Large Urbanized Areas (population &gt; 1,000,000). Many are regional centers and destinations. Buildings have mixed uses, are built up to the roadway, and are within a well-connected roadway network.</td>
<td>Retail, Office, Institutional, or Multi-Family Residential</td>
<td>&gt;4, with some shorter buildings</td>
<td>Mostly attached buildings with no or shallow (&lt;10°) setbacks</td>
<td>Yes</td>
<td>Mostly on side or rear, often in shared off-site parking facilities</td>
<td>&gt;100</td>
<td>&lt;2,500</td>
<td>&lt;600</td>
<td>&gt;10</td>
<td>2</td>
</tr>
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</table>
Summary

Several major geometric factors within the street are likely to have a strong impact on driver attentiveness in urban and transitioning complete streets projects. Intersection and driveway density, lane width (particularly narrow lanes), sight distance, medians, and bicycle lanes are the easiest to measure and the most likely to have a direct impact. The provision of pedestrian features, street trees, and obstacles near the road-bed, like vegetation, barriers, or on-street parking are the most likely to have an impact on driver behavior. Several of these are equally easy to quantify, at least in a parametric sense (presence vs. absence). Sidewalk width, use, and horizontal obstacles near the roadway are not as easy to document, but have the potential to be categorized so that their impacts can be evaluated. Land use patterns may also be categorized in terms of both intensity and type as a part of an evaluation. It may be possible to frame a multivariate exploration of these parameters using econometric modeling to identify the impact each variable has on speed, attentiveness, and safety. The datasets from the SHRP2 Naturalistic Driving Study as well as local FDOT Inrix data may provide ample data to explore many of these variables. However, previous research has failed to identify a reliably strong correlation between driver speed or safety and these variables. In the future, evaluation of how signage impacts driver behavior could also be attempted.

Rather than approaching the problem from a granular, feature-oriented perspective, it may be more productive to address the issue in terms of the mental frameworks that drivers use to identify distinct contexts and adjust their behavior. Although this approach is more methodologically complex, it has the chance to identify what is distinctive about each context so that the critical features and public interaction strategies can be identified. Information from a multivariate exploration can strongly inform schema exploration and vice versa. Research into this topic holds out hope that multimodal contexts can be designed so that users that are currently
in conflict can be harmonized into a mutually supporting community where mode choice is a reality. Figure 2.4 provides a graphical summary of the variables to be considered.

**FIGURE 2.4: Contextual Independent Variables**
CHAPTER 3: PSYCHOLOGICAL MODELS OF ATTENTION
IN URBAN SPACES

Background

To address the issue of vulnerable users in complete streets environments, researchers and designers need to think about urban space from a psychological perspective, with a comprehensive theory or model that addresses driver behavior from a uniquely urban point of view. Several authors have provided excellent summaries of overall driving theory, each one a part of what Shinar (2017) calls as a “jigsaw puzzle in which many pieces are made to fit together to form a coherent picture”. Table 3.1 identifies the major conceptual benchmarks identified in these summaries over time, highlighting the ones that are critical to urban driving situations. Extending the metaphor, the outside edges of the puzzle appear complete, so this analysis attempts to assemble a tiny corner of the puzzle that is dramatically different than the rest—how is driving behavior in low speed, urban, multimodal contexts substantively different from driving in other contexts and what are the implications of those differences? Is there a mental framework, a schema, or a perceptual nuance that is unique to urban contexts and what would that mean in terms of designing safe spaces for all users?

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4 Portions of this chapter/section have been submitted for publication. See Appendix B for citations.
<table>
<thead>
<tr>
<th>Author</th>
<th>Year</th>
<th>Concepts</th>
</tr>
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<tbody>
<tr>
<td>Gibson &amp; Cooke</td>
<td>1938</td>
<td>Field: Life space containing the person and his psychological environment  &lt;br&gt; Car as a tool, vision defines the field  &lt;br&gt; Valences-positive attracts, negative repels  &lt;br&gt; Field of safe travel: perceived unimpeded potential paths  &lt;br&gt; Minimum stopping zone</td>
</tr>
<tr>
<td>Blumenthal</td>
<td>1968</td>
<td>Socio-technical problem; requires systems approach  &lt;br&gt; Accidents: Imbalance between system demands and driver capabilities  &lt;br&gt; Failures may be inevitable; plan for it</td>
</tr>
<tr>
<td>Shinar</td>
<td>1978</td>
<td>Individual differences  &lt;br&gt; Driver as information processor; Inattention/distraction  &lt;br&gt; Visual search vs. prediction failures  &lt;br&gt; Driver experience/education  &lt;br&gt; Intentional volitional errors</td>
</tr>
<tr>
<td>Michon</td>
<td>1985</td>
<td>Human as intelligent fallible problem solver  &lt;br&gt; Control Heirarchy: Strategic, tactical, operational levels  &lt;br&gt; Behavioral conditioning vs. Internal state models  &lt;br&gt; Taxonomic models: traits, task analysis  &lt;br&gt; Risk models: compensation, homeostasis, threshold, avoidance  &lt;br&gt; Distinction between performance (capability) and behavior</td>
</tr>
<tr>
<td>Ranney</td>
<td>1994</td>
<td>Drivers compensate for limitations (behavioral adaptation)  &lt;br&gt; Attention switching within selective attention  &lt;br&gt; Mental workload; information processing speed  &lt;br&gt; Data driven vs. memory driven processing  &lt;br&gt; Speed selection motives: pleasure, risk, time, expense  &lt;br&gt; Risk taking as utility maximization, minimize attention paid  &lt;br&gt; Preattention and conspecuity  &lt;br&gt; Automaticity: active control vs automatic components  &lt;br&gt; Multiple resource theory  &lt;br&gt; Visual levels: Passsive noticing, global search, specific scanning  &lt;br&gt; Behavior hierarchy: Skill-based, rule-based, knowledge-based  &lt;br&gt; Control hierarchy interaction with behavior hierarchy  &lt;br&gt; Drivers barely conscious of skill- and rule-based decisions  &lt;br&gt; Error production factors vs. error recovery factors  &lt;br&gt; Monitoring failures vs. problem-solving failures  &lt;br&gt; Consistency vs. novelty</td>
</tr>
<tr>
<td>Fuller</td>
<td>2005</td>
<td>Driving task difficulty, not risk shapes decision making  &lt;br&gt; Driver maintains safety margins from hazard, lane tube; automized control  &lt;br&gt; Task Capacity Interface Model: difficulty means demands exceed capacity  &lt;br&gt; Task demand is under driver control through speed selection  &lt;br&gt; Preferred level of arousal guides preferred task demand</td>
</tr>
<tr>
<td>Vaa</td>
<td>2014</td>
<td>Learning/operant conditioning: stimulus → response → reinforcing stimulus  &lt;br&gt; Driving is social interaction  &lt;br&gt; Survival motive develops the ability to avoid danger via biological monitoring  &lt;br&gt; Emotions vs. feelings (eg biological stress vs conscious affect)  &lt;br&gt; Cognitive span/chunking, 7+/−2: real limits in memory span  &lt;br&gt; Pre-cognitively limited alternatives chosen using &quot;gut&quot; (bounded rationality)  &lt;br&gt; Emotions/feelings guide the driver to handle most risks  &lt;br&gt; Driving Affordances</td>
</tr>
<tr>
<td>Shinar</td>
<td>2017</td>
<td>Information processing rate determines speed selection  &lt;br&gt; Attention; Long term and short term memory characteristics  &lt;br&gt; Schema: sets of experiences and relevant rules of behavior  &lt;br&gt; Situation awareness: perception, comprehension, anticipation  &lt;br&gt; Theory of planned behavior: norms → attitudes → intentions → behavior  &lt;br&gt; Information processing and motivation: slips, lapses, mistakes, violations</td>
</tr>
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Attention in an Urban Setting

Driving environments can be cluttered, providing an abundance of stimuli to the driver that must be sorted and prioritized in terms of the tasks at hand. However, what makes urban driving unique is the face-to-face interaction with other people outside of their cars. In his landmark park study of New York City, William Whyte (1980) found that “What attracts people most…is other people.” Humans are hard-wired at a subconscious level to recognize people, particularly faces, in a scene regardless of their attentional state. We even see them when they are not really there: pareidolia is recognized as a nearly universal innate ability to see faces in everyday objects, which can become heightened in certain individuals. Liu et al. (2014) found that normal men were able to see faces or letters in images of completely random noise when primed to do so about 1/3 of the time and this is tied to the structure of the brain. The specific portion of the brain activated when identifying a face (the face fusiform area) was very different than the areas that were activated when identifying a letter. Neuropsychologists have identified several patterns and pathways that are activated specifically when perceiving the human form. EEG readings show a specific waveform called N170 that is reliably tied to face identification (Bentin, Allison, Puce, Perez, & McCarthy, 1996). N170 is also appears when faces are in peripheral vision, though with longer reaction times (Rigoulot et al., 2011). Furthermore, facial recognition is processed within the dopamine (reward) pathways, making the recognition of a face inherently rewarding (Rypma et al., 2015). It is the degradation of the dopamine pathway in Alzheimer’s dementia that reduces their ability to recognize faces.

However, it is not just facial recognition that is neurologically prioritized. Mirror systems located in the motor cortices are activated when watching people move, and have been reliably
identified within EEG patterns as a reduction in a particular frequency band, called mu wave suppression (Hobson & Bishop, 2017).

Our eyes are drawn to see people subconsciously and reflexively. In a free viewing eye fixation test consisting of paired scenes with and without people, 67% of the time, the first fixation was on the person (Fletcher-Watson, Findlay, Leekam, & Benson, 2008). Even in crowded assemblies of pictures and at eccentric angles up to 16°, faces had a significant recognition advantage over non-faces, even clock-faces (Hershler, Golan, Bentin, & Hochstein, 2010). There is also evidence that the amplitude, or signal strength, of the N170 ERP varies with facial expression, meaning that we are not just looking for people, but for facial expressions (Hinojosa, Mercado, & Carretié, 2015). There is evidence that it is the dopamine pathways, the primary human reward mechanism, that is critical in facial recognition (Rypma et al., 2015). Some facial expressions can be reliably identified at 135 feet, including happy and surprised, and angry, at least for men (Hager & Ekman, 1979), although the expressions used were somewhat exaggerated and female expressions were not as consistently identified. Other, more subtle expressions including fear and sadness could be reliably identified at distances of 90 feet, the width of a large intersection.

There is even a preferential processing for faces in peripheral vision, although it takes longer to process. Typical reaction times for faces in peripheral vision (15° and 30° from focal center) were around ¾ of a second with fearful faces recognized slightly faster than neutral ones (Rigoulot et al., 2011). In free-viewing fixation tests where the person was not as prominent, the latency (time to first fixation) for seeing the person was 3.5 seconds for cued respondents and around 4 seconds for uncued respondents. (Zwickel & Võ, 2010) Viewing a scene for anything less than ¼ of a second precludes any visual search (Cole & Jenkins, 1980), but most glance
durations in driving range between $\frac{1}{2}$ second to 3 seconds, with the majority of the glances in the
$\frac{3}{4}$ to 1.5 second range (Green, 2002).

This innate ability to identify faces in our visual field does not stop when we drive, but it
has limits. Most glance studies are performed at rest to identify an individual’s potential
performance limits, while the driving task occurs at speed and in a visually and mentally cluttered
environment (behavior). The biggest difference between static visual search and driving related
visual activity is that the faster a person is driving, the less time a person or scene can be observed,
with objects gaining more prominence as the driver approaches them until they are passed and
disappear from view. It has been well documented that a perceptual narrowing effect occurs at
higher speeds due to two factors: increased visual workload (Jo, Lee, & Lee, 2014), and focus on
the roadway at a longer distance with higher speeds (Rogers, Kadar, & Costall, 2005). This tunnel
effect is particularly prominent for inexperienced drivers. As drivers increase in experience, the
variance in their glance behaviors widen horizontally, particularly for rural and suburban roadways
(Robbins & Chapman, 2019) but the higher the speed, the more tightly the glance clustering
remains around the center of the horizon line and the intermediate distance roadway environment
regardless of the driver’s experience. Researchers have identified a common repetitive pattern of
glances that moves between the road far head (3-4 seconds of travel time), the road at a closer
distance (1-2 seconds of travel time), and then the mirrors or objects/people in the mid-ground left
or right (Underwood, Chapman, Brocklehurst, Underwood, & Crundall, 2003). This pattern leaves
roadside features or objects outside of a narrow visual cone less conspicuous, especially at higher
speeds. In lower speed, higher conflict environments, drivers looked more at the right, left, and
mirror positions to deal with the increased number of potential conflicts that are not as likely in
suburban or rural contexts. It could also be argued that the perceptual narrowing that occurs at
higher speeds are related to the decreased likelihood of experiencing the neurologically rewarding face-to-face interactions that occur at human speed based due to the contextual and perceptual limitations inherent in high-speed movement.

Of course, attention plays a significant role in the driver behavior as well. A stimulus that fails to engender attention is lost both to memory and processing. Much has been written about Highway Hypnosis (Williams, 1963) and Driving Without Awareness (DWA) (Charlton & Starkey, 2011). However, recent research has found that when drivers are queried in the moment about the traffic situation, they have complete recall of the details, but their recall diminishes dramatically over time (Richards & Charlton, 2020). This could be an instance of the Zeigarnik effect (1938), a trained memory nuance first noticed in the ability of café waiters to retain complete details of an entire table’s orders without any notes until the table has left, at which time none of the details remained in memory. Driving is the ultimate over-rehearsed skill and the statistical rarity of vehicle incidents hints that drivers are well trained to notice salient information as it is needed.

However, there is a more subtle explanation. William’s initial description of highway hypnosis relied on an incomplete understanding of the distinction between a wide range of trance states and a hypnotic state. His descriptions included instances of hypnosis, even including the hypnotism of two students and their somewhat successful driving excursions⁵. However, most of what he described as highway hypnosis was associated with fatigue, drowsiness or microsleep and the attention decrement associated with those states. Since then, neurological studies (Egner, Jamieson, & Gruzelier, 2005; Rainville & Price, 2003) have identified one of the primary

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⁵ Williams reports that their response time was lessened, but few errors or lapses occurred.
characteristics of hypnotism as an elevated level of focused attention along with the suspension of the metacognition/self-monitoring systems in the brain’s frontal lobe. Since driving requires significant mental resources, it should not be surprising that the mental effort required to self-monitor would become less important and therefore less involved as drivers gain experience. In essence, drivers train themselves to enter a semi-hypnotic state that reflects high alertness and awareness of the road and potential conflicts, but only minimal feedback from their metacognitive architecture unless it is made necessary by increased complexity or a potentially rewarding feedback, like a human face.

Whether the issue is with automatic, subconscious, hypnotic, or monitoring states, driving in urban situation adds the need to address frequent change rapidly when the risks are largely external. It is rare that a driver would be at any substantial risk of harm in a highly urban, pedestrian focused environment. There are minor risks to vehicles from scrapes or fender benders, but the vast majority of the risk of serious injury or fatality is borne by the vulnerable users in the space. The increase in speed and risky driving behaviors identified during the COVID 19 lockdowns of 2020 could be attributed to the lessened expectation of seeing people in that space allowing for a level of automatic driving behavior that would not be possible under typical urban conditions (Katrakazas, Michelaraki, Sekadakis, & Yannis, 2020; Tucker & Marsh, 2021). However, the neurological visual preference for the human face or form may provide sufficient stimulus to preemptively elevate cognition from the hypnotic-monitoring state to a metacognitive situational awareness when there is a reasonable, conditioned expectation that it is warranted.
The Conditioned Anticipation of People (CAP) Model

The core of the Conditioned Anticipation of People (CAP) model of urban driving is that there are at least two major mental patterns used in typical driving: CAP and non-CAP. Within a CAP-type context, the driver pre-emptively retains full conscious operation including metacognitive evaluation in anticipation of dopamine-laden human, face-to-face interaction (mirroring and connection), with only skill-based and minor rule-based functions operating with a high level of automaticity. It is important to note that the metacognition required may remain below a cognitive/logical level, at the social perception stage not the social cognition stage (Pineda & Hecht, 2009), but must still be pulled into action when face-to-face interaction is possible. It may be possible for drivers with extensive experience in densely populated CAP-type environments (like taxi drivers) to operate with rule-based or strategic automaticity, possibly by disregarding or automatizing all but the most critical of personal interactions, but the vast majority of the driving public experiences these contexts as a small subset of their overall driving experience and therefore retains full metacognition on their situational awareness. The actual presence of people (APP) reinforces the need to retain metacognitive monitoring via reflexive N170 activation and mu suppression upon seeing the faces and movement of the people in the context. This also reinforces that place as a CAP-type context. As there is an emotional reaction and mirroring effect when faces interact, a positive emotional affect is likely to amplify the reward to the driver and therefore reinforce the location as a CAP-type context. A CAP-type location that shows no APP over multiple successive trips or a consistent negative or neutral affect may be down-graded to a non-CAP context in the driver’s mind. This could explain the disregard New York City drivers have for others in their environment. In familiar, non-CAP contexts, drivers operate largely without metacognition, with frequent mind wandering (Burdett et al., 2019). This continues until
a situation of uncertainty arises and metacognitive activity is recruited to sit in judgement over an affect-level ("gut-based") bounded reality, the set of choices screened for importance via their affective potency (Vaa, 2014). Incidents of high affective involvement further cement the incident in memory, in addition to the memory imprint caused by the metacognitive processes, leading to medium term, post-trip and subsequent trip recall, like remembering where you were pulled over for speeding. An APP in a previously identified non-CAP context may fail to be perceived due to a mismatch between the driver’s speed and perception capacity, but if it is recognized, it is likely to be flagged as a potential outlier that brings full cognition to the surface momentarily, only to recede into an automatic state quickly. However, if the APP experience is repeated, the APP is a familiar person, or there is a strong affective expression from the APP, the area may be flagged immediately as a CAP-type location, with the driver actively looking for APP’s over the next few trips, either confirming it as a CAP-type place, or non-CAP based on the driver’s subsequent experience. Of course, all of this presumes a history of experience on the part of the driver. Novice drivers require full metacognition on all operations until they have created the automatic patterns that make metacognition unnecessary, but may be unable to distinguish when this elevated level of metacognition is needed and disregard salient features that signal a CAP-type place.

The human limitations on the perception of faces, particularly the emotional affect of the people in the environment, form the geographic boundaries of the PPP and dictate the operating speeds within the PPP. Although the static human form can be observed up to 300 feet away, facial expressions are only reliably distinguishable within 100 feet. Because the driver is typically visually oriented in the direction of travel, there is an elongated visual impact zone around the vehicle that extends in the direction of travel. This impact zone may extend as much as 300 feet forward, anticipating the potential or need for a face-to-face interaction, and upon identifying a
human form, subsequent glances are likely to be drawn to that form, reflexively looking to decode facial expressions. The visual impact zone is not likely to extend much more than 90-100 feet horizontally from the lane of travel which equates roughly to a 17-20° window from the center of the driver’s line of sight. When a roadway width fits within this scale and there are pedestrian-active uses like shops with doorways, on-street parking, driveways, crosswalks or plazas, then CAP behavior may occur automatically even if APP’s are only present intermittently. Where APP’s are rare or there are few contextual markers of human activity within this impact zone, driving behavior is likely to revert to an unmonitored state.

Table 3.2 summarizes how speed and distance interact at the significant distance and time breakpoints.

**TABLE 3.2: Speed/Distance/Time Interaction**

<table>
<thead>
<tr>
<th>mph</th>
<th>kph</th>
<th>fps</th>
<th>Time elapsed (s)</th>
<th>Distance travelled during typical glance types</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>90 ft</td>
<td>135 ft</td>
</tr>
<tr>
<td>20</td>
<td>32</td>
<td>29.3</td>
<td>3.1</td>
<td>4.6</td>
</tr>
<tr>
<td>25</td>
<td>40</td>
<td>36.7</td>
<td>2.5</td>
<td>3.7</td>
</tr>
<tr>
<td>30</td>
<td>48</td>
<td>44.0</td>
<td>2.0</td>
<td>3.1</td>
</tr>
<tr>
<td>35</td>
<td>56</td>
<td>51.3</td>
<td>1.8</td>
<td>2.6</td>
</tr>
<tr>
<td>40</td>
<td>64</td>
<td>58.7</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>45</td>
<td>72</td>
<td>66.0</td>
<td>1.4</td>
<td>2.0</td>
</tr>
<tr>
<td>50</td>
<td>80</td>
<td>73.3</td>
<td>1.2</td>
<td>1.8</td>
</tr>
<tr>
<td>55</td>
<td>89</td>
<td>80.7</td>
<td>1.1</td>
<td>1.7</td>
</tr>
<tr>
<td>60</td>
<td>97</td>
<td>88.0</td>
<td>1.0</td>
<td>1.5</td>
</tr>
</tbody>
</table>

Studies of retroreflective markings show that a walking person can be consistently identified at a distance of roughly 300 feet (100 m) (Sayer, 1998), although moving the markings to the joints or moving parts of a person or cyclist can increase that distance for young drivers to nearly 900 feet (300 m) (Edewaard, Fekety, Szubski, & Tyrrell, 2020). As was mentioned earlier,
facial expressions are discernable within a range of 90 to 135 feet. Assuming a typical glance duration (1.5 seconds), facial expressions cannot be consistently decoded at speeds any higher than 45 mph. Even under ideal conditions, they are not in the driver’s field of vision long enough to be discerned. The identification of a person in a cluttered field of vision may take much longer than the typical glance duration, but typical roadside clutter rarely obscures the human form, even at night (Tyrrell et al., 2009). In still photographs, it took roughly 3.5 seconds for an alerted respondent to identify the person in the picture. If the driver is traversing a location where a pedestrian is expected, both the biological movement of the person and the increasing prominence of the person with the approach of the vehicle could drop this search time substantially. Assuming a worst case 3.5 second search time, the presence of a person may be identifiable up to 30 mph, but their expression is not likely to be discernable. If the driver does not expect to see a person, it is likely to take 4 seconds to identify them in a busy environment, which means that up to about 45 mph only the form of the person, but not their expression can be identified before the driver passes them. Past 45 mph, an unalerted person may not even see the pedestrian before they have passed them by. The narrowing of the field of vision at higher speeds ultimately results in a similar corridor functional width regardless of the speed. This is rarely an issue in highway driving because pedestrians are rarely within 90 feet of the roadway, and when they are, the pedestrian is often very conspicuous because of the wide recovery zones dictated in most locations. However, stroads (high-speed corridors with multiple commercial uses) pose a particularly difficult problem since pedestrians may use these corridors, or even try to cross them while drivers are moving at speeds that makes both recognition and reaction difficult. These locations are the most dangerous for pedestrians. This effect may also explain why highly conspicuous workers in construction zones are still in significant danger when working on high-speed highways.
There are several studies that provide supporting evidence for this concept. A smiling pedestrian increased the percentage of drivers that would stop for them to cross (p<0.001), both at a marked crosswalk and at other locations in the road (Guéguen, Eyssartier, & Meineri, 2016). In addition, drivers proceeded at a lower speed after a smiling interaction. Another study that may provide incidental evidence for this hypothesis relates to bicyclists biological movement (Edewaard et al., 2020). Bright clothing that covered the moving legs of the bicyclist were conspicuous over 200 meters (600 feet) ahead in the daytime while the controls were only visible at 50 meters (150 feet). Similar results were seen for nighttime conspicuity of pedestrians. Those that had retroreflective tape on their extremities or joints were visible as much as 275 meters (825 feet) away and reliably seen at 200 meters for young participants, while those with a retroreflective jacket could only be seen at 20 meters (60 feet) and were missed entirely about 70 percent of the time (Tyrrell et al., 2009). It is interesting to note that visual clutter in the environment had no significant impact on a person’s ability to see the pedestrian. An unrelated, circumstantial piece of evidence comes in terms of the crash statistics during the COVID-19 lockdowns. Drivers used higher speeds and there were measurable increases in vulnerable user crashes despite lower vehicle volumes (Katrakazas et al., 2020; Tucker & Marsh, 2021). One of the distinguishing characteristics of the street life during the pandemic was the notable absence of pedestrians in environments where they had previously been common. Without the interaction with human faces, drivers paid less attention and drove more quickly than before.
CHAPTER 4: DATA

Naturalistic Driving Data

To evaluate driver behavior in complete streets contexts, an extensive data tabulation was ordered from the second Strategic Highway Research Program (SHRP2) Naturalistic Driving Study (NDS). The goal of the tabulation was to identify how these three main dimensions, speed, caution and attention, are impacted by different feature combinations in complete streets contexts. The SHRP2 NDS data was collected in 6 cities across the US between 2010 and 2012 and included 3,000 participants, 50 million vehicle miles, 5 million trips, and over a million hours of video (Victor et al., 2015). To address the widest range of driving contexts, Tampa, Florida and Seattle, Washington were chosen as the test cities. Tampa reflects a prototypical suburban environment with a vehicle-oriented design pattern, large, disconnected blocks, marginal transit availability, and only occasional pockets of walkable environments. In contrast, Seattle predates the post WWII suburban development boom, has small, regular block sizes, multiple interconnected transit systems, and their planning departments have been intentional about providing successful pedestrian spaces for multiple decades.

The Attention Tabulation

Although a region-wide data tabulation was possible for speed and acceleration data, eye tracking information to measure driver attention had to be tabulated by the Virginia Tech Transportation Institute on a frame-by-frame basis to protect the privacy of the participants. The data tabulation process allowed for eye tracking evaluations every 1/10th of a second, similar in

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6 Portions of this chapter/section have been submitted for publication. See Appendix B for citations.
quality to those collected in a driving simulator. The UCF team then converted these tabulations into a time on-task ratio. The VTTI tabulator was tasked with identifying whether the driver was on-task or off-task 10 times a second, with glances in the mirrors or forward view categorized as on-task. Vulnerable user presence and roadway LOS was tabulated simultaneously. However, the extensive labor involved in generating this tabulation meant that only 2,000 single-second epochs of data could be collected within the project’s budgetary limitations. It was decided that 10 epochs would be collected for each location, with an equal number of locations selected from each geographic area. For each epoch, the percent of time on-task and the number of simultaneous ongoing tasks were established as the two attention domain dependent variables. The secondary tasks that were identified included a coding for external stimulus, which may or may not be related to the driving task. For instance, noticing a pedestrian or other environmental feature could be either a part of the overall driving task or a distraction from it. To account for this, the number of tasks the person was engaged in was tabulated as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>Tabulated Multitasking Behaviors</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>Driving only</td>
</tr>
<tr>
<td>1</td>
<td>Driving with External Stimuli Only</td>
</tr>
<tr>
<td>2</td>
<td>Driving with a secondary task (with or without external stimuli)</td>
</tr>
<tr>
<td>3</td>
<td>Driving with two or more secondary tasks (with or without external stimuli)</td>
</tr>
</tbody>
</table>

Only a small fraction of drivers performed 4 or more tasks simultaneously (around 1%). This was not a large enough a portion of the data to analyze separately. Approximately 71% of the drives had full 100% on-task behavior, while 2% were completely off-task during the selected epoch. In addition to the eye-tracking data, multiple other variables were also tabulated for the study points. Secondary tasks, traffic density, and vulnerable user presence were tabulated at the
epoch level. User data was also provided which included age group, sex, and other driver characteristics.

*Site and Epoch Selection*

To identify the locations within each region, a list of subareas was generated and 3 locations were selected from each subarea, reflecting the range of roadway types in that area. Since this project is focused on complete streets and multimodal environments, only locations with transit services or extensive pedestrian and bicycle infrastructure were selected. The locations were selected at the midpoints of the NDS identified roadway segments, with epochs collected as near as possible to these midpoints. Figure 1 shows the distribution of sites in the Tampa Bay and Seattle regions.

**FIGURE 4.2: Study Areas and Sites**

The epochs were selected that best matched the 85th percentile speed of the segment in order to reflect the stable free-flow conditions that result from the context at that location. Epochs were only selected from trips that occurred between 7 am and 10 pm, to avoid any overnight or uncharacteristically uncongested behavior.
Contextual Features

In terms of the contextual features, there were dozens of measurements made for each location taken from time adjusted (2010-2012) Google Earth images. Cross sectional features were measured for both sides including sidewalk, tree-lawn (grass), onstreet parking/type, bike lanes/type, bus lanes, travel lanes, and median width/type. There were 6 different types of corridor width measured as shown in Figure 4.2.

![FIGURE 4.3: Corridor Width Measurements](image)

Building to building width was measured from face to face and capped at 1,000 feet. Width at eye height was measured in terms of the width of the corridor between any repetitive features aligned along the corridor that could be seen at 3.5 feet, the driver’s eye height. These included trees, onstreet parking, light poles, or fences. Features were only considered linearly aligned if they appeared to create a vertical limiting plane in the direction of the vehicle’s travel. Right of way (ROW) width was measured from the outside edges of the sidewalk, as most ROW lines terminate at that location. Drive lane width was taken as the uninterrupted width of the roadway.
where drivers maneuver in their through path. Where a raised median was present, this measurement only included the direction of travel, but it included both directions of travel where a striped median or turn lane was present. Lane width was measured from the gutter edge to the center of any street markings. Where adjacent lanes were different widths, the average was taken. Several median conditions were also tabulated both in terms of width and type including no medians, raised medians with grass, striped medians, concrete medians, turn lanes, and one-way flow.

Several measurements were taken in the direction of travel. Both block length and driveway spacing were measured, although only one of them could be included in the model at a time. Tree presence was catalogued both in terms of canopy coverage and in terms of their configuration with respect to the roadway (linear, scattered, none). The visual aspect ratio of the buildings around the roadway was measured (height/corridor width). Lighting type was categorized based on their purpose: high, that primarily supports the driver’s view; medium to serve pedestrians and drivers; and low that serves pedestrians only. Two different sight distance measurements were made, one that measured how far ahead in the road could be seen (capped at 1,000 feet) and the distance to the first major obstacle within a 20° cone of vision (Uniform Field of View). The number of functional doorways per 100 feet was also measured. Several types of bike lanes and bus lanes were also tabulated but were not found to be significant.

From a system standpoint, roadways were visually classed in terms of the typical arterial, collector, and local street hierarchy. Land use was categorized into downtown core, commercial, office, residential, and industrial. The Walkscore was also tabulated for each location. Table 1 provides a summary of the major variables measured for roadway context. Table 2 summarizes several of the major contextual variables used in this analysis.
### TABLE 4.1: Primary Context Feature Measurements

<table>
<thead>
<tr>
<th>Category</th>
<th>Measurement</th>
<th>From/to or details</th>
<th>Logic or description</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Corridor</strong></td>
<td>Building</td>
<td>Building faces</td>
<td>Overall openness of the corridor; widest activity space</td>
</tr>
<tr>
<td>Eye Height</td>
<td>Linearly aligned obstacles at 3.5 feet high</td>
<td>Regularly spaced obstacles in proximity to the vehicle at the driver’s eye height</td>
<td></td>
</tr>
<tr>
<td>Right of way</td>
<td>Outside edge of sidewalks</td>
<td>Legal cross section limits</td>
<td></td>
</tr>
<tr>
<td>Edge of Pavement</td>
<td>Curb faces or paved shoulders</td>
<td>Primary limit of vehicle movement within the corridor</td>
<td></td>
</tr>
<tr>
<td>Drive Lane</td>
<td>Through lane assembly striping</td>
<td>Width of the through lanes; when a raised median is present, only one side is measured. This is the area that is most likely to include moving vehicle conflicts immediately adjacent to the vehicle.</td>
<td></td>
</tr>
<tr>
<td>Lane width</td>
<td>Gutter edge to striping center</td>
<td>Functional operational limits of vehicle movement during travel</td>
<td></td>
</tr>
<tr>
<td>Number of lanes</td>
<td>Number of lanes in the direction of travel</td>
<td>Increasing the number of lanes may increase the number of vehicle conflicts</td>
<td></td>
</tr>
<tr>
<td><strong>Direction of Travel</strong></td>
<td>Block length</td>
<td>Edge of pavement to edge of pavement on the block face</td>
<td>Distance between frequent vehicle conflicts; short blocks are historically associated with pedestrian friendly contexts</td>
</tr>
<tr>
<td>Driveway spacing</td>
<td>Average space between driveway edges</td>
<td>Distance between potential conflicts</td>
<td></td>
</tr>
<tr>
<td>Doorway Density</td>
<td>Doorways per 100 feet of block face</td>
<td>Proxy for human activity; only active, functional doors included</td>
<td></td>
</tr>
<tr>
<td><strong>Visual Impact</strong></td>
<td>Tree presence type</td>
<td>Linear</td>
<td>Linear trees were aligned in the direction of travel adjacent to the roadway or sidewalk;</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Scattered</td>
<td>Trees present in the streetscape, but with no orientation relative to the roadway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Occasional</td>
<td>Single trees with no relationship to each other, the system, or the roadway</td>
</tr>
<tr>
<td></td>
<td></td>
<td>None</td>
<td>No trees</td>
</tr>
<tr>
<td>Aspect ratio</td>
<td>building height/corridor width</td>
<td>Measures sense of enclosure</td>
<td></td>
</tr>
<tr>
<td>Sight distance</td>
<td>roadway sight distance</td>
<td>Distance that another vehicle can be observed within the roadway ahead, capped at 1,000’</td>
<td></td>
</tr>
<tr>
<td>Room sight distance</td>
<td>Distance to first major visual obstacle</td>
<td>Distance to first visual barrier within a driver’s uniform field of view, a 20° cone of vision around the vanishing point</td>
<td></td>
</tr>
<tr>
<td><strong>Pedestrian Features</strong></td>
<td>Sidewalk type</td>
<td>Suburban unbuffered</td>
<td>Suburban area sidewalk with no buffering from the travel lanes</td>
</tr>
<tr>
<td></td>
<td>Urban</td>
<td>Sidewalk within the urban core, often unbuffered or buffered with parking only</td>
<td></td>
</tr>
<tr>
<td><strong>Parking type</strong></td>
<td>Onstreet parking</td>
<td>Striped onstreet parking</td>
<td>Striped parking aligned with the edge of the roadway</td>
</tr>
<tr>
<td>Permitted</td>
<td>Unstriped onstreet parking</td>
<td>Wide outside lane where onstreet parking is permitted but striping is not provided</td>
<td></td>
</tr>
<tr>
<td>Angle</td>
<td>Angle parking</td>
<td>Onstreet parking striped at an angle to the curb edge; can be back in or forward in</td>
<td></td>
</tr>
<tr>
<td><strong>System</strong></td>
<td>Hierarchy</td>
<td>Arterial, Collector, Local</td>
<td>Observational classification of roadway hierarchy</td>
</tr>
<tr>
<td>Walkscore</td>
<td>Numeric from Walkscore.com</td>
<td>Measure of the area’s walkability in terms of land use accessibility to common residential services</td>
<td></td>
</tr>
</tbody>
</table>
Crash Statistics

Crash history was tabulated for each study segment for 2016 through 2019, the earliest data that was publicly available. Tabulations for the Florida sites were drawn from Signal 4 Analytics, a state funded clearinghouse at University of Florida (Bejleri, 2014). Crash data for Washington State was taken from their Collision Analysis Tool ("CAT," 2021). For each location, the segment was windowed within the analysis tool to identify all crashes that occurred on that segment and at its ends. Only crashes that were related to the segment in question were included in the tabulation. Crash summaries were reviewed to identify whether any vulnerable users were involved in the incident and a separate tabulation of VRU incidents was generated. Additionally, the segment lengths were also tabulated (from the intersection centerlines) in order to calculate the segment crash rate. It appeared that there were substantially more incidents reported in Tampa than in Seattle, so a location variable was included in the analysis.
CHAPTER 5: DISCUSSION OF ANALYSIS AND RESULTS

If the CAP model is valid, then the presence of a vulnerable user alone (APP) should have an impact on the driver’s attention level, but only slightly. The presence of contextual design features that support pedestrian presence should provide the primary impact on attention, not just APP. Since attention behavior is a result of repeated exposure of APP, heightened risk, or affect laden interactions with APP, then contextual variables may have a wide range of impact on attention.

Attention and Context Features

Single Variable Analysis

This was first tested using a simple one-way repeated measures ANOVA analysis (Harnett & Murphy, 1985; Rosner, 2015). The correlation between attention and Vulnerable Road User (VRU) presence was highly significant, but with a small effect size (p=0.003, $\eta^2=0.005$). This is consistent with the CAP model in that the presence of a vulnerable user has an impact on driver behavior, but only a momentary impact unless there are repeated experiences with either that location or a location type that reflects CAP conditions. If the context indicated that people could be seen there regularly, then attention was drawn at a high level, but the presence of a person alone at that moment was not sufficient to elicit a dramatic change. Women were significantly more likely to attend to VRU’s than men (p=0.001, $\eta^2=0.006$) but again, the effect size was small.

7 Portions of this chapter/section have been submitted for publication. See Appendix for citations.
To evaluate the impact of the context features, a repeated measures ANOVA was performed for time on-task, multitasking, and vulnerable user presence. Table 5.1 summarizes the results of this analysis, ordered in terms of the significance of the impact on time on-task.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Time On-task</th>
<th>Multitasking</th>
<th>Vulnerable Users</th>
</tr>
</thead>
<tbody>
<tr>
<td>Edge of Drive Lane width</td>
<td>2.258</td>
<td>2.384</td>
<td>2.578</td>
</tr>
<tr>
<td>Edge of Pavement width</td>
<td>2.026</td>
<td>2.259</td>
<td>3.294</td>
</tr>
<tr>
<td>Building to Building Width</td>
<td>2.011</td>
<td>2.203</td>
<td>5.691</td>
</tr>
<tr>
<td>Driveway spacing (2-way)</td>
<td>1.800</td>
<td>1.249</td>
<td>3.835</td>
</tr>
<tr>
<td>Block length (two-way)</td>
<td>1.737</td>
<td>1.927</td>
<td>4.278</td>
</tr>
<tr>
<td>Doorways per 100 ft</td>
<td>1.650</td>
<td>1.649</td>
<td>7.091</td>
</tr>
<tr>
<td>Eye height width</td>
<td>1.678</td>
<td>1.923</td>
<td>2.045</td>
</tr>
<tr>
<td>Lane width</td>
<td>2.030</td>
<td>1.965</td>
<td>1.887</td>
</tr>
<tr>
<td>Angle Parking</td>
<td>4.588</td>
<td>0.535</td>
<td>1.753</td>
</tr>
<tr>
<td>Unstriped Onstreet Parking</td>
<td>3.854</td>
<td>1.612</td>
<td>0.127</td>
</tr>
<tr>
<td>Tree Canopy Coverage</td>
<td>1.638</td>
<td>1.495</td>
<td>1.636</td>
</tr>
<tr>
<td>Walkscore</td>
<td>1.323</td>
<td>2.085</td>
<td>7.367</td>
</tr>
<tr>
<td>One-way</td>
<td>2.167</td>
<td>0.176</td>
<td>16.931</td>
</tr>
<tr>
<td>Number of Stories</td>
<td>1.500</td>
<td>1.120</td>
<td>13.941</td>
</tr>
<tr>
<td>Right of Way width</td>
<td>1.256</td>
<td>1.839</td>
<td>1.821</td>
</tr>
<tr>
<td>Suburban unbuffered sidewalk</td>
<td>1.605</td>
<td>0.700</td>
<td>1.567</td>
</tr>
<tr>
<td># of directional lanes</td>
<td>1.449</td>
<td>0.265</td>
<td>4.295</td>
</tr>
<tr>
<td>Trees, Linear arrangement</td>
<td>1.489</td>
<td>0.668</td>
<td>6.596</td>
</tr>
<tr>
<td>Seattle (base: Tampa)</td>
<td>1.439</td>
<td>36.17</td>
<td>3.487</td>
</tr>
<tr>
<td>Sight distance</td>
<td>1.110</td>
<td>1.015</td>
<td>0.945</td>
</tr>
<tr>
<td>Uniform Field of View distance</td>
<td>1.104</td>
<td>1.432</td>
<td>1.635</td>
</tr>
<tr>
<td>Sidewalk width</td>
<td>1.099</td>
<td>1.656</td>
<td>9.928</td>
</tr>
<tr>
<td>Collector (Arterial)</td>
<td>0.849</td>
<td>1.978</td>
<td>1.786</td>
</tr>
<tr>
<td>Bike lane width</td>
<td>0.996</td>
<td>2.069</td>
<td>5.619</td>
</tr>
<tr>
<td>Onstreet Parking</td>
<td>0.723</td>
<td>0.312</td>
<td>0.127</td>
</tr>
<tr>
<td>Local road (Arterial)</td>
<td>0.676</td>
<td>2.411</td>
<td>0.036</td>
</tr>
<tr>
<td>Corridor Visual Aspect Ratio</td>
<td>0.957</td>
<td>1.056</td>
<td>2.003</td>
</tr>
<tr>
<td>Bus lane width</td>
<td>0.594</td>
<td>0.006</td>
<td>6.603</td>
</tr>
<tr>
<td>Center area width</td>
<td>0.512</td>
<td>1.460</td>
<td>3.086</td>
</tr>
</tbody>
</table>

As the model predicts, many of the features that had the highest predictive level for the presence of vulnerable users were also the features that had the largest impact on driver attention.
The number of functional doorways per 100 feet had the largest effect size on attention and the highest correlation and effect size for the number of vulnerable users as well. The variables that are associated with the corridor width, which would impact driver’s ability to see a person at the side of the road, had the next strongest impact on driver attention, both in terms of significance and effect size, and had highly significant correlations and large effect sizes in vulnerable user presence. Variables like block length and driveway spacing also showed strong correlations and effect sizes for both attention and vulnerable user presence. Shorter blocks are easier to walk and more visually engaging to the pedestrian. It also has a direct effect on the driver in that short blocks are also more demanding to the driver, increasing the frequency of the potential conflicts the driver must face, resulting in full metacognitive engagement. The increased workload demanded by shorter blocks and frequent driveways are likely to decrease the time that drivers desire to use the space and would explain why many find driving in an urban setting especially demanding and fatiguing. It would be interesting to identify the typical urban trip end length in subsequent research. A better understanding of this phenomena may be useful for travel demand modeling.

Although lane width has a significance level that is similar to the other corridor width variables for attention, it has a much smaller effect size and no correlation to vulnerable user presence. Narrower lane widths increase the risk to drivers from adjacent vehicles or infrastructure, increasing the need to attend to lane position, but the potential risk to the driver that this narrowing provides is not as attractive as a narrow corridor and the corresponding PPP level it communicates to the driver. Other variables like angle parking or onstreet, unmarked parking show a similar pattern statistically. They increase the potential of vehicle conflicts, increasing driver workload, but provide only secondary potential for face-to-face interaction due to the typical
rarity of vehicle turnover and therefore a small effect size on attention. It could be expected that areas with higher turnover, like loading zones, may have a more significant impact.

There were many of variables that had a strong correlation with vulnerable user presence, but only minor or negligible impact on attention. For instance, Walkscore is a high-level evaluation of the connectivity and availability of land uses that would support a person’s ability to walk for functional reasons—but a driver cannot see a Walkscore in the built environment itself, so it has only minimal impact on attention. One of Walkscore’s weaknesses is that it measures the accessibility of an area in terms of complementary land uses but does not measure the number of people who walk in the area and the contextual variables that make the walking environment look suitable for walking. Both grass buffers between the sidewalk and the roadway and number of stories had a significant correlation with vulnerable user presence and a strong effect size, but no significant impact on attention. Grass buffers make pedestrians feel more comfortable but increase the distance between the vehicle and the person, which reduces the potential of visual connection between the two. Number of stories and aspect ratio are both an indirect measure of density and ultimately increases the number of pedestrians in an environment, but many tall buildings, particularly in suburban center cities have large parking areas and minimal or only occasional pedestrian activity. If people get in cars inside the building and leave, it does not matter how many people are in that area. The drivers rarely see people on the street to connect with or be concerned about. Streets surrounding these non-urban high-rises are typically multilane wide roadways and often clustered in one-way pairs, which results in high-speed, vehicle movements in and out of the city center, without any real pedestrian activity, the downtown correlate to suburbanites who pull into their garages and rarely see their neighbors. Other variables with high vulnerable user correlation but low attention correlation results include sidewalk width, bus lane width, and
median/turn lane width. High values for each are common in urban cores with their higher person density, but the wider roadway widths that often accompany these features can reduce the potential for pedestrians and drivers to interact and therefore reduce driver attentiveness.

**Econometric Attention Modeling**

Obviously, context reflects a combination of many variables that have dynamic interactions. To address these interactions, a multiple mixed order probit fractional split model was used to analyze the data.

**The Mixed Ordered Probit Fractional Split Model**

This type of econometric model is used when the dependent variable reflects a fractional split, generally between 0 and 1 and the potential independent variables reflect a combination of discrete and continuous readings. The dependent variable for attention was tabulated as a binary on-task vs. off-task variable at 1/10th of a second over 1 second epochs for each reading. These readings were therefore converted to a percentage of the epoch spent on-task. The model structure is derived as follows based on the model proposed in Eluru, Chakour, Chamberlain, and Miranda-Moreno (2013):

Let: \( q (q=1,2,\ldots,Q; Q = 200) \) be an index to represent site,

\( p (p=1,2,\ldots,P; P=10) \) be an index to reflect the measurements recorded at various times at each site, and

\( k (k=1,2,3,\ldots,K; K \text{ varies for each dependent variable}) \) be an index to represent categories within the dependent variable.
Using these variables, the latent propensity for the dependent variable (attention, speed, acceleration, jerk, or lane position) at the \( q \)th site and the \( p \)th interval is:

\[
y^*_{qp} = (\alpha' + \delta'_q)z_{qp} + \epsilon_q
\]

(1)

This latent propensity \( y^*_{qp} \) is mapped to the dependent variable category proportion \( y_{qpk} \) by the \( \psi \) thresholds (\( \psi_0 = -\infty \) and \( \psi_k = +\infty \)). The remaining variables are defined as follows:

- \( z_{qp} \) is an \((L \times 1)\) column vector of attributes (not including a constant) that influences the propensity associated with the dependent variable,
- \( \alpha \) is a corresponding \((L \times 1)\) column vector of mean effects,
- \( \delta_q \) is a \((L \times 1)\) column vector of unobserved factors moderating the influence of attributes in \( z_q \) on the dependent variable for site \( q \).
- \( \epsilon_q \) is an idiosyncratic random error term assumed to be identically and independently standard normal distributed across all \( q \) sites.

Since the model cannot be estimated using conventional maximum likelihood approaches, a quasi-likelihood approach was used. The parameters to be estimated in our latent propensity equation are \( \alpha \), the \( \psi \) thresholds, and the variance terms \( \delta_q \). First, we assume that:

\[
E(y_{qpk}|z_{qpk}) = H_{qpk}(\alpha, \psi, \delta_q), \quad 0 \leq H_{qpk} \leq 1, \sum_{k=1}^{K} H_{qpk} = 1
\]

(2)

where \( H_{qpk} \) is the ordered probit probability for the dependent variable category \( k \), defined as:

\[
P_{qpk} = G(\psi_k - \{(\alpha' + \delta'_q)z_q\}) - G(\psi_{k-1} - \{(\alpha' + \delta'_q)z_q\})
\]

(3)

where \( G(\cdot) \) is the cumulative distribution of the standard normal.
This model ensures that the proportion for each attention level is between 0 and 1 (including the limits). Based on this, the quasi-likelihood function for a given value of the \( \delta_q \) vector may be written for each site \( q \) as:

\[
L_q(\alpha, \psi|\delta_q) = \prod_{p=1}^{P} \prod_{k=1}^{K} P_{qpk} \cdot d_{qpk}
\]

\[
= \prod_{p=1}^{P} \prod_{k=1}^{K} \left\{ G[\psi_k - \{(\alpha' + \delta'_q)z_q\}] - G[\psi_{k-1} - \{(\alpha' + \delta'_q)z_q\}] \right\} \cdot d_{qpk}
\]

(4)

Where \( d_{qpk} \) is the proportion of vehicles in the dependent variable category, \( k \).

The unconditional likelihood function for site \( q \) can be computed as:

\[
L_q(\alpha, \psi, \delta_q) = \int_{\delta_q} L_q(\alpha, \psi|\delta_q) \cdot dF(\delta_q)
\]

(5)

where \( F \) is the multidimensional cumulative normal distribution.

Therefore, the quasi log-likelihood function is:

\[
L(\Omega) = \sum_q L_q(\alpha, \psi, \delta_q)
\]

This likelihood function involves the evaluation of multi-dimensional integral of size equal to the number of rows in \( \delta_q \). For this analysis, a quasi-Monte Carlo (QMC) method similar to (Bhat, 2001) for discrete choice models to draw realizations for \( \delta_q \). A 150 draw Halton sequence was used to optimize the calculations.

**Time on Task Model**

Because there were ten readings per site, panel effects were evaluated but were found not to be significant and therefore were disregarded. Table 5.2 summarizes the results of this model:
### TABLE 5.2: Mixed Ordered Probit (MOP) Fractional Split Time On-task Model

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Category</th>
<th>$\alpha$</th>
<th>t-stat</th>
<th>p-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Constant</td>
<td></td>
<td>-1.2443</td>
<td>-9.034</td>
<td>0.000</td>
</tr>
<tr>
<td>Gender</td>
<td>Female</td>
<td>0.1700</td>
<td>3.086</td>
<td>0.002</td>
</tr>
<tr>
<td>Age</td>
<td>16-24</td>
<td>-0.1271</td>
<td>-2.183</td>
<td>0.029</td>
</tr>
<tr>
<td>Presence of VRU</td>
<td></td>
<td>-0.2028</td>
<td>-3.518</td>
<td>0.000</td>
</tr>
<tr>
<td>LOS B/C/D (base: A)</td>
<td></td>
<td>0.1861</td>
<td>2.556</td>
<td>0.011</td>
</tr>
<tr>
<td>Travel Lanes (base: 1 lane)</td>
<td>2-lane</td>
<td>0.2357</td>
<td>2.586</td>
<td>0.010</td>
</tr>
<tr>
<td></td>
<td>3-lane</td>
<td>0.3638</td>
<td>2.047</td>
<td>0.041</td>
</tr>
<tr>
<td>Edge of Pavement Width (feet)</td>
<td></td>
<td>-0.0070</td>
<td>-2.639</td>
<td>0.008</td>
</tr>
<tr>
<td>One way</td>
<td></td>
<td>-0.4133</td>
<td>-2.130</td>
<td>0.033</td>
</tr>
<tr>
<td>Onstreet parking</td>
<td>Permitted</td>
<td>-0.1575</td>
<td>-2.023</td>
<td>0.043</td>
</tr>
<tr>
<td>Street Trees</td>
<td>Linear</td>
<td>0.1357</td>
<td>1.918</td>
<td>0.055</td>
</tr>
<tr>
<td>Suburban unbuffered sidewalk</td>
<td></td>
<td>0.1412</td>
<td>1.779</td>
<td>0.075</td>
</tr>
<tr>
<td>Driveway Spacing</td>
<td>(feet)</td>
<td>-0.0003</td>
<td>-2.375</td>
<td>0.018</td>
</tr>
<tr>
<td>Heirarchy (base: arterial)</td>
<td>Collector</td>
<td>0.1133</td>
<td>1.556</td>
<td>0.120</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>0.1836</td>
<td>1.737</td>
<td>0.082</td>
</tr>
</tbody>
</table>

Among the demographic variables, age and gender have an impact on the amount of time during the study epoch that drivers were on-task, with women generally more on-task than men and younger drivers less focused. There was no significant impact from the site city that could not be explained by other contextual variables. This implies that drivers in Seattle are not significantly different in terms of time on-task than drivers in Tampa, despite the fact that their built environments are dramatically different. Based on this result, the variable was dropped from the analysis.

In terms of human activity, the presence of vulnerable users decreases driver’s on-task behavior to a small degree, all else being equal, similar to the scale of the impact of sex and age. This may be due to the difficulty in establishing and coding whether an external distraction is an on-task or off-task behavior. As expected, even a slight increase in traffic density increases on-task behavior. The sample includes largely low-density traffic flows (mostly Level of Service “A”
and “B”) in order to limit the impact of congestion and focus on the impact of the built environment features.

In terms of the roadway cross section, 4-lane and 6-lane roadways are generally built to handle higher volumes and the resulting increase in the number of conflicts requires a higher level of on-task attention. Offsetting this effect, wide open corridors with few interruptions provide fewer potential conflicts and require less attention. The MOPFS model can only include one corridor width variable at a time. Therefore, to compare the effects of different corridor width measurements on attention, Table 5.3 summarizes the estimates, t-statistics, and statistical significance for each of the 6 corridor width types when included within the same overall model formulation. While the width of the roadway pavement, lane width, and the width of the drive corridor at eye height have a significant impact on on-task behavior, the width of the drive lane, the ROW width, and the building to building widths do not. This is consistent with the data from the ANOVA analysis and the CAP model. Widths that did not relate to the driver’s ability to see pedestrians in their field of motion, like lane width and drive-lane width had little impact on driver attention. Also, corridor widths that are not readily visible to the driver, like ROW width, also had no impact on time on-task.

**TABLE 5.3: Corridor Width Model Comparison, Time On-task**

<table>
<thead>
<tr>
<th>Corridor Width</th>
<th>$\alpha$</th>
<th>$t$-Stat</th>
<th>$p$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building to Building</td>
<td>-0.0001</td>
<td>-0.152</td>
<td>0.879</td>
</tr>
<tr>
<td>Right of Way (ROW)</td>
<td>-0.0019</td>
<td>-1.084</td>
<td>0.279</td>
</tr>
<tr>
<td>Pavement Width</td>
<td>-0.0064</td>
<td>-2.378</td>
<td>0.017</td>
</tr>
<tr>
<td>Drive Lane</td>
<td>-0.0028</td>
<td>-0.916</td>
<td>0.360</td>
</tr>
<tr>
<td>Lane Width</td>
<td>-0.0379</td>
<td>-2.753</td>
<td>0.006</td>
</tr>
<tr>
<td>Width at Eye Height</td>
<td>-0.0041</td>
<td>-3.357</td>
<td>0.001</td>
</tr>
</tbody>
</table>
Only one-way flow showed a significant impact on time on-task, but this varied depending on the corridor width variable used. One-way flow was only significant when paired with pavement width and the width at eye height. The only parking feature that had a significant impact on time on-task was unmarked onstreet parking, which decreased attention levels. It appears that the additional width added to the roadway may be the dominating property this feature type, increasing the distance between the vehicle and any pedestrians that could be in the space. Features with marginally significant impacts include street trees with a linear presentation, and unbuffered suburban sidewalks. Street trees scattered throughout the environment with no relationship to the roadway showed no impact on driver attention. Similarly, several sidewalk conditions were analyzed and only the suburban unbuffered condition showed a marginal impact on time on-task, both individually and when considered in concert with the other variables. Roadway hierarchy also showed only marginal for impacts on time on-task once other variables were considered, with a marginally significant difference only seen between arterials and local streets. The significance of the roadway hierarchy was marginal for pavement width and eye-height width, but became significant when considering the other 4 corridor widths.

*Time On-task Elasticities*

In non-linear model systems, it is not easy to identify the magnitude of the impact on the dependent variable so an elasticity analysis was performed to better interpret the influence of the independent variables. Table 5.4 provides the elasticities calculated at the mean for each variable. This reflects the percent change in the on-drive percentage expected with a single unit change in the independent variable. The first four human activity based categorical variables have a similar scale impact on driver attention, ranging from 3-5% each. Adding a lanes to a corridor increases ratio of time on-task but this would be offset by the increase in roadway width required to
accommodate the additional laneage. For instance, widening from a 2-lane roadway to a 4-lane roadway would increase the number of directional travel lanes from 1 to 2, yielding an 5.8% increase in on-task behavior. However, adding even 20 additional feet of width to the corridor (for two directional lanes) decreases time on-task by nearly 15%. Unfortunately, the implications for road diets are less clear. Without a visual change to the corridor width, like adding striped, regularly-used onstreet parking or post-delimited bike lanes, the time on-task may not significantly change because the visual corridor width doesn’t change as through lanes are converted to turn lanes or potentially unoccupied onstreet parking. In a similar way, driveway spacing can have a large impact on attention. Increasing driveway spacing 1 standard deviation (178 feet) potentially decreases driver on-task behavior by 35%.

**TABLE 5.4: On-task Driving Ratio Elasticities**

<table>
<thead>
<tr>
<th>Variable Description</th>
<th>Category</th>
<th>Mean*</th>
<th>Elasticity (% change)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gender</td>
<td>Female</td>
<td>0.55</td>
<td>4.570</td>
</tr>
<tr>
<td>Age</td>
<td>16-24</td>
<td>0.25</td>
<td>-3.379</td>
</tr>
<tr>
<td>Presence of VRU</td>
<td></td>
<td>0.37</td>
<td>-5.441</td>
</tr>
<tr>
<td>LOS B/C/D (base: A)</td>
<td></td>
<td>0.22</td>
<td>4.531</td>
</tr>
<tr>
<td>Travel Lanes (base: 1 lane)</td>
<td>2-lane</td>
<td>0.27</td>
<td>5.638</td>
</tr>
<tr>
<td></td>
<td>3-lane</td>
<td>0.10</td>
<td>8.074</td>
</tr>
<tr>
<td>Pavement Width</td>
<td>(feet)</td>
<td>43.54</td>
<td>-0.747</td>
</tr>
<tr>
<td>One way</td>
<td></td>
<td>0.07</td>
<td>-11.718</td>
</tr>
<tr>
<td>Unstriped on-street parking</td>
<td></td>
<td>0.23</td>
<td>-4.080</td>
</tr>
<tr>
<td>Street Trees</td>
<td>Linear</td>
<td>0.31</td>
<td>3.304</td>
</tr>
<tr>
<td>Right Sidewalk Type</td>
<td>buffered</td>
<td>0.15</td>
<td>3.539</td>
</tr>
<tr>
<td>Driveway Spacing</td>
<td>(feet)</td>
<td>172.35</td>
<td>-0.196</td>
</tr>
<tr>
<td>Hierarchy (base: arterial)</td>
<td>Collector</td>
<td>0.46</td>
<td>3.305</td>
</tr>
<tr>
<td></td>
<td>Local</td>
<td>0.14</td>
<td>4.589</td>
</tr>
</tbody>
</table>

* or fraction of the sample in that category

All else being equal, a one-way street elicits roughly 12% less time on-task at mid-segment than a bidirectional corridor of the same width. The impact of an unmarked onstreet parking area or an unbuffered suburban sidewalk decreases time on-task, but their effects are small. Arterials
elicit much less time on-task than local streets. In terms of activity, the presence of a vulnerable user reduces time on-task around 5%. This is consistent with the momentary glances that vulnerable users elicit when they enter a driver’s field of view. Obviously, since we are only taking a single second epoch in the middle of the segment, the data would capture a small fraction of those glances and therefore the small, but measurable, increase in “distraction” is understandable and consistent with the CAP model. Increasing from LOS A to B also elicits an increase in on-task behavior of roughly 5%. As the study collected its data at speeds consistent with the 85th percentile for that location, the vast majority of the data for attention was collected at these lower LOS levels. However, the statistically significant difference indicated by this small change in LOS presages the much higher attention levels required by higher levels of congestion.

**Multitasking Model**

In light of the potential issues distinguishing between whether an external stimulus is a distraction or an on-task behavior, the number of tasks that the driver carried out during the 1 second attention epoch was tabulated as described earlier. A traditional ordered probit model was used to identify the likelihood that a driver would multitask during a midsegment, free-flow drive (see Eluru (2013) or M. Abdel-Aty (2003) for mathematical details). The model coefficients, t-statistic, and significance are shown in Table 5.5.
TABLE 5.5: Ordered Probit Model for Multitasking

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Category</th>
<th>$\alpha$</th>
<th>t-Stat</th>
<th>p=</th>
</tr>
</thead>
<tbody>
<tr>
<td>Threshold 0-1</td>
<td></td>
<td>0.352</td>
<td>2.971</td>
<td>0.003</td>
</tr>
<tr>
<td>Threshold 1-2</td>
<td></td>
<td>0.768</td>
<td>6.459</td>
<td>0.000</td>
</tr>
<tr>
<td>Threshold 2-3</td>
<td></td>
<td>1.759</td>
<td>14.229</td>
<td>0.000</td>
</tr>
<tr>
<td>Young</td>
<td>(16-24)</td>
<td>0.280</td>
<td>4.748</td>
<td>0.000</td>
</tr>
<tr>
<td>Directional lanes</td>
<td>2 lanes</td>
<td>-0.233</td>
<td>-2.919</td>
<td>0.004</td>
</tr>
<tr>
<td>(base: 1)</td>
<td>3+ lanes</td>
<td>-0.268</td>
<td>-2.192</td>
<td>0.028</td>
</tr>
<tr>
<td>Pavement width</td>
<td>(feet)</td>
<td>0.005</td>
<td>2.228</td>
<td>0.026</td>
</tr>
<tr>
<td>Sidewalk type</td>
<td>Urban</td>
<td>0.232</td>
<td>2.705</td>
<td>0.007</td>
</tr>
<tr>
<td>Sidewalk width</td>
<td>5-10 feet</td>
<td>-0.110</td>
<td>-1.727</td>
<td>0.084</td>
</tr>
<tr>
<td>(base: 0-5’)</td>
<td>&gt; 10 feet</td>
<td>-0.238</td>
<td>-2.641</td>
<td>0.008</td>
</tr>
<tr>
<td>Sight distance</td>
<td>(feet)</td>
<td>0.000</td>
<td>2.403</td>
<td>0.016</td>
</tr>
<tr>
<td>Door density</td>
<td>(doors/100’)</td>
<td>-0.029</td>
<td>-1.764</td>
<td>0.078</td>
</tr>
</tbody>
</table>

Demographically, multitasking is more prevalent in our sample for young drivers, but there were no differences in terms of gender. The study site location (Tampa vs. Seattle) had a slightly higher significance than on time on task, but was again small and was dropped from the analysis. The presence of vulnerable users appears no longer provides a significant impact on attention when it is measured in terms of multitasking level. This confirms the complexity of identifying whether the recognition of things in the environment are part of the driving task or a distraction from it (or both).

Similar to the time-on-task results, adding lanes adds complexity that increases driver attention, but this again is offset by the decrease in focus that comes with a wider corridor. While only suburban unbuffered sidewalk types were significant for time on task, the more nuanced multitasking assessment brings out the significance of urban sidewalks, with their increased complexity, and overall sidewalk width, in an offsetting fashion, making the impact of wide sidewalks in suburban environments particularly important. These are features that are strongly
correlated with vulnerable user presence in our dataset and in real life, presaging the presence of people that the CAP model prioritizes.

In terms of the longitudinal roadway features, increasing sight distance increases the level of multitasking. Similar to driveway spacing, this feature is measured in terms of long distances and has a wide range of values, so changes in the level of multitasking can become very large despite the seemingly small size of the estimate. The density of the doors that open on the corridor has a marginally significant impact on multitasking as well, commensurate with their relationship with regard to regular human presence.

Table 5.6 summarizes a comparison of how different corridor widths interact with multitasking behavior using the same model structure. Similar to the previous results, width at eye height, pavement width, and drive lane width all have a significant impact on multitasking, with increases in corridor width increasing the number of tasks that participants engaged in. This is strong confirmation for the CAP model in that eye height corridor width—the width most likely to indicate whether vulnerable users are in the driver’s field of view—has the most significant (and strongest) impact on driver multitasking, followed closely by pavement width. Drive-lane width is largely associated with potential conflicts between vehicles instead of people and has a lower significance level. The building to building width has a marginally significant impact on multitasking which may reflect the wide variation in the measure (30-570 feet). Only those corridor widths that have building to building distances in the range of 100-150 feet are likely to have impacts in terms of the CAP model while building arrangements with parking lots intervening are likely to allow for much higher levels of multitasking. Again, neither ROW or lane width have a significant impact.
### TABLE 5.6: Corridor Width Comparison, Multitasking

<table>
<thead>
<tr>
<th>Corridor Width</th>
<th>Estimates</th>
<th>t-Stat</th>
<th>p=</th>
</tr>
</thead>
<tbody>
<tr>
<td>Width at Eye Height</td>
<td>0.0045</td>
<td>3.369</td>
<td>0.0008</td>
</tr>
<tr>
<td>Pavement Width</td>
<td>0.0047</td>
<td>2.228</td>
<td>0.0259</td>
</tr>
<tr>
<td>Drive Lane</td>
<td>0.0050</td>
<td>2.080</td>
<td>0.0375</td>
</tr>
<tr>
<td>Building to Building</td>
<td>0.0006</td>
<td>1.660</td>
<td>0.0968</td>
</tr>
<tr>
<td>Right of Way</td>
<td>0.0020</td>
<td>1.416</td>
<td>0.1567</td>
</tr>
<tr>
<td>Lane Width</td>
<td>0.0043</td>
<td>0.466</td>
<td>0.6411</td>
</tr>
</tbody>
</table>

**Multitasking Elasticities**

As was described earlier, nonlinear model coefficients are difficult to translate except in terms of sign. **Table 5.7** summarizes the change in the probability of a particular multitasking level based on a single unit change in each variable. For instance, holding all else equal, an increase in the number of directional lanes from 1 to 2 (line 2), increases the proportion of drivers with no secondary tasks by 17%, decreases the probability of drivers who are observed to be looking at external stimuli in the environment by 6.7%, decreases the probability of drivers participating in a secondary task by 20%, and decreases the probability of a driver participating in 2 or more secondary tasks by 40%.

### TABLE 5.7: Elasticities for Multitasking Level

<table>
<thead>
<tr>
<th>Variable</th>
<th>Type or Units</th>
<th>Multitasking Level</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>16-24</td>
<td></td>
<td>-21.199</td>
<td>5.081</td>
<td>23.719</td>
<td>56.421</td>
</tr>
<tr>
<td>Number of Lanes (base: 1)</td>
<td>2</td>
<td></td>
<td>17.404</td>
<td>-6.661</td>
<td>-19.852</td>
<td>-39.998</td>
</tr>
<tr>
<td>Sidewalk type</td>
<td>Urban</td>
<td></td>
<td>-17.367</td>
<td>4.364</td>
<td>19.263</td>
<td>46.354</td>
</tr>
<tr>
<td>Sidewalk Width (base: 0-5')</td>
<td>&gt;10'</td>
<td></td>
<td>8.312</td>
<td>-2.702</td>
<td>-9.420</td>
<td>-20.279</td>
</tr>
<tr>
<td>Pavement width</td>
<td>Feet</td>
<td></td>
<td>17.857</td>
<td>-7.020</td>
<td>-20.452</td>
<td>-40.390</td>
</tr>
<tr>
<td>Sight distance (feet)</td>
<td></td>
<td></td>
<td>-1.543</td>
<td>0.450</td>
<td>1.737</td>
<td>3.908</td>
</tr>
<tr>
<td>Doorway density doors/100'</td>
<td>doors/100'</td>
<td></td>
<td>0.511</td>
<td>-0.184</td>
<td>-0.584</td>
<td>-1.196</td>
</tr>
</tbody>
</table>

57
Young drivers appear to be dramatically more likely to participate in multitasking behavior, which is not encouraging since many of them are not sufficiently experienced to manage a high level of vulnerable user risk at an automatic level in a multimodal environment. It also appears that they may be less sensitive to the attention-getting impact of the human face and form due to their lack of experience. It is important to remember that this data was collected between 2010 and 2012, at the peak of the shift to smartphones, a shift that was more widely accepted among the young (O'Dea, 2021). It would be interesting to identify how this trend has changed in the intervening years.

As was identified previously, an increase in the number of travel lanes increases driver workload, but increasing from 2-3 lanes appears to have much less of an impact than the initial increase from single lane to multilane configurations. The number of lanes and pavement width an offsetting impact, with the typical additional width that corresponds to a roadway lane (around 11’) having a roughly equivalent impact in the opposite direction, in terms of moving from one lane to two. However, the additional pavement width added at 3 lanes or more dramatically increases multitasking while the increase due to the number of lanes is more modest. In essence, there appears to be little difference in the level of multitasking that goes on for typical two- and four-lane roadways, but multitasking increases dramatically for 6 lane roadways. This is consistent with the CAP model in that the driver’s field of view is likely to encompass both the roadway and sidewalk in a 2-lane or 4-lane configuration, but may not be wide enough to cover the sidewalk in wider roadways. It appears that sidewalk type and sidewalk width also have offsetting impacts in urban areas, but significant changes in multitasking level outside of those areas.

An increase in sight distance has a dramatic impact on driver attention as well, with large increases in multitasking behavior for every additional foot of sight distance added. This may be
related to the speed with which the driver feels comfortable moving. Longer sight distances often result in higher speeds (Angelastro, 2011). There is a reduction in uncertainty with respect to oncoming vehicles or conflicts when sight distance is longer. However, this may also be a confirmation of the CAP model as well. Increased speed is associated with a visual tunnelling effect, which may reduce the amount of face to face interaction between drivers and vulnerable users in the space.

Active doorway density also impacts multitasking behavior. This may be one of the biggest differences between the downtown areas in Seattle and Tampa. While many of the streets in Seattle are lined with restaurant or retail uses in the first floor of the high-rises, Tampa has comparatively fewer sidewalk facing doorways. First floor retail, where it exists, is often accessed internally from a parking garage or elevator, rather than the sidewalk. This reduces the quantity of what Jane Jacobs calls “eyes on the street,” resulting in a corresponding decrease in driver attention. Many would call any downtown an “urban” location, but there is a dramatic difference between the street-level human activity patterns in a demonstrably urban location like Seattle and a suburban location like Tampa. The effect size is comparatively small (5-10% shifts at most).

**Crash History and Attention**

Attention has long been considered one of the primary antecedents to vehicle crashes. Clearly, many crashes occur because of lapses in attention, but not every attentional lapse causes a collision. Thankfully, driving is quite forgiving. However, that disconnect between action and reaction can reinforce risky behavior, especially when the risks are rarely yours to bear.

Such is the situation with driving in a multimodal urban context. The most significant risks are rarely borne by those that impose them, potentially leading to even more risky behavior.
However, in terms of exposure, the most urban environments are far safer to pedestrians and bicyclists than their suburban counterparts, both in real numbers and in terms of exposure (Rodriguez, Sklar, & Zaccaro, 2018). Even the concept of “safety in numbers” flies in the face of exposure statistics, and yet has consistently shown strong evidence of its validity (Elvik & Bjørnskau, 2017). The question is why. Each individual crash is likely to have multiple contributing causes, some more proximal than others. Is there a unique characteristic or pattern in an urban environment that protects vulnerable users in a way that is absent from suburban contexts? Is there something fundamentally different about the type of attention that drivers use in truly urban settings? Does the potential of a different attentional pattern carry over into overall crash rates?

Table 5.8 summarizes the significance levels of the features that were previously found to have strong correlations or econometric associations with attention, vulnerable user presence, or both. The goal of this summary is to identify which of the measured contextual variables have an impact on driver attention. Those variables can then be tested to identify whether they have a significant impact on crash history as well.

Segment level crash data was collected from statewide databases for each of the study sites (Bejleri, 2014; "CAT," 2021) for the years from 2016 through 2019, reflecting the earliest consistent data available from these databases. Crashes at intersections at the ends of the segment were included if they occurred within the intersection or within a turning movement to or from the segment. Segment lengths were also tabulated for scaling to crash rates. The amount of time for which data was collected (roughly 2,000 seconds) is far too small to allow for any confidence in terms of relating attention and accident rates directly, no matter how carefully the epochs were selected. Crashes occur infrequently and each has unique characteristics that are difficult to
capture in terms of the momentary glimpses at driver attention. However, the environmental features tabulated for each segment are likely to have a consistent impact on the incidents that occurred within those segments.

A log-linked negative binomial (NB) analysis scaled based on the segment length was performed for each of the contextual variables that had an impact on attention, vulnerable user presence, or both using the log of the crash rate as the dependent variable (see M. A. Abdel-Aty and Radwan (2000) for a similar process).
### TABLE 5.8: Significance Comparison of Context Features on Attention

<table>
<thead>
<tr>
<th>Context features</th>
<th>Single Factor ANOVA</th>
<th>% Time On-Task</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>VRU On-Task Multitask VRU On-Task Multitask</td>
<td></td>
</tr>
<tr>
<td><strong>Cross Section</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lane Width</td>
<td>***</td>
<td>**</td>
</tr>
<tr>
<td>Drive Lane</td>
<td>*** ***</td>
<td>*** ns</td>
</tr>
<tr>
<td>Width at eye height</td>
<td>*** **</td>
<td>*** ***</td>
</tr>
<tr>
<td>Pavement width</td>
<td>*** ***</td>
<td>***</td>
</tr>
<tr>
<td>ROW width</td>
<td>** ns</td>
<td>** ns</td>
</tr>
<tr>
<td>Building face width</td>
<td>*** *** ***</td>
<td>*** ns</td>
</tr>
<tr>
<td>One-way streets</td>
<td>*** ns</td>
<td>ns</td>
</tr>
<tr>
<td>Directional Lanes</td>
<td>** ns</td>
<td>ns</td>
</tr>
<tr>
<td>2 directional lanes (base:1)</td>
<td>ns</td>
<td>** ns</td>
</tr>
<tr>
<td>3 directional lanes (base:1)</td>
<td>ns</td>
<td>* ns</td>
</tr>
<tr>
<td>Center lane/median width</td>
<td>**** ns</td>
<td>+</td>
</tr>
<tr>
<td><strong>Parking</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unstriped onstreet</td>
<td>ns</td>
<td>+</td>
</tr>
<tr>
<td>Angle</td>
<td>ns</td>
<td>* ns</td>
</tr>
<tr>
<td><strong>Sidewalk</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>width</td>
<td>*** ns</td>
<td>*</td>
</tr>
<tr>
<td>width: 5’-10’ (base: 0-5’)</td>
<td>*</td>
<td>+</td>
</tr>
<tr>
<td>width &gt;10’ (base: 0-5’)</td>
<td>*</td>
<td>**</td>
</tr>
<tr>
<td>Urban unbuffered</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Suburban unbuffered</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>Direction of Flow:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Doorway density</td>
<td>*** ***</td>
<td>** ***</td>
</tr>
<tr>
<td>Block Length</td>
<td>*** ***</td>
<td>**</td>
</tr>
<tr>
<td>Driveway spacing</td>
<td>*** **</td>
<td>ns</td>
</tr>
<tr>
<td>Sight Distance</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>UFOV**sight distance</td>
<td>** ns</td>
<td>*</td>
</tr>
<tr>
<td>Linear street sight distance</td>
<td>* ns</td>
<td>ns</td>
</tr>
<tr>
<td>Tree canopy</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td><strong>Built context</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of stories</td>
<td>*** ns</td>
<td>ns</td>
</tr>
<tr>
<td>Visual aspect ratio</td>
<td>*** ns</td>
<td>ns</td>
</tr>
<tr>
<td><strong>System</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Arterial</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Collector</td>
<td>ns</td>
<td>ns</td>
</tr>
<tr>
<td>Walkscore</td>
<td>***</td>
<td>+</td>
</tr>
</tbody>
</table>

**Legend:**
- **ns** not significant
- **p ≤ 0.05**
- **p ≤ 0.01**
- **p ≤ 0.001**

*Significance for Multinomial Models taken from the same or similar variable combinations

**Useful Field of View (20 degree cone around fovea)**
Table 5.9 summarizes a comparison a series of NB analyses using a consistent variable set and different corridor widths. Tampa reports crash rates that are significantly larger than Seattle. This could be due to different reporting standards, but it would be difficult to tell without examining a large sample of the individual crash reports.

Corridor width measurements show the most inconsistency in terms of crash rates. The most significant correlation and widest potential range was for the building face to building face measurement, however, as this width increased, crash rates decreased. A 10% increase in the building to building width is projected to decrease the crash rate about 12%. This may be due to access functions being shifted away from the roadway corridor as the space between the buildings increases and off-street parking is provided.

The next most significant measure was for the edge of pavement width. A 10% increase in the pavement width was correlated with a 4% increase in crash rates. Additional pavement width is generally provided on an as-needed basis, which means that there is likely to be a relationship between the vehicle activity in the corridor and the pavement width. More activity and potential conflicts lead to more crashes. Drive lane width shows a similar pattern with edge of pavement width. Increasing the width at eye height also increases crash rates, although this variable’s interaction within the multivariate models is often confounded by other context features that are along the edge of the roadway. Each of these measures have strong correlations (in the same direction) for attention and vulnerable user presence. The wider the corridor, the less attention is paid and the fewer vulnerable users are there. In terms of these three cross-section based widths, a one foot increase in width generally translates to a 1% increase in crashes. In theory, this could be attributed to the decrease in driver attention levels resulting from a decrease in the expectation of vulnerable users in the space.
<table>
<thead>
<tr>
<th>Parameter</th>
<th>Building Face Width</th>
<th>ROW Width</th>
<th>Edge of Pavement</th>
<th>Eye Height</th>
<th>Drive Lane</th>
<th>Lane Width</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Intercept)</td>
<td>-6.198 0.002 0.000</td>
<td>-6.542 0.001 0.000</td>
<td>-6.698 0.001 0.000</td>
<td>-6.433 0.002 0.000</td>
<td>-6.566 0.001 0.000</td>
<td>-6.656 0.001 0.000</td>
</tr>
<tr>
<td>Tampa (base: Seattle)</td>
<td>1.558 4.752 0.000</td>
<td>1.508 4.519 0.000</td>
<td>1.536 4.645 0.000</td>
<td>1.610 5.004 0.000</td>
<td>1.554 4.729 0.000</td>
<td>1.513 4.539 0.000</td>
</tr>
<tr>
<td>Building Aspect Ratio (h/w)</td>
<td>1.375 3.957 0.000</td>
<td>1.499 4.476 0.000</td>
<td>1.491 4.443 0.000</td>
<td>1.397 4.042 0.000</td>
<td>1.448 4.256 0.000</td>
<td>1.500 4.482 0.000</td>
</tr>
<tr>
<td>Arterial (base: local)</td>
<td>0.958 2.607 0.000</td>
<td>0.818 2.266 0.003</td>
<td>0.668 1.950 0.015</td>
<td>0.924 2.520 0.001</td>
<td>0.872 2.392 0.002</td>
<td>0.807 2.241 0.003</td>
</tr>
<tr>
<td>Collector (base: local)</td>
<td>0.329 1.390 0.182</td>
<td>0.320 1.377 0.206</td>
<td>0.250 1.284 0.314</td>
<td>0.318 1.374 0.206</td>
<td>0.328 1.388 0.193</td>
<td>0.323 1.382 0.204</td>
</tr>
<tr>
<td>Block Length (ft)</td>
<td>-0.001 0.999 0.002</td>
<td>-0.001 0.999 0.000</td>
<td>-0.002 0.998 0.000</td>
<td>-0.001 0.999 0.000</td>
<td>-0.001 0.999 0.000</td>
<td>-0.001 0.999 0.000</td>
</tr>
<tr>
<td>Number of Lanes</td>
<td>0.696 2.005 0.000</td>
<td>0.688 1.990 0.000</td>
<td>0.343 1.409 0.040</td>
<td>0.808 2.243 0.000</td>
<td>0.791 2.205 0.000</td>
<td>0.679 1.972 0.000</td>
</tr>
<tr>
<td>One-way street</td>
<td>-0.509 0.601 0.185</td>
<td>-0.681 0.506 0.094</td>
<td>-0.132 0.876 0.753</td>
<td>-0.732 0.481 0.056</td>
<td>-0.795 0.452 0.039</td>
<td>-0.653 0.520 0.087</td>
</tr>
<tr>
<td>Walkscore</td>
<td>0.007 1.008 0.074</td>
<td>0.008 1.008 0.053</td>
<td>0.008 1.009 0.069</td>
<td>0.009 1.009 0.039</td>
<td>0.011 1.011 0.012</td>
<td>0.008 1.008 0.064</td>
</tr>
<tr>
<td>Sidewalk Width (ft)</td>
<td>-0.044 0.957 0.018</td>
<td>-0.035 0.966 0.075</td>
<td>-0.038 0.963 0.049</td>
<td>-0.050 0.952 0.012</td>
<td>-0.013 1.011 0.049</td>
<td>-0.036 0.965 0.058</td>
</tr>
<tr>
<td>Corridor width</td>
<td>-0.004 0.996 0.001</td>
<td>-0.001 0.999 0.827</td>
<td>0.019 1.019 0.008</td>
<td>-0.007 0.993 0.047</td>
<td>-0.042 0.987 0.026</td>
<td>0.006 1.007 0.828</td>
</tr>
<tr>
<td>Corridor width range</td>
<td>30-570; µ=120</td>
<td>33-180; µ=69</td>
<td>17-108 µ=44</td>
<td>14-166; µ=48</td>
<td>12-116; µ=32</td>
<td>9-24; µ=12</td>
</tr>
<tr>
<td>Log Likelihood</td>
<td>-605.23</td>
<td>-609.83</td>
<td>-606.41</td>
<td>-607.89</td>
<td>-608.02</td>
<td>-609.83</td>
</tr>
</tbody>
</table>
The fact that lane width shows no significant impact on vehicle crashes in our study when these other attention-related variables are taken into consideration is an important finding on its own. In the past, reducing lane width has been associated with increases in sideswipe and rear end crashes (Rista et al., 2018), but it may also result in a reduction in other types of crashes that are more serious resulting in no significant impact on crash rates. This deserves future exploration. In terms of attention, lane width is not as strongly related to attention as the other corridor widths.

Right of Way (ROW) width showed no significant impact on vehicle crashes, which is not surprising since ROW width is difficult or impossible for drivers to see and shows only minimal impact on driver attention and vulnerable user presence.

Similar to building to building corridor width, both block length and Walkscore™ have the potential for wide swings in their predicted crash rates because their range can change substantially and each show a crash rate increase of about 1% for every single unit increase in these values. The decrease in attention seen with longer block lengths is likely due to the accompanying reduction in risk from cross-street conflicts. There is a tradeoff here because although there are fewer crashes with longer blocks, both vulnerable user presence and driver attention decrease.

The predominant characteristic for generating a Walkscore is the geographic accessibility of land uses that will support residential uses, but this index measure does not focus on the built environment features that relate to the quality of the walking environment or the number of people that use the available pedestrian facilities rather than vehicular access. As a result, Walkscore has mixed results with respect to attention and vulnerable user presence. The increase in crash risk with an increase in Walkscore may reflect the increasing number of conflicts that occur when retail and commercial enterprises are mixed at a fine grain resolution, which often coincides with increases in vehicle traffic as well. As an individual variable, it has strong correlations to attention.
and vulnerable user presence, but it rarely shows significance when used in conjunction with other variables. An increased Walkscore may merely reflect a tendency toward an increase in overall activity and therefore an increased level of potential conflicts that could contribute to a crash.

An increase in the aspect ratio of the corridor or number of lanes increases crash rates for the same reasons. Higher corridor aspect ratios reflect both an increase in overall activity due to land use density/intensity and an intensification of activity within the corridor, in the immediate proximity of the roadway. The number of lanes is often dictated by the vehicle demand in the corridor and increased demand increases the potential exposure for crashes. Similarly, an increase in hierarchical classification intensifies the likelihood of vehicular activity, resulting in commensurate increases in crash rates.

On the other hand, increased sidewalk widths are usually provided in areas where high numbers of vulnerable users are likely. This is correlated with a slight decrease in driver multitasking and the expected increase in vulnerable user presence. The decrease in multitasking tied to the CAP-type environment appears to be contributing to the lowered crash rates.

Hierarchical classification often would appear significant in initial attention/VRU presence multivariate model formulations, only to become insignificant as other variables were added. The overall trend was that lower hierarchical classifications would result in higher levels of attention and VRU presence, although the differences were only significant when comparing arterials and local streets. The same result is seen in terms of crashes: there is a clear statistical difference between crash rates on local streets and arterial streets, but the information is less conclusive in terms of collectors. This corresponds well to the behavior of this variable in terms of attention and vulnerable user presence and supports the CAP model in that the regular presence of vulnerable
users on local streets (compared to arterials) increases driver attention and reduces overall crash rates.
CHAPTER 6: CONCLUSIONS AND IMPLICATIONS

The statistical analyses within this study provide strong support for the CAP model of driver attention in urban settings. Interactions in urban environments are unique because of the presence of vulnerable users and their safety is highly dependent on an elevated level of driver awareness. Graciously, areas that either habitually have people within the driver’s field of view or have visual features that cue drivers to expect people in that space reflexively elicit attention levels that take those vulnerabilities into account. Without the conditioned presence of people or features that visually communicate the potential of their presence, drivers cannot rely on these reflexive mechanisms and must make a cognitive-level choice to look for vulnerable users despite the fact that they do not expect to see them—an unlikely prospect. Any number of driver distractions including speed, congestion, or internal musings are likely to disrupt driver attention and leave bicyclists or pedestrians vulnerable. Maintaining the level of attention required to protect vulnerable users may be unrealistic when they are not close enough to the vehicle to be noticed. In this situation, attention is allocated based on a regularly “out of sight, out of mind” basis. In order for higher levels of attention to be generated, the environment must regularly include interactions with the human form, preferably face to face interactions. This means that the cross section must be narrow enough for people to be seen within the driver’s field of view as they move through the space, and vehicles must be moving slowly enough to give time for those interactions to occur. Given a wide open space, with expansive parking lots or high speed,
multilane arterials, there can be no reasonable expectation that drivers will give anything more than highly automatized behavioral responses with only the minimum amount of attention required to function under fairly optimal circumstances.

One implication of the CAP model is that this higher level of attention is difficult for drivers to maintain for long distances. The CAP model brings into question the safety of including onstreet bike-paths or narrow sidewalks alongside high-speed vehicular traffic within the ROW. This does not automatically eliminate the possibility of complete streets, but it may require reconsidering active user facilities at a corridor, community, or network level instead. Rather than trying to serve all modes within a single ROW, a network that includes lower speed areas in which drivers can successfully interact face-to-face with pedestrians and bicyclists away from higher speed arterials is likely to be safer and more successful while it reduces the fatigue and workload associated with city streets. Some experts have derisively called pedestrian friendly areas nested within vehicle-oriented arterial networks “pedestrian petting zoos,” bringing into question the potential success of these plans. Their critique may have merit in terms of the economic success, but this research confirms that a clear delineation between pedestrian and non-pedestrian areas may be necessary to assure safety for vulnerable users.

The CAP model of driver attention can explain how some built environment features modify crash patterns seen within this study, particularly how wider sidewalks and lower hierarchical levels shift the nature of driver attention. Additionally, there appears to be a trade-off in terms of accident types due to lane width that could be a reflection of the CAP model effect. Despite a previously established increase in sideswipe and backing crashes with reduced lane widths, there was no increase in overall crash rates due to lane width, leading to the assumption
that other crash types were reduced. This shift in accident type could be a result of the increased attention that CAP-type environments elicit and is worthy of additional study.

This analysis supports the contention that attention will continue to be a leading indicator of vulnerable user crashes. These are a rare but increasing proportion of all vehicle crashes. There is a difficult hurdle to be overcome in terms of increasing vulnerable user safety. The features that make them safer attract more vulnerable users, who now have more exposure to a driving public that has yet to adjust to their presence, often increasing the number of crashes (MacLeod et al., 2018). It takes time for drivers to become conditioned to anticipate people in their driving spaces and adjust their behavior accordingly. Roadway designers can help by emphasizing the distinction between spaces that are geared toward welcoming vulnerable users and those that are not. There are clear differences in the crash rates seen on arterials and local streets, but much uncertainty in the middle—uncertainty that may be contributing disproportionately to vulnerable user crashes.

Implications

Unfortunately, this model provides a compelling prediction for the reason stroads are often so dangerous for pedestrians and are often held up as the primary examples of roadways that are “dangerous by design.” A stroad is a wide roadway, often an arterial, that attempts to provide a high level of mobility and connectivity at the same time, often with frequent driveways, retail strips, and high speeds (Marohn Jr, 2019). Although the complete streets movement has, with the best of intentions, attempted to retrofit walking and biking into these environments, neither drivers nor pedestrians feel safe enough to use them for modes other than driving. Areas in the vicinity of these roadways can be retrofitted into more pedestrian friendly zones incrementally, with the installation of a CAP-type street network interior to the main circulation network or substantial road diet reconstruction.
The CAP model can be used to outline the physical limitations that the human mind puts on the scale of an urban (people-focused) space. Assuming the following:

1. Facial expressions are the primary driver of CAP type behavior. Biological movement cues drivers that faces may be present, but it is the decoding of facial expressions that is most critical in terms of reinforcing an area as a CAP-type location.

2. All facial expressions can be decoded at 90 feet. Extreme expressions can be decoded at 135 feet (Hager & Ekman, 1979).

3. Drivers focus between 1 and 2 seconds in front of them, creating a focus area that is centered around 1.5 seconds of travel time in front of the vehicle. Glance durations are in a similar range (Green, 2002). If a person’s facial expression (or the biological movement equivalent of an affect) cannot be fixated within a 1.5 second glance, the person is disregarded by the driver.

4. Driver’s UFOV extends roughly 20° from the driver’s fovea when looking at the center of the horizon (Wolfe, Dobres, Rosenholtz, & Reimer, 2017). Faces are preferentially recognized up to 30° (Rigoulot et al., 2011), but because this takes additional latency time and may require more processing, the 90 foot threshold for facial recognition is more likely than the 135 foot threshold (extreme facial expressions). Perceptual narrowing reduces the full UFOV to 60% of its width at 65 mph (Rogers et al., 2005) and this narrowing of the driver’s focus is roughly linear between 20 mph and 65 mph.

Using these quantities, a sketch of the typical urban field of view from the perspective of the driver is shown in Figure 6.1.
The orange area identifies the moving limits of driver vision in front of the vehicle. What is fascinating about this graphical mapping of the driver’s visual space is the consistency of the 60 and 90 foot wide corridor as a limiting factor for driver attention. Regardless of the speed, drivers are not likely to see and process the presence of a person in the environment at a distance much wider than about 60 to 90 feet. This corresponds roughly to four, 11-foot wide lanes with a 2-foot tree lawn and a 6-foot sidewalk on each side. A five-lane section approaches the 60’ limitation in roadway pavement alone, once curbs and margins are included. This may explain why the corridor width and number of lanes had offsetting impacts on attention levels up to about 4 lanes of width, but showed dramatic drop-offs in attention at 6 lanes or more. In essence, the human perceptual
limitations mean that pavement widths more than about 60 feet or building face to face widths more than about 90 feet will dramatically reduce driver attention because there is no way to perceive the people in the space at speed. This is consistent with the anthropological evidence that can be gained from reviewing pre-vehicular city design. A quick review of city centers in Europe and Asia show that the areas with the oldest development have the narrowest streets. Many of the arterials have widths in the range of 40 to 60 feet between building faces, and local streets with widths of 25 feet or less. Plazas or marketplace corridors were slightly wider, but rarely went over 150 feet in width and 300 feet in length. At walking or horse speeds (20-25 mph) the built environment conformed tightly to these same perceptual limitations.

Also notice that drivers moving more than 40 mph cannot see and decode a facial expression before they have passed the person. This could be both cause and effect for speed outcomes. Attention will be much lower when drivers are moving more than 40 mph. However, they are likely to slow under 40 mph when a person is within that 60 foot wide area around the car.

The CAP model also brings up serious questions about the conspicuity of a bicyclist in contrast to a typical pedestrian or a person riding a stand-up scooter. The physical profile of a bicyclist is much smaller visually, in a less-than-natural body position, and nearly impossible to see from a facial feature standpoint. The reflexive advantage in terms of neurological recognition that a pedestrian has from an evolutionary standpoint may be lost when the person is on a bicycle, particularly those that are hunched over, rather in more vertical, cruising position.

In terms of form based codes, the number of functional, operational, active doorways or businesses per block has a more substantial impact on driver behavior than was previously anticipated and therefore should be given a higher priority wherever possible. Form based codes
should incorporate limitations on corridor widths where pedestrians are expected to be common. Onstreet parking and bus lanes should be considered in terms of their potential to move pedestrians outside of the driver’s viewshed or block the driver’s view of them. On-street bike lane networks should be shifted to narrow, pedestrian oriented areas or the zones directly in front of the buildings rather than be incorporated into a corridor that is too wide or fast for drivers to attend to them. High speed corridors with wide roadway cross sections cannot elicit driver attention at a level that will create a safe environment for a vulnerable user and therefore should have multi-use paths, cycle tracks or other types of bicycle facilities that are separated from the passenger vehicle flow. From a system standpoint, the bicyclist will need additional wayfinding and network map communication to identify safe routes and the enforcement of speed limits should be draconian in these areas. In essence, there should be two classifications of roadways: those that are narrow enough to maintain driver’s attention on vulnerable users and those that are not. The impact of block length and driveway spacing should also be taken into consideration. Vehicle oriented areas should have strong access management limitations to reduce conflicts between vehicles. Lower speed, active systems should have minimal access management limitations with high visibility for cyclists to see and be seen in terms of potential vehicle conflicts that may occur at the more frequently spaced driveways.

One unexpected outcome is the implication for wide roads within dense urban cores, where drivers are appear to be just as inattentive as they are on the highway or stroad environments. Density alone cannot create a space that is pedestrian focused and driver attention adjusts to this dynamic with great consistency. A vehicle-oriented city, typical of many of the suburban cities in the south, will result in lower levels of driver attention. A major highway does not cease being a
major highway because it goes through a downtown core, particularly when it does so with 4 or more lanes of width.

As driving without metacognition is a learned skill that appears to be acquired within the first few years of driving, driver education should recognize that the skills acquired in the early years of driving are differently applied for more experienced drivers. More experienced drivers should be trained to identify locations where they need to reengage full metacognition, including specific locations or events that can cue drivers to examine their behaviors at a more conscious level.

One of the most critical implications of the CAP model is that this higher level of vigilance is demanding in terms of driver workload. There are perfectly appropriate distractions and activities that help drivers manage their ability to attend to the salient information in the environment. The types of glance behaviors that maintain situational awareness can in one moment be a powerful information source and a distraction or frustration in the next. The elevated workload that an urban environment elicits, both in terms of visual clutter and human presence may be perfectly acceptable for short periods of time, but may lead to failures and lapses during longer drives. Tracing out driver’s tolerance for this type of high-workload driving will allow planners to appropriately space highway interchanges and plan the appropriate scale for pedestrian prioritized areas.

It is possible that the area that the driver can tolerate this level of attentiveness fits well with the geographic extents of a walkable area, which is typically a circle with a ¼ mile radius. This distance may be based less on the limits of driver vigilance than on driver conditioning: the typical distance that drivers are required to maintain this type of attention becomes the distance they are willing to tolerate. The distance a person can recognize the shape of another human sets
the limits of a successful pedestrian scale block to no more than 600 feet, roughly 1/10th of a mile. This distance is even used in mall design as an upper limit on the visually uninterrupted length that can be successful (Garreau, 2011). Large cities in the US often have either arterial corridors, freeway off-ramps into the core, or transit accessibility at roughly 1/3 to ½ mile spacing—3 to 5 blocks wide. This creates a corollary to the anthropological concept of Marchetti’s Constant (Marchetti, 1994), which links the size of a city with the speed of the travel modes available using a 70 minute travel budget. Despite the expansion of the overall city that occurs when travel modes increase in speed, the geographic scale of the activity clusters within those cities are still governed by the size of the modes that use them based on the increment of time that must be allocated to the slower mode. Even in vehicle-oriented cities, activity centers (malls or shopping centers) are rarely larger than ½ mile in diameter and have stores that are roughly the size of a city block. Larger centers are clustered with anchors spaced at 600 feet apart and sight distances that never exceed that same distance. Even parking lots are scaled in this way. A typical parking area is no more than 500 feet deep and only regularly used for a distance extending about 600 feet from the back of the store. Multimodal travel then consists of clusters of “marginal Marchetti” areas that can be traversed in the marginal time allocated for that mode. For example, a typical trip from a suburban area to a downtown core may start with a 30 second walk to the car (150 feet in an apartment complex), a 30-minute drive downtown, leaving only a 3-5 minute margin for walking to the office from the car, explaining the typical ¼ mile (5 minute) walk zone that is accepted practice for designing walkable spaces. Conceptualizing multimodal travel on this basis may lead to a better understanding of the tradeoffs made for multimodal or chained trips. On the other hand, it would not be surprising to find a match between the scale that pedestrians are willing to walk and the
scale that drivers are willing to tolerate this higher level of focus is linked to the number of faces they encounter, regardless of the speed.

The appropriate resolution and scale for each mode is critical. At a system level, transportation engineers and planners need to create a much higher level of distinction between different hierarchical tiers that takes the speed, geographically tolerable range, and risks of each mode into account. The successes of the Barcelona superblock conversions hints at the potential for networks that serve different modes at different scales.

**Opportunities for Future Research**

One of the limitations of this study is that driver attention was measured at comparatively low traffic densities and high speeds. Although this was done intentionally in order to elicit the impact of the context on driver behavior without having to address the confounding issues associated with congestion or interruption, ultimately, this reflects a small portion of typical driving patterns. Future research should examine attention and multitasking in a wider range of settings.

A second limitation is that attention is only a leading indicator for the safety outcomes that are desired and vulnerable user crashes are very infrequent, making statistical analysis difficult. Future work should address how attention and vulnerable user crashes are related using the larger time-series dataset that includes information throughout Tampa and Seattle. The most critical factor for all vehicle crashes is conflict exposure. Increasing conflicts will increase vehicle crashes. Most urban environments have extraordinarily high levels of vehicular conflicts in conjunction with the additional mental workload associated with interacting with the faces and forms of people in the vicinity of the vehicle. It should not be surprising that they often have the
highest crash rates, although the low speed inherent in these locations makes these crashes typically less severe than higher speed suburban crashes. It should not be surprising that the development patterns and typical roadway design features in suburban areas dominated by the automobile are safer in terms of vehicle on vehicle crashes.

It may be interesting to research how the inclusion of photographic faces or paradoleic or abstract faces change driver behavior, although this runs the risk of crying wolf—over exposing drivers to non-rewarding stimuli that makes them disregard input that is vital for their operational safety.

Although this study used a reasonable sample size of individual locations consisting of a wide range of multimodal contexts, a more longitudinal, stream of consciousness type of attention analysis could be used in the future to identify patterns of on-task and off-task behavior. For instance, are there cueing locations, like gateway treatments, or block entries where situational awareness is captured and other locations where attention is less likely to be maintained?

It was hoped that this study could have included variables like context classification (urban transect class) or bicycle stress index could have been analyzed, but much of the geography studied has yet to be classified according to these schemes. Bicycling and walking as functional travel modes has seen a society-wide increase since the NDS data was collected in 2011, particularly with the increase in pedal-assist bicycles and open streets over the last year. This raises questions about how the increased number of people in and around the driving space are impacting driver awareness, if at all, during this transition.

The CAP attention model brings up serious questions regarding driver workload and attention maintenance in urban spaces that can provide ample fodder for future exploration. Future research should explore the following questions:
1. How does a high number of pedestrians in a dense urban environment impact the attention behavior of drivers that regularly use the space? What strategies do taxi drivers use or misuse to navigate this type of sensory-laden atmosphere?

2. Are the driver workload limitations dependent on distance, time, or the number of faces they encounter?

3. Is a minute spent in an urban traffic setting equivalent to a minute in bumper-to-bumper traffic or a minute on a highway? Should this additional load be factored into travel demand projections for terminal time or time-based costs?

4. What are the limits of a “marginal Marchetti?” Are there limitations in terms of the amount of time, space, or faces that a person is willing to walk or bike in an urban environment that impact operational conditions in urban spaces? How does this marginal effect impact mode transfer decisions or routes?
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From: UCF Institutional Review Board (IRB)
Date: June 4, 2021
Re: IRB Coverage

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Renea Carver
IRB Manager
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