ALTERNATIVE SEGMENTATION SCHEMES FOR THE DESIGN OF TRAFFIC MAPS

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ABSTRACT

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Drivers in urban environments constantly face the problem of congestion. As a geographic hindrance that is growing rapidly in both frequency and severity, congestion represents a major burden to drivers and transportation systems alike. At the same time, recent advancements in technology have given cartographers unprecedented access to high-quality, real-time traffic data that is readily employed in traffic maps from various sources. Previous research has demonstrated that providing drivers with relevant, time-based information reduces environmental uncertainty, yielding benefits to individuals as well as the transportation network as a whole. Unfortunately, many of the available traffic maps are variations of a single design approach which is replete with ambiguity that hinders the task of travel time estimation. This is largely due to the irregular segmentation of the transportation network used in conventional traffic map design. To address this issue, two prototype designs are proposed that present regular, fixed segmentation schemes. The first approach employs segments that have a fixed length of distance, removing the users' need to estimate incomplete distances along the route. The second approach represents travel time directly by fixing segment length to a unit of travel time. Results of a user-based experiment strongly favor the regularly-segmented approaches for the purpose of travel time estimation and suggest that conventional traffic map designs are not adequate for this task. Traffic maps utilizing the fixed-minute segmentation were greatly preferred by users and were associated with significant improvements in travel time estimation.

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Chapter 1

INTRODUCTION

A major problem facing the United States and indeed the world is the burden of traffic. Whether it is delaying commuters on their way to work, disrupting the flow of goods and services, or clogging major cities, congestion is problem that affects millions, if not billions, of people every day. This burden is also growing rapidly. New drivers and automobiles are produced by the hour and the number of vehicles on the roadways increases continuously. Yet the transportation networks remain largely unchanged; they cannot possibly be modified fast enough to provide a supply that keeps pace with the ever-growing demand. The end result is congestion that is frequent in both time and space.

Congestion affects both travelers and freight shippers who “must plan around traffic jams for more of their trips, in more hours of the day and in more parts of town than in 1982” (Schrank & Lomax, 2009, p. 10). Furthermore, congestion carries an annual price tag that is more than $20 billion higher than it was just seven years ago. This represents an average annual cost of $760, as well as 36 hours spent in delay, for every driver in the United States. These figures are nearly three times higher than what they were only three decades ago.

We often think of congestion as a personal inconvenience without much consideration to how large the problem of congestion really is. Schrank & Lomax noted that congestion has led Americans to spend 4.2 billion additional hours on the road, using 2.8 billion gallons of fuel, which encumbered drivers with a total cost of $87.2 billion in traffic-related expenses. A problem of this magnitude demands attention and the drivers who are directly affected by it could benefit greatly from any improvements made. Among the suite of possible solutions is the accurate and efficient delivery of real-time traffic data. Al-Deek & Khattak (1998) note that much of the congestion is caused by drivers making uninformed decisions about their routes. Poor decisions become exacerbated in the presence of existing congestion as drivers become unsure of when, where, or if they should divert or stay on course. As the number of unsure drivers increases, system efficiency diminishes and congestion becomes likely to arise or worsen.

It is clear that a need exists for the efficient and dynamic delivery of useful traffic information that could help users make decisions while on the road or during pre-trip planning. Time-based information is especially crucial. While the phenomenon of congestion does have a range of monetary and physical costs, the cost of time is perhaps the number one concern to many drivers. We live in a fast-paced world, full of deadlines, meetings, and responsibilities. Anything that may prolong or delay us from reaching our destination represents a cost in time that, if given the opportunity, would be readily avoided.

Congestion particularly affects commuters in large urban environments who must deal with traffic-related delays on a daily basis. Given the dynamic, unpredictable nature of congestion, it represents a constantly changing obstacle to commuters. This is largely due to the uncertainty that is imposed whenever congestion arises. The cognitive maps people build during their everyday travels are full of various waypoints, routes, and other spatial knowledge. Human beings have an almost instinctive familiarity with the trips they make often. We “know them like the back of our hands.” Although the waypoints and routes rarely change, the temporal conditions of those routes often do. The amount of time required to make a trip can change at a moment’s notice, unknown and unannounced. In these cases, congestion clouds our cognitive maps; the route remains familiar but the time-cost becomes a mystery, or foggy at best.

Although there are many possible solutions to the problem of congestion, and indeed the problem is so large that no single solution will suffice (Schrank & Lomax, 2009), providing travelers with high-quality and easily-used traffic information would be substantially beneficial. Even if the improvements were realized by only 1% of drivers in the United States, the affected population would still number in the millions.

Current technology enables the real-time acquisition of traffic data that can be accessed by a wide array of devices, including radios, GPS units, and mobile phones. Despite these technological advances, millions of drivers still do not have reliable access to relevant traffic information that could improve their decision-making and aid them in avoiding congestion. By filling in the temporal gaps in drivers' cognitive maps and reducing their environmental uncertainty, a greater number of individual drivers would have the potential to avoid congestion and the resultant delays. At the macro scale, the combined effect of an increase in well-informed drivers could also yield system-wide improvements — a consequence that has already been noticed when a large portion of drivers have enhanced information about their environment (Mahmassani & Jayakrishnan, 1991).

Presently, these enhancements often come in the form of broadcasts made possible by Advanced Transportation Information Systems (ATIS) and Intelligent Transportation Systems (ITS). These technologies enable the collection and dispersal of information about the transportation network that can improve drivers' decision making, reduce system-wide congestion, and make travel a safer, more reliable experience (Al-Deek & Khattak, 1998).

Maps are an increasingly common component of ATIS and in-vehicle navigation; they also have a long history of attempting to provide information quickly and efficiently. Now, more than ever, maps can take advantage of mobile devices and cell phones, which are becoming increasingly widespread (Ishigami & Klein, 2009). This presents an opportunity to reach a large audience and provide real-time traffic information to drivers in an efficient and proven format.

Although mobile maps and traffic have been studied in great detail independently (see Walker et al. (1991); Al-Deek & Khattak (1998); Clarke (2004); Fujii et al. (2009)), little to no published research exists on traffic maps *on* mobile devices, or on the cognitive aspects associated with traffic maps alone. This is unfortunate, given the popularity of mobile devices and the ease with which they can access visual information, such as maps.

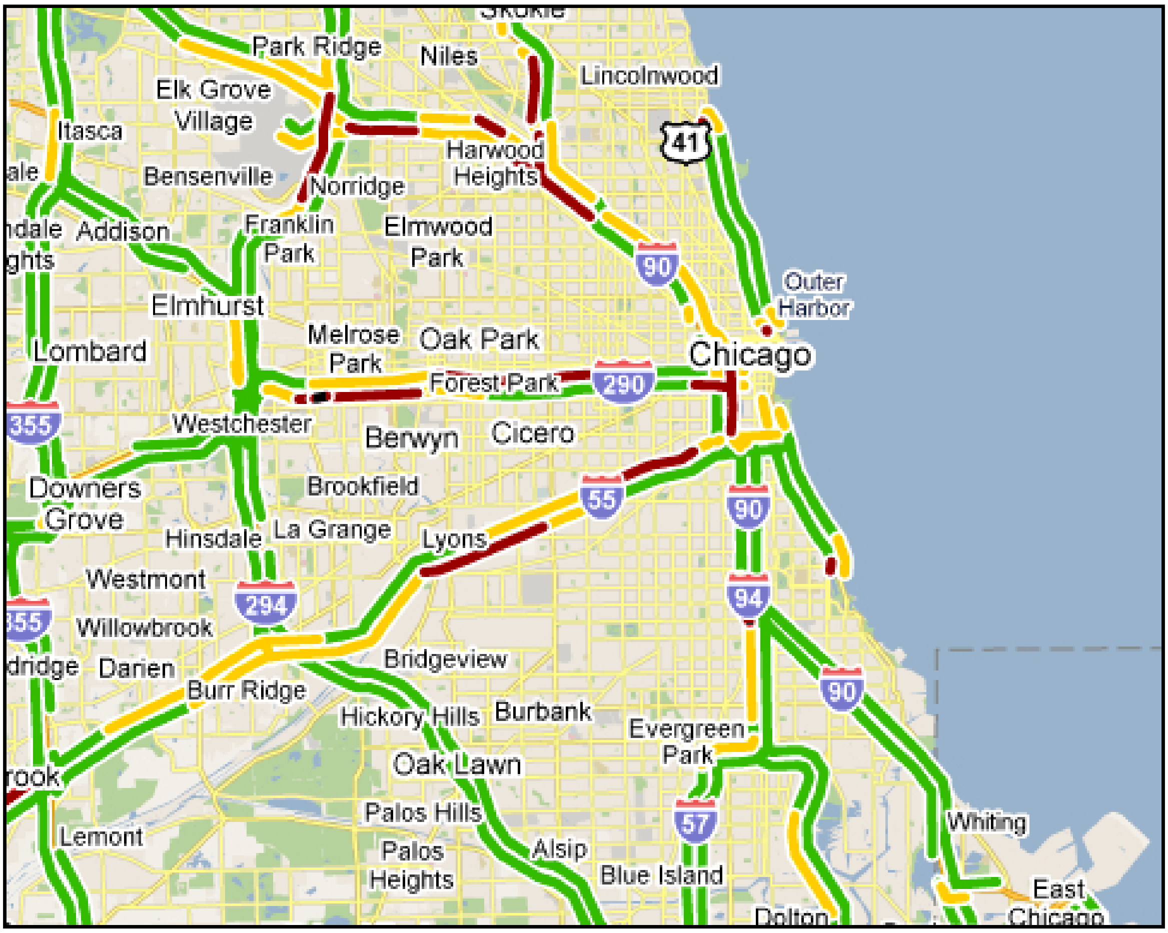


Figure 1: A typical traffic map, as provided by Google Maps. Red, yellow, and green are used to indicate velocity, a proxy for the severity of congestion. For interpretation of the references to color in this and all other figures, the reader is referred to the electronic version of this thesis.

The purpose of this thesis is to examine traffic maps within the context of cognition in a two-fold manner. First, existing research on the in-vehicle use of mobile devices will be used to guide a critique of current traffic map designs. The results of the critique will provide an evaluation of traffic maps that have not commonly been subjected to such research. This critique will then facilitate the creation of two new traffic map designs that will attempt to alleviate some of the problems thus revealed. Secondly, a conventional and widely used traffic map design (Figure 1) will be compared to the new alternatives in a user-based experiment, focused on common traffic map usage. Although there are several reasons one might use a traffic map, for many users, especially those accessing the maps from a mobile device, route selection and travel time estimation are likely very common.

Traffic maps help even very experienced urban travelers reduce environmental uncertainty and the stresses associated with not knowing time-costs that separate their origins and destinations. They enable better wayfinding decisions and potentially improve system-wide efficiency. Some of the most common tasks associated with traffic maps include identifying the fastest route and avoiding congestion, both of which depend on travel time and velocity estimation. Such tasks are very difficult to perform with conventional traffic maps, which provide ample opportunity for improvement. In order to utilize a conventional traffic map for selecting the fastest route or identifying an expected delay, the user must first solve a set of sub-tasks, which include:

1. Estimate the distance of the desired route.
2. Estimate the velocity based on the current traffic conditions.
3. Perform the arithmetic necessary to convert the determined velocity and distance into time.

The difficulty in performing these tasks is increased by the presence of ambiguous segments representing various levels of congestion in the conventional traffic map. A single route may be composed of several different segments, each representing a different velocity and distance. An effective strategy for computing all this information is left for the user to figure out. Not only is such a task burdensome in its own right, but conventional design practices have not done much to improve it. The current traffic maps rarely reveal the velocities represented by a particular color and often utilize a straight scale bar that is not congruent with curvy or irregular routes. This significantly reduces the user's ability to make accurate time-cost estimates.

In addition to providing insight into how traffic maps might be improved or designed in new ways, this research has implications beyond cartography. In their 2008 report for the National Highway Safety Administration (NHSA), Ascone et al. found that nearly 6,000 drivers were killed in accidents related to distracted driving, which accounted for 16% of all fatal crashes that year. The source of distractions in the report include in-vehicle mapping units and cell phones, devices which have been shown to demand a great deal of the operator's attention (Walker et al. (1991); Parkes et al. (1991); Srinivasan (1997); Drews et al. (2009); Horrey et al. (2009); Ishigami & Klein (2009)). Improved traffic map design will not solve this problem outright. It is however unlikely that the habitual use of these devices will decrease, therefore any effort that reduces the distraction they impose is a step in the right direction.

Increasingly, the categories of cell phones and in-vehicle mapping units used by the NHSA need not be separate, as the technologies continue to converge. In 2009, Garmin — a popular manufacturer of GPS units — released their first map-enabled hybrid Smartphone. Google Maps has been a standard application on Smartphones for years, and the online version is accessible to any mobile phone with an Internet connection.

Due to the popularity of these mobile mapping applications and their inherent relationship to vehicular travel, it is reasonable to assume that traffic maps are included in the map types used by drivers. It is therefore necessary that an assessment of traffic maps be done within the context of reducing the attention such maps require, while maintaining continuity with previous studies on map use and mental workload.

1.1 Research Goals

The goals for this thesis are to:

1. Identify key limitations in conventional traffic map designs.
2. Develop prototype design strategies to reduce the limitations.
3. Test the performance of the prototype traffic map designs against the existing standard in terms of travel time estimation.

1.2 Research Questions

To reach the goals set for this thesis, the following questions must be addressed:

1. In what ways can current traffic map designs be improved?
2. Can map readers quickly and accurately determine travel time from existing map designs?
3. Does an improved design, guided by a critique of traffic map designs, improve the accuracy of users' travel time estimations and/or the time required to make the estimations?

1.3 Hypotheses

Hypothesis 1: When provided with a distance and a velocity, most people cannot accurately perform the necessary arithmetic to determine travel

time. In order to determine travel time (t), a distance (d) and velocity (v) must be known (or assumed), and the arithmetic $t = \frac{d}{v}$ be performed. Mental arithmetic, especially division, is a difficult task. If map readers cannot quickly and accurately perform it, they cannot reasonably be expected to determine travel time from a map that requires such cognitive ability.

Hypothesis 2: Map readers cannot adequately determine route distance when using a conventional traffic map. The current traffic map designs in popular use employ a *linear* scale bar to assist with estimating distance along a *nonlinear* transportation network. This incongruity is likely to be a burden to map readers, impeding their ability to accurately estimate the distance of a route. This would greatly diminish a key component of an accurate travel time estimation.

Hypothesis 3: Map readers cannot accurately estimate travel times from conventional traffic maps. Current traffic map designs employ hue as the main identifier of traffic quality. These hues are allocated to segments along the route, each of which is associated with a different velocity and an unknown length. The combined task of estimating the length and velocity of these segments is likely to pose a significant challenge to map readers. Failure to accurately determine a single component of the travel time equation will result in error, and this calculation must be performed for every individual segment along the route and then averaged for a final value. This task presents a large opportunity for error propagation, and poor performance is expected.

Hypothesis 4: Traffic maps that are designed to facilitate the common task of travel time estimation will be associated with a faster, more accurate estimations. Current visualization strategies are more of an artifact of data collection strategies than they are an attempt to streamline the exchange of traffic information. Instead of using segments that vary in their representation of distance and velocity, the segmentation of the transportation network can be fixed to a standard unit the map-reader is more familiar with. A fixed segmentation scheme may take one of two forms: 1) An equal-interval scheme in which the segments are always the same length or 2) A fixed-duration scheme, where segments represent a constant unit of time. In this way, the task of distance estimation is made significantly easier, or in the case of the fixed-duration scheme, it is removed entirely. This cartographic treatment is expected to improve travel time estimations in terms of accuracy and time-to-completion.

1.4 Research Relevance

The empirical investigation of mapping techniques has been at the center of academic cartography in the United States for nearly 60 years (see Robinson's *The Look of Maps* (1952)), and our understanding of the map-human relationship has grown tremendously since (MacEachren, 2004). Nevertheless, traffic maps, which are used by millions of daily users, have gone without much study, especially from a cognitive viewpoint. An examination of conventional traffic maps and the potential creation of a superior alternative would help streamline the flow of much-needed information about an increasingly troubling geographic phenomenon. Congestion is a dynamic, unpredictable geographic hindrance affecting millions of daily drivers around the world. The resultant spatial uncertainty and suboptimal wayfinding decisions made by drivers reduces the overall performance of the transportation network, which has substantial costs in both time and money. Efficient traffic maps offer a potential solution to this problem.

The relationship between mobile devices and distracted driving is important. Traffic map generation is not only a likely use for such devices, but also represents an area of cartography that has not been given much empirical consideration. Although many previous studies have demonstrated that maps affect our attention (Walker et al., 1991; Parkes et al., 1991; Srinivasan, 1997; Horrey et al., 2009), none have evaluated traffic maps or the task of travel time estimation.

Furthermore, the cognitive influence of traffic maps is largely unknown. We do not yet know which aspects of their use are troublesome, or even if they perform perfectly well. Without an empirical evaluation of traffic maps, cartographers can only speculate. The results from this thesis will shed light on these issues, and attempt to clarify the source of the errors that are associated with travel time estimation. This would reveal where current maps are performing poorly, as well as provide new techniques and approaches to map design. This research aims to better our understanding of traffic map interpretation and address a topic that is long overdue for examination.

The remainder of this thesis will cover a review of relevant literature, which includes the areas data collection methods, traffic sensor placement, spatial knowledge and cognition, human vision and lastly, mental workload and attention. Following the literature review, the experimental design will be described along with the expected results, materials used, and procedures employed to both create and test the new prototypes. Results and analyses will then be provided prior to a discussion on the meaning of the findings. The last sections will cover the limitations of this thesis and provide a summary concluding the research done.

Chapter 2

LITERATURE REVIEW

The call for empirical cartography in the United States can be traced to *The Look of Maps*, published in 1952 by Arthur Robinson. In this book, Robinson argued for an objective view towards cartography. In contrast to subjectivity, where maps are critiqued based on their aesthetic or artistic nature, Robinson laid the foundation for an empirical cartography in which a map's quality was determined by how well it performed a given task. This was an important distinction to make, and it remains so today. If a map is said to be superior to another, it must be demonstrably proven to be so. Before this idea, cartographic techniques largely followed convention, a practice that laid its defense on rhetoric and opinion (e.g, red is good for elevation maps because soil is also red). Unjustified adherence to convention is a practice criticized by Robinson:

> "Tradition and familiarity maintain a strong hold. On the other hand, it is reasonable to expect that the developments in the science of vision and the spreading appreciation of the importance of design may combine with the marked increase of interest in cartography in recent years to promote more critical examination of many of the long standing conventions" (pg 12).

This review attempts to outline the literature that is related to congestion, mobile maps, and cognition from an objective viewpoint akin to Robinson's.

2.1 The State of the Literature on Traffic Maps, Cognition, and Mobile Devices

At present, maps can be found almost everywhere. Where they once hung from walls, maps now light up electric displays regularly with unprecedented popularity. Recent advancements in technology have brought maps into vehicles and onto mobile devices, such as cell phones. While they were once luxury items or gadgets owned only by a tech-savvy few, these devices are now ubiquitous (Ishigami & Klein, 2009). The growth in the popularity of these devices can likely be attributed to the information age, the pervasiveness of wireless networks (WiFi), lower costs, and an increased demand for knowledge on the go.

Because of their habitual use while the car is in motion, these devices also pose a danger for motorists and pedestrians alike (Walker et al., 1991; Parkes et al., 1991; Srinivasan, 1997; Drews et al., 2009; Horrey et al., 2009; Ishigami & Klein, 2009). In a study on the behavioral responses elicited by these devices, Golledge (2002) warns that "distracting a driver from visually assessing traffic conditions (especially when traffic is moving at speed) is potentially very dangerous." As these devices saturate our markets and become more universal, these safety concerns only grow. This suggests that an understanding of traffic map design and its affect on human behavior is critical (Walker et al., 1991).

Given the apparent need for such research and the proliferation of devices capable of displaying traffic maps, we might expect the literature to be replete with study after study outlining the effects of their use. Unfortunately, this is not the case and others have noted that research in this area has been surprisingly scarce (Walker et al., 1991; Fujii et al., 2009).

Traffic mapping represents the pairing of many technologies and fields. The rest of this review will reflect these different components, starting with the transportation networks themselves, Advanced Traveler Information Systems (ATIS) and Intelligent Transport Systems (ITS) strategies that inform drivers, and data reliability. Lastly, human behavior and spatial knowledge construction will be discussed alongside the topics of cognition, mental workload, and map interpretation.

2.2 Sensor Placement and Transportation Networks

Before addressing traffic maps specifically, it is important to understand how they are created and how the data are collected. Liu et al. (2009) explain that in the U.S., traffic data are often collected from sensors beneath the roadway called Inductive Loop Detectors, or IDLs (Liu & Danczyk, 2009). The State of California, which served as the study area for this research, employs two basic types of IDLs: single loop detectors, which only detect if a vehicle passes by, and double loop detectors which can measure velocity directly. Both detectors monitor an electrical current that is triggered whenever a vehicle passes overhead. Originally designed as a form of counting mechanism, the single loop detectors can also be used to report the speed of traffic. This is done by assuming an average vehicle length and then dividing that value by the amount of time the vehicle was detected. Even though the double loop detectors can record traffic speed directly, the California Department of Transportation Freeway Performance Measurement System (PeMS) uses a more sophisticated algorithm to determine velocity based on network flow in preference to the more error-prone but direct measurement.

Once a sensor is triggered, data are sent to a small cabinet on the side of the road called a Front End Processor (FEP). Front End Processors control and regulate the detectors and record when, and for how long, the detectors connected to it were triggered. From the FEP the data are sent to an off-site server where they are aggregated by district (of which there are 12 in the State of California). A router connected to the server then distributes the data over a wide-area network (WAN) that is accessed by the PeMS servers to capture the data in 5-minute intervals. Once captured, the data can be viewed through the web-based interface developed by PeMS, or downloaded over a File Transfer Protocol (FTP) server in a raw format.

Ideally, such sensors would be placed at regular distance intervals along the highways, allowing for the collected data to represent an equal sampling of the area of interest. Unfortunately, the sensors are not placed in such a way (see Figure 2), largely due to budgetary constraints and the fact that their placement was originally devised for other purposes (Liu & Danczyk, 2009).

In their research, Liu & Danczyk sought a way to determine optimal sensor position that addressed the needs of several stakeholders, including construction companies and transportation agencies. By likening road segments to chromosomes, they treated traffic sensors as genes within a genetic algorithm. In this way, biological concepts such as gene crossover and offspring generation can be used to determine the ideal locations for the sensors. The placement suggested by this method took into consideration the existing sensor configuration, and was found to be superior to the placement currently in use. The cartographic implication is that sensor placement is irregular and suboptimal, therefore some degree of interpolation and aggregation will be required, and utmost care must be taken to ensure the data are collected and displayed accurately.

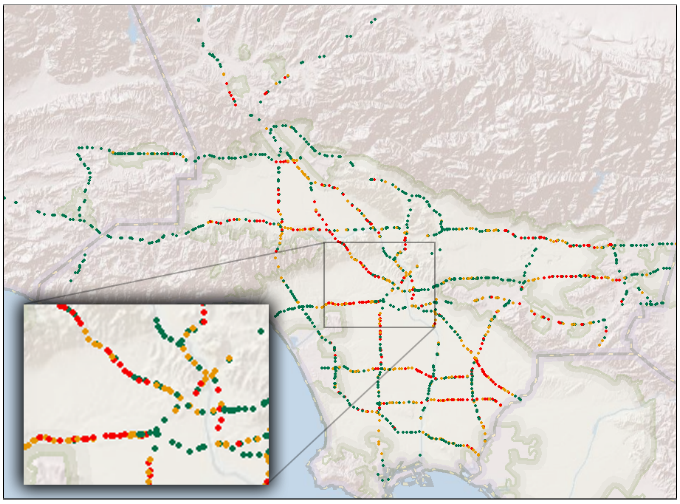


Figure 2: The ILD data for this thesis is comprised of 4,236 individual sensors for mainline highways around the Los Angeles area.

2.3 ATIS, ITS, and System Performance

The performance of a transportation network is a consequence of its users, the decisions they make, and the ability for the network to supply service equal to its demand (Golledge, 2002). These decisions can be influenced by the use of ATIS and ITS (Mahmassani & Jayakrishnan, 1991; Al-Deek & Khattak, 1998; Golledge, 2002; Chorus et al., 2007). These systems collect information about current traffic conditions via the sensors, which are then used to determine travel speeds and the amount of congestion within a particular segment of the roadway. The derived information may then be provided to drivers. How and if ATIS and ITS are used by drivers depends on the particular driver and the availability of the information system, and will ultimately affect network efficiency (Golledge, 2002).

A transportation network is said to be most efficient when the flow of its users is at an equilibrium (Mahmassani & Jayakrishnan, 1991; Mahmassani & Chang, 1987). This occurs when drivers enter and exit a particular transportation corridor independently. Due to an accident, adverse weather, or numerous other reasons, congestion can arise when many drivers attempt to make the same travel decisions. The choice to remain on course or to seek an alternate route can also be influenced by information provided by an in-vehicle display using ATIS (Parkes et al., 1991; Al-Deek & Khattak, 1998; Golledge, 2002).

In their evaluation of the system-wide affect of ATIS, Al-Deek & Khattak (1998) found that ATIS-equipped drivers made better decisions and fewer late route diversions, which increased network efficiency. Although ATIS is beneficial to the individual and to the network, the benefits are dependent on the market saturation of the device, and are highest when saturation exists but is low (Al-Deek & Khattak, 1998). Once ATIS-equipped drivers make up approximately fifty percent of the users of the network, diminishing returns are introduced and system performance suffers (Mahmassani & Jayakrishnan, 1991). The resultant equilibrium and efficiency then exist only when drivers make decisions that are independent from one another, and this is best achieved when ATIS and ITS are provided and used intelligently.

2.4 Network Data Collection and Reliability

Many different metrics for measuring and reporting travel time have been developed. One such measurement is the *Travel Time Index* (TTI), used by Schrank and Lomax (2009). This index produces a ratio of peak-period to free-flow travel time, resulting in an intuitive scale that ranges from 1 (no difference between peak-period and free-flow) to any greater number (for example, a TTI of 1.75 means there is a 75% increase in travel time). In addition to its ease of use, TTI can be aggregated to produce citywide averages, allowing for cities to be compared or ranked based on their average travel times. This can be used to identify areas with particularly high travel times (such as Los Angeles, Santa Ana, and Long Beach, TTI = 1.49), and reveal transportation systems which could benefit most from improvement (Schrank & Lomax, 2009). As demonstrated by a number of studies from the previous decade, this improvement can be in the form of ATIS- and ITS-based in-vehicle displays (Mahmassani & Jayakrishnan, 1991; Al-Deek & Khattak, 1998; Golledge, 2002; Clarmunt et al., 2000). At present, these displays are likely to take the form of a traffic map.

Other methods for improving the efficiency of transportation networks have been proposed. These methods are not based on enhanced information distribution (ATIS, ITS, etc). Instead, they rely on economic principles or direct manipulation of the network to achieve the desired results. In an evaluation of these alternative methods, Rosenbloom (1978) proposed shorter work weeks, a decentralized workplace, and artificially increased fuel and toll prices. Note that under these practices only the demand for the system is reduced; its supply potential remains unchanged. For this reason, it cannot be said that such practices are an improvement *to* the system. Further opposition to these claims is provided by Schrank & Lomax (2009), who state quite simply that "higher fuel prices are not the answer." Their reasons for such a response are that: (1) modest fuel prices do not suffice; increases would have to be incredibly high and happen over a short period of time, (2) the new prices would have to remain in effect and not be reduced cyclically, as they currently are, and (3) even under ideal circumstances, this approach does not address the bulk of the congestion problem (Schrank & Lomax, 2009). Without superior alternatives, the goal of increasing the efficiency of transportation networks must therefore be focused on ATIS- and ITS-like systems. In addition to the effectiveness these systems, a web-based survey performed by Chorus et al. (2007) indicated that there is a high demand for time-based information to be provided to drivers, a need that intuitively-designed traffic maps could satisfy.

2.5 Spatial Knowledge Construction

Whether they are aware of it or not, humans are constantly acquiring spatial information from their environment, which manifests itself in the brain as a cognitive map. Gollege & Garling (2004) insist that these mental representations are often based on landmarks that are encountered during routine commutes, past experiences, and the spatial relationships that are noted by the traveler. This information then serves as the spatial construct for an internal counterpart of the real world that is unique to each traveler. Once created, cognitive maps are continuously updated as new information is acquired, and many decisions rely on this information. This process of enhancement and revision allows for different levels of knowledge to exist. Leiser & Zilbershatz (1989) argue that there are four such levels. Level one is reached when the traveler recognizes basic landmarks and uses them as a framework for constructing their spatial understanding. Level two represents the ability to determine direction based on intersections (a form of landmark). Upon reaching the third level, travelers are able to memorize sequences of rules, which are derived from the previous level. At the fourth and final level, the “survey level,” the traveler has created a network-like assemblage that associates bearing changes with landmarks (Leiser & Zilbershatz, 1989). Due to the utility this knowledge has when making travel decisions, it is likely that anything that enhances or impedes the creation or understanding of cognitive maps will influence travel behavior (Gollege & Garling, 2004).

The internal creation, recall, and use of spatial information also varies among individuals. In their research on how well various in-vehicle navigation systems can be perceived, Fujii et al. (2009) noted that males were able to recall routes with greater accuracy than females, and that the ability to interpret and transcribe mapped information decreased with age. Likewise, both the frequency with which one operated a vehicle and confidence in reading maps were associated with a greater understanding of the information being displayed by the in-vehicle device.

Without knowing the severity or duration of a traffic event, drivers’ spatial knowledge is incomplete. Successfully delivering traffic information to drivers through more intelligently designed maps could largely alleviate this problem. Drivers with access to additional information about their environment can make more informed decisions than those without such access. This difference is likely to positively influence driver behavior which, at the micro scale, grants drivers an opportunity to avoid congestion by selecting a less congested route. At a more macro level, a system of well-informed drivers making good decisions can expect improvements in performance that reduce the frequency or severity of congestion. When considering the number of drivers and the ubiquity of traffic, the benefits become difficult to overstate.

2.6 Classed vs Unclassed Data

How and if maps are classified is a subject of debate, and depends upon the circumstances of their use. In 1971, Jenks & Caspall presented a paper critical of choropleth maps with several classes, and claimed that the difficulty of interpreting the map increased with the number of classes it contained. Waldo Tobler, on the other hand, contended that as forms of visual information, maps should be treated much like pictures or remotely sensed imagery. Under this treatment, unclassed data will provide a greater and more transitional range of values, thereby remaining most honest to the data being mapped (Tobler, 1973). Still, concern remained about map readers' inability to interpret the large amounts of data encoded in unclassed maps.

Indeed Jenks & Caspall were correct that such a difficulty exists. This is reported in a study by Brewer & Pickle (2002), who asked users to compare several different classification methods and assessed the readers' ability to interpret maps based on these methods. It was determined that a quantile classification was superior to the others, which were based on hybrid equal area intervals, box-plots, standard deviations, natural breaks (Jenks' method), minimum-boundary-errors, and the shared area method. The authors found the results somewhat surprising, since the quantile method is one of the simplest known. The need to enhance the clarity of cartographic design is also made clear by Arthur Robinson in *The Look of Maps* (1952). As was done in the research by Fujii et al. (2009), the individual assessment of particular map features can reveal the elements which perform poorly, iteratively converging towards a superior map design.

2.7 Human Vision and Image Properties

A map's design cannot be critiqued, within the context of cognition, without a solid understanding of how maps are interpreted by human beings, and how that interpretation is based on past experiences. Some believe that these experiences come early, that map interpretation is a basic task, and even that children are well-prepared to make inferences from maps. Liben & Downs (1989) dispute this claim, arguing that map interpretation is a learned skill that is dependent on spatial knowledge construction that is procedurally enhanced over time. In their study that examined research from several different fields in which maps were evaluated, Liben & Downs found that maps are not so obviously seen as conceptualizations of the real world. Rather, maps represent a collection of symbols that we individually link to referents, a process that is only successful when paired with a spatial understanding of the relationship between those referents in the real world.

The idea that humans interpret visual stimuli as collections of individual components is mirrored in Irving Biederman's research on human image understanding. He found that objects in color photographs were identified more quickly than simpler line drawings, though error rates were higher with the photographs (Biederman, 1987). This finding suggests that the difficulty of interpreting an image increases with the number of objects contained within that image, meaning that each object or component is demanding its own, separate, interpretation — a concept which has been applied to computerized visual search routines (Ullman, 1984; Itti & Koch, 2000; Rodriguez-Sanchez et al., 2007). The conclusion drawn by Biederman was shared by Daniel L. Schwartz (1995), who also found that subjects identified realistic images with higher error than a more abstract counterpart. In questions about reasoning and problem solving, Schwartz also found that humans assess situations differently when viewing stimuli that closely resemble their referents compared to when the stimuli are of schematic form. In other words, the logic used by subjects to determine relationships between real objects is not the same as that used to make inferences about abstract ones. This is an important realization for cartographers, as it suggests that we cannot expect map readers to solve problems on a map in the same way they would in real space. Moreover, disparities may exist between map readers' spatial knowledge and their ability to interpret maps.

Other research has been conducted on the visual properties of objects in a visual display, and how these properties affect recognition and interpretation. Such properties include brightness, color or chromaticity, shape, salience, and figure-ground relationships. The latter of these properties is the focus of the research by Kienker & Sejnowski (1986) that attempted to model human figure recognition using various parameters, including how the figure was drawn (outlines vs several techniques for a solid figure) and where attention was allocated. Their results indicate that the visual discrimination between figure and ground is dependent upon the entire composition of the image, and which component receives attention. Results like these, when paired with previously-mentioned studies, suggest that humans seek to identify features of an image separately, with accuracy favoring abstractions of those features. Therefore the successful interpretation of an image, or map, rests on the readers' ability to rapidly and accurately distinguish figure from ground.

Common examples of figure-ground discrepancies can be found in numerous optical illusions, images that trick us into seeing something that defies our expectations, or cause us to see different shapes that swap back and forth without notice. A classic example is the 'vase-face' image, in which a white vase is made visible by the silhouettes of two adjacent faces. The ease and reliability with which these illusions occur demonstrates a shortcoming in the human visual system that games and picture books have made a household familiarity. Despite how many of these books have classified these visual tricks as 'magical,' science has shown that they are not beyond understanding.

In research involving the famous 'vase-face' image and many like it, Lindauer & Lindauer (1970) asked university students to identify which component (e.g., the faces or the vase) was the figure, and which was the ground. Overwhelmingly, the students identified the darker of the shapes to be the figure — a response that increased as the brightness difference between the shapes increased. When reduced to simple outlines with no difference in brightness, students almost always saw a face. While easily tricked by clever images, humans do show an adeptness at quickly identifying abstract or schematic forms, as also noted in the research previously mentioned.

This is an encouraging fact because maps, as abstractions of the real world, are almost always more schematic than realistic. Traffic maps in particular present many opportunities to take advantage of difference in figure-ground relationships, since both the transportation network and its various segments must be readily identified. This can be done implicitly through the network's schematic nature, or explicitly through carefully chosen differences in brightness.

Even in the presence of color brightness plays a significant role. Stark differences in hue are negated by similarities in brightness, a property that presents challenges to cartographers and map readers alike. In *Semiotics of Visual Language* (Saint-Martin, 1990), the author argues:

> "A more luminous color recedes in depth, and colors of the same luminosity regroup in perception. The contrast between two colored regions depends more on their different luminosities than on their chromatic diversity: a red figure on a green ground becomes indistinct, if the two regions have an equal luminous intensity. The luminous quality then dissolves their boundaries" (pg 37).

The properties of luminance and hue are made even more important in the context of red-green colorblindness, which appears in scientific literature dating back to the 19^{th} century. Although we have expanded our knowledge since, that at least 4% of men are affected by colorblindness has been known for over 130 years (Jeffries, 1880). Modern research extends the estimates of the prevalence of red-green colorblindness, stating that it may affect up to 7-10% of males; the estimates for females are difficult to make due to the rareness of the condition in women (Murray, 1943). Nonetheless, segments of red and green with similar luminosities and shared boundaries are a hallmark of the typical traffic map design.

2.8 Attention, Mental Workload, and Driver Performance

Within cognitive psychology, there is a great deal of research on attention and vision. Unlike studies that focus on *how* figures in a scene are interpreted, attention-based research gives particular emphasis to the concept of attending to several visual stimuli in parallel. More precisely, the goal of many studies within this field is to categorize sources of stimuli based on their influence to the users' capacity to perceive them, as well as quantifying that capacity and how it affects other tasks (**?**).

The capacity to perceive visual stimuli, especially from multiple sources, varies as some stimuli require more effort than others (Horrey et al., 2009). This effort is sometimes referred to as *cognitive investment* or *mental workload*, and is experienced whenever a mentally-engaging task is performed. Scientific literature is replete with studies on the mental workload required to use maps or mobile devices, and how their use affects driver performance.

During previous decades, the use of paper maps by drivers was not uncommon. This method of acquiring route information was compared to an in-vehicle electronic LCD display by Parkes et al. (1991). In their research, the LCD-based text display was found to be superior to paper maps by requiring fewer glances from the driver, and a lower duration of time spent per glance. This suggests that the information presented on the LCD could be interpreted faster, and therefore required a lower mental workload to process effectively.

Claiming that it is the mind, not the hands and feet that control a vehicle, Ishigami

& Klein (2009) assert that paying attention to one task necessitates withdrawing from another. This has been demonstrated in several studies in the past, and has been shown to adversely affect the performance and safety of the driver. In 1991, Walker et al. noted that an estimated 12% of drivers would leave their lane when placing a call on a cellular phone. Similarly, the visual demands of an in-vehicle navigation device can overload the user and jeopardize safety. During the same study, it was reported that the use of highly complex visual devices resulted in more missed gauge changes, longer reaction times, and increased the time necessary to complete a route.

The severity of mental workload and its negative effects on driver performance also varies among users, and appears to decrease with experience. In a study that evaluated peripheral task detection — that is, noticing one event while attending to another — Patten et al. (2006) found that the performance of newer, low-mileage drivers was particularly affected by a secondary task. The difference in reaction times between the groups was on average 250 milliseconds. Requiring a quarter of a second more to respond while driving is not trivial; such a time allows for a vehicle at highway speed to travel an additional 25 feet before the driver acknowledges the event.

Within the same year as Patten et al.'s research, Horberry et al. (2006) also performed an experiment aimed at driving distraction and concurrent tasks. In this study, participants operated a driving simulator while exposed to one of two concurrent tasks, which included manipulating the in-vehicle radio and using a hands-free phone. While in the simulator, the participants encountered both simple and complex road environments, and their performance was recorded alongside other factors such as age. Although age did play a role in the speed at which drivers navigated the complex route, a reduction in performance associated with the additional stimuli was consistent across all age groups. The authors note that while both forms of stimuli significantly affected performance, it was the operation of the in-vehicle radio that was most detrimental, further supporting the body of evidence that the requirement to look at something is a cognitively demanding task.

Also during 2006, Wittmann et al. performed an experiment to uncover the relationship between the position of an in-vehicle display and its effect on driver performance. By positioning a lighted display in one of seven different locations inside the vehicle, and varying the distance between the driver and the display, the authors discovered two major findings. First, the position of the display has a strong relationship with reaction times while driving. Moreover, vertical displacement of the display showed a greater influence on driver performance than a horizontal configuration. Secondly, the cognitive influence of a device increases in proportion to its distance from the driver. When the display was located at great distances, causing the driver to spend additional time without a view of the simulated road, performance decreased precipitously (Wittmann et al., 2006). These findings suggest that a less imposing device will require less visual dedication from its user, allowing for more focus to be allocated to driving or other tasks.

Despite having comparatively lower mental demands, audio-based navigational systems also degrade driver performance, and have even been referred to as “annoying” by test subjects (Srinivasan, 1997). This is largely due to the discrete nature of audio-based navigational cues, which occur only at certain points in time that may not coincide with the users’ desire to be informed. Srinivasan noted that in addition to audio messages being related to increased reaction times while driving, the participants in the study also expressed wishes to shut the devices off. Others have attempted to pair audio and visual stimuli in an attempt to maximize the benefits of both, but ultimately found the combination to be detrimental to user performance. In a study on a paired audio-visual stimuli and users’ ability to pair these signals with events, Liu et al. (2009) found that the audio and visual signals did not additively enhance the pairings as expected. Rather, the signals competed and interfered with one another.

In a more recent study on navigational maps on mobile devices, Fujii et al. (2009) evaluated the behavioral patterns that were exhibited while participants interpreted a map while concurrently performing other tasks, such as answering questions and pointing out locations. During this time, participants were navigating a route on a personal computer, to approximate the experience of a more sophisticated simulator. Over the course of the experiment, map design conditions were varied in their degree of complexity. Not surprisingly, difficulty in the interpretation of the maps increased with their visual complexity. In addition to a degradation in subjects' ability to navigate the route, the authors also found that subjects referred to the display on average 4 to 6 times per minute, with a duration of up to 4 seconds per glance. The same data in other terms implies that drivers spend between 4 and 24 seconds per minute with their eyes not on the road — enough time to travel over 300 ft, or over 20 car lengths, entirely unaware of the upcoming route.

Yet even more worrying, drivers seem to be unable to detect increases in the cognitive demands imposed by these devices. In a comprehensive study on the effects of mental workload on driver performance, Horrey et al. (2009) tested participants' ability to perform mental tasks, before and during driving. The mental tasks included a guessing game and an arithmetic problem. While performing a single task, participants reported that the guessing game required more mental effort than the arithmetic problem. However, in a dual-task situation where participants experienced either the guessing game or the arithmetic problem while driving, they reported no difference in the mental demands between them. Although they were said to be equally engaging, the guessing game was associated with a significantly greater decrease in driver performance.

While driving simulators present a wealth of opportunity to study the cognitive influence of concurrent tasks, they also reveal exciting ways in which mental workload can be measured. An example exists in Just et al. (2008)'s use of functional Magnetic Resonance Imaging (fMRI) to measure the activity in participants' brains as they performed a driving task along with a listening task. Without the requirement to listen and answer questions (a single-task condition), subjects completed a driving route with high success. Those in the dual-task condition showed a marked decrease in driving performance, as well as a 37% reduction in parietal lobe activity. The latter finding has profound implications for cartographers: the parietal lobe is responsible for spatial processing.

The effects of secondary tasks, especially those involving the use of mobile devices, can be seen outside of the simulator as well. Acknowledging the growth of mobile technology, Drews et al. (2009) proposed that cellular phones and navigation devices provide "additional sources of distraction...readily available and widely used by drivers," a statement later supported by their research. In their analysis of automobile accidents, it was found that almost a quarter of the drivers had used their mobile phone within the ten minutes prior to the crash. Further, no difference between the use of a hands-free phone and a hand-held phone were found; both types of phones, as well as the manipulation of radio and navigational devices by the drivers, were associated with slower reaction times, more frequent deviations in lane position, and more time without a forward view of the road (Drews et al., 2009). Decreased reaction times witnessed under the supervision of a scientist must be taken seriously when these lapses in performance can manifest as real-world injury, or worse.

Links between concurrent tasks and increased mental workload are so well established that in addition to exploring the connections, emerging studies are focusing on methods to detect mental distraction as it occurs. By pairing a driving experiment with a support vector machine (SVM), which is a method for pattern recognition that can be tuned towards a desired sensitivity over time, it was found that detecting cognitive distraction is not only feasible, but shows a success rate up to 85% (Kutila et al., 2007). In their research, Kutila et al. imposed cognitively-engaging tasks, such as arithmetic problems, on drivers completing a 45-minute course. Using the amount of time the driver held their lane and the number of eye and head movements made, the SVM adaptively acquired the ability to recognize when the driver became distracted. It is worthwhile to note that the calculation of arithmetic problems — a key requirement to estimating travel time with current traffic maps — lead to a high enough loss in performance that the SVM could be triggered.

Once distraction is detected, it then becomes a matter of how to handle or acknowledge it. One idea proposed is vehicle automation. If the task of driving, in whole or part, is relegated to the vehicle then it might be expected that driver focus can shift elsewhere, thereby reducing the stress or mental workload experienced. To test this theory, Funke et al. subjected college-aged drivers to various stress-inducing conditions within a driving simulator. One group of students randomly lost control of the test vehicle due to simulated wind or black ice, whereas the second did not encounter such hazards even though they were told to expect them. Additionally, both groups experienced various driving conditions, which included a partially-automated vehicle (participants did not have to control velocity). On the whole, participants in the automated condition noticed pedestrians and responded to external stimuli frequently and with higher performance. However, workload indices calculated indicated that cognitive demand was not reduced (Funke et al., 2007). Rather than reducing the amount of mental workload experienced, it appears that the automation of a vehicle causes the driver to simply reallocate attention to other tasks or procedures. While this finding might mean that the reallocated attention could be safely diverted to map-reading, vehicle automation is not yet commonplace. In the contexts of reducing mental workload and cartography, this leaves the creation of intuitive maps to be a more immediate endeavor.

Increasingly sophisticated methods for detecting distraction exist as well. Recall the research that employed fMRI data to quantify workload in drivers, performed by Just et al. (2008). In conjunction with determining an amount of workload, thresholds may be set to allow devices measuring changes in the body to suggest when distraction is occurring. The types of measurements are not limited to fMRI. Electrocardiograms (EKG) may be used to measure elevated heart rates, and basic electrical activity of the brain can be recored through electroencephalogram (EEG) devices, which may also report overall alertness (Brookhuis & de Waard, 2010). This research demonstrates the great strides that have been made in the study of mental workload, as well as the rising pace with which technology is advancing science in this area. But Brookhuis & de Waard temper their arguments with a discussion on ethics, which currently prevent these kinds of studies outside of the simulator, especially those involving altered states of mind — e.g., driving under the influence of alcohol. Their work not only furthers the validity of simulated driving exercises, it reminds us that the use of simulators is often necessary.

2.9 Summary

There are several studies linking increases in mental workload while reading a map to decreases in performance in secondary tasks, like driving. Additionally, the mental workload associated with map interpretation was found to increase as designs become more complex. Further, simulators provide excellent opportunities to evaluate mental workload and its effects. Like all other forms of information delivery, great care must be taken when choosing what information will be provided and how it will be presented. Together, these concepts suggest that the safest and most efficient map design will be one based on simplicity. This may be achieved through a symbol based approach, the carefully selected inclusion of secondary street information at an appropriate brightness, and expertise in proper data classification and presentation.

Chapter 3

METHODS

3.1 Overview and Goals

The methodology of this thesis is designed to evaluate conventional traffic map design and potential improvements. This is done through comparisons made between two new traffic map designs and those that are currently in use. Because the new traffic map designs were derived from a critique of the existing approaches, it is necessary to provide an overview of that critique. Additionally, the use of Geographic Information Systems (GIS) and the techniques used to achieve the desired map designs will be discussed, as such designs have not yet been employed by other cartographers. Lastly, the methods used to create and perform the experiment that investigated the hypotheses introduced in Chapter 1 will be discussed in detail. The goals of this thesis are:

1. To identify key limitations in conventional traffic map designs.
2. To develop prototype design strategies to reduce the limitations.
3. To test the performance of the prototype traffic map designs against the existing standard in terms of travel time estimation.

3.2 An Evaluation of Conventional Traffic Maps

There are a number of commercial and government services providing traffic maps, each of which employs its own design, but all are variations on a common approach. Some of these services are illustrated in Figure 2. The main design choice common to these and nearly all other current traffic maps is the use of red, yellow, and green segments along the transportation network. It is no accident that these hue choices mirror those used in stoplights. In addition to being one of three colors, the lengths of the segments vary depending on the underlying velocity data, which is derived from the Inductance Loop Detectors (ILDs) embedded in the roadways.

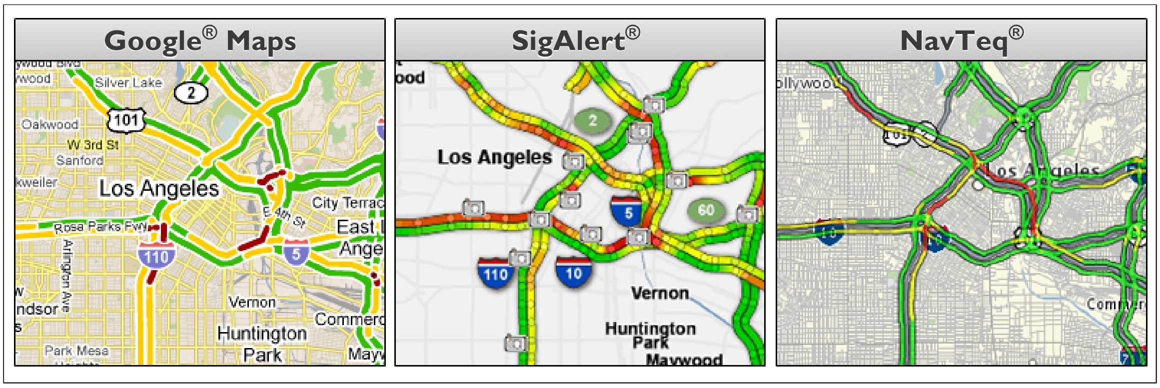


Figure 3: Current traffic map designs from three popular vendors (captured at different times). Each employs colored segments of variable length and velocity from which the user must estimate the desired information. The arrangement of the detectors is faintly preserved in the Sig-Alert map.

The task of travel time estimation requires that the user first make two estimations: distance and velocity. Once this is done, the user must then perform the arithmetic function $t = \frac{d}{v}$. Error may be introduced at any or all of these stages (see Figure 3). In the case of the current traffic map designs, this process of estimation and arithmetic must be done for every segment, as each has its own velocity category and a map length. This presents an enormous opportunity for error propagation, which grows in proportion to the number of segments to be estimated.

Due to the ambiguous segmentation used in current traffic map designs and their requirement for the user to estimate both velocity and distance, two new approaches to traffic map design are proposed. Both approaches discard ambiguous network segmentation in favor of a fixed segmentation based on units familiar to the map-reader. The first approach attempts to remedy the problem of distance estimation by dividing the transportation network into segments at fixed distance intervals. This will be referred

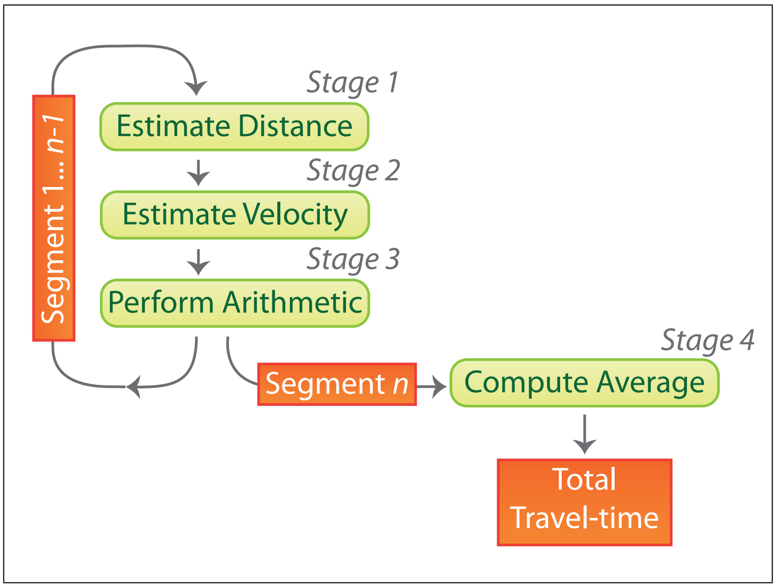


Figure 4: Estimating travel time with current traffic map designs. Error can be introduced at any stage. Stages 1-3 have additional opportunities for error equal to the number of segments in the route.

to as the *fixed-interval* design. By fixing the segment length to a known unit of distance, the map-reader need only count the segments to determine the total distance of the route. In this way, the burden of distance estimation could be greatly reduced.

The second approach, which will be referred to as the *fixed-minute* design, divides the transportation network into segments with a length equal to an amount of travel time, which is unique to the current traffic conditions. This approach inoculates the map-reader from estimation entirely. In the fixed-minute design, the travel time of a route is equal to the number of segments in that route. No arithmetic or estimation is required.

As the two approaches being proposed are new, the methods for their creation will follow.

3.3 Data Acquisition and Creation of the Equal-interval Design

All traffic data was acquired via File Transfer Protocol (FTP) from the Performance Measurement System (PeMS), provided by the California Department of Transportation. Within PeMS, the state of California is divided into twelve districts. Due to its notoriety in terms of severe traffic conditions, the Los Angeles area (District 7) was selected to provide adequate coverage of differing levels of congestion. The data provided by PeMS included: 1) A sensor configuration file (Extensible Markup Language, or XML format), detailing the position, direction, and name for all ILDs in the state, and 2) traffic data for the subset of sensors within District 7 (Comma-separated Values, or CSV format), which comprise 4,923 sensors in total.

The sensor configuration file is state-wide while the traffic data are specific to an individual district. For this reason, the appropriate sensors must be identified and selected from the configuration file. This was done using regular expressions (regex) for basic string-matching. The results of the matching were then reformatted to the CSV format and joined with the traffic data. The resultant file was then loaded into ESRI ArcMap where it was saved as an ESRI shapefile.

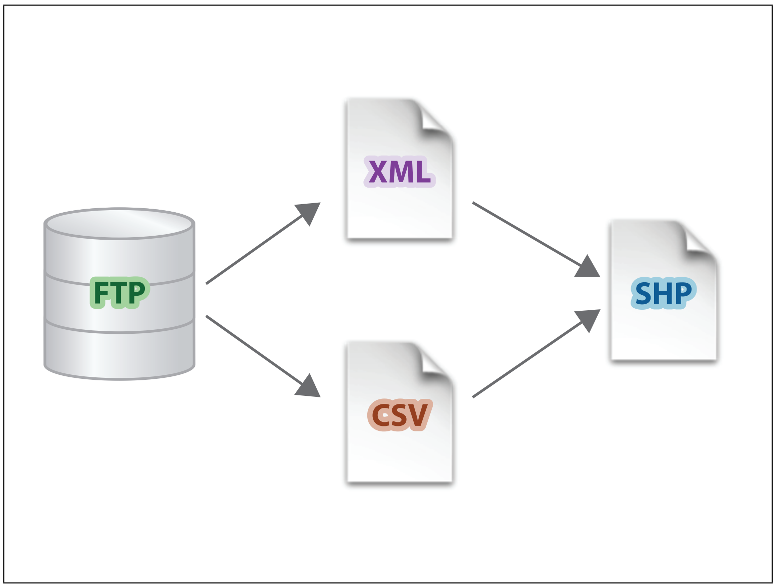


Figure 5: The traffic and sensor configuration data are joined to create an ESRI shapefile, which makes the display and calculation of the data readily available to many GIS operations.

Data for the transportation network was acquired from the National Atlas of the United States from 2009. Once loaded into the GIS, the expressways and highways were separated from the other roads, as the PeMS does not supply information for smaller arterial streets. Together, these data representing the highways and expressways will be referred to as *roadways* in the remainder of this thesis. Next, each roadway was duplicated so that there were appropriate eastbound-westbound and northbound-southbound pairs. The northbound and eastbound roadways were visually shifted +3 display units in ArcMap to enable the map-reader to distinguish two lanes at a scale equal to Google Maps zoom level 9 (approximately 1:1,155,581). Finally, each roadway was split into 5-mile segments, as illustrated in 6. This was done for both directions, using the end opposite of the direction of travel as the starting point for the split operation (e.g., the east-most end was the starting point for all westbound highways).

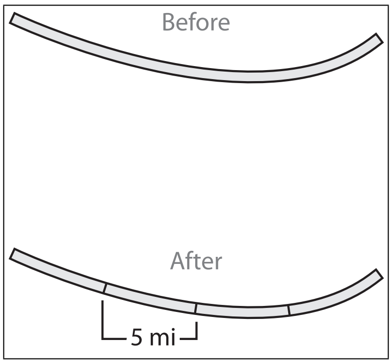


Figure 6: Each roadway is split into 5-mile segments, for both of its directions.

The shapefile containing the velocity data for each sensor was then overlaid, and sensors for eastbound and northbound roadways were also shifted +3 map units. All sensors within a 5-mile segment were then given an ID that matched the segment, allowing for the aggregation of their values to be applied to the segment. Each segment then contained as its value the average velocity recorded by all sensors within that segment. The segments were then classified according to the classification scheme used by Google's traffic maps, seen in Table 1. To maintain further consistency with Google's design, the same hues and basemap were also used. The result is provided in Figure 7.

Hue	Red	Yellow	Green
Velocity	0 - 24 mph	25 - 49 mph	≥ 50 mph

Table 1: The classification scheme employed by Google's Traffic Maps.

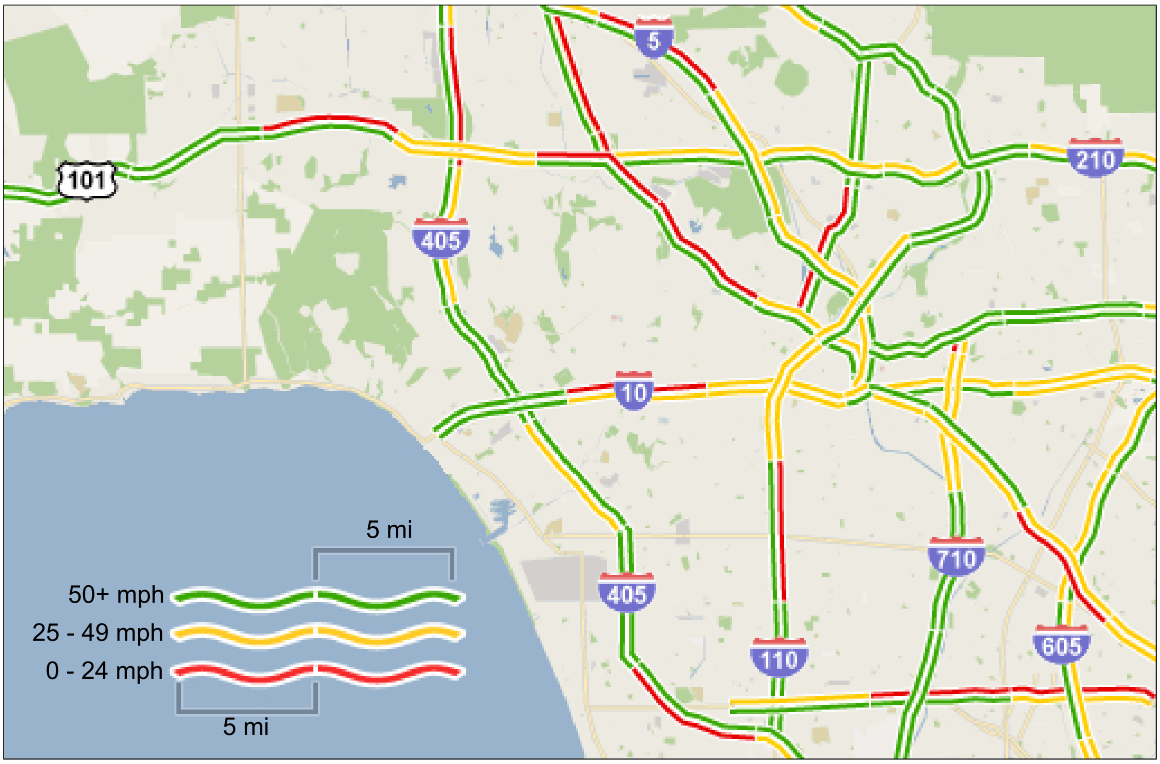


Figure 7: The final equal-interval map, adherent to the classification, hues, and base map used by Google.

3.4 Creation of the Fixed-minute Design

The fixed-minute design utilized the same roadways and sensor data as the equal-interval map. The difference in the design is entirely due to the cartographic procedure used. As with the previous map, the two datasets were overlaid and the necessary shifting of the northbound and eastbound data took place.

Before the roadways could be represented with segments at 1-minute intervals, they were first prepared by being split into a large number of segments exactly 52.8 feet ($\frac{1}{100}$ mile) in length, seen in Figure 8. In this way, the roadways do not have to be re-segmented for each new set of data; only those segments which represent 1-minute of travel need to be identified and made apparent to the user. The specific length of 52.8 feet has two advantages. First, it is mathematically and computationally convenient, given the velocity data are in miles per hour. Second, such a small length results in sub-pixel precision on a modern digital display. The map-reader, and indeed the display device, would not be able to visually distinguish two adjacent segments. This enables segments to be selected and symbolized at every perceivable location along a route.

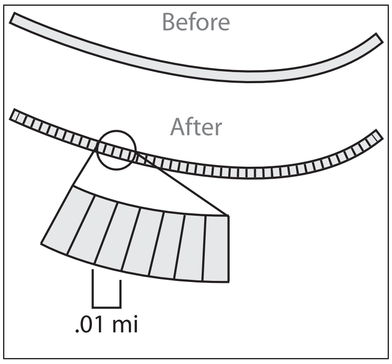


Figure 8: Each roadway is split into segments with length equal to 52.8 ft, for both directions.

A surface of velocity values was created by isolating a single roadway and direction and performing inverse-distance weighted interpolation (IDW) to generate a surface of travel time for every location along the route, with a cell size also equal to 52.8 feet. The sensors are already influenced by other distant sensors in a complex way on the actual transportation network. For this reason, the interpolation was performed using the standard formula:

$$w(x, y) = \sum_{i=1}^{N} \lambda_i w_i$$

where λ_i was calculated with $p = 4$ such that:

$$\lambda_i = \frac{\left(\frac{1}{d_i}\right)^4}{\sum_{k=1}^{N} \left(\frac{1}{d_k}\right)^4}$$

This was done in order to reduce further influence of one sensor on another within the IDW operation. Once created, map algebra was performed on the surface to convert the cell values into the time required to travel through that cell, given the velocity contained therein. Calculating this value, and adjusting the time from hours to seconds, was done in the following way:

$$t_{seconds} = \frac{d}{v} = \frac{\frac{1}{100}}{\frac{cell\ value}{3600}}$$

The travel time surface was then spatially joined with the segmented roadway. Each of the numerous 52.8 ft segments then contained as its value the number of seconds needed by a vehicle to travel through the segment. The final step involved identifying those segments where a sequential cumulative sum of 60 seconds was reached, resetting the sum to zero each time this was true.

In this way, each identified segment becomes an isochrone line representing 1 minute of travel time. A Python script was created to perform this function. It operates on a

CSV file containing segment ID's and time field (`SegID` and `TimeSec`, respectively). The script is included in Appendix A.

Alternatively, this functionality can be added directly within ArcMap provided that a new field is added to the roadway shapefile. Then, assuming a field name of `ticMark`, the script in 5.4 can be modified to simply change the new field's value to 1. The symbology can then be applied on a conditional basis (e.g., where `ticMark == 1`).

Finally, the fixed-minute map is styled according to Google's hue and base map. Additionally, every fifth 1-minute segment of each roadway was made bold to enable easier counting over long routes. The final map is depicted in Figure 9.

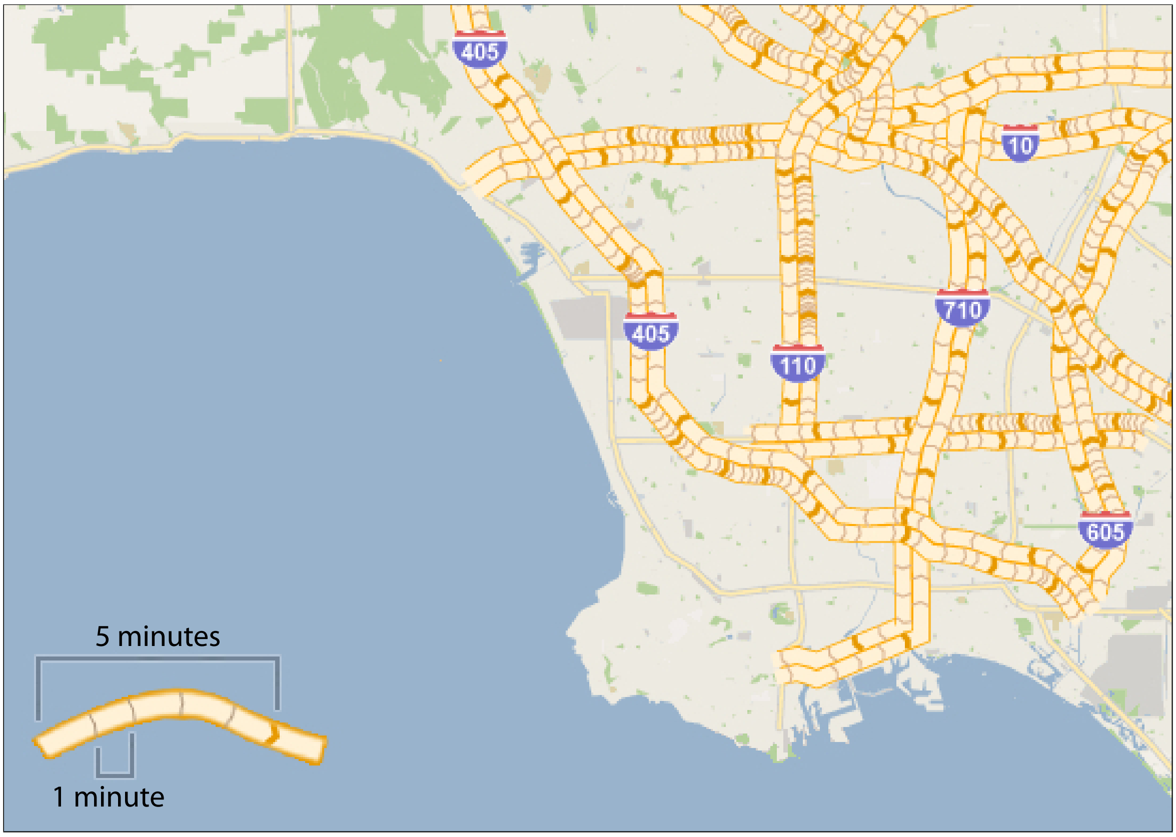


Figure 9: The final fixed-minute map after applying a color scheme and base map that matched Google's design.

3.5 Experimental Design

University students were solicited to participate in a computer-based experiment as a means to evaluate the newly created prototypes and compare them to the conventional traffic map. A total of 49 students volunteered to answer 60 questions as well as pre- and post-test questionnaires. The main questions were categorized into six different question types (Table 2).

Category	**# Questions**
Travel Time Arithmetic	10
Distance Estimation (Control)	10
Distance Estimation (Equal-interval Experimental Segmentation)	10
Travel time Estimation (Control)	10
Travel time Estimation (Equal-interval Experimental Segmentation)	10
Travel time Estimation (Fixed-minute Experimental Segmentation)	10

Table 2: Participants were asked a total of 60 questions, 10 from each category.

The order of questions and categories was randomized into four distinct sequences, and each sequence had an equal probability of being selected by any participant. Upon answering a question the participants were asked if they were confident in their answer, with 'yes' or 'no' as the options to choose from. For all main questions, the time taken to respond, or time-to-completion, was also recorded. Suggested by Walker et al. (1991), response time can serve as a proxy for mental workload.

Prior to seeing the questions from the categories in Table 2, the subjects were asked for basic background information, which included age, gender, and whether or not the participant had a valid driver's license. Upon completion of the 60 questions, a post-test questionnaire was given. The post-test asked if participants had used traffic maps in the past, if they believe they'll use traffic maps in the future, which traffic map design was preferred, and why that design was preferred. Additionally a space for general comments was provided so that participants could give their feedback on any aspect of the experiment.

Questions that included maps and predefined routes utilized graphical pins to designate the starting and ending position for the route. Pin placement varied to indicate ten possible routes for each of the five map-based question types. The routes also varied in their length and composition of traffic conditions (if present), and none of the routes required changing roadways more than once (e.g., if a route began on I-405 East a single road change would allow the route to end on I-710 North. The route could not then continue to a third roadway to end on I-105 West). Limiting the number of road changes to zero or one prevents the introduction of an additional variable for analysis, as the difficulty in estimating travel time or distance is very likely to increase with a high number of road changes for any map design. In this way, only the cartographic representation of the network segmentation varies across map designs, keeping the focus on the intended variables.

When each map first appeared to a participant, the route to be considered is highlighted brightly and the base map is given a darkened monochrome appearance for 1 second. After that time the highlight fades smoothly and the base map is given normal coloration over a period of 500 milliseconds (Figure 10). At this point the map remains unchanging, the timer begins, and the participant is free to answer the question using all the time he or she requires. The maps in all of the map-based categories cover the same extent and scale (Google zoom level = 9). Likewise, interactivity was disabled so the maps could not be panned or zoomed further. Only the information provided by the map at its present level of detail was available to each participant.

All of the maps featured a transportation network in the state of California. This reduces the possibility for participants at a Michigan university to be familiar with the study area. Additionally, all city labels and points of interest were removed from the maps so that participants could not aid their responses with any previous knowledge about those locations and the distances or travel times between them.

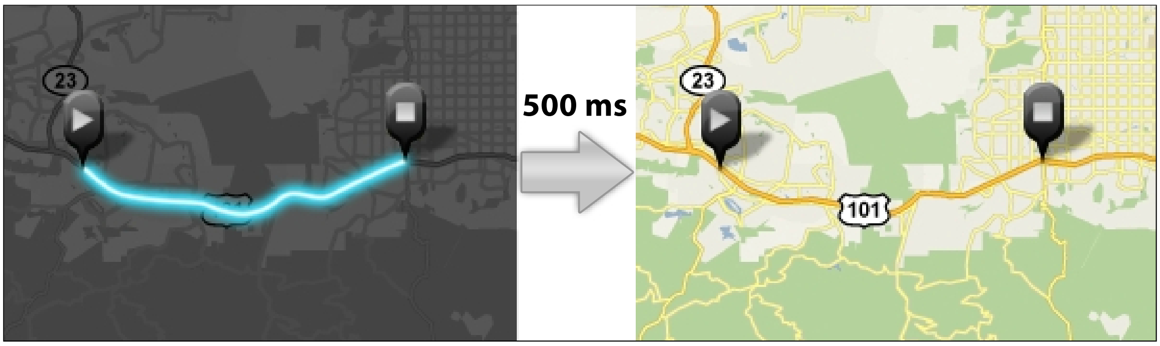


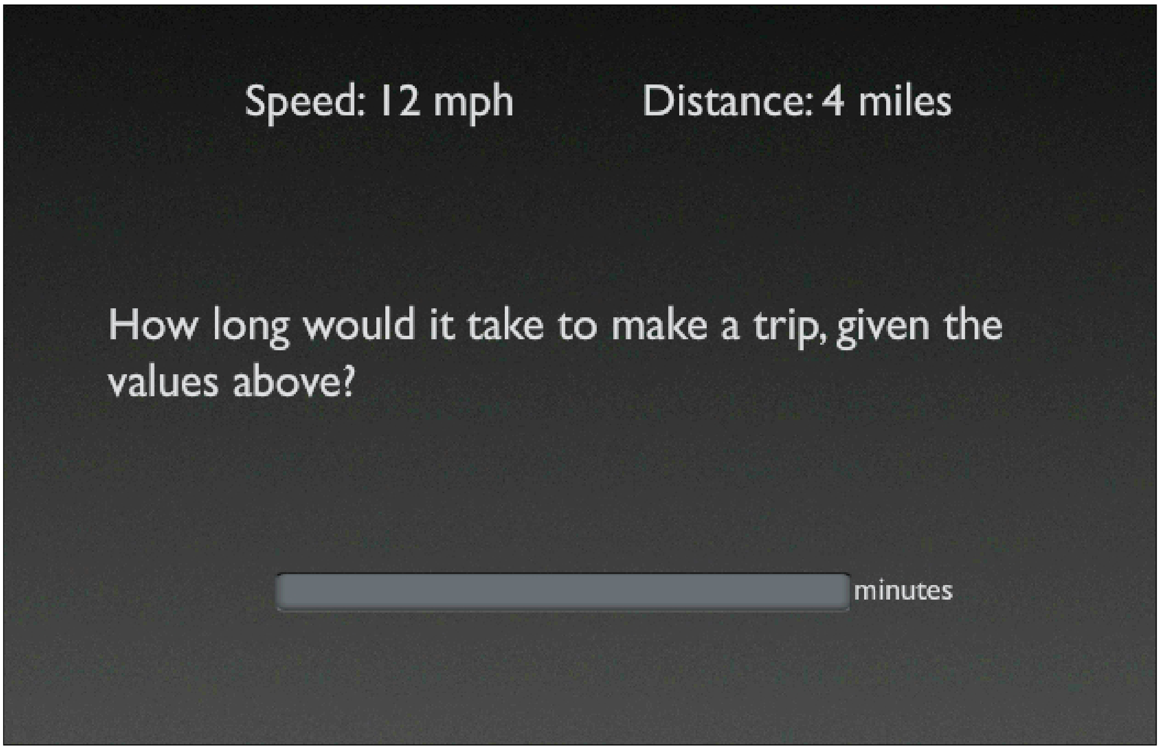
Figure 10: Before and after the route fade effect. It is particularly useful when a route includes a destination that might be reached in multiple ways.

3.5.1 Travel time Arithmetic Questions

The travel time arithmetic questions were designed to assess participants' ability to perform the proper mathematical computation of travel time. Questions from this section of the test provided participants with a velocity and a distance, and asked them to determine how many minutes the trip would take (Figure 11).

The difficulty of the arithmetic questions varied from easy to moderate, and covered a range of distances and velocities that one might encounter in a real-life setting (i.e., no provided velocity exceeded the maximum California speed limit, and no distance was disproportionately short or long).

Questions of this type were added in order to evaluate the source of error in travel time estimations. High accuracy in travel time calculations when provided a distance and velocity paired with poor performance in a map-based setting would suggest that map interpretation is the source of the error. Conversely, poor arithmetic performance but high success in distance estimation would imply that error in travel time estimations



Speed: 12 mph Distance: 4 miles

How long would it take to make a trip, given the values above?

Figure 11: A typical question from the travel time Arithmetic category.

is due to the inability to perform arithmetic. Identifying the source of error is a key element in determining which designs perform well, but also *why* certain designs might perform as well as they do.

3.5.2 Map-based Distance Estimation

In order to evaluate participants' performance with distance estimation, a control had to be established for a baseline comparison. The control used in these map-based questions was an unaltered map of the Los Angeles area provided by Google. The purpose of this question type was to assess the ability of participants to estimate distances along an irregular and curving route using a map based on a conventional scalebar.

The distance questions provide the participant with a full map view, as would typically be seen from Google maps. Answers were recorded in miles.

To address the role of a fixed segmentation scheme, an experimental map design was created. This design is identical to the Google map, with the exception that the roadways are split into 5-mile segments. The scale bar for the alternative distance map is reflective of this change, and emphasizes the non-euclidean nature of the transportation network, which can be seen in Figure 12.

Responses to questions from this category will allow a direct comparison to the previously mentioned maps that have not undergone a equal-interval segmentation treatment. Such a comparison will determine if a segmentation scheme based on fixed, familiar units improves distance estimation. In conjunction with the arithmetic questions, the information acquired helps narrow the source of travel time estimation error to a particular stage in the estimation process (recall Figure 4). Success with arithmetic and failure to correctly estimate distance from a map without a fixed segmentation scheme would indicate an inadequacy in distance estimation that is detrimental to overall accuracy.

Beyond measures of accuracy, recording the time to respond also enables detailed revelations. Perhaps non-fixed and fixed segmentation schemes have similar accuracies, but one design type is associated with significantly faster response times. This would suggest a more intuitive design that can be interpreted with greater ease, even if the end result is the same; the implication then is that the intuitive design imposes lower cognitive demands and therefore makes a better choice for in-vehicle use.

3.5.3 Travel time Estimation

Following arithmetic and distance estimation, the next category of questions exposed participants to actual traffic maps. In this category, there were three design conditions: the control, a traffic map based on equal-interval segmentation, and a map based on fixed-minute segmentation. The control map used in this set of questions was taken directly from Google Maps (Figure 13), the de facto standard and most popular online mapping service.

The text paired with the travel time estimation maps read: "Using the route that was

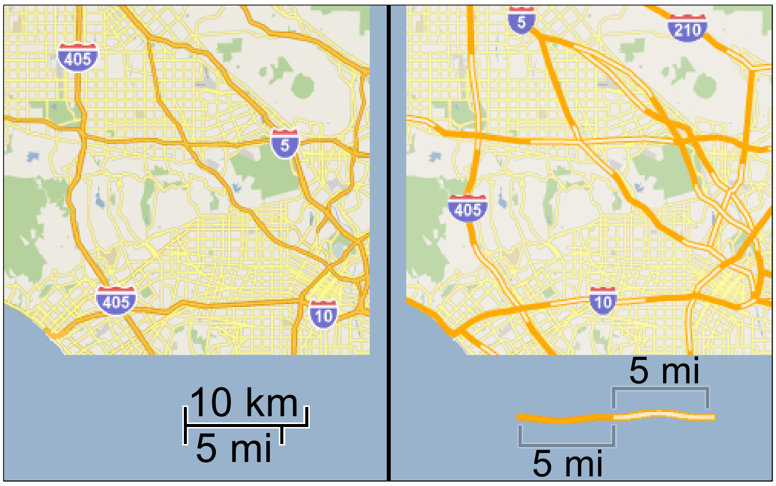


Figure 12: The control and segmented map designs. The experimental map on the right has been enhanced by the inclusion of segments at 5-mile increments.

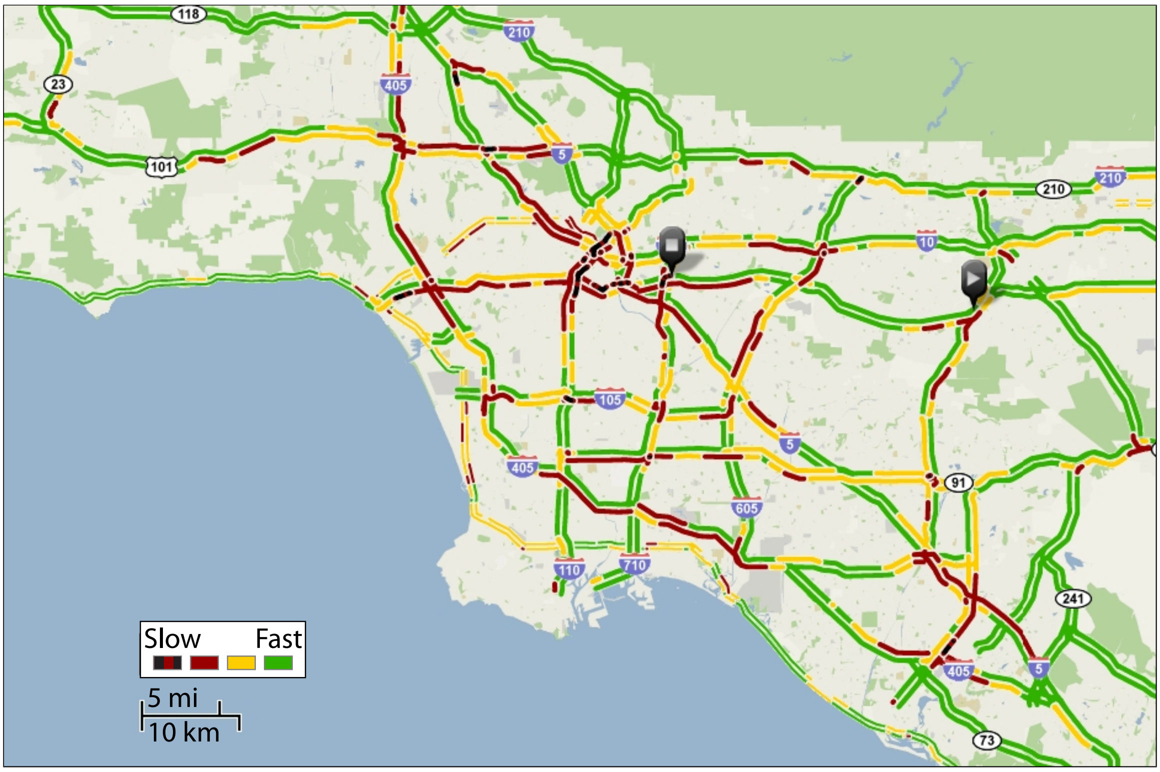


Figure 13: The control traffic map, with pins indicating one of ten routes shown to participants.

highlighted, what is the travel time between the pins?" Participants were instructed to enter their responses using minutes as the units.

Experimental Design 1: Equal-interval Segmentation: Previous research on map design and human vision suggests simpler designs outperform complex designs in their ability to be interpreted (Walker et al., 1991; Parkes et al., 1991; Fujii et al., 2009). One attempt to simplify traffic map design involved fixing segment lengths to a standard and familiar distance. A length of 5 miles was chosen for the segments, congruent with the experimental condition in the distance estimation questions (recall Figure 7).

Experimental Design 2: Fixed-minute Segmentation: A further degree of simplification is present in the third traffic map design condition — the fixed-minute design (recall Figure 9). This experimental design uses time rather than distance as the basis for segment length. Such a design is free from user error introduced in distance estimation and arithmetic. By delivering the information in the same units as required by the task for which the map is intended, the potential for error should be significantly reduced.

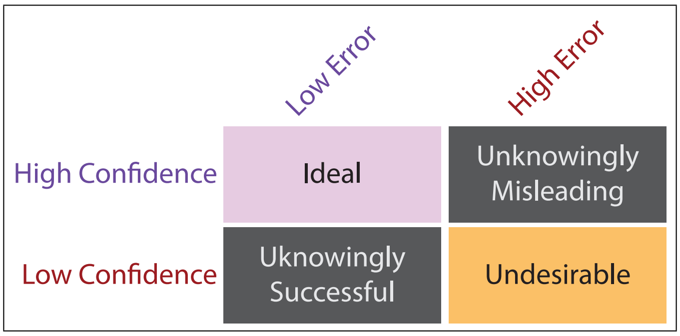
These three design conditions sequentially reduce the number and complexity of the tasks the map-reader must perform to acquire the intended information.

3.5.4 User Confidence

Not only does confidence reveal a participant's expected outcome in their individual success with a question or map design, it also allows for the discovery of relationships between confidence and error that might otherwise go unnoticed. These relationships can be particularly telling in terms of user interfaces and human behavior. Confidence and error can be paired in four basic ways (Figure 14).

For example, if users are continually confident but also consistently wrong in their answers, that might suggest that a map design is untrustworthy. It may be imbuing more confidence than it is worthy of and misleading its users. This would be a troublesome scenario outside of an experiment and in a real setting, as map readers are most often not informed when they've made an error; there is no researcher to turn to for questions, no screen showing the correct answer, nor any indication that they've made a mistake. Yet the confidence invoked by the map would instill a feeling of satisfaction in the user, who would likely continue using the map oblivious to their own error.

The opposite situation is just as worrying. In this case, the map-reader would be accurately making conclusions while simultaneously having no confidence in those conclusions. Without a prompt that indicated a correct response, the user would be unaware of their own success. Despite their correctness, the map-reader wouldn't feel confident and would therefore be likely to abandon the use of such a design or prefer others in its place. Ideally, confidence and success would always be matched.



	Low Error	High Error
High Confidence	Ideal	Unknowingly Misleading
Low Confidence	Uknowingly Successful	Undesirable

Figure 14: User confidence and map error can reveal interesting properties about design and map characteristics.

3.6 Expected Results

Due to the relationship between complexity and map interpretation, it is expected that sequential improvements will be noticed in both accuracy and time-to completion as the map designs become more simplified. The ambiguity previously identified in the control traffic map is likely to significantly impair both distance and travel time estimations.

3.6.1 Arithmetic Ability

Although the formula for converting distances and velocities into times is not complicated when written or explained, it is challenging to perform mentally. This is especially true when the values are not whole numbers. It is expected that participants will have high rates of error in their calculations. Without a basis for comparison, no assumptions are made about the time to complete the arithmetic questions. However, it is predicted that the response times will be sufficiently long to suggest that such problems are not trivial or readily solvable with ease. Low to moderate levels of confidence are expected, further suggesting that mental arithmetic is difficult and users are aware of their inability to perform it well.

3.6.2 Equal-interval Segmentation and Distance Estimation Expectations

It is assumed that map readers will have great difficulty in applying a linear scale bar present in traditional maps to non-linear transportation networks. For this reason, it is expected that accuracy in distance estimations will be greatly improved with the equal-interval design.

Similarly, the time taken to respond to questions based on the equal-interval segmentation is expected to be much shorter than the times associated with the control condition, while participants' confidence is likely to be higher with the equal-interval design than the control. Two reasons for these predictions exist. First, the equal-interval segmentation embeds the scale bar directly into the transportation network. This takes much of the guesswork out of the estimations and reduces the task to a counting procedure. While users will still have to estimate the distances where the end of a route does not coincide with the end of a segment, these short distances are unlikely to affect accuracy as much as an unsegmented design that requires this kind of guesswork the entire route. Users will be able to determine, for example, that approximately half a segment is about $2\,\frac{1}{2}$ miles and that a quarter of a segment is a little more than a mile.

Secondly, by embedding the scale bar, users do not have to continuously refer to a legend to reassure themselves of the scale in use. The map and the legend are one, reducing both the number of eye glances away from the focus of the map and the time spent not looking at that focus. Together, the shorter time required and the increased potential for accuracy are likely to encourage higher confidence in distance estimations with the equal-interval map design.

3.6.3 Travel time Estimation and Segmentation Schemes

Since accurate distance measurements are a prerequisite to travel time estimations, the difficulty with using a linear scale bar to estimate distances along an irregular route are expected to be problematic in the control traffic map design. Inaccuracies in distance estimations paired with the inability to perform arithmetic are expected to combine and severely affect travel time estimations. The ambiguous velocities in the control legend are also expected to exacerbate this problem, diminishing travel time estimation accuracy even further. Due to the need to refer to a legend that is entirely separate from transportation network, and the combined challenge of assuming correct velocities and performing the proper arithmetic, it is also expected that the control condition will be associated with the highest response times.

The equal-interval segmentation scheme is predicted to show an improvement in travel time estimation. Reasoning for this prediction is based on the previous expectations that a equal-interval design will lead to distance estimations that are more accurate. Improved distance measurements, even when paired with an unchanged arithmetic ability, should yield more accurate travel times. With fewer opportunities for error to propagate (one less task is required per segment), it is expected that the equal-interval design will improve travel time estimation accuracy significantly. Although response times are likely to decrease, the task of travel time estimation is still very similar between the control and equal-interval designs. For this reason, response times are expected to be shorter with the equal-interval segmentation, but not substantially so.

The fixed-minute segmentation scheme is expected to be associated with the least amount of error in travel time estimations. By reducing the need for users to estimate distance or perform any arithmetic, the only task required of them is counting segments. Since counting is arguably easier than arithmetic, and there is no need to estimate distance, error is predicted to markedly low with this approach. Likewise, time-to-completion is also expected to be significantly reduced with the fixed-minute design. The less complicated nature of the task will likely allow users to determine travel times very accurately. This reduced mental engagement and time involved to interpret the fixed-minute map is also expected to increase user confidence well above that found in the other design approaches.

3.6.4 Map Preference

The final measure of map performance in this experiment is how much users prefer using a particular map design. Expectations for the other measures of map performance (accuracy and time-to-completion) favor the fixed-minute design, and it is predicted that this will also be apparent in user preference. A map that is easier to use, requires less time to interpret, and continuously rewards the user by reaffirming their correct responses (i.e., elicits higher confidence) is indicative of a more positive user experience. With the prediction that the previous expectations are met, the fixed-minute design is likely to be strongly preferred by users.

3.7 Participants

A total of forty-nine students at Michigan State University volunteered for this study. Subjects volunteered for this research by signing up during classes in which the study was announced and briefly introduced. During the introduction, explanations of the research were deliberately vague so that potential volunteers were aware that a study was taking place without knowing what criteria or variables were going to be evaluated. The gender composition among the subject pool was approximately equal, with twenty-seven male participants and twenty-two female. The ages of the participants ranged from 18 to 33 (mode: 20). All participants indicated that they had a driver's license valid in the United States. Each subject received $10 as compensation for participating in the study, which required approximately 20 to 30 minutes of time to complete.

Note that the subject pool is composed of adults with at least some university education (for reference, only about a quarter of adults in the U.S. have a bachelor's degree). This may introduce bias and produce results that indicate performance that is slightly higher than what could be expected from the general public. In some cases, this could prove beneficial; if university students cannot perform a certain task well it is unreasonable to expect those with less education to do as well or better. Certain map interpretation exercises that prove to be problematic for the subjects in this study may be even more problematic to others.

3.8 Materials

3.8.1 Hardware

Sixteen Dell Precision 690 computers equipped with Dell 1907 FPt displays were used for the study. The computers were configured with Microsoft Windows XP (Microsoft, Inc., 2001) and had identical settings, including 1280 x 1024 screen resolution and a refresh rate of 60 Hertz.

3.8.2 Software

The study was designed in *Adobe Flash CS4* (Adobe Systems, Inc., 2008) using the ActionScript 3 programming language. Animation for the fade effect was created with the *Tweener* library, version 1.33.74 (MIT License). The study was accessed externally through the Mozilla Firefox web browser (Mozilla Corporation, 2010), which ran in full-screen mode. Data from the study was recorded anonymously and delivered by a PHP script that arranged the data into a comma-separated values file.

3.9 Procedure

Participants completed the study in the computer lab of the Geography Building at Michigan State University (Room 201). The computer lab was reserved for six different one-hour time periods, from which volunteers chose the time they wished to participate. The number of participants taking the study at any one time ranged from three to twelve. The computers used were arranged at 90° angles so that participants were unlikely to disturb one another and could not see others' responses.

Once all participants arrived at their scheduled time, they were thanked for their participation and were free to choose a seat of their liking. Two consent forms (see Appendix A) indicating the researchers responsible for the study, the tasks involved, and participants' right to withdraw were handed out, as required by the Institutional Review Board (IRB). Participants were instructed to read the form carefully and then sign and return one copy, retaining the other for their records. While participants read and signed the consent forms, the door to the computer lab was posted with a sign requesting that others not knock or attempt to enter.

After each participant had returned a signed copy of the consent form, the format for the test was explained and instructions for entering responses and navigating the test were given. At this time, participants were free to begin the study, starting with the pre-test that acquired basic subject background information. This was followed by a brief on-screen tour of the test that familiarized participants with the test interface and the question formats they would encounter.

At the completion of the tour, users were notified that the actual test would start once they indicated that they were ready. Immediately after the participant chose to continue, the experimental test began. In order to complete the study, all 60 questions had to be acknowledged, which included the option to skip a question without providing a response, in compliance with IRB protocol (note: none of the forty-nine participants chose to skip a response). During the experimental test, participants could not use calculators, write anything down, or use any tools that might assist them in their responses.

Completion of the experimental test lead to a brief post-test, in which participants were asked about their experience and which map type they preferred. This allowed participants the opportunity to supply their opinion about the map designs presented to them, as well as their overall thoughts on the test itself. Once the post-test was completed, participants were presented with a 'submit' button. Upon clicking the button, their data were combined with existing responses and stored anonymously in a spreadsheet-style format.

When participants had completed the study, they were again thanked for their participation and given the $10.

Chapter 4

RESULTS AND ANALYSIS

Performance for each map design was evaluated in terms of accuracy and time-to-completion. Accuracy, or conversely error, was measured in two ways depending on the question type. For arithmetic questions it is unreasonable to expect perfect accuracy or an absolute absence of error. Therefore percent error was used, which provides the additional benefit of reducing error bias related to the magnitude of the values being estimated. Accuracy for the map-based questions, which include the distance and travel time estimation portions of the experiment, was measured in mean error. For comparison between map types, absolute mean error was used to prevent the effect of positive and negative errors canceling one another out, though the raw error was examined for directional bias.

The time-to-completion, or response time, for all questions was measured by the amount of time required for the user to submit a response after the question appeared.

Responses to the arithmetic questions were examined separately, while responses to the map-based questions were compared within the following groupings:

	Design Condition Compared		
Group 1: Distance	Control	Equal-interval (no velocity)	
Group 2: Travel Time	Control	Equal-interval	Fixed-minute

Table 3: Map designs were grouped and compared based on the estimation task they were associated with.

4.1 Arithmetic

Percent error was used to evaluate the accuracy of math questions. For the purpose of this study, a window of ±15% was used for hypothesis testing. This presents a reasonable threshold for error without being overly generous or unfairly conservative (for example, if the actual answer is 60 minutes, this threshold allows 'correct' responses to be within ± 9 minutes of that value).

The overall results of the arithmetic portion are summarized in Tables 4 and 5.

Absolute Percent Error				
n	**Min**	**Max**	**Median**	**$\bar{x}$**
490	0.00	316.70	4.17	16.47

Table 4: Magnitude of percent error across all arithmetic questions.

Percent Error				
n	**Min**	**Max**	**Median**	**$\bar{x}$**
490	-90.08	316.70	0.00	3.07

Table 5: Percent error from forty-nine participants responding to ten arithmetic questions.The mean is slightly positive, but not significantly so.

Overall, participants exhibited adequate arithmetic ability and did not perform poorly in converting distances and velocities into travel times. While the mean of absolute percent error was higher than the predetermined threshold of 15, this difference is not significant ($t = 1.01, df = 489, p = 0.31$).

The per-subject results show that nearly 3 out of 4 responses demonstrate adequate skill in calculating travel times (Figure 15). Out of 490 total responses to the arithmetic questions, 362 (74.08%) of them were within the pre-determined error window. Additionally, only 11 subjects had an average percent error that exceeded 15%; the remaining 38 subjects (77.55%) all had mean percent errors within ±15%.

These results were not expected and are contrary to the prediction made in *Hypothesis 1*. This suggests that map readers do not have innate difficulties with the mental

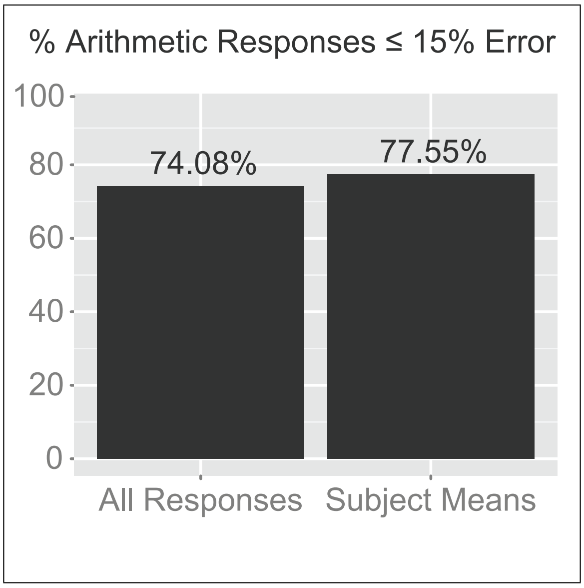


Figure 15: Nearly 75% of all responses to arithmetic were within the error window. The percentage of participants with individual means within ±15% of the correct value was also very high.

arithmetic involved in travel time estimation. It is therefore likely that the failure to adequately determine travel times from a traffic map derive from an inability to accurately interpret the map, which is a direct consequence of the map's design.

Additionally, a directional bias in travel time estimations was not revealed by the arithmetic test (refer to Table 5). Participants did not significantly over- or under-estimate travel times ($t = 1.88, df = 489, p = 0.06$). The number of subjects with positive mean percent errors was 28, which accounts for 57.14% of the subject pool. This is not significantly larger than half (t = 1, df = 48, p-value = 0.1612).

The participants' ability to perform arithmetic at a satisfactory level this frequently, and without a directional bias, suggests that travel time arithmetic is not a substantial burden to map readers. A caveat is that the subjects in this study were university students, many of which were likely to have had recent courses in mathematics and more familiarity with, if not only fresh exposure to, complex arithmetic.

Participant responses to the arithmetic portion of this study are also associated with high levels of confidence. Out of 490 possible individual responses, 427 of them were marked “confident.” Similarly, once shown the correct answer alongside the response given, the majority of participants also felt their responses were close to the actual values (Figure 16).

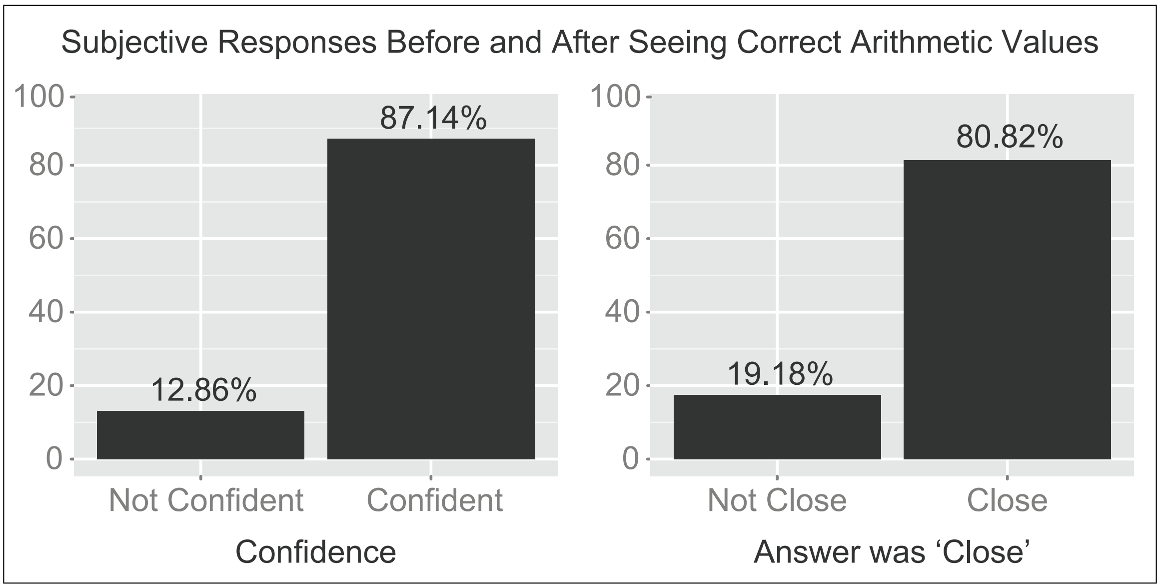


Figure 16: Participants were overall very confident with the arithmetic portion of the test (left), and later felt their responses were close to the actual values (right).

Not only did participants perform the arithmetic successfully based upon objective criteria, participants also felt confident when doing so. It can therefore be determined that the task of arithmetic for travel time estimation was not particularly difficult to the map readers in this experiment.

4.2 Distance Estimation

Following the arithmetic portion, participants responded to twenty questions asking them to estimate distances between two pins on a map. Ten of the questions were paired with a map without a segmented network while the others where paired with a map based on a fixed-minute segmentation scheme.

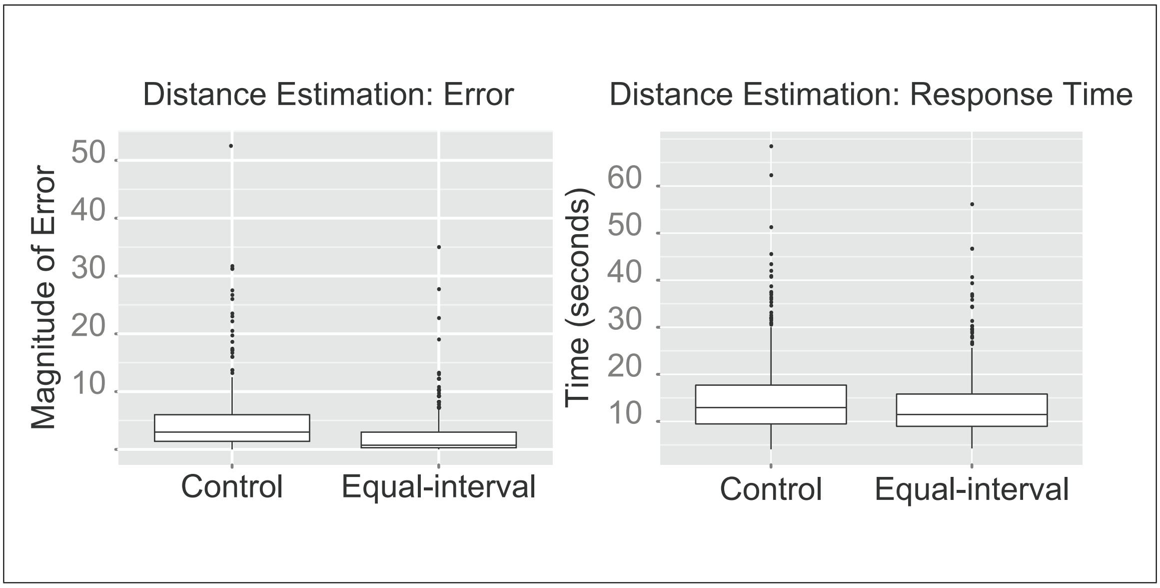


Figure 17: Overall, the equal-interval segmentation was associated with lower errors and lower response times.

The equal-interval segmentation scheme improved accuracy and response times (Figure 17). In both cases, these differences were statistically significant (Table 6). When evaluated based on the number of responses and subject means that were within ±15% of the correct value, the equal-interval segmentation was associated with great improvements over the control (Figure 18). When using the equal-interval map, almost all participants (48 out of 49, or 97.96%) had a mean percent error within the threshold considered correct. The improvement in distance estimation is also revealed in an increase in total correct responses, which account for 375 out of the total 490 (76.53%).The control stimuli produced a subject mean error below or equal to 15% for only 19 subjects (38.78%). In terms of total responses, 210 out of 490 (42.86%) were within the 15% threshold.

Further, the increased accuracy with the equal-interval design did not come at an additional cost to the user; such responses were made even faster than those using the non-segmented, conventional map design.

		Control	**Equal-interval**	**T-test**	
Error	$\bar{x}$	4.54	2.42	**t**	7.86
	median	3.00	0.73		
	min	0.00	0.10	**df**	489
	max	52.50	34.99	**p**	$< .001$
Response Time	$\bar{x}$	14.86	13.19	**t**	3.93
	median	12.94	11.47		
	min	4.07	4.25	**df**	489
	max	68.35	56.02	**p**	$< .001$

Table 6: A comparison of the results from the distance estimation portion of the experiment shows that the equal-interval segmentation scheme improves accuracy and response time.

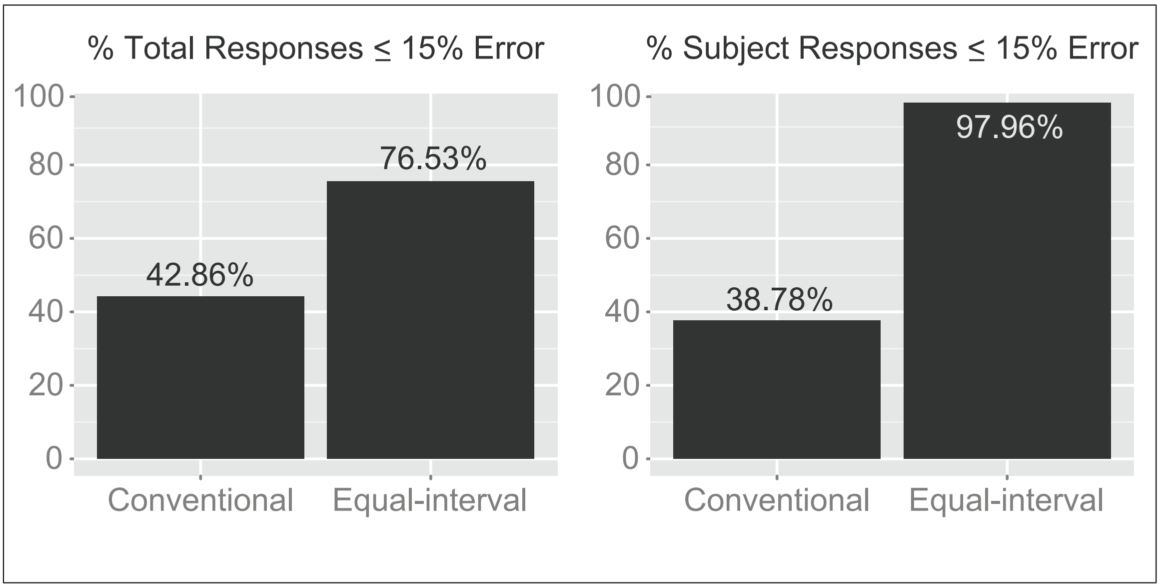


Figure 18: The equal-interval map was associated with great improvements in distance estimation.

Although confidence was moderately high with both map designs (Figures 19 and 20), the segmented design was associated with the highest amount of confident responses (79.80% vs 96.53%, respectively). This is particularly important as there were differences in the relationships between confidence and error between the map types as well. In the case of the control map, confident responses ($\bar{x}\ error = 3.75$) were more accurate than those marked not confident ($\bar{x}\ error = 7.66$). This difference is associated with a t-value of -4.467 ($p < .001$). Conversely, there was no difference in accuracy between confident and non-confident responses to the segmented map design ($\bar{x}\ error = 2.37$ vs $\bar{x}\ error = 3.85, t = -1.64, p = 0.12$). The control map elicited fewer confident responses, likely due to the lack of accuracy associated with the responses. This effect did not occur with the segmented design.

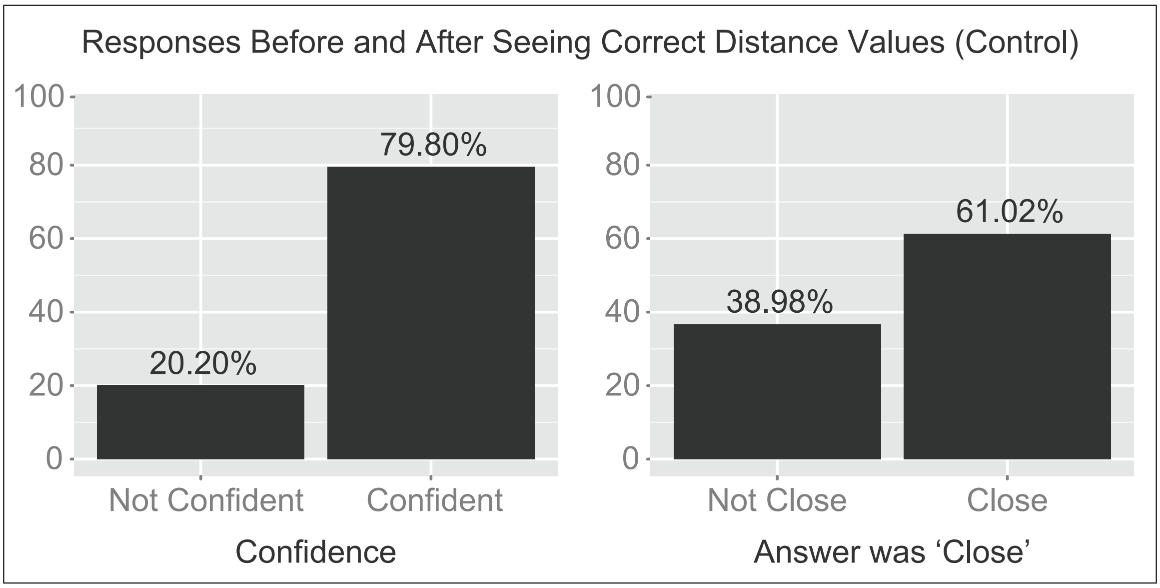


Figure 19: Almost 80% of responses were confident with the control (distance) map, though the percentage of responses indicating a close response was moderately low.

In addition to evoking responses that were almost always confident, the equal-interval segmentation seems to inoculate the user from any loss in accuracy associated with a

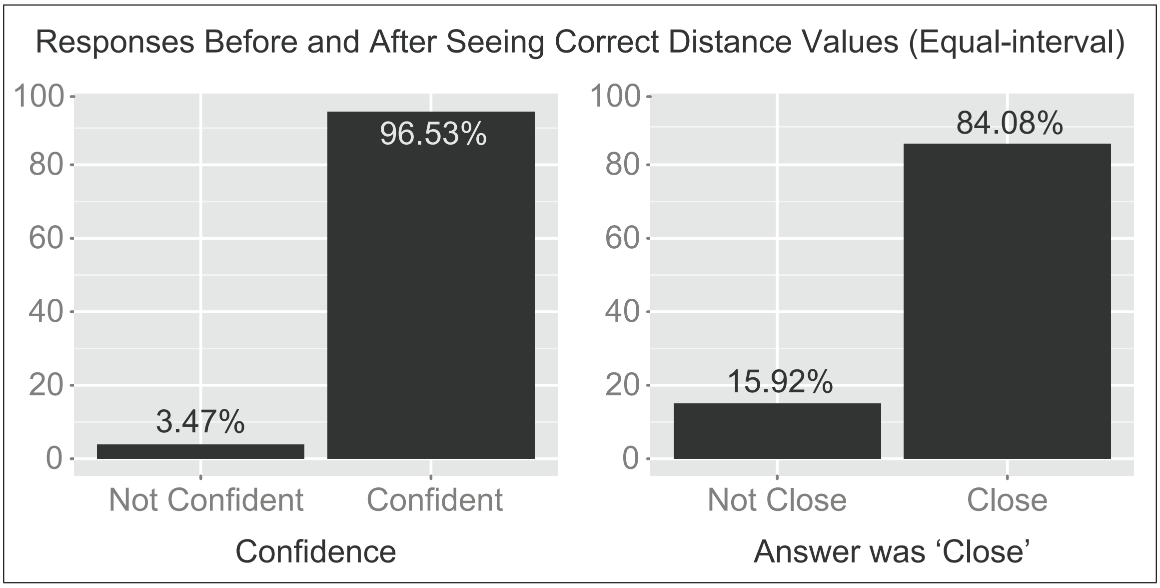


Figure 20: Confidence was dramatically higher with the segmented map, and the vast majority of participants felt their responses were close.

lack in confidence. In this way, the segmented design was both more rewarding and more forgiving.

Both design types were evaluated for directional bias. The control map was strongly associated with overstated distances, with 45 out of 49 responses overstating the correct value. The experimental map was not associated with such a bias and the number of negative and positive responses was approximately equal (25 vs 24, respectively).

4.3 Travel Time Estimation

Large differences were noted in travel time accuracy and response times across the traffic map design types (Figure 21). Participants estimated travel times with an average error of ± 19.77 minutes when using the Google traffic map. The equal-interval traffic map design improved accuracy significantly, reducing the average error to ± 13.57 minutes. The largest improvements were seen with the fixed-minute traffic map, which was associated with an average error of ± 5.52 minutes. These travel time errors were subjected to ANOVA, which indicates that the differences are significant (Table 7).

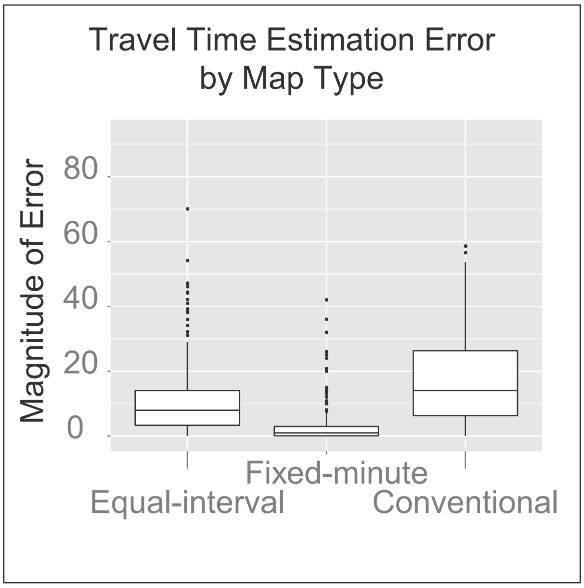


Figure 21: Fixed segmentation schemes greatly improve travel time estimations.

Out of the 490 possible responses to the travel time estimation questions for each map type, the conventional traffic map was associated with only 135 responses (27.55%) within the ±15% error window. The equal-interval map produced similar results, with 129 (26.33%) being within ±15%. The fixed-minute map produced 389 correct responses, accounting for 79.39% of the total.

ANOVA p-Matrix of Error

	Equal-interval	**Fixed-minute**
Fixed-minute	0.011	-
Google	0.044	< 0.001

Table 7: ANOVA reveals that each result is significantly different (alpha = 0.05) from the others.

Subject means reveal a similar trend. Roughly half of the subjects (26, or 53.06%) had total means within the error window when using the conventional traffic map. Similarly, only 25 (51.02%) subjects had total means at or below 15% with the equal-interval traffic map. The fixed-minute traffic map was again associated with the highest number of correct responses; 43 subjects (87.76% of them) had average means within the accepted window of error (Figure 22).

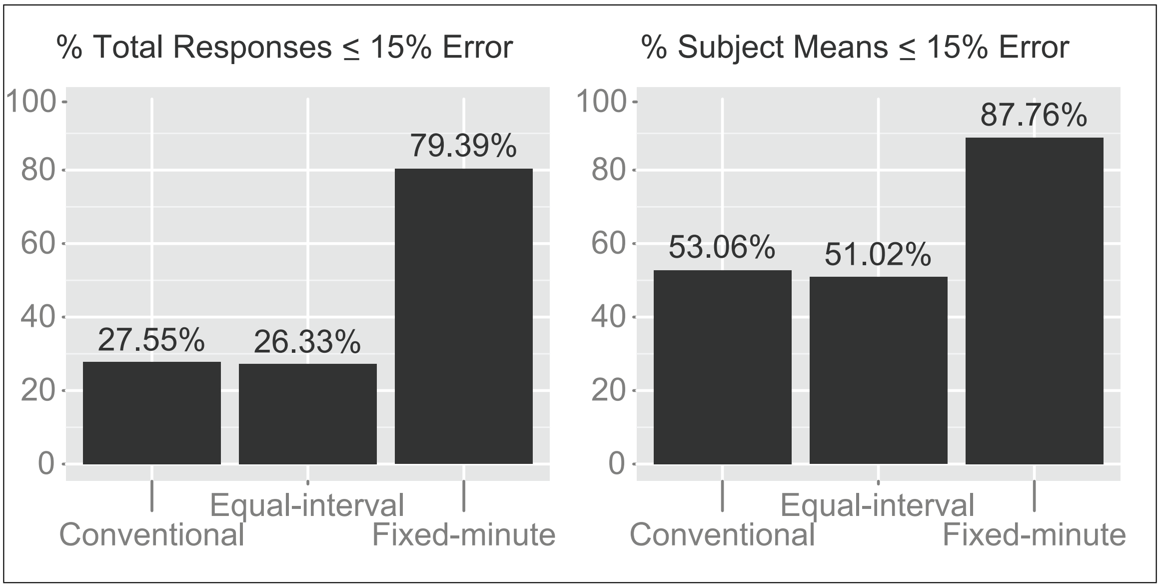


Figure 22: The fixed-minute design improved the number of correct responses substantially.

Errors were varied in their directions as well. Participants significantly underestimated travel times by an average of 11.77 minutes with the conventional traffic map ($t = -16.28, p < 0.001$). Only two participants consistently overestimated travel time with the conventional traffic map. Conversely, participants overestimated travel times by an average of just 1.49 minutes with the equal-interval design ($t = 2.30, p = 0.01$). This also occurred with the fixed-minute design, which was associated with an average overestimation of only 1.31 minutes ($t = 5.06, p < 0.001$).

Similarly, response times also varied across design types (Figure 23). The fixed-minute segmentation scheme was again associated with the best results (lowest response time, $\bar{x} = 18.64$ seconds). Likely due to the similarities in the interpretation tasks involved, the Google design and the equal-interval design share similar response times ($\bar{x} = 26.03$ seconds and $\bar{x} = 28.07$ seconds, respectively). Response times associated with the fixed-minute map were the only results to be significantly different from the others. ANOVA indicates that the slight increase in response times noted with the equal-interval map were not significantly different than those associated with the Google map (Table 8).

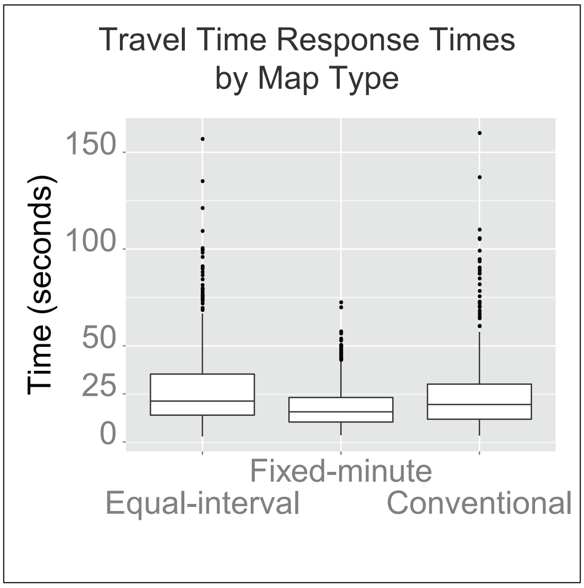


Figure 23: Response times were also lower with the fixed-minute design, while the Google and equal-interval designs were very similar in this regard.

ANOVA p-Matrix of Response Times

	Equal-interval	**Fixed-minute**
Fixed-minute	0.007	-
Google	0.536	0.307

Table 8: The differences in response times between the Google design and the equal-interval segmentation were not significantly different, though those associated with the fixed-minute segmentation were.

Relationships between confidence and map type were also noted. Out of all the individual responses to the Google map design, 40.82% of them were marked as confident.

The equal-interval map improved confidence be eliciting confident responses 56.69% of the time, and the fixed-minute map was associated with the highest amount of confident responses at 94.56% (Figure 24). Confident responses were not more accurate with the Google design ($t = 1.57, p = 0.12$), nor did confidence affect accuracy with the equal-interval design $t = 0.39, p = 0.70$) or the equal-interval design ($t = 1.87, p = 0.07$).

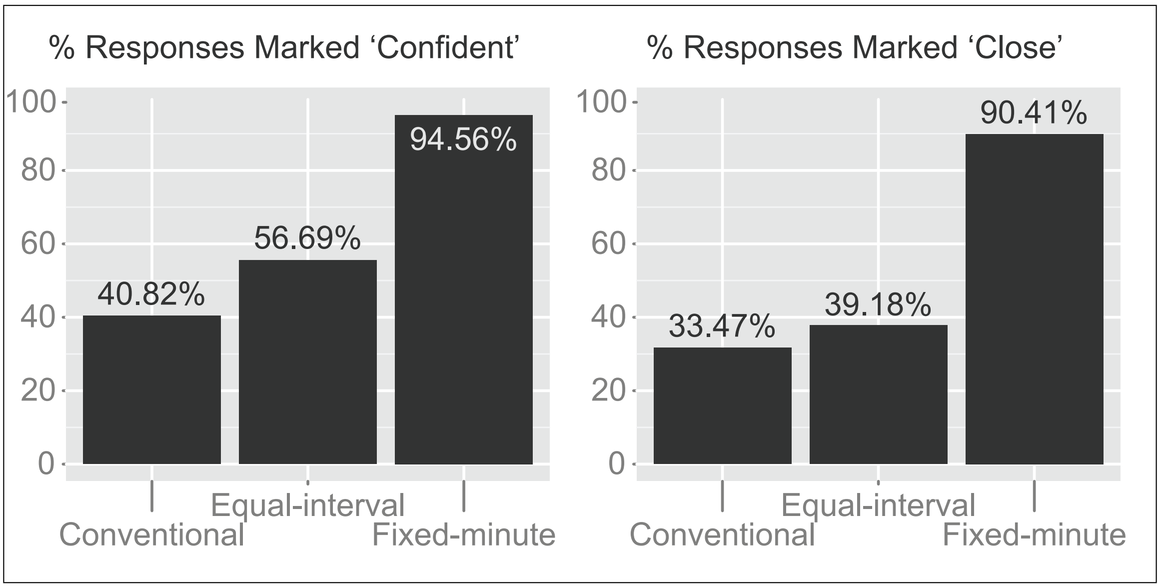


Figure 24: Confidence was improved by both segmented designs, though the fixed-minute design was associated with very high confidence. Similar associations were seen between the map designs and responses marked close.

4.4 Map Preference and Subjective Feedback

Participants overwhelmingly preferred the fixed-minute traffic map design, with 46 of 49 of them choosing it as the one they liked the most. Only three participants chose the equal-interval design, and none preferred Google's traffic map (Figure 25).

Out of the 49 participants, 33 (67.35%) responded that they had used a traffic map in the past, and 44 of them (89.80%) said that they expect to use traffic maps sometime

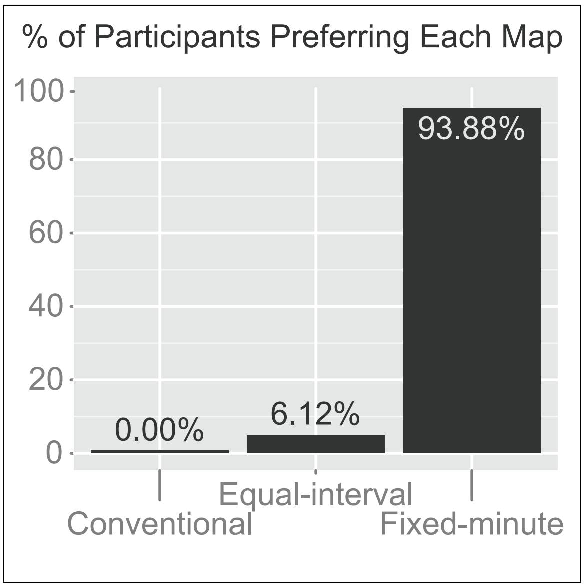


Figure 25: None of the participants chose the Google map as their favorite, while the vast majority preferred the design based on a fixed-minute segmentation.

in the future.

Feedback also came in the form of comments which cannot be quantified but do provide insight into user opinion. One participant commented:

> "It was really easy to tell how long it would take to get somewhere, right down to the minute, because you could count if you had to. I hated the [Google and equal-interval maps] because you really had to think, and do math in your head, which I did not enjoy.
>
> I felt the only maps that were helpful were the ones which did not involve speed at all."

Another participant shared similar thoughts regarding the fixed-minute map, " This map was easiest to tell how far away something was both in terms of distance and in time. The other maps were confusing."

Despite the popularity and the public availability of the Google traffic map, one user added, "I really hope they never start using the type of maps that had 3 different colors for slow, fast, etc. I'd never get anywhere on time." This sentiment was shared by another participant, who left the following:

> "I found that it took me a long time to figure out the maps with the different color indicators showing how long (fast, slow, etc.) it would take to get through the area. I thought the range of speeds given for each color were not specific enough, and it was difficult to determine the travel time."

These comments, and the others like them, suggest that the addition of colored classes and ambiguous segmentation is a burden that affects travel time estimation. While the empirical results allow for an objective comparison of the different design variables, the subjective feedback sheds light onto why the results turned out the way they did. Aside from representing a larger and more difficult set of tasks which results in high amounts of error and long response times, interpreting the Google traffic map and the equal-interval design is a task that, on the whole, users did not enjoy.

Chapter 5

DISCUSSION

5.1 Arithmetic Ability

5.1.1 Error and Accuracy

The results from this experiment suggest that map readers do not have difficulty performing the arithmetic to convert velocities and distances into times. Participants had an average percent error of 16.47. This did not exceed the threshold of 15% at significant levels. Furthermore, a directional bias was not present and participants neither under- or over-estimated travel times when performing the arithmetic.

5.1.2 Confidence

Confidence with arithmetic was also high, and the subjective response to whether or not an answer was close to the actual value was also high. More than 87% of responses indicated confidence and 80.82% of responses were identified as being close to the actual value after seeing it. This might suggest that responding to the arithmetic questions was a rewarding experience. If on the other hand responses were confident but rarely close, this would imply that the user feels positive about their ability initially but changes his or her opinion later. A constant change in an opinion and an indication that despite one's confidence he or she still cannot do well would likely be a very frustrating scenario.

5.1.3 Potential Bias

It is important to recall that the participants in this study do have the advantage of at least a partial University education with a tested mathematics aptitude and a recent history of math coursework. It cannot be said that the same performance would be enjoyed by the general public. In fact, it would be fair to hypothesize that arithmetic performance would be lower — perhaps low enough to significantly exceed the 15% threshold. This would be unlikely to change the relationship of the results for the map interpretation exercises, but increased error propagation and lower overall accuracy would likely be noticed. This caution also applies to the following sections of this chapter.

5.2 Distance Estimation

5.2.1 Error and Accuracy

On the whole, participants had better performance with distance estimation than was expected. The control condition was associated with an average error of 4.54 miles, and the equal-interval design demonstrates improvement by eliciting an average error of only 2.42 miles. Additionally, the control condition lead to a much higher maximum error (52.50 miles vs 34.99 miles), suggesting that the control map left a larger window for participants to make a mistake.

5.2.2 Response Time

Participants were also able to make the more accurate distance estimations more than one second faster with the equal-interval design. The average response time for the control condition was 14.86 seconds while the equal-interval design was associated with a response time averaging 13.19 seconds. Allowing users to make more accurate estimations in less time represents a significant improvement in map design. Instead of having increased accuracy come at a cost, the improved estimates came even faster to users.

5.2.3 Confidence

The success of the equal-interval segmentation for estimating distance is also revealed by the participants' confidence in it. Unlike the control condition which elicited confident responses only 79.80% of the time, 96.53% of responses to the equal-interval design were marked as confident. Similarly, only 61.02% of responses were classified as "close" by participants using the control map while 84.08% of responses were classified this way for the equal-interval design.

This suggests that participants were aware of the improvements in distance estimation associated with the equal-interval design. Participants felt confident using it and their confidence was often justified.

5.3 Travel Time Estimation

5.3.1 Error and Accuracy

Participants performed significantly better with both alternative traffic map designs than they did with the conventional design. The average error in travel time estimations associated with the conventional traffic map was just short of 20 minutes (19.77). Actual travel times for the conventional map questions ranged from about 19 minutes to nearly 74 minutes. An error of 20 minutes represents 25-100% of the actual travel times for the routes. This is a substantial amount of time to be uncertain about. In contrast, the equal-interval segmentation was associated with an average error of only 13.57 minutes. Improvements over both designs were seen with the fixed-minute segmentation, which produced an average error of just 5.52 minutes.

Such a large improvement associated with the fixed-minute segmentation demonstrates the benefit of reducing the complexity of a map's design. By eliminating classed data and the need to estimate distances and velocities, the fixed-minute design does not involve any computation or estimating on the user's end. This may also be due to the symbology being more congruent with the actually phenomenon being mapped. In a transportation network, congestion causes vehicles to become backed up, reducing the space between one vehicle and the next. The symbology used in the fixed-minute map does exactly the same thing. When congestion is high, travel times increase and it takes a greater amount of minutes to travel a short distance. This reduces the distances between the symbols, effectively causing them to become congested as well. Fixed-minute segmentation represents congestion with congestion.

A secondary benefit of the fixed-minute map is that it is not reliant on hues, and therefore does not pose problems for individuals with red-green color blindness. A colorblind-friendly traffic map can be created by making the red and green hues different in their luminosity, or by slightly increasing the amount of blue in the green segments. Despite these relatively easy solutions, conventional traffic maps continue to use hues that are troublesome for those with red-green colorblindness, providing yet another advantage for the fixed-minute map.

Not only did the conventional map fail to allow users to make reasonably accurate travel time estimations, it was also associated with estimated travel times that were significantly lower than the actual values. When using the conventional traffic map, participants most often underestimated travel times with an average of 11.77 minutes. It is unclear why this may be. Participants performed better than expected at arithmetic and distance estimation with a conventional map, and neither task revealed a directional bias. Yet when the tasks are combined, participants rarely provided accurate responses and a very large directional bias occurs. For reasons that are not yet known, it appears that the conventional traffic map not only conveys information in a more complicated way, but its design has a mitigating effect on the perception of delays due to congestion. A frequently assumed benefit of the conventional map is that its reliance on hue alone enables the map-reader to quickly judge the severity of congestion at a glance. However, the conventional traffic map significantly downplays the severity of congestion, leading users to believe conditions are better than they actually are.

The sequential improvement in accuracy that was revealed across the traffic map designs was predicted in *Hypothesis 4*. Each design represent a more simplified strategy to distance estimation (Figure 26). In the case of the conventional traffic map, distance is uncertain and velocity is ambiguous; the legend does not provide any numerical basis to guide velocity estimates. The equal-interval design removes ambiguity as well as the need to estimate full distances, but still leaves room for uncertainty when estimating velocities. Only the fixed-minute design removed both ambiguity and uncertainty. This simplified design was expected to be associated with the highest levels of accuracy, and the hypothesized relationships appeared in the results of this study.

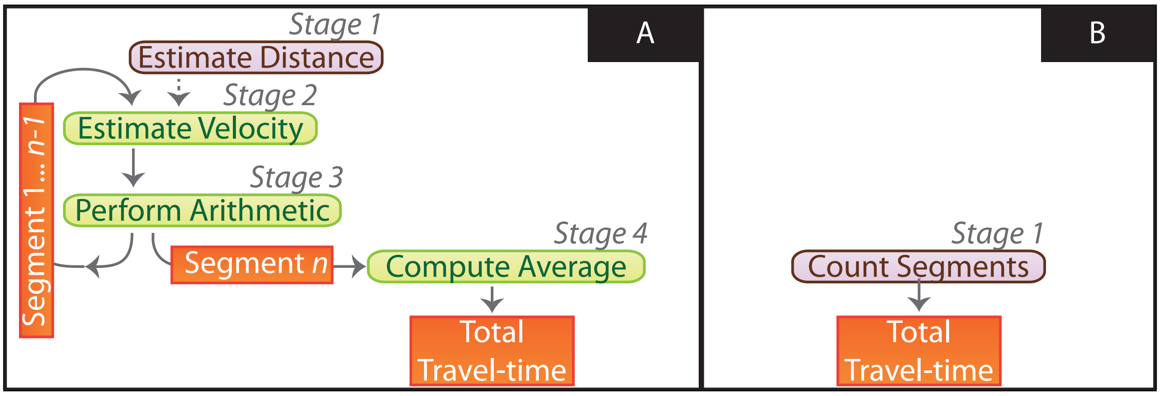


Figure 26: Possible strategies for estimating travel time with the prototype designs. The equal-interval approach (A) only requires distance estimation once, whereas the fixed-minute design (B) transforms the entire task of travel time estimation into a counting exercise. See Figure 4 for comparison.

These findings suggest that velocity estimation is the largest source of error when estimating travel times with conventional traffic maps. It can be argued that improvements in data classification may alleviate this problem and improve map readers' ability to estimate travel times. Maps that are entirely free of velocity and distance classifications are better yet, as demonstrated by the fixed-minute map which substantially improved travel time estimations.

Both of the traffic maps based on a fixed segmentation scheme enabled participants to make estimations that were closer to reality. This suggests that these maps facilitate spatial knowledge that is more congruent with the actual environment and the phenomenon of congestion. An increased similarity between the interpreted data and the real world allows users to make decisions based on a level of precision that did not previously exist. Outside of a laboratory setting, the improvements in traffic-related decisions would allow drivers to choose better routes or make better decisions about avoiding congestion.

While the benefits to the individual would be immediately recognized, network performance would also be influenced, as noted by Mahmassani & Jayakrishnan (1991). A transportation system utilized by drivers with access to accurate information about their environment has the potential to become increasingly efficient. If this were to occur on a system-wide scale across the entire network, congestion could be reduced at the macro level, reducing the substantial costs associated with congestion that were revealed by Schrank & Lomax (2009).

5.3.2 Response Time

Participants had the lowest response times when using the fixed-minute traffic map (18.64 seconds). Response times associated with the conventional map and the equal-interval map were similar (26.03 and 28.07 seconds, respectively). Response times are important measurements because they provide insight into the difficulty of a task and can be used as a proxy for mental workload (Walker et al., 1991). Within this context, it can be argued that the fixed-minute map is the most intuitive and easiest for map readers to interpret.

While the conventional traffic map and the equal-interval map shared similar response times, the equal-interval design elicited higher accuracy in travel time estimations. The similarity in response times is likely due to the similar tasks involved with the interpretation of these map types. Both maps have a somewhat similar appearance and both use hue as the primary visual variable. Furthermore, the addition of a fixed segmentation scheme that was advantageous in pure distance estimation tasks did not convey similar results in travel time estimation tasks. This indicates that it is perhaps the combined arithmetic and velocity estimation that dictates the majority of time taken to interpret these maps.

Research has demonstrated that lower response times are indicative of a lower mental workload associated with performing a cognitive task, such as map interpretation (Walker et al., 1991; Parkes et al., 1991; Horberry et al., 2006; Horrey et al., 2009). This suggests that the designs based on a fixed segmentation require less cognitive engagement from their users. While it cannot yet be said that this reduction in cognitive engagement will manifest in safer, better-performing drivers or pedestrians that are more aware while using these maps, it does nonetheless open the door for such a possibility. Noted by Ishigami & Klein (2009), paying attention to one thing requires the withdrawal from another. If this is true, the converse must also be true: a facilitated reduction in attention from one thing frees attention that can then be allocated elsewhere. It is therefore not unreasonable to hypothesize that maps associated with a lower cognitive demand will also be associated with higher performance in concurrent tasks.

5.3.3 Confidence

Fixed segmentation schemes elicited more frequent confident responses than conventional traffic maps. Nearly all responses to the fixed-minute traffic map were confident (94.56%). This represents a frequency of confident responses that occurs more than twice as often than those associated with the conventional traffic map (40.82% of responses were confident). The equal-interval traffic map improved confidence more than 15% over the conventional map as well.

A similar relationship between the map types was observed with the number of responses marked "close." The conventional map only caused participants to say their answer was close 33.47% of the time. A slight improvement was associated with the equal-interval map, with 39.18% of responses being close. Again, the fixed-minute map proved far superior in comparison, eliciting close responses 90.41% of the time.

The largest difference between confident and close responses was noted with the equal-interval traffic map. This suggests that the map initially invoked feelings of confidence that was not entirely warranted. On the other hand, only a small decreased was observed between confident and close responses to questions about the fixed-minute map. The implication then is that the fixed-minute map often rewarded participants; they felt confident entering their response, and then they saw their response next to the correct answer and the vast majority of the time were satisfied with their answer.

5.3.4 Map Preference and Subjective Feedback

Participants overwhelmingly preferred the fixed-minute traffic map (46 out of 49 participants chose it as their favorite), followed by the equal-interval map (chosen by only 3 participants). No participants preferred the conventional traffic map. Although it was somewhat anticipated that participants would prefer the maps based on fixed segmentation schemes, the magnitude of the preference for the fixed-minute traffic map was wholly unexpected. A review of the results indicates why this might have occurred. In every metric used (error, response time, confidence, and whether or not the user felt close), the fixed-minute traffic map outperformed the others. The fixed-minute map represented a much simpler task that required less time and cognitive ability and did not mislead participants by evoking undue confidence.

Moreover, participant responses as to why they chose the map they did reveals a quality of map interpretation that is difficult to measure: participants simply *enjoyed* using the map. Forty-six participants who chose the fixed-minute traffic map frequently used the words “enjoyed” and “liked” in their feedback. The high levels of confidence and preference associated with the fixed-minute traffic map suggest that users felt good about making decisions with it, they were confident their decisions were correct, and they remained satisfied with their responses after seeing the correct value. Previous sections have demonstrated the empirical evidence that suggests a fixed-minute design is superior for travel time estimation. However, these results provide insight into the *user experience*, which on the whole, was extremely positive.

Much has been said regarding the improvements to both micro- and macro-scale user behavior within a transportation system as a result of higher quality traffic information. But if nothing else, the fixed-minute design provided users with a map that was not only enjoyable to use and strongly preferred, it was associated with very low error and short response times. These alone are reasons that make a strong case for improvements in traffic map design and a possible shift towards fixed segmentation schemes — especially those based on units of time.

5.4 Limitations

The primary limitation of this study is that the prototype maps produced are not dynamic or readily deployable. Both the equal-interval and fixed-minute traffic map represent static snapshots in time. Although these maps were created successfully, the methods used for their creation are not intended for real-time display of traffic conditions. Largely based on raster operations, the current methodology would be too intensive to both computing power and time to be implemented for dynamic mapping in their present form. Alternative methodologies might take advantage of technologies such as Scalable Vector Graphics (SVG), Adobe Flash, or a raster-based overlay built on the Google Maps Application Programming Interface (API).

This study also did not ask users to estimate velocities alone from the traffic maps used. The decision to omit such questions was made deliberately. The classes used by the conventional traffic map represent large ranges in velocities (e.g., 25 to 49.9 mph). Any value submitted by a participant within those ranges would have to be considered correct, assuming that the response fell within the correct class.

It is also not known which traffic map design enables users to quickly and most accurately determine the severity of congestion at a glance. Often times a precise amount of time required to make a trip may not be the information a map-reader desires; he or she may only be interested in where traffic is “good” or “bad.” It can by hypothesized that a hue-based traffic map facilities this type of task the best, but empirical research has not been done for this task. In either case, hue could be easily added to the fixed-minute traffic map to enable users to determine accurate travel times or to acquire an at-a-glance assessment of the traffic conditions.

Chapter 6

CONCLUSION

Congestion represents a geographic phenomenon that is pervasive, dynamic, and detrimental to individuals and infrastructures alike. The size of the congestion problem in the United States is difficult to overstate. Daily drivers in the U.S. number in the millions, and annual costs — in both time and money — are represented in the billions. Despite efforts, congestion in America is only getting worse (Schrank & Lomax, 2009).

At the same time, numerous studies have demonstrated that travelers have a need for high quality traffic information (Chorus et al., 2007), and satisfying that need can lead to improved driver behavior that affects the entire transportation system in a positive way (Mahmassani & Jayakrishnan, 1991; Golledge, 2002). The problem of congestion is one faced every single day and accounts for an enormous hindrance to travel, the supply of goods, and less quantifiable quality of life factors.

Recent advancements in technology have enabled the real-time display of traffic information on mobile devices of many types. Maps are commonly accessed in this fashion, and traffic maps present a wealth of opportunity to provide drivers with up to date information on current traffic conditions. Although other media has been used to disseminate real-time traffic information, maps are preferable for two reasons.

First, a map depicts the information visually. Delivered in this way, the information does not have to be read from top to bottom or left to right as text would; the map reader need only glance at the area of interest. This is also preferable to audio delivery, which requires the listener to attend to the message in its full duration in order interpret its final meaning.

Secondly, traffic data presented in map form allows the user relate the information to the spatial environment, fostering knowledge generation and a better understanding of the severity of congestion and its extent. This facilities improved decision making that is at the heart of ITS/ATIS strategies. These strategies are only effective when drivers have the ability and information to make decisions, which often include re-routing or altered trip plans. Traffic maps show many possible routes at once, making this possible. Audio or text-based data delivery methods are route-specific, preventing users from making such decisions or planning routes that may change at any time during travel.

It is clear that a segmentation scheme based on a fixed unit of measurement improves distance estimation in maps, and in the case of traffic maps, travel time estimations as well. These improvements were seen in the form of lower errors and often, lower response times which were sometimes substantially lower (refer to Figure 23 and Table 8). In no case did improvements in distance or travel time estimation come at the cost of increased response times. Together, the pairing of lower error and quicker interpretation suggest that fixed segmentation schemes are superior to non- or ambiguously-segmented designs for the purpose of travel time estimation.

Users also strongly preferred a fixed-minute segmentation for traffic maps. This type of map represents a novel approach to symbolizing dynamic, time-based phenomena. Although significantly high levels of success were seen with the fixed-minute traffic map in this study, several questions remain. While the fixed-minute design improved travel time estimations, it is not yet known if this design will hinder or facilitate more coarse assessments of traffic conditions. Additionally, the performance of the fixed-minute traffic map has not yet been evaluated on mobile displays, at multiple scales, in oblique views, or in the presence of concurrent tasks. Future research could benefit from additional analysis of this new map type, or attempts to create others like it.

This research has also shown the gap between cognitive cartography and traffic mapping can be easily bridged. Scientific literature is replete with studies on each topic independently. Despite being seeming disparate, there are several overlaps between traffic research, studies on mobile device use, and visual image interpretation.

Cartographers and the public alike have unprecedented access to both traffic and geographic information, as well as technologies capable of displaying these data. As technologies continue to emerge and evolve, it is essential that we understand how these technologies are being used, how they may be used in the future, and to what extent they can be improved. Above all, conventions must always be challenged and, in the case of demonstrable proof, be replaced when superior alternatives exist.

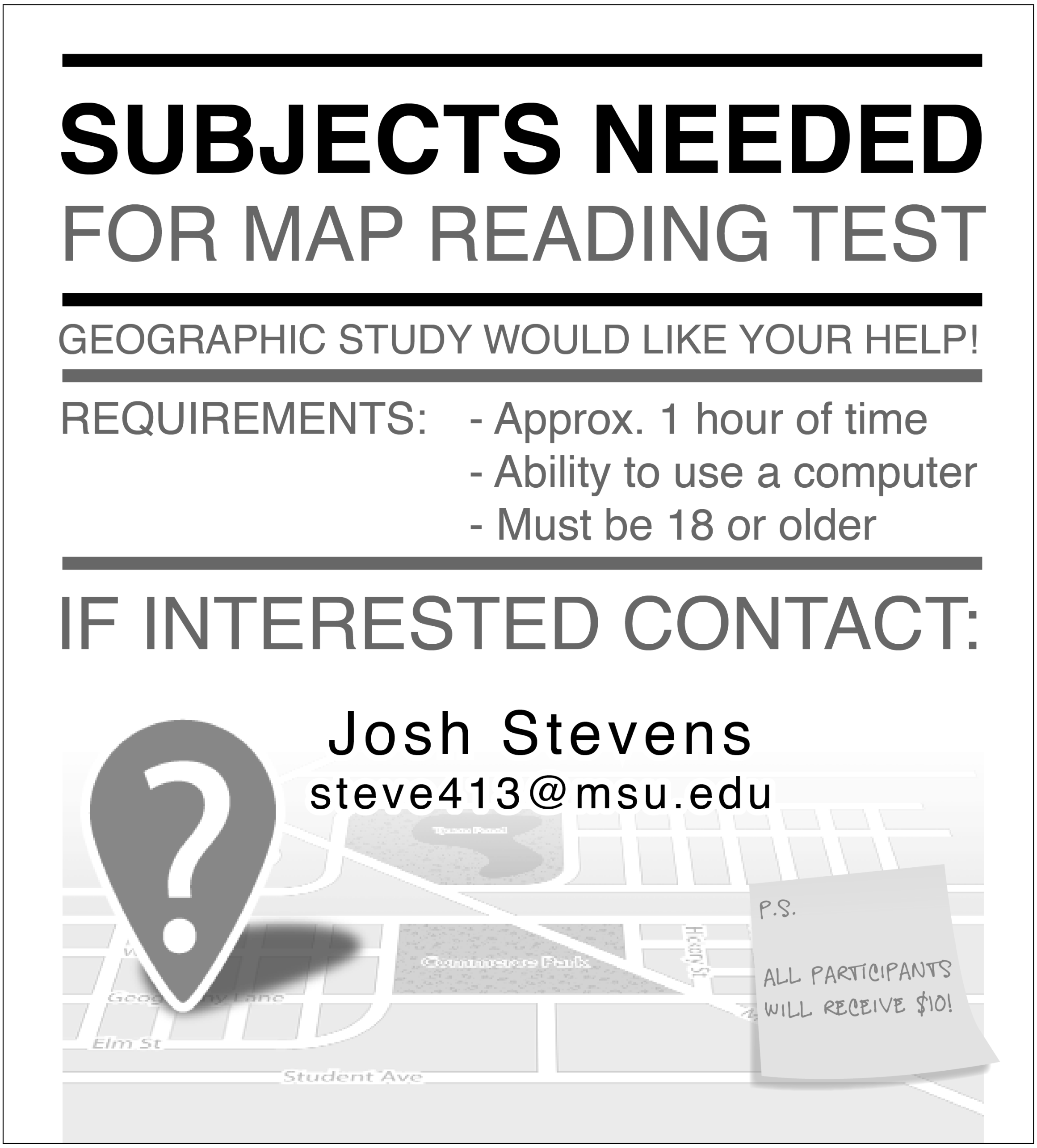
APPENDICES

Appendix A: Python Code for Identifying 1-minute Segments

```
# Copyright 2011 Joshua E. Stevens
# Python code to identify 1–minute intervals from a prepared CSV file

# This program is free software: you can redistribute it and/or modify
# it under the terms of the GNU General Public License as published by
# the Free Software Foundation, either version 3 of the License, or
# (at your option) any later version.

# This program is distributed in the hope that it will be useful,
# but WITHOUT ANY WARRANTY; without even the implied warranty of
# MERCHANTABILITY or FITNESS FOR A PARTICULAR PURPOSE.  See the
# GNU General Public License for more details.

# You should have received a copy of the GNU General Public License
# along with this program.  If not, see <http://www.gnu.org/licenses/>.
#######################################################################

# Setup script to handle csv input/output
import csv

# Read in data
in_data = csv.reader(open(’segment_times.csv’, ’rb’))

# Get fields and data required
SegID = []
TimeSec = []

for row in in_data:
    TimeSec.append(row[4]) # row 4 contains the times for each segment
    SegID.append(row[5]) # row 5 contains an ID unique to each segment

# Search for 60–second markers and save their location
travelTime = 0
ticMark = []
i = 1

while(i < len(TimeSec)):
   travelTime += float(TimeSec[i])
   if(travelTime >= 60):
       # Save locatation of tick mark
       ticMark.append(SegID[i])
       travelTime = 0 # Reset travel time to continue for next segment
   i += 1
```

```
# Write new CSV file to join later
outfile = ”ticMarks.csv”
output = open(outfile,”w”)

output.writelines(’”TicMark”’) # Make header
for each in ticMark:
    output.writelines(’\n’)
    output.writelines(each)
output.close()
```

Appendix B: Advertisement for Soliciting Participants



SUBJECTS NEEDED

FOR MAP READING TEST

GEOGRAPHIC STUDY WOULD LIKE YOUR HELP!

REQUIREMENTS:
- Approx. 1 hour of time
- Ability to use a computer
- Must be 18 or older

IF INTERESTED CONTACT:

Josh Stevens
steve413@msu.edu

P.S.

ALL PARTICIPANTS WILL RECEIVE $10!

Figure 27: The flyer used to solicit participants.

Appendix C: Consent Form

Research Participant Information and Consent Form

You are being asked to participate in a research project. This study is being conducted by Joshua Stevens, under the advising of Dr. Kirk Goldsberry. This document provides information about the study, and the risks and benefits of participation to empower you to make an informed decision. Participation in this study is completely voluntary. You should feel free to ask the researchers any questions you may have.

Alternative Segmentation Schemes for the Design of Traffic Maps
Joshua Stevens, Graduate Student
Kirk Goldsberry, Assistant Professor
Department of Geography
Michigan State University
116 Geography Building, East Lansing, MI 48824
steve413@msu.edu, kg@msu.edu

1. PURPOSE OF THE RESEARCH:

You are being asked to participate in a research project about map-reading.
This study investigates the effectiveness of different techniques for mapping traffic data. Many current maps are designed in such a way that they are easy to produce but do not perform well for those who use them. This research aims to discover what aspects of these particular maps are troublesome and to identify possible solutions for improving traffic maps.

2. WHAT YOU WILL DO:

You will be asked to submit answers to questions presented on a computer screen. These questions will ask you to solve a basic arithmetic problem, estimate a distance between two locations on a map, or to identify which of two routes is the shortest, longest, or fastest to travel. Occasionally, questions will ask you to estimate travel speeds or the time necessary to complete a route given the information provided. Some of these questions will be timed, though you will not see the timer or know which question is being timed. After each response, you will be asked how confident you are that your answer was correct. At times, you will be shown the value you submitted along with the correct value and asked to if you believe whether your answer is similar or 'close.' Use your best judgment for what you feel is similar based on the task being performed.

Prior to the test you will answer basic questions about yourself. These questions include gender, age group, and driving status. Once the test is complete you will have an opportunity to share your opinions on the test and which maps you preferred.

3. YOUR RIGHTS TO PARTICIPATE, SAY NO, OR WITHDRAW:

Participation in this research project is completely voluntary. You have the right to say no. You may change your mind at any time and withdraw. Your answers will then be destroyed and will not be included in the results of this study. You may choose to stop participating at any time. Should you choose to withdraw from the study, you will not receive the advertised compensation. You will not, however, be penalized in any other way.

4. COSTS AND COMPENSATION FOR BEING IN THE STUDY:

You will not incur any costs for participating in this study. You will be compensated $10 for completing the test in full. Withdrawal prior to the completion of the test will result in your compensation being prorated for the time spent up to that point, to the nearest $1.

5. CONTACT INFORMATION FOR QUESTIONS AND CONCERNS:

If you have concerns or questions about this study, such as scientific issues or how to do any part of it, please contact the researcher Joshua Stevens (Graduate Student, Department of Geography, Michigan State University, 116 Geography Building, East Lansing, MI 48824, steve413@msu.edu, 517-507-2292) or Dr. Kirk Goldsberry (Assistant Professor, Department of Geography, Michigan State University, 116 Geography Building, East Lansing, MI 48824, kg@msu.edu, 517-353-0308)

If you have questions or concerns about your role and rights as a research participant, would like to obtain information or offer input, or would like to register a complaint about this study, you may contact, anonymously if you wish, the Michigan State University's Human Research Protection Program at 517-355-2180, Fax 517-432-4503, or e-mail irb@msu.edu or regular mail at 207 Olds Hall, MSU, East Lansing, MI 48824.

6. DOCUMENTATION OF INFORMED CONSENT.

Your signature below means that you voluntarily agree to participate in this research study.

______________________________	______________________
Signature	Date

You will be given a copy of this form to keep.

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