Studying the Effectiveness of MOVE: A Contextually Optimized In-Vehicle Navigation System

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ABSTRACT
In-vehicle navigation has changed substantially in recent years, due to the advent of computer generated maps and directions. However, these maps are still problematic, due to a mismatch between the complexity of the maps and the attentional demands of driving. In response to this problem, we are developing the MOVE (Maps Optimized for Vehicular Environments) system. This system will provide situationally appropriate map information by presenting information that uses appropriate amounts of the driver's attention. In this paper, we describe our findings of studies to help shape the design of the MOVE system, including studies on map reading and in-vehicle navigation, and studies on the effectiveness of a variety of contextually optimized route map visualizations in a simulated driving context.

Results show that contextually optimized displays designed for the MOVE system should significantly reduce perceptual load in the context of driving. In our laboratory experiment there was a six-fold decrease in the total map display fixation time and nearly threefold decrease in the number of glances needed to interpret the contextually optimized display compared to a static display.

Author Keywords
Maps, in-car navigation systems, visualization, human attention, perceptual optimization, dynamic displays.

ACM Classification Keywords
H5.2. Information interfaces and presentation: User Interfaces; I6.8. Simulation and Modeling: Types of Simulation.

INTRODUCTION AND MOTIVATION
In-vehicle navigation has changed fundamentally in the past five years, with the advent of computer-generated maps and directions. Drivers now rely less on devising routes from traditional maps. Instead, online map services and global positioning systems (GPS) can be used. The simple activity of entering an origin and destination will typically generate an accurate route. However, while computerized map-generation systems are easy to use, and the information generated is generally precise, they are often less than efficient methods for navigating and learning a route.

Driving itself requires a lot of concentration. Drivers need to pay attention to the road, instrumental panels, and other information sources such as road signs or landmarks in order to get appropriate information for driving. Additionally, more and more devices are in use while driving: cellular phones, car stereos, and in-vehicle navigation systems, to name just a few. These may be helpful while driving, but also significantly affect driving as a primary task. In particular, current navigation systems typically do not carefully consider a driver's cognitive load and attentional state – delivering all information in the same way regardless of context.

Based on this understanding, we are developing the MOVE (Maps Optimized for Vehicular Environments) system, a contextually optimized in-vehicle navigation system. Our system works on the principle of optimizing the information presented to the driver at any given time, so that only the appropriate amounts of attention need be given to the navigational interface.

To design the system to be usable and safe, we first needed to know how people currently interact with maps. We conducted a preliminary study on map reading and navigation. We also reviewed a body of human factors research related to fixation time and numbers of glances for static maps as initial guidelines [6, 9, 13, 19, 20], and drew principles from research on visual perception, cartography, and detail-in-context systems. With this knowledge, we developed the basic framework for the MOVE system and four alternate presentation styles to present within that framework. A study was then conducted to evaluate the visualizations, to understand if perceptual load might be reduced with an optimized navigation system. The work presented here focuses on the optimization and presentation of visual information. As a first step this study has been performed in the lab. Now that the potential for dramatic improvements have been demonstrated (e.g., a six-fold reduction in time spent looking away from a very simple

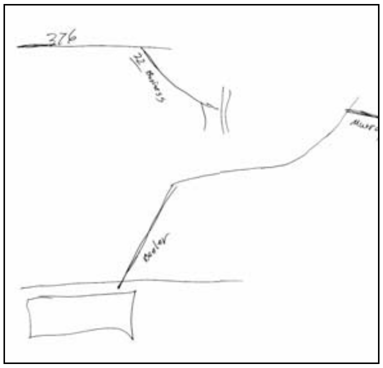


Figure 1. A map generated for use from a home to a local mall. Much of the pertinent information such as cross-streets and exit numbers are left off the map. However, critical roads are represented, and critical junctions are represented as thicker lines.

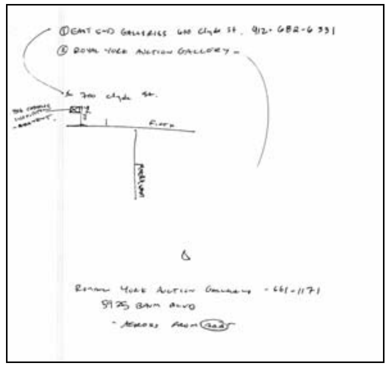


Figure 2. A map generated for a participant to use himself. Neighborhoods play an important role in this representation; arrows map the exact location of the destinations and provide important annotations.

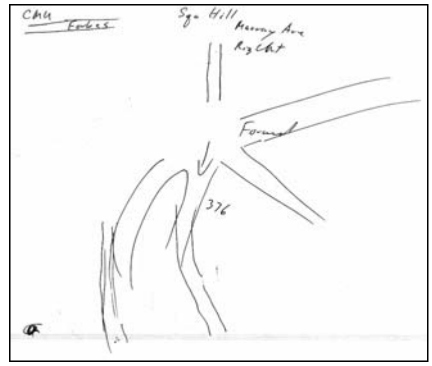


Figure 3. A representation for a route from a participant's home to a local mall. A particularly difficult 5-point intersection was afforded more size and detail.

driving simulation), we can safely move to more realistic testing in a vehicle, and eventually to a direct demonstration of safety improvements.

BACKGROUND STUDIES AND RELATED WORK

In order to understand the factors that affect perceptual load while driving, we conducted preliminary research on the following issues: how people read maps, make directions, and use directions while driving; current guidelines related to perceptual load in human factors research; and related visualization research in the HCI literature. Finally, we have also considered a set of map generalization principles from the cartography literature.

Study 1: Map Reading and Navigation

We conducted a four-month study to understand how people read maps, make directions, and use directions while driving [15]. We drew inspiration from research on navigation, on map reading, and on the role of prior knowledge in helping people find their way to a destination, to provide an overarching structure for our research and to generate themes and protocols for our studies.

The goal of navigation is to achieve movement through a space, and is based on three kinds of knowledge: landmark, route, and survey [23]. We found that drivers continually monitor their location relative to a given route, possibly involving a map or some representation of the route, and occasionally change routes if circumstances warrant. Road maps and Internet line-by-line directions are somewhat helpful to drivers. Landmarks are critically important, no matter how well the driver knows the route.

When navigating, drivers break the route into smaller steps, or subgoals. The steps may be as small as those in line-by-line directions, or they may be made up of schematized sections of the route that drivers already know (for example, home to the on-ramp of the nearest major highway). To move from goal to goal, drivers rely mostly on information about landmarks, paths (important streets), and nodes (intersections of two important streets). Landmarks act as confirmation points, marking points, and orientation mechanisms. Landmarks may be more or less salient depending on the driver's point in the route.

As drivers become more familiar with an environment, they develop a cognitive map, or a deliberate representation of prior knowledge about a route [8], and their dependency on external aids such as landmarks, written or verbal directions, and signage decreases. Landmarks play an important role in cognitive maps. For example, a landmark may be salient because it is tied to one's past experience (for example, one's childhood house or former place of work could be a salient landmark).

Together these findings show that tracking progress, and maintaining an awareness of one's position along a route is of significant importance to navigating drivers.

In our study, fifteen participants ranging in age from 20-54 performed a series of three navigation tasks. We wanted to understand how drivers give written or drawn directions to familiar, not-so-familiar, and unfamiliar places, and what criteria are valued about printed maps and atlases. Participants were asked to generate directions to use while driving themselves, while giving directions to another driver, and to give to a person who would be driving separately. We also wanted to understand the utility of the LineDrive system which takes a related approach, providing abstracted maps targeted to route navigation [25]. Participants were asked to use LineDrive directions to drive to two unfamiliar destinations.

When asked to create a representation of a route, participants often made two versions of maps: a version for other people driving who did not know the route (Figure 1), and a version that they would prefer to use for themselves

(Figure 2). Abstracted, flattened, and simplified representations were consistently produced, except at critical junctions where more detail was needed (Figure 3).

Our studies revealed that by far, abstraction, distortion, and landmarks were uniformly the most important characteristics of the representations that participants generated. Personal preferences for navigation played the greatest role in how drivers navigate and generate directions.

Human Factors Research

From the literature, we gathered information on numbers of glances and fixation times measured in studies of a variety of driving tasks from several cultures [14, 21, 24]. Studies show that on average, a driver usually spends approximately 0.78 seconds (SD = 0.65) and 1.26 glances (SD = 0.40) to read a speedometer and 1.10 seconds (SD = 0.30) to check the left mirror. These research results have led to safety guidelines for the design of devices to use while driving. According to the VICS Promotion Council's report, an average of 2.7 glances and a total of 4.10 seconds fixation time is the maximum safely allowed when driving at 30km/h [22]. Rockwell also noted that drivers are reluctant to go without roadway information for more than 2 seconds (and rightly so) [18].

Additionally, guidelines have been created for the amount of text-based information that can be safely read while driving. Ito reported that drivers can read an average of 6.2 Japanese characters per second while driving, which is the equivalent of an average of 11 Roman characters per second [10, 12].

Overall, human factors research and safety guidelines clearly point to the fact that only a limited amount of information can be conveyed safely to the driver. As a result, any design for a new system cannot overtax the driver perceptually. If a system can be designed that reduces the number of glances and fixation times, it may very well increase safety while driving.

Visualization Systems

While driving, it is difficult to scan a map or directions and to find needed information without taking one's eyes off the road for periods of time. One possible remedy for this situation is to render important or complex map details at an enlarged scale within the context of the rest of the representation of the route (Figure 3), giving the driver only the detail that is currently needed within the context of an existing body of information. We were inspired by a body of HCI literature that examines methods for presenting information at greater detail while maintaining a sense of the surrounding information context.

In a typical user interface, scrollbars or navigation buttons are used to access content that is too large for the display. However, such explicit "hands on" interaction is most likely not appropriate in a driving context. Zoomable UIs, "magic" lenses, fish-eye views, and detail-in-context visualizations which distort reality and provide areas of contextual detail have all been explored for information visualization [2, 3, 4, 5, 7, 16]. Detail-in-context UIs allow the user to access all of the content simultaneously, and to access detailed information when needed, surrounded by relevant context. Meanwhile, other contexts which are not of interest to the user are perceptually minimized.

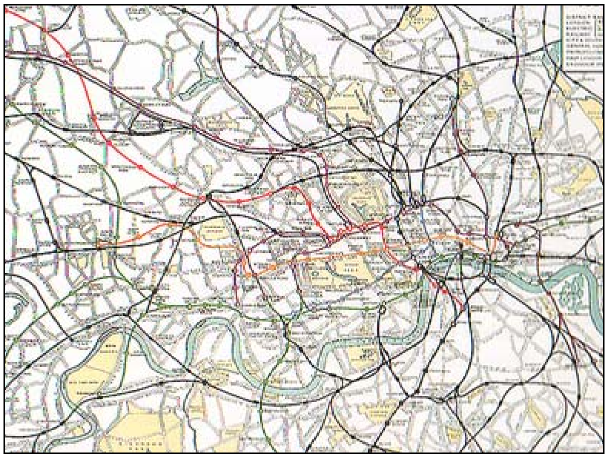
Other research has examined dynamic information that exploits the element of time to make bodies of information accessible beyond the constraints of the display. For example, a dynamic news reader used time, combined with visual cues such as size, color, and emphasis, to present key headlines which faded in importance as time passed [11].

MAP GENERALIZATION

A map is an abstracted two-dimensional representation of a three-dimensional reality which is rich in detail. As such, all maps are based on the use of abstraction. Some forms of abstraction act by simply omitting information which is less relevant to the task at hand. Other forms of abstraction may retain (partial) information, but simplify or distort it to make it more discernable in a given task context.

As a classic example, the London Underground maps of the 1920s (Figure 4a) and 1990s (Figure 4b) clearly illustrate how abstraction can benefit legibility. Figure 4a maintains significant detail about surrounding city features, and accurate paths within the city for each underground line. In contrast, Figure 4b eliminates significant amounts of detail, and presents the path of each line in a schematic rather than realistic fashion. By spreading elements apart (unrealistically) it also provides space for visual detail conveying information about, for example walking connectivity between stations, which could not have been presented legibly on Figure 4a (but which is critical to the task of navigating underground). In Figure 4b, the reduction of overall information and the use of distortions of the actual geometry make it possible for the user to focus on the most relevant information without being distracted by less relevant information. The end result is significantly easier to user (despite the fact that the system is now larger and more complex).

Use of abstractions such as those illustrated in the classic London Underground map have been refined and systematically described by cartographers as a process of *generalization*. Following the treatment in [17], we have been guided in our design by a process of generalization having at least five distinct aspects: *selection*, *simplification*, *displacement*, *smoothing*, and *enhancement*. Features are *selected* for emphasis in a map to support the specific theme or task associated with the map. These features are typically given more prominent symbols than background features, and hence tend to draw more of the user's attention to themselves. *Simplification* is a process of reducing detail – for example in a path, reducing angularity by eliminating points along the path. *Displacement* avoids graphic



(a) A Portion of the 1920’s London Underground Map

(b) A Portion of the 1990’s London Underground Map

Figure 4. Comparison of London Underground maps.

interference by shifting apart features that otherwise would overlap or coalesce. *Smoothing* also diminishes detail and angularity. In contrast, *enhancement* adds detail to selected map features and is used to convey more information of higher importance to the task or context.

The LineDrive system, shown in Figure 5, has successfully used abstraction for static maps accompanied by line-by-line directions [1]. LineDrive uses abstraction and generalization to generate the route, unlike many other map databases. For example, a typical map generated from an on-line database maintains the same scale throughout the whole map. LineDrive will vary the scale of the route, placing different importance on different sections of a route. Less importance may be put on highways, and higher importance on local roads. Abstraction, distortion, and simplification of the route are performed based on the importance of each segment. Unlike most on-line map databases, LineDrive uses road labels and landmarks judiciously. The culmination of these techniques allows the driver to understand the entire route easily, and to reduce their perceptual load for understanding the map.

Our research has been greatly inspired by the LineDrive system. It provides a number of good approaches to issues of abstraction. However, because it is a static display, it may be possible to optimize this kind of information even more. A contextually optimized display might be aware of the driver’s situation at various times during the drive. For example, the system could reveal more or less information based on the current location within the overall route or the speed of the car. In the next section, we discuss our vision for the design and implementation of the MOVE system.

MOVE DESIGN PRINCIPLES

Based on our navigation studies and review of existing systems and cartography, we generated the following design principles for the MOVE system. First, to reduce perceptual load, information should be presented in an abstract manner at all times while driving. The level and nature of abstraction will change depending on the driver’s context. Second, the system will exploit time as a design element to present dynamic, optimized displays. Third, some level of interaction with the system should be achieved automatically. For example, instead of direct input, it may be beneficial to use the position, direction, and speed of the vehicle to select relevant information.

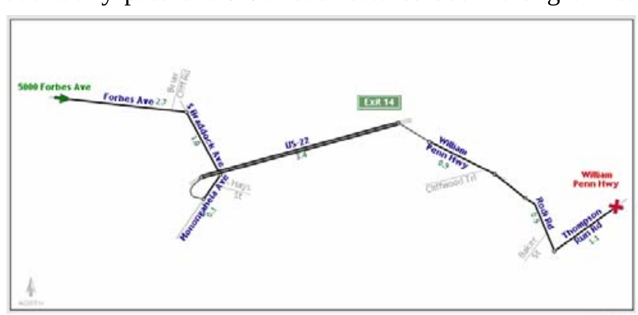
ABSTRACTION

In general, when driving, the actual curvature and even the length of the road are relatively unimportant to the driver. Our first study gave us a body of examples of simplified and straightened route depictions. Even if a driver is not familiar with the route, she will still easily comprehend an abstracted rendition of the area.

In our MOVE design, abstraction has been achieved through the aspects of map generalization described above. We now consider the details of each of these aspects.

Map Feature Selection

A *route* is made up of the set of road segments a driver will eventually pass over. Various features occur along or near



	Directions	Elapsed Distance
1	Begin at 5000 Forbes Ave on Forbes Ave and go East for 2.6 miles	2.6
2	Turn right on S Braddock Ave and go South for 0.9 miles	3.6
3	Turn right on Monongahela Ave and go Southwest for 400 feet	3.6
4	Turn right on ramp at sign reading "I-376 E to Monroeville" and go North for 300 feet	3.7
5	Bear right on US-22, I-376, Penn Lincoln Pky and go East for 3.4 miles	7.1
6	Exit US-22, I-376, Penn Lincoln Pky via ramp at sign reading "Exit 14 US-22-BR to Monroeville" and go Southeast for 700 feet	7.2
7	Continue on William Penn Hwy, US-22-BR and go Southeast for 0.8 miles	8.1
8	Turn right and go Southeast for 700 feet	8.2
9	Continue on Rodi Rd, Yellow Belt and go Southeast for 0.8 miles	9.0
10	Turn left on Thompson Run Rd and go Northeast for 1.1 miles to William Penn Hwy	10.1

Figure 5. An example of LineDrive directions.

that route. Feature selection of the map generalization process considers which of these features to include, as well as how much prominence should be given to each feature, with particular rendition alternatives eventually being chosen for each feature.

While driving, we largely pay attention to the road segment we are currently passing over. Other sections of roads, either along the route or nearby, as well as lakes, rivers, parks, municipal boundaries, and other map features, are typically not important unless they are useful for navigating a route. For example, a cross street within a route becomes meaningful since it could be used as a milestone of a route, in this case serving as a landmark. On the other hand, roads some distance from the route are unlikely to be important. Overall, selection for the MOVE display is based on importance to the overall task and the local context it is being performed in. Significant reduction in content is shown in comparison to a conventional static map.

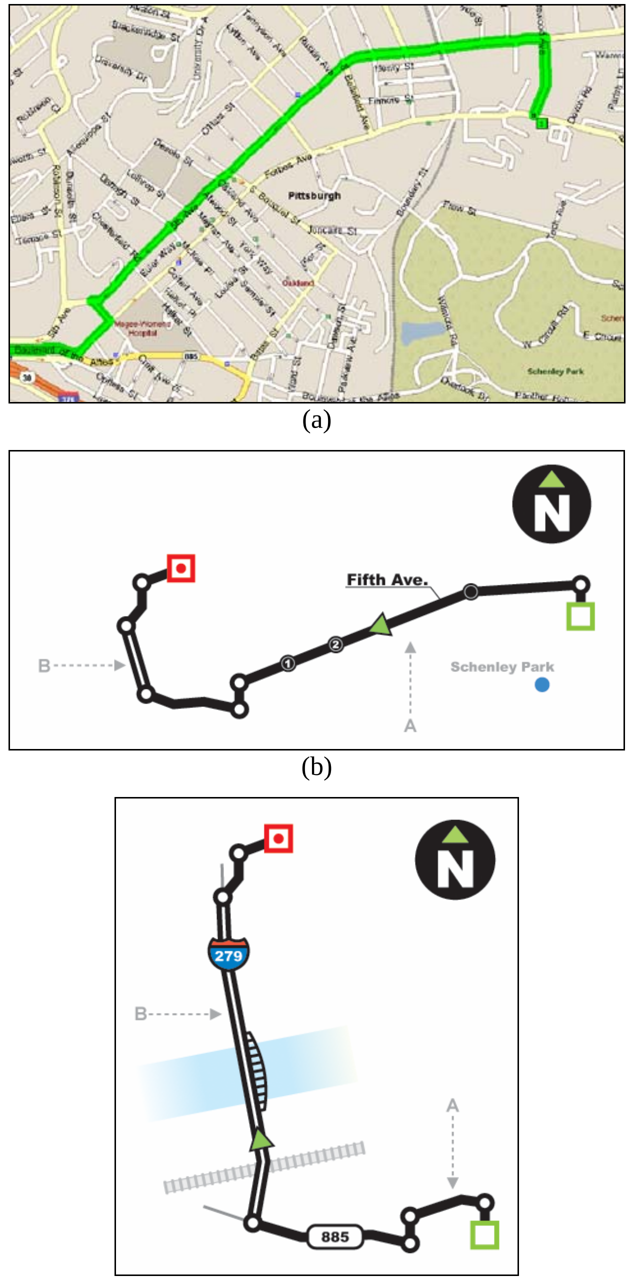
In particular, MOVE normally shows only the main route and its related map elements such as nodes and cross streets. Cross streets are only displayed on the screen when the vehicle is approaching them. Most road labels are also eliminated from the screen and are only presented when necessary to the current context. Most frequently, nearby segments of the overall route are presented (with emphasis on the current segment), the next cross street and the next turn). When approaching a turn, the next two cross streets are selected (and displayed in an enhanced form). Figure 6 illustrates this. Figure 6a is a conventional map showing the section labeled “A” in Figure 6b. In the conventional map, there are many cross streets and labels, while the MOVE rendition shows very few.

Simplification/Smoothing

Only a limited area of the road can normally be seen while driving. Actual road shape and scale on a map are typically not as important to navigation as information about milestone landmarks and indications of when and where to turn. This was reflected in our studies, where participants drew maps that distorted the actual curvature of a road. For example, a highway is usually represented with a straight line because we aren’t concerned about the actual curvature of the road. Similar simplification and smoothing is done in MOVE displays. In Figure 6c, the section labeled “B” has been straightened by reducing detail and angularity.

Relative Scaling

Scaling is another mechanism for differentially manipulating the salience of different map features. MOVE arbitrarily distorts the actual road length. In particular, the current road segment and segments associated with nearby turns are rendered at considerably larger scale than route segments far ahead or behind. In Figure 6b and c, the sections labeled A and B have different scaling factors based on the importance of the section in this driving context.



(a) (b) (c)

Figure 6. Abstraction by map generalization.

Displacement

While placing symbols and labels on the screen, it is possible that they will interfere with each other. For example, a label can overlap with other labels or symbols, and cross streets might overlap each other due to distortions of the route. In these cases, MOVE relocates labels and symbols to avoid interference. For example, in Figure 6b, a road label, ‘Fifth Ave.’ has been relocated in order to avoid overlap with the landmark label, ‘Schenley Park’, and the bridge symbol and river in Figure 6c have been relocated to avoid the railroad tracks.

Enhancement

In the right places, detail can enhance navigation. Although many MOVE displays abstract away detail, enhancement is used when features are important to the current driving context. More detail is applied (primarily through the use of enlarged scale and the selection of additional features) at the final destination of the route, for features associated with the next or current turn, and for features associated with the road segments between the current position and the next turn. For example, as illustrated in Figure 6b, extra cross streets are selected for display when nearing a turn, and these are enhanced with "countdown" number labels indicating how many cross streets are left to pass prior to making the turn.

DYNAMIC INFORMATION INTERACTION

When a driver seeks a specific location on a map, a detailed interaction takes place with the information that is presented. This is in keeping with our studies, which showed that drivers break an entire route into sub-goals, focusing on one goal at a time.

The MOVE system accommodates this navigation behavior in two ways. First, it uses the most detail to render the section of the route that the driver is traversing, related to the current sub-goal. Second, the system uses the position and speed of the vehicle to automatically determine what segment of the route should be displayed at any time.

Automating the selection of information to display based on context information (such as: position along the route, speed, and even night vs. day or bad weather conditions) should also contribute to lowering the total attention that the driver needs to expend on a map display. In particular, if the right information can already be displayed in most cases, it should dramatically reduce the need for many explicit interactions (e.g. adjusting the scale of the display), which will reduce cognitive and attentional loads, as well as the need to physically interact with input devices controlling the display.

MOVE PRESENTATION STYLES

To explore dynamic interactions with information in the MOVE system, we created four visualization methods as candidates for the study. As described below, these include:

Zoom in Context (ZC)

In zoom in context (Figure 7), the system automatically zooms into the segment of the route that the driver is currently traversing. The rest of the route remains on the screen at a reduced size. This presentation method affords showing the entire route at once, which is useful for getting an overview of the route. However, the vehicle's current position, indicated by the cursor, will not remain in the center of the display.

Route Scrolling (R)

Route scrolling was designed to overcome the problem discovered in the zoom in context presentation method. In route scrolling (Figure 8), the vehicle's current position remains in the center of the screen. However, the driver is not able to see the entire route, making the task of getting a full overview nearly impossible. Additionally, the route scrolling method does not make effective use of screen real estate. This is because the fixation target remains in the center of the screen, reserving half of the screen for a part of the route that has already been traversed.

Zoom in Context + Route Scrolling (ZC+R)

This presentation method (Figure 9) combines the above two methods. The system automatically zooms into the segment of a route that the driver is traversing, while those segments that have passed scroll from the screen. An overview of the route is provided; however, the fixation target does not remain in the center of the screen.

Zoom in Context + Small Overview (ZC+O)

This presentation method automatically zooms into the section of the route that the driver is currently traversing, while providing a small overview of the entire route (Figure 10). While seeing both the overview and the detail together might be beneficial, the driver will have two areas of focus on the display. This may increase fixation time and number of glances.

In the next section, we describe a study to evaluate the effectiveness of the four visualization methods and compare it with a static abstract visualization.

EVALUATING EFFECTIVENESS OF MOVE DESIGNS

To understand the effectiveness of our candidate designs, we performed a study measuring effects of the four contextually optimized display conditions described above, plus an extra condition related to the use of cursors, on a simulated driving task. Since these displays present information tailored to a given driving context, we believe they should be able to convey necessary information, but at a reduced perceptual load for the driver. Specifically, we hypothesized that the presentation methods would be able to reduce the number of glances and fixation times needed to comprehend them, and therefore reduce the perceptual load needed to use an in-vehicle navigation system. To test this hypothesis, we measured fixation times and numbers of glances in a simple simulated driving task. Our study showed that contextually optimized displays designed for the MOVE system do significantly reduce perceptual load. With the contextually optimized displays, total map display fixation time per task averaged 861.98 ms (compared to an average of 5428.72 ms for static displays) and average number of glances away from the driving simulator was 1.52 (compared to an average of 4.53 for static displays).

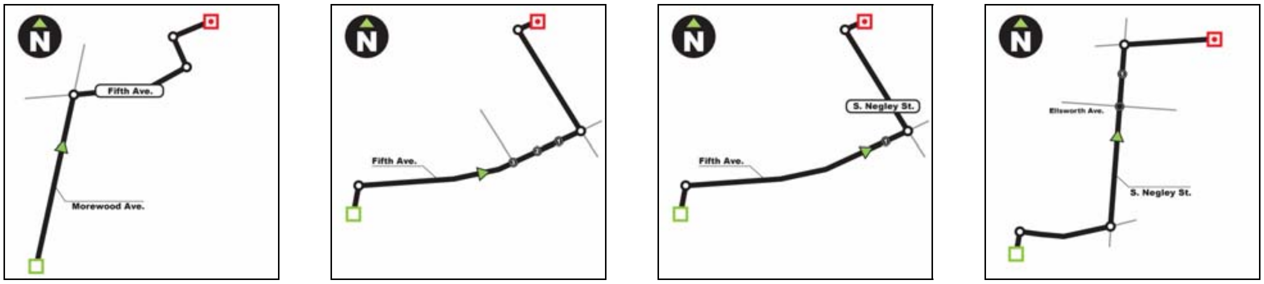


Figure 7. Zoom in Context (ZC)

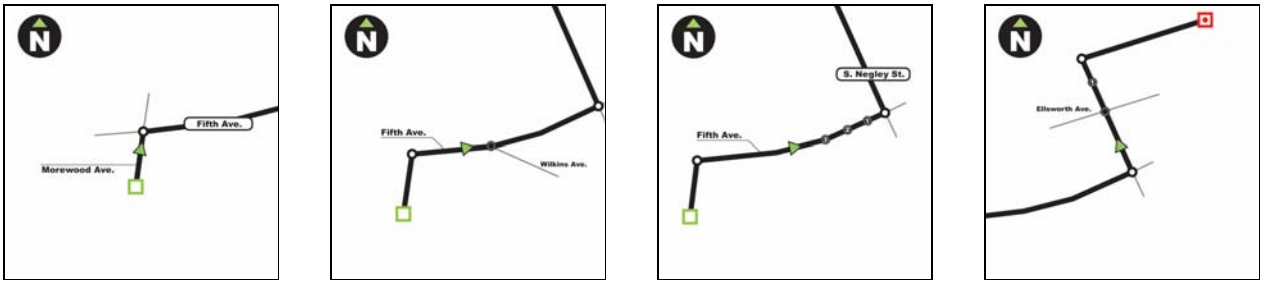


Figure 8. Route Scrolling (R)

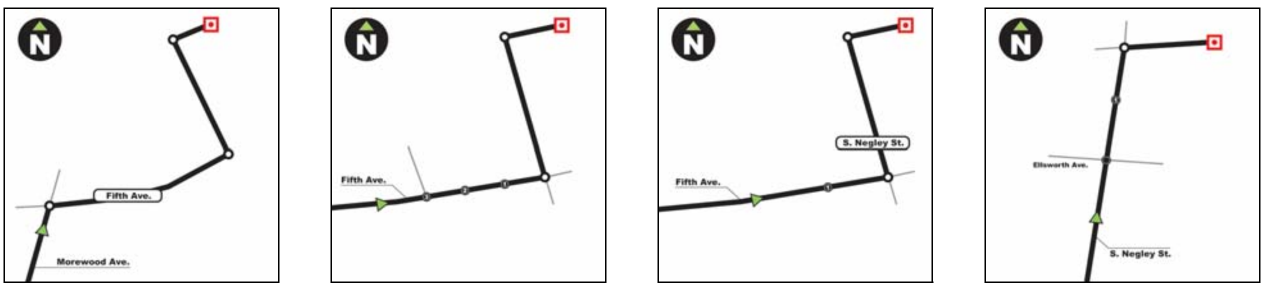


Figure 9. Zoom in Context + Route Scrolling (ZC+R)

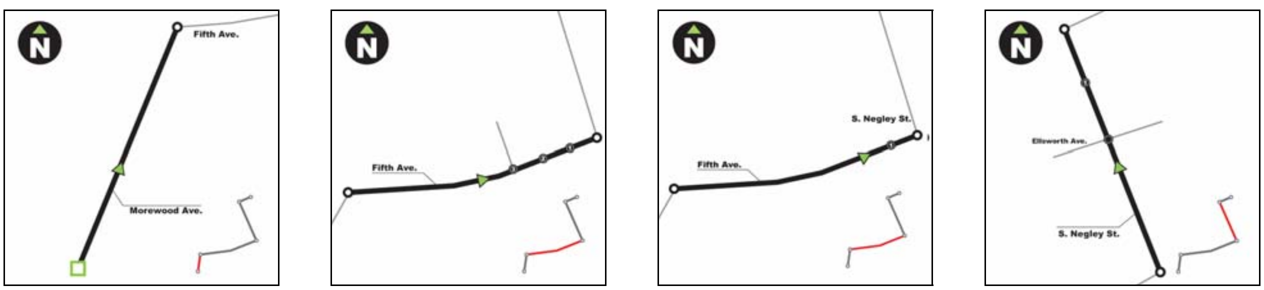


Figure 10. Zoom in Context + Overview (ZC+O)

Study 2: MOVE Visualization Styles vs. Static Abstract Maps

Our study used a dual task attention saturating framework, where participants were performing a primary task demanding high levels of attention (using a desktop driving simulator) and at the same time performing a secondary task (interacting with the navigation display) whose effects on the first task could be measured [23]. Two displays were used in a laboratory setup as shown in Figure 11.

As a primary task, subjects performed a simple tracking task that loosely simulated driving on a display located directly in front of them, shown in Figure 12. The road scrolled from the top to bottom of the display. Subjects controlled their position relative to the center of the road by moving a circular red cursor to the left and right using a steering wheel input device. Subjects were told to maintain a central position on the road during the experiment. The tracking task measured each subject's driving performance by capturing the distance (in pixels) subjects had allowed their simulated vehicle to wander beyond the boundary of the road every 10ms. This measurement was indicative of whether the primary tracking task was affected by the secondary task.

A second display, used for the contextually optimized route maps or static map, was placed to the right side of the primary display. While using the driving simulator, subjects were periodically forced to review the route display in order to answer questions related to specifics about the route: for example, "What is your next turn?", "What is your next intersection?", and "How many more minutes to the next turn?" Subjects answered the questions verbally as soon as they found the information they needed from the secondary display.

Two video cameras recorded the data from the study. The first, placed directly in front of the subject, was used to capture eye movement and fixation times. The second, placed behind the subject, recorded both displays.

Twenty subjects from the university community, aged 19-56, 12 male and 8 female, completed the study. All subjects completed all of the conditions in randomized order. A baseline driving task was performed before the start of the experiment.

In the main experiment, four MOVE presentation methods were used. Each presentation method had four different example routes heading north, south, east and west. LineDrive was used for the static condition for baseline comparison. We chose LineDrive because it reduces visual information significantly as compared to traditional paper maps. We chose not to compare our concept to current in-vehicle navigation systems, because these systems are not using optimization to select and present map elements. While comparison with other in-vehicle system does have merit, we found it most important to compare our work to the best available and closest alternative. To control for typographic consistency, we chose a simple LineDrive route rendition and enlarged it slightly to make it comparable to the MOVE visualizations. The static LineDrive map was also presented on the secondary display. (In a separate experiment we also included a condition where the LineDrive display was presented on paper. While we will not present the details of those results here, there were very similar, indicating that the presentation medium alone is unlikely to alter the large effects described below.)

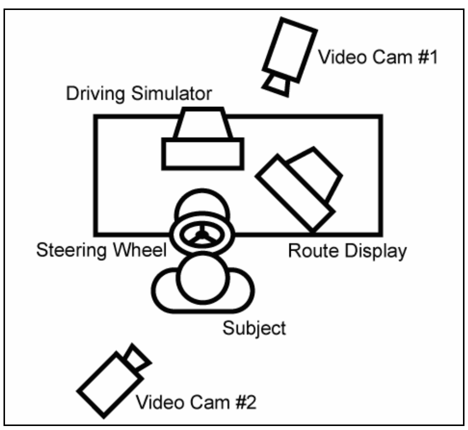


Figure 11. Study configuration

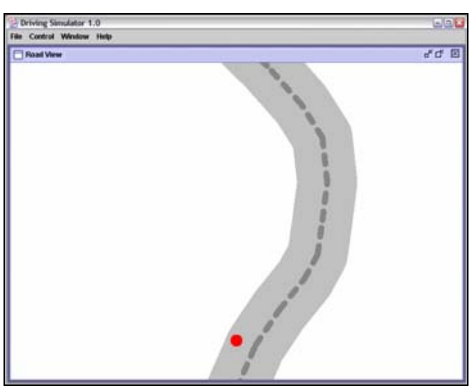


Figure 12. Subjects were simply following the center of the road in Driving Simulator by moving steering wheel.

In order to isolate the effects of having a cursor indicating current position, we also included a fifth display type: a Zoom in Context display (as described above), but without the cursor which would normally indicate the vehicle's current position.

RESULTS AND DISCUSSION

We analyzed the data with five criteria. First, we compared MOVE (the mean of the four presentation methods) with LineDrive (LD). Second, we compared LD with ZC without cursor. Third we compared ZC with ZC without cursor. The main purpose of these comparisons was to understand the function of the cursor in the map reading task. Fourth, we compared each presentation method in order to understand which presentation would be better. In this case, ZC was used for baseline comparison. Finally, we compared east, west, south, and north of four presentation methods. In this comparison, east was used as baseline. As indicated above, we used three measures of performance: number of glances per question, total map display fixation time per question, and average distance off the road in the driving simulation. Frame-by-frame analysis of the video was done at the points of glance using a specific protocol for determining the end frame.

Measure	LD Mean	MOVE Mean	Significance
Number of Glances	4.53	1.52	$t(19)=27.16$, $p<.0001$
Total Fixation Time (ms)	5428.72	861.98	$t(19)=20.77$, $p<.0001$
Ave Dist. off Road (pixels)	0.0996	0.0204	$t(19)= 2.304$, $p=.033$

Table 1. Primary Study Results (N=20) (LineDrive vs. MOVE)

Table 1 presents the main results from our study comparing performance using LineDrive maps with the overall performance of the contextually optimized displays. The contextually optimized displays show dramatically better performance in all measures showing six-fold decrease of fixation time and three-fold decrease of number of glances (statistically significant in all cases). The measures of fixation time and average distance off the road, which we would expect to be related, exhibit very similar behavior. Our main hypothesis was supported by the experimental data, suggesting that contextually optimized displays, as in the MOVE system, can reduce the driver's perceptual load while navigating.

Measure	LD Mean	ZC w/o Cur Mean	Significance
Number of Glances	4.53	1.76	$t(19)=22.08$, $p<.0001$
Total Fixation Time (ms)	5428.72	1049.36	$t(19)=18.77$, $p<.0001$
Ave Dist. off Road (pixels)	0.0996	0.0383	$t(19)= 2.872$, $p=.010$

Table 2. Primary Study Results (N=20) (LineDrive vs. ZC without Cursor)

Table 2 compares LD and ZC without cursor in order to help understanding the contribution being made by vehicle location information. Interestingly, even without the vehicle location cursor, contextually optimized displays substantially reduced fixation time, no. of glances, and improved driving performance. All of the measures were statistically significant. The reason may be because when reading the static map, participants actually performed two tasks: searching for context and then finding needed information. Within the contextually optimized display, even though there was no cursor to give specific location information, zooming in to the context helped the participant to substantially reduce search time.

Measure	ZC Mean	ZC w/o Cur Mean	Significance
Number of Glances	1.42	1.76	$t(19)=5.64$, $p<.0001$
Total Fixation Time (ms)	787.17	1049.36	$t(19)=5.35$, $p<.0001$
Ave Dist. off Road (pixels)	0.0127	0.0383	$t(19)= 1.300$, $p=.209$

Table 3. Primary Study Results (N=20) (ZC vs. ZC without Cursor)

However, when we compared ZC to ZC without cursor, we saw a small, but statistically significant difference. Even though this effect is much smaller than the six-fold effect of the primary result, this shows that cursor information is helpful in locating information (Table 3).

Measure	ZC & ZC+R Means	ZC & R Means	ZC & ZC+O Means
Number of Glances	1.42 & 1.53 $t(19)=2.05$, $p=.055$	1.42 & 1.57 $t(19)=3.68$, $p=.002$	1.42 & 1.56 $t(19)=3.43$, $p=.003$
Total Fixation Time (ms)	787.17 & 832.25 $t(19)=1.18$, $p=.094$	787.17 & 925.63 $t(19)=3.90$, $p=.001$	787.17 & 902.86 $t(19)=4.10$, $p=.001$
Ave Dist. off Road (pixels)	0.0127 & 0.0182 $t(19)=0.80$, $p=.435$	0.0127 & 0.0258 $t(19)=1.55$, $p=.137$	0.0127 & 0.0249 $t(19)=1.13$, $p=.273$

Table 4. Primary Study Results (N=20) (ZC vs. ZC+R, R, ZC+O)

Table 4 presents the comparison results of four presentation methods. ZC was used for baseline comparison. In general, there was no significant difference in driving performance. There was also no significant difference found between ZC and ZC+R. However, there was a small but statistically significant difference in the measure of no. of glances and total fixation time in the comparison of R and ZC+O with ZC.

This is possibly due to design defects in R and ZC+O. Because R lacks the zoom-in-context feature, it may be less effective. Additionally, this visualization style effectively used only one quarter of the screen real estate for presenting pertinent information (Figure 13). In ZC+O, two information sources create complexity on the screen, forcing the driver to perceive two pieces of information at once. Due to the presentation of the route, sometimes the small overview would overlap the large rendition of the route. This creates additional complexity, and a problematic use of screen real estate (Figure 13).

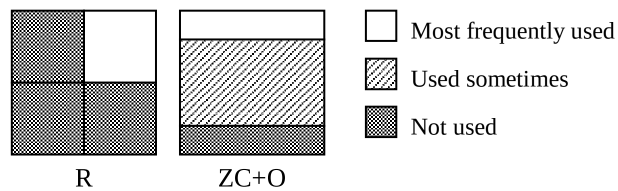


Figure 13. Use of screen real estate in R and ZC+O. Only small part of the screen was used for information display.

Finally in comparing East, West, North, South visualizations in MOVE, there were no significant differences. This may be due to the fact that this was a laboratory study, and cardinal information may be less salient than in a real driving situation.

CONCLUSION AND FUTURE WORK

This paper has presented early research and concepts relating to the MOVE system, which will provide contextually optimized maps for in-vehicle navigation. Our studies show that the use of abstracted and simplified route depictions support the way people generate and use maps. Our experimental results show that our contextually optimized displays should dramatically decrease the driver's perceptual load during navigation tasks. Specifically, the dynamic displays were able to substantially reduce not only the number of glances but also the fixation time for each navigation task. Additionally, we found that driving performance was less affected when subjects used contextually optimized displays.

Despite very promising results, work is still needed to further validate these results both inside the lab and especially in the context of real driving. However, because the differences found here are so large (i.e., a factor of six less time looking away), even if notable effects of the differences between the laboratory and actual driving conditions are found, we can still expect substantial improvements.

More understanding is also needed about whether cardinal orientation – changes in the display heading north-up vs. south-up, east-up or west-up – will be a significant factor when driving. Future testing in a driving simulator, as well as road tests in the vehicle, will begin to provide answers to these questions.

Finally, these initial studies have focused only on the processing of visual information. However, other research indicates that perceptual load can be reduced when auditory information augments visual information. Our future studies will help to understand how auditory information might be included in the MOVE system.

ACKNOWLEDGEMENTS

This work has been funded in part by General Motors Corporation and in part by the National Science Foundation under Grant IIS-01215603. Thanks to Marisa Manheim and Erika Persson for their assistance with study 1.

REFERENCES

1. Agrawala, M. and Stolte, C. Rendering Effective Route Maps: Improving Usability through Generalization in *SIGGRAPH 2001.* (2001). Los Angeles, CA: ACM Press. pp. 241-249.
2. Bederson, B.B. and Hollan, J.D. Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics in *UIST 1994.* (1994). Marina Del Ray, CA: ACM Press. pp. 17-26.
3. Bederson, B.B. Fisheye Menus in *UIST 2000.* (2000). San Diego, CA: ACM Press. pp. 217-226.
4. Bederson, B.B., Meyer, J., and Good, L. Jazz: an extensible zoomable user interface graphics toolkit in Java in *UIST 2000.* (2000). San Diego, CA: ACM Press. pp. 171-180.
5. Bier, E.A., Stone, M.C., Pier, K., Buxton, W., and DeRose, T.D. Toolglass and Magic Lenses: The See-through Interface in *SIGGRAPH 1993.* (1993). Anaheim, CA: ACM Press. pp. 73-80.
6. Campbell, J.L., Carney, C., and Kantowitz, B.H. *Human Factors Design Guidelines for Advanced Traveler Information Systems (ATIS) and Commercial Vehicle Operations (CVO)*, U.S. Department of Transportation, Federal Highway Administration, Technical Report FHWA-RD-98-057. (1997). Washington, D.C.
7. Furnas, G.W. Generalized Fisheye Views in ACM *CHI 1986.* (1986). Boston, MA: ACM Press. pp. 16-23.
8. Golledge, R.G., *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes.* (1999). Baltimore, MD: Johns Hopkins University Press.
9. Green, P., Levison, W., Paelke, G., and Serafin, C., *Preliminary Human Factors Guidelines for Driver Information Systems.* The University of Michigan Transportation Research Institute, Technical Report UMTRI-93-21. (1993). Ann Arbor, MI.
10. Green, P., *Visual and Task Demands of Driver Information Systems.* The University of Michigan Transportation Research Institute, Technical Report UMTRI-98-16. (1998). Ann Arbor, MI.
11. Ishizaki, S. Multiagent Model of Dynamic Design: Visualization as an Emergent Behavior of Active Design Agents in *CHI 1996.* (1996). Vancouver, B.C. Canada: ACM Press. pp. 347-354.
12. Ito, T. and Miki, Y. Japan's Safety Guideline on In-Vehicle Display Systems in *Proceedings of the Fourth ITS World Congress.* (1997). Brussels, Belgium: VERTIS.
13. JAMA (Japan Automobile Manufacturers Association) *Guideline for In-Vehicle Display Systems*, version 2.1.
14. Kishi, H., Sugiura, S., and Kimura, K. Visibility Considerations for Automobile Navigation Displays (in Japanese) in *Jidosha Gijutsu (Journal of the Society of Automotive Engineers of Japan)*. (1992). **46**(9): pp. 61-67.
15. MacEachren, A.M., *How Maps Work: Representation, Visualization, and Design.* (1995). New York, NY: Guilford Press.
16. Mackinlay, J.D., Robertson, G.G., and Card, S.K. The Perspective Wall: Detail and Context Smoothly Integrated in *CHI 1991.* (1991). New Orleans, LA: ACM Press. pp. 173-176.
17. Monmonier, M.S., *How to Lie with Maps*. (1996). Chicago, IL: The University of Chicago Press. pp 25-42
18. Rockwell, T.H. Spare Visual Capacity in Driving - Revisited: New Empirical Results of an Old Idea in *Vision in Vehicles II.* (1988). Amsterdam: Elsevier Science B.V. (North-Holland). pp. 317-314.
19. Society of Automotive Engineers, *SAE Recommended Practice Navigation and Route Guidance Function Accessibility While Driving*. (SAE 2364). (2000). Warrendale, PA: Society of Automotive Engineers.
20. Society of Automotive Engineers (April 2002 revision), *SAE Recommended Practice Calculation of the Time to Complete In-Vehicle Navigation and Route Guidance Tasks*. (SAE J2365). Warrendale, PA: Society of Automotive Engineers.
21. Taoka, G.T. Duration of Drivers' Glances at Mirrors and Displays in *Institute of Transportation Engineers Journals*. (1990). **60**(10): pp. 35-39.
22. VICS Promotion Council, *VICS Promotion Council Safety Committee Report on Information Display*. (Chapter 2 “Safety” Group). (1993). Tokyo, Japan: VICS Promotion Council.
23. Wickens, C.D. and Hollands, J.G., *Engineering Psychology and Human Performance.* 3rd ed. (2000). Upper Saddle River, NJ: Prentice Hall.
24. Wierwille, W.W., Antin, J.F., Dingus, T.A., and Hulse, M.C. Visual Attentional Demand of an In-Car Navigation Display System in *Vision in Vehicles II.* (1988). Amsterdam: Elsevier Science B.V. (North-Holland). pp. 307-316.
25. MapPoint, http://mappoint.msn.com