University of Minnesota

A Next Generation Non-Distracting In-Vehicle 511 Traveler Information Service

FINAL REPORT

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16. Abstract (Limit: 250 words)

This study investigates the current features of state and proprietary traveler information applications, elements of good design and usability, human factors issues regarding visual and cognitive distraction, and makes recommendations for the next generation of Minnesota's traveler information application, MN 511. Traveler information systems were created to serve drivers by providing accurate information about traffic and road conditions before drivers began their trip. The advancement of cellular telephones provided a new opportunity for drivers to access traffic and road information en-route, but introduced considerable cognitive distraction on drivers navigating the complex phone trees. The evolution of traveler information systems onto smartphone applications has eased the cognitive demand previously imposed by phone tree systems, but has shifted the demand to drivers' visual resources. The dichotomy between state-funded 511 travel information applications and proprietary traveler information applications is primarily determined by the features each contains. The common features included in the current proprietary traveler information applications provide insight into the opportunities for future iterations of MN 511 mobile applications. The MN 511 application can continue to improve by incorporating select features from proprietary applications, such as voice commands, route guidance, saved places, and travel time estimates, while taking into account cognitive workload and visual distraction. This is important because publicly funded traveler information applications have a greater responsibility, compared to proprietary applications, to account for distraction and ensure the safety of its users.

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Executive Summary

Traveler information systems were created to serve drivers by providing accurate information about traffic and road conditions before drivers began their trip. The advancement of cellular telephones provided a new opportunity for drivers to access traffic and road information en-route, but introduced considerable cognitive distraction on drivers navigating the complex phone trees. The evolution of traveler information systems onto smartphone applications eased the cognitive demand previously imposed by phone tree systems, but shifted the demand to drivers' visual resources. Manipulating a cell phone, for calling or texting, has been demonstrated to be hazardous to safe driving and consequently, has been made illegal in many states (e.g. Horrey & Wickens, 2004; Rakauskas, et al., 2005; Radeborg, Briem, & Hedman, 1999; Strayer, Drews, & Johnston, 2003). Public state traveler information applications have largely been created with the intent that drivers will only access the information "pre-trip" and not en-route. Unfortunately, some drivers will persist despite application warnings and will use smartphone applications while driving. This study investigates the current features of state and proprietary traveler information applications, elements of good design and usability, human factors issues regarding visual and cognitive distraction, and makes recommendations for the next generation of Minnesota's traveler information application, MN 511.

The dichotomy between state-funded 511 travel information applications and proprietary traveler information applications is primarily determined by the features each contains. The common features included in the current proprietary traveler information applications provide insight into the opportunities for future iterations of MN 511 mobile applications. The MN 511 application can continue to improve by incorporating select features from proprietary applications, such as voice commands, route guidance, saved places, and travel time estimates, while taking into account cognitive workload and visual distraction. This is important because publicly funded traveler information applications have a greater responsibility, compared to proprietary applications, to account for distraction and ensure the safety of its users.

Good usability and a proper interface can be achieved by providing users with a) controls and displays that are highly visible and easily interpretable, b) internal consistency, c) an interface that is consistent with their convention and previous experiences, d) timely visual and auditory feedback, e) explicit messaging to help users recognize and correct the error, and f) control and freedom to undo incorrect actions. Features that improve usability and user's trust in a system during *pre-trip* planning, using either a 511 application or navigation application, include presenting a route overview (ideally with a destination entry), the ability to remember the user's preferences (e.g. layers or destinations), and providing users with all the available alternative routes and all the necessary information that the users will need to weigh these alternatives. Usability and user's trust in a system providing *en-route* information can be increased by providing users with a) sufficient detail about the starting location/direction at the beginning of route guidance, b) the target address and an indication of whether the destination is on the left of right side of the road as driver approaches the destination, c) precise distance information, d) timely, brief and concise auditory turn-by-turn directions, e) auditory directions that are synced up with the visual display, f) a clutter free interface through layering, use of 2D maps as opposed to 3D maps, and labeling street names parallel with the street orientation, g) the benefits of a

suggested detour, and e) timely rerouting guidance. However, these features are best implemented by integrating a 511 traveler information system with a navigation system.

Visual distractions produce a larger decrement in driving performance than cognitive distractions, which are often imposed by auditory message, suggesting that re-design efforts should be first channeled towards reducing visual demand through usability standards and subsequently channeled toward reducing auditory demand. Cognitive distraction can also be potentially reduced by implementing a) a multimedia system that uses auditory presentations for alerting functions and visual display to present details of the turn and spatial information and b) a speech interface with high recognition rate.

MN 511 currently includes many features which enable it to be competitive with other states; however, it lacks some of the more advanced features which today's technology-savvy users come to expect. Recommendations for improvement include clutter reduction, reduction in visual distractions, customizable features (e.g. points of interest, favorite routes, and history of addresses and locations) and inclusion of *route specific* verbal information. Moving towards a multi-media system is highly encouraged. The overall recommendation, given the in-depth investigation into 511 and proprietary applications nationwide, is for Minnesota to integrate MN 511 with a low-distraction navigation system that would thereby reduce driver stress and convert to a text-to-speech based system to meet the needs of today's drivers and result in higher user satisfaction.

Chapter 1. Introduction

The use of traveler information systems has a long history of providing support and guidance to drivers both in Minnesota and nationwide. The consistent goal through the evolution of traveler information systems has been to enhance traffic flow and improve safety by keeping drivers informed regarding road and traffic conditions. The genesis of traveler information systems began to address drivers' needs "pre-trip" by allowing drivers to access information and make travel decisions from their home or office, for example (McQueen, Schuman, & Chen, 2002). Users making calls from landlines have full cognitive capacity at their disposal for information processing and thus are less susceptible to dangers of distraction should the system require maximal mental demand. The structure of these systems still required intuitive structure and flow to limit user frustration; however, poor design had little danger beyond infrequent use by its intended population.

The advent and proliferation of cellular phones complicated the use and requirements of traveler information systems, often called 511, because drivers were able to use the information "on-trip" (McQueen, Schuman, & Chen, 2002) where cognitive resources are less readily available; therefore, good usability and intuitive structure is essential for 511's success and safety. An extensive body of literature demonstrates the danger of distraction for drivers engaged in handheld and hands-free phone conversations (e.g. Horrey & Wickens, 2004; Rakauskas, et al., 2005; Radeborg, Briem, & Hedman, 1999; Strayer, Drews, & Johnston, 2003). Kelley and colleagues (2005) demonstrated that navigating through complicated 511 phone menus while driving is of equal risk to that of a hands-free phone conversation. Indeed, previous work done by the University of Minnesota demonstrated that drivers reported increased mental effort and had delayed driving response time while interacting with the Minnesota 511 phone menu compared to driving alone (Rakauskas & Ward, 2007). The most sophisticated 511 phone menus have now been modernized to locate the position of a driver to provide the most relevant information to them, as well as customize the information presented based on a driver's preferences. These advancements in intelligent 511 phone systems have improved usability, while reducing distraction potential and risk, and have continued to meet the goal of providing up-to-date traffic and road conditions to drivers.

While many states are continuing to modernize and update their 511 phone based systems, a majority of states have shifted their attention to smartphone application based systems. These applications contrast with existing distracted driving laws which prohibit drivers from texting or otherwise interacting with a cell phone while driving. Many states, including Minnesota, have embedded an immediate pop-up agreement upon launching the application requesting that drivers agree to not use the application while driving. This attempts to retain the application as a "pre-trip" tool for access to information and route decision making. Although such an approach serves a sound safety and legal rationale, it is widely known that drivers can and do use 511 smartphone applications as an "on-trip" information source. Given that many of the state 511 smartphone applications have just recently been developed, little research exists regarding the distraction potential of using these new systems while driving. Relevant findings can be drawn from studies examining other types of in-vehicle traveler information systems, such as GPS-based systems. Additionally, human factors and usability principles can be utilized to deduce the extent to which 511 smartphone applications, Minnesota 511 in particular, are likely to pose a substantial risk to driving safety.

The purpose of this investigation is to examine the current state of 511 smartphone based systems available across the nation, determine how proprietary applications compare and contrast with state applications, and describe the human factor principles that should be taken into consideration in designing traveler information applications. This examination will also describe how Minnesota's 511 smartphone application compares to other states' and the usability issues and distraction potential that may be present in Minnesota's 511 smartphone application. Finally, recommendations are made to improve Minnesota's 511 smartphone application to improve usability, user satisfaction, and most importantly, to reduce the distraction potential for drivers who chose to access it while driving.

Chapter 2. Traveler Information Application Review

Chapter 2 provides a review of the present and commonly used state and proprietary traveler information applications on the market. The review describes the prevalence of various features of the applications in the marketplace. This establishes which features, at a minimum, would allow the state of Minnesota to remain competitive with other state DOT's 511 applications, as well as indicate the status quo for many proprietary applications. These summaries illustrate the wide range of features available in each state's 511 application, as well as identify a stark contrast in the capabilities between state and proprietary applications.

2.1. State 511 Traveler Information Smartphone Application Review

This review aims to establish which features, at a minimum, would allow the state of Minnesota to remain competitive with other state's 511 applications. Additionally, it may inform the design or modification of the current 511 application. Information was gathered through online sources and through an online survey request to states' Department of Transportation. The survey queried states regarding the existence or status of their 511 application, the features of the application, any information collected from the application, and the extent to which distraction was considered in the design of the application. Fully completed surveys from 21 states were received and the information shared was incorporated into the summary. States with an asterisk by their name indicate those who responded to and completed the survey request. All states were examined in this investigation, including those who did not respond via survey; however, the results of the status of the 511 application of the non-responsive states were limited to public information on mobile application marketplaces.

The summary identifies and describes the prevalence of various application features in the marketplace. Based on a combination of public user reviews and the survey results from 21 respective states' Department of Transportation, a breakdown of the basic pros and cons is provided for each state's application.

2.1.1 Status of 511 Smartphone Applications by State

The adoption of 511 smartphone application systems is varied across the country from state to state. Below is an in-depth summary of the current state traveler information applications on the market. Some states have chosen not to create a 511 smartphone application; instead, some have opted for a mobile version of their 511 website while others may have yielded to existing proprietary traveler information applications to avoid having to compete with them.

Table 1 indicates the frequency of 511 applications (app) across 50 states. The table denotes if a state has an app in the marketplace (shaded in blue) or if it is in progress (shaded in green), if they have a mobile version of the traveler information website (in addition or in place of an app), by whom the app was built, and if the app has social media alerts. State applications are grouped according to production company or in-house production. Based on the findings of this investigation, 26 states currently have a traveler information smartphone application on the market or are in progress; however, mobile versions of the states' 511 websites are slightly more common with 30 states offering them. All states' 511 full version websites can be viewed from smartphones, but without a mobile version of the site, users must view small text, zoom in on each feature, and scroll side to side once zoomed in. This solution is not an ideal solution for good usability and is highly problematic and dangerous for use while driving. Finally, many states also rely on social media (Facebook, Twitter, YouTube, RSS, and texting) as alternative methods of disseminating traveler information to road users.

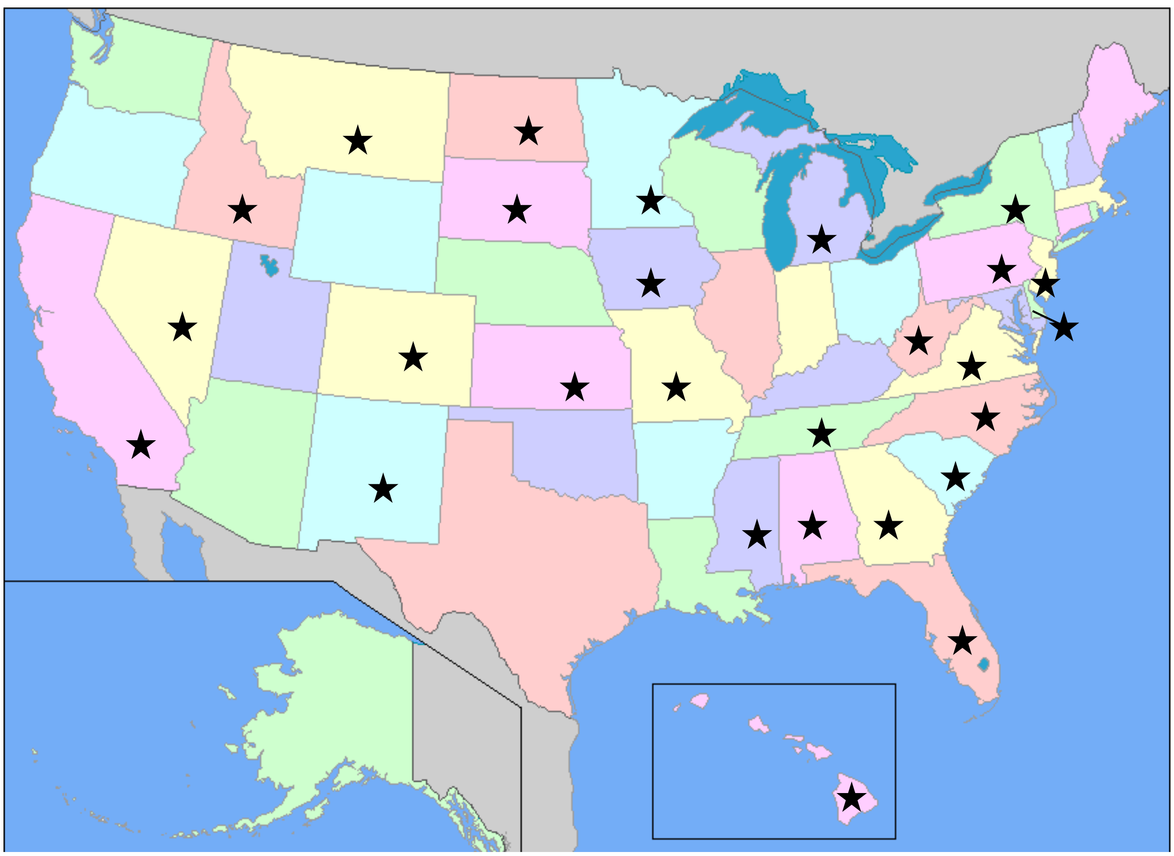

Figure 1. Map representing the frequency of 511 smartphone applications across the United States. Stars indicate states with applications which are current or in progress.

Table 1. Frequency and status of Traveler Information (511) Applications by state

	511 smartphone app	Mobile Web Version	App name	Built by:	Social Media Alerts
Alabama	In Progress	Yes	n/a		
Alaska	No	Yes	n/a		Twitter and Facebook
Arizona*	No	Yes	n/a		Twitter and YouTube
Arkansas	No	No	n/a		Twitter
California*	Yes, Southern CA	Yes + QR	IE511		Twitter, Facebook, and YouTube
Sacramento	In progress	No		Castle Rock Associates	
Colorado	Yes	Yes		urHub	Text & Email
Connecticut	No	No			Twitter
Delaware	Yes	Yes	DelDOT	In-house	Twitter
Florida	Yes	Yes	Florida 511	LogicTree	
Georgia*	Yes	No	GDOT 511	Iteris, inc.	Twitter, Facebook, and YouTube
Hawaii	Yes	No	Go Akamai (O'ahu only)	ICx Transportation Group, Inc.	
Idaho*	In Progress	Yes		Castle Rock Associates	
Illinois	No	No			Twitter
Indiana	No	No			
Iowa*	Yes	Yes	Iowa 511	TransCore, LP	Twitter and Facebook
Kansas*	In Progress	Yes			
Kentucky	No	Yes			
Louisiana	No	Yes			Twitter and Facebook
Maine	No	No			
Maryland	No	Yes			Twitter
Massachusetts	No	No			Twitter
Michigan*	In Progress	No			
Minnesota*	Yes	Yes	Minnesota 511	Castle Rock Associates	Twitter
Mississippi*	Yes	Yes	MDOTTraffic	NIC Inc.	
Missouri*	Yes	Yes	MoDOT Traveler Information	In-house	Twitter, Facebook, and YouTube

Blue = State has 511 mobile application for smartphones

Green = State has 511 in the process of building app or plans to build app in the near future

White = No 511 application available to public

* Indicate states that responded to survey

Table 1. Frequency and statue of Traveler Information Applications by state: Continued

Montana*	Yes	Yes	MDT Travel Info	In-house	Twitter, Facebook, and YouTube
Nebraska	No	No			
Nevada*	In Progress	Yes	My511NV	-Unknown	Twitter and Facebook
New Hampshire	No	Yes			Twitter
New Jersey	Yes	No	SafeTrip NJ	Information Logistics, Inc.	
New Mexico	Yes	Yes	NMRoads	In-house	RSS
New York	Yes	Yes	511NY Mobile App	In-house	
North Carolina*	No	Yes –no map, just 511 info			Twitter
North Dakota*	Yes	No	ND Roads (North Dakota Travel)	In-house	RSS
Ohio	No	Yes: OHGO.com			Twitter and RSS
Oklahoma	No	No			Twitter and YouTube
Oregon	No	Yes: TripCheck.com			Twitter
Pennsylvania*	In Progress	Yes	511 PA		
Rhode Island*	No	No			
South Carolina	Yes	No	SCDOT 511	Iteris, Inc.	Twitter
South Dakota	Yes	No	SDDOT 511	Iteris, Inc.	Twitter
Tennessee*	Yes	Yes	TDOT SmartWay	In-house	
Texas*	No	Yes			
Utah*	No	Yes			
Vermont	No	No			Twitter
Virginia	Yes	No	VDOT 511	Iteris, Inc.	
Washington*	No	No			
West Virginia	Yes	No	WV 511 Drive Safe	Information Logistics, Inc	
Wisconsin	No	Yes			Twitter, YouTube, Facebook, and RSS
Wyoming*	No	Yes			Text alerts

Blue = State has 511 mobile application for smartphones
Green = State has 511 in the process of building app or plans to build app in the near future
White = No 511 application available to public
* Indicate states that responded to survey

2.1.2. 511 Smartphone Applications Common Features

Table 2 indicates the prevalence of common features among the states' 511 applications. The table denotes (in orange) if a state's current application has a corresponding feature. This table indicates which features tend to be most common or standard for current 511 applications and should be included, at a minimum, to remain competitive with other states. The table also displays the average rating (out of 5 points) from Google reviews (via Google Play Store) which provide a proxy for evaluation since an in-depth investigation of each application is no feasible. These reviews are not intended to suggest that an application features good usability or is free of distraction. The common or standard features include: free of charge, mapping, weather conditions, construction, incidents and closures, traffic density/times, and cameras. Weather conditions and traffic density/times are the two features which are not available through select applications, while GPS location tracking on the map is rarely featured across the applications. With distraction as a key consideration in design, West Virginia and New Jersey feature a hands-free, eyes-free application, so no map is available for users to view.

Table 2. State Applications – Common features

	Google Reviews	Cost	Map	Weather conditions	Construction	Incidents and Closures	Traffic density /times	Cameras
California southern*	3.5/5.0	Free						(live)
Colorado	2.9/5.0	Free						(live)
Delaware	4.6/5.0	Free						(live)
Florida	4.2/5.0	Free	**					(live)
Georgia*	2.8/5.0	Free	**					(static)
Hawaii	3.3/5.0	Free						
Iowa*	3.8/5.0	Free						(live)
Minnesota*	3.0/5.0	Free						(static)
Mississippi*	4.7/5.0	Free						(live)
Missouri*	4.0/5.0	Free						(live)
Montana*	4.6/5.0	Free						(static)
New Jersey	3.7/5.0	Free	**					
New Mexico	3.8/5.0	Free						(live)
New York	2.8/5.0	Free						
North Dakota*	4.4/5.0	Free						
South Carolina	4.0/5.0	Free	**					(static)
South Dakota	4.3/5.0	Free						(static)
Tennessee*	3.3/5.0	Free						
Virginia	3.4/5.0	Free	**					(live)
West Virginia	3.4/5.0	Free	**					

Orange = Application has this feature	* Participated in survey
White = Application does not have this feature	** Tracks user location (GPS)

2.1.3. 511 Smartphone Applications' Less Common Features

Table 3 indicates the frequency of the less common features in the current states' 511 applications. The table denotes (in orange) if a state's current application has a corresponding feature. These features indicate which states' 511 applications tend to be more advanced. These features are recommended for implementation to offer more sophisticated assistance to motorists. The more advanced features observed were submit report/incident (from the driver), voice alerts, pre-trip route, background running, changeable message signs (CMS), history/favorites/saved, filtered/layers/alerts, and push alerts. The ability to save favorite information and customize the filtering or layering of information (e.g. superimposing traffic and weather conditions at once, but restricting information about road construction) increases usability and user satisfaction.

Table 3. State Application – Less common features

	Submit report/ incident	Voice alerts	Pre-trip route plan	Background running	CMS **	History/ Favorites / Saved	Filtered/ Layered Alerts ***	Push Alerts
California southern*					(orange)		*** (orange)	
Colorado								
Delaware					(orange)			
Florida	(orange)	manual (orange)	(orange)				(orange)	
Georgia*			(orange)		(orange)	(orange)	*** (orange)	(orange)
Hawaii								
Iowa*					(orange)		*** (orange)	
Minnesota*							(orange)	
Mississippi*						(orange)		(orange)
Missouri*			(orange)	(orange)	(orange)	(orange)	*** (orange)	
Montana*							*** (orange)	
New Jersey		(orange)					(orange)	
New Mexico					(orange)			
New York								
North Dakota*			(orange)	(orange)		(orange)	*** (orange)	
South Carolina					(orange)		*** (orange)	
South Dakota								
Tennessee*			(orange)		(orange)	(orange)	(orange)	(orange)
Virginia			(orange)			(orange)	*** (orange)	(orange)
West Virginia	(orange)	auto (orange)		(orange)			(orange)	(orange)

Orange = Application has this feature | White = Application does not have this feature

* Participated in survey
** Changeable Message Signs
*** These include heterogeneous alerts (e.g. the map shows cameras + construction + incidents + traffic all at once)

2.1.4. 511 Smartphone Applications Pro and Con Evaluation

User reviews gathered from the Google Play Store and each state's response to the online survey provided insight into which aspects of the state's 511 application were beneficial to users and which were perceived as having poor design or functionality. Potentially related to launch dates, some state applications had fewer reviews than others which made drawing conclusions regarding their strengths and weaknesses more difficult. Table 4 details the most commonly mentioned user cited pros and cons by state and features an additional comments section for each state, where applicable. The most commonly rated features for the "pros" section were: customizable features (e.g. combination of presentation of information, destination, pre-defined routes), filtering, layering, hands-free, and cameras. The most commonly rated features for the "cons' section were: attention/text heavy, slow running and crashing, and pressing "back" difficulties (i.e. difficulties with returning to the previous screen).

Table 4. State 511 Application Pro and Con Evaluation

	Pros	Cons	Comments
California southern (IE 511)*	1. Users can customize the combination of incidents shown on the map 2. Incident descriptions are easy to open and close 3. Displays bus and rail provider times, carpool and vanpool maps, and Park and Ride information	1. Pressing "back" on phone closes app- to go back, need press top right corner (uncomfortable while driving or 2 hands) 2. Does not save map preferences (must choose from list of events each time)	State has plans to move phone based apps to mobile webpages using html 5
Colorado		1. Too many advertisements 2. GPS runs in background and slows the phone operation by consuming too many resources 3. Cumbersome 4. Limited and inconsistent highway information	
Delaware	1. Traffic maps and cameras are real-time		
Florida	1. Estimated travel times based on location and direction of travel 2. Syncs to MyFL511 routes from website. 3. Option of text, map, or audio updates 4. Filter construction alerts	1. If user stops incident alerts, must reload and reset the application to resume alerts 2. Text-heavy applications (attention-demanding to find relevant info) 3. text-to-speech: have to first find the incident then press play	

Table 4. Pro and Con Evaluation: Continued

	Pros	Cons	Comments
Georgia*	1. Pre-defined route has customizable info (incident->area->road->incident list->choose incident) 2. Map has layered/filtered events (by incident type) 3. News/alerts section is organized to priority 4. User can set up profile to receive personalized travel notifications 5. Live Changeable Message Signs (CMS) are easy to read	1. Attention-heavy (visual/manual); no voice 2. Pressing back takes you through each previous action (waste time, distraction) 3. Alerts section has some information irrelevant to current commute (e.g. construction areas/times/dates) 4. Special Events section is can be irrelevant to commute 5. Reviews: events are outdated; unreliable construction info; leading users distrust 6. Large menu with small print leading to trouble navigating through screens 7. Prone to be slow, freeze or crash 8. Review: traffic often inaccurate with intermittent cameras	Collects info on location of application users.
Hawaii	1. Travel time estimation is helpful	1. Intermittent camera availability 2. Data loads slowly	
Iowa*	1. Zoomable, scrollable display 2. Highway rest areas listed with commercial vehicle restriction information 3. Part of a larger Iowa DOT suite of apps containing aviation (Airport directory, weather, etc), bike maps, DL Docs, etc. 4. Voice commands and number selection provide shortcuts for "road reports(1)", "metro reports(2)", "truckers reports(3)", "nearby states 511(4)", and "help(##)", etc.		"[In the next year,] we're moving to a hands-free, eyes-free app that will be more interactive with the driver without having them need to type or do anything on the screen. We hope to … personalized routes integrated with the app." "Our initial launch is for a non-driver, but we always had our long term plan to have it be hands-free, eyes-free..." (survey response)

Table 4. Pro and Con Evaluation: Continued

	Pros	Cons	Comments
Minnesota*	1. Zoomable Google map display 2. Has all basic features of traffic report/road information 3. Allows you find current location 4. Organized into menu of features 5. Access to menu is quick and easy (1 click)	1. Distracting/Attention (manual, visual, cognitive distraction) 2. Small features (need to stare rather than glance to read features; demands significant attention) 3. Have to "find" the target (e.g. search for specific road, hard to zoom in on exact location) 4. Much clicking involved to reach each destination feature (must click on each tab and zoom in on each location's notification) 5. No navigation or route info. 6. Driver has to use mental resources to combine information 7. Must re-open app each time after closing (no background run) 8. No speech-to-text input/output 9. No points of interest (e.g. MOA, Lake Calhoun) or address input 10. Runs slowly and is unreliable 11. Hitting "back" puts you through all previous actions 12. Once the cam is viewed, the image will not be updated 13. No legend for colors	
Mississippi*			Fully considered driver distraction while designing app.
Missouri*	1. Winter road conditions, incidents, work zones, and traffic speeds are the four most useful features for customers 2. Camera feature is popular, but there isn't a streaming option	1. No streaming for cameras 2. Currently, the app does not utilize active alerts to users (text alerts, audible alerts, etc.). 3. Default options for road conditions is 'off' so people think roads are clear when in fact they have not switched the toggle to 'on'	"Several features have been tabled [for] consideration on the effects of distracted driving, e.g., users of the app cannot currently provide any reporting. Strictly provides info to user."
Montana*		Potential issues arise with color-blind users	
New Jersey	Hands free, real-time advisories; User can alter the mile range for the advisory radius	1. Outdated work zone information and new work zones not entered. 2. Provides alerts not relevant resulting in confusion and distraction	
New Mexico			Incorporated an "I'm not driving" agreement for users

Table 4. Pro and Con Evaluation: Continued

	Pros	Cons	Comments
New York		1. Rare traffic stream updates 2. Not streamlined enough 3. Frequent crashes	
North Dakota*	1. Current radar 2. NWS wind speeds 3. Message center for important messages 4. Load restriction info 5. Searchable text versions		
South Carolina	1. CMS easy to read/see 2. fast speed (cams, other) 3. heterogeneous alerts	1. text-heavy (except CMS), list-heavy (read through to find relevant info) 2. small print	
South Dakota	1. Helpful camera views 2. Winter road reports	1. Map legend is difficult to find	
Tennessee*		1. System lacks many features that would be useful 2. Doesn't have many of the same features on the website 3. Doesn't properly track location	Some consideration was given to driver distraction. "Knowing that some drivers will use the app unsafely our marketing is geared toward "Know before you go" and [passenger use]."
Virginia	1. Voice alerts 2. Application keeps track of user location as driver moves; notifies driver of problems ahead (voice) 3. choose distance of alerts received (5,10 mi ahead) 4. Basic (No cameras) vs. passenger (cameras)	1. Travel times: text-heavy (list, words)	
West Virginia	1. Hands-free (reads off all info within radius, no visual attention needed) No visual information 2. Option to adjust mile radius of alerts picked up 3. Background running 4. Can "pause" app then "play" again 5. If no GPS signal, highest precision location tool available used (e.g. cell tower)	1. No map (for quick traffic overview or alerts) 2. only find out about alerts as you go (no pre-planning) 3. no navigation 4. too much distracting info regarding irrelevant surrounding routes 5. Always have to be tuned in to what app is about to say in case you miss it	

2.1.4. Survey Feedback: Driver Distraction

The survey sent to states queried them regarding the extent to which they considered driver distraction in the design of the application. The table below demonstrates the variability in the extent to which states took distraction into account. While 33% fully considered distraction, the remaining reporting states considered distraction to a lesser extent or not at all.

Table 5. States' consideration toward distraction

"To what degree did you consider driver distraction when designing your application?"			
#	Answer	Response	%
1	Did not consider distraction (non-driving use only)	3	20%
2	Minimal consideration	4	27%
3	Some consideration	3	20%
4	Fully considered in the design to allow safe use while driving	5	33%
	Total	**15**	**100%**

2.1.5. Survey Feedback: Information Privacy

Finally, the survey sent to states queried them regarding the extent to which information is collected about the driver from their application. The table below demonstrates that it is less common (i.e. less than or equal to 25%) for states to collect location information, crash reporting, or driver demographics. A majority of the reporting states collect no information from application users or use.

Table 6. Frequency of information gathered by state DOTs

"Please indicate what information (if any) your state DOT collects from application users/use."			
#	Answer	Response	%
1	Driver demographics	1	6%
2	Location	4	25%
3	Crash reporting	2	13%
4	Weather reporting	0	0%
5	Road conditions (i.e. potholes)	0	0%
6	Speed	0	0%
7	Other	0	0%
8	No data collected from users/use	10	63%

2.2. Proprietary Traveler Information Smartphone Application Review

The features of commonly marketed proprietary traveler applications are displayed to highlight potential user expectations for state 511 applications. While some of these features may not be feasible for a state DOT to provide, they will, nonetheless, impact users' experiences and perception of the usefulness and quality of a 511 application. This review is by no means an exhaustive investigation of all of the applications available on the market. The applications included in this review were chosen due to their popularity and the range of features they represent.

The summary identifies and describes the prevalence of various application features in the marketplace. Based on a combination of public user reviews and an internal investigation of the features of each application, a breakdown of the basic pros and cons is provided for each proprietary traveler application.

2.2.1. Features of Proprietary Apps

Table 7 indicates the frequency of common features of proprietary traveler applications. The table denotes (in orange) if an application has a corresponding feature. This table indicates which features tend to be most common or standard for current proprietary applications and represent what users are likely to expect from a state application. Live maps, navigation, and GPS location services are automatically included in all applications included in the table. Navigation (or turn-by-turn routing) and GPS location are infrequently included in state 511 applications given their complexity and cost. The average Google user rating (out 5 possible points) is displayed for each application.

Other common features include: free of charge, voice commands, travel times, history/saved places, background running, push notifications, zoom-able, points of interest, traffic density, and road work. The features that are less standard include: alternative routes, incidents, speed limits, incident reporting by user, traffic cameras, offline ability, lane assistant, weather conditions, speed assistant, and speed camera notification. Offline ability appears to be directly related to the cost of the application. Users who do not wish to grant access of their personal information to the application's company are limited to applications at cost.

It is difficult to ascertain the degree to which these applications were designed with distraction in mind. In particular, Sygic features a head-up display to limit visual distraction from the interface. This is a valuable feature, especially in states, like Minnesota, which have legislation preventing drivers from mounting devices on the windshield or within the view of the road because it limits eye or head movements away from the road while staying within the boundaries of the law. Furthermore, voice commands with turn-by-turn navigation assist drivers in their route while simultaneously lowering driver workload and need to visually inspect a map. Some features, like those included in Waze, have the potential to increase distraction and workload by providing non-driving relevant social media updates. More extensive research must be conducted to properly conclude the distraction potential of these applications compared to state 511 applications, like MN 511.

Table 7. Features of top navigation, traffic, and map applications

*All feature live maps, navigation, & GPS in US	Google Maps	Garmin ® Navigator Premium	Sygic + Traffic + Head-up Display (HUD)	Waze	INRIX	MapQuest
Google Reviews	4.3/5.0	3.6/5.0	4.2/5.0	4.6/5.0	3.9/5.0	4.3/5.0
Cost	Free	$7.95/month	33.99 + 16.99 (1 yr traffic subscription)	Free	Free	Free
Voice Commands						
Travel Times						
History/ Saved Places						
Background running						
Push notification						
Zoom-able						
Points of Interest						
Traffic Density						
Roadwork/ Construction						
Alternative Routes						
Incidents						
Speed limits						
Submit/ Report Incidents						
Cameras						
Offline availability	Not default					
Lane Assistant						
Weather/Road Conditions						
Speed Assistant		(major roads)				
Speed Camera Notification		(major roads)				

2.2.2. Proprietary Traveler Applications Pro and Con Evaluation

The proprietary applications were reviewed regarding which features of the applications were favored by users and which were observed as having poor usability or design. The evaluation was created based on user reviews and an internal review of the applications. Table 8 details the most commonly mentioned user cited pros and cons by application and includes additional comments section for each applications, where applicable. The most commonly rated features for the "pros" section were: navigation and routing, accuracy of information, voice commands and customizability. The most commonly rated features for the "cons' section were: difficulty with the voice commands (e.g. computerized voice, volume control, and access), attention-heavy features, and interface issues (e.g. accessing features, understanding information, and clutter).

Table 8. Proprietary Traveler Application Pro and Con Evaluation

Application	Pros	Cons	Comments
Google Maps	1. Alternative routes option 2. "Save map to use offline" option 3. Frequent updates to resolve issues	1. Automated voice is unpleasant 2. Street names are not verbalized instead 'turn left' or 'turn right' instructions are given. 3. Construction zones should be updated more frequently 4. Darker lines and bolder colors should be used for better visibility 5. No location history if you're not signed in to your Google account	- Google Maps is one of the best free apps for navigation on the market based on usability measurements.
Garmin ® Navigation Premium	1. Simple and easy interface 2. High quality 3D map option 3. Update maps frequently	1. Complaints about high data and resource use. 2. There appear to be a lot of bugs and follow up bug fixes 3. Not worth the monthly price for premium 4. No integrated options for sharing location with other apps (e.g. contacts, Google Maps)	- Option to pair a separate HUD device through Bluetooth technology - Last mile navigation, customizable voice options, multi-route trip planner and customizable speed alerts are other key features included in app

Table 9. Proprietary Traveler Application Pro and Con Evaluation (continued)

Application	Pros	Cons	Comments
Sygic	1. Spoken street names 2. Add-in purchases to make commute easier (e.g. traffic times, Head-Up Display, voice of Homer Simpson) 3. 3D cities 4. Notifications for upcoming speed limit changes 5. Maps are stored on phone for later use	1. Needs larger buttons 2. Few complaints about the map layout or usability, mostly about reliability and functionality.	- Uses TomTom maps - Maps stored on device and available offline - Multiple built-in non-distracting qualities (e.g., Head-up Display, spoken street names)
Waze	1. Accurate for traffic information 2. Powered by millions of users so the info is constantly updating 3. Pop-up notifications occasionally appear along your chosen route or within a preset radius. Slow traffic, incidents and accidents, and police presence and speed cameras are among the possible triggers for notifications (reviews.cnet.com). 4. Links to Facebook events	1. Voice command is difficult to find (hidden) on menu 2. Occasionally pop-ups for local business appear, but only when vehicle is at a standstill. 3. The Menu and Reporting buttons are hidden in the interface because they are in the corner of the screen. 4. Too many taps/swipes/clicks to get to final selection of destination when using navigation system 5. Map is cluttered with symbols (other Waze drivers show up on the map)	- Not a reasonable substitute for full navigation app - Connect with Facebook friends nearby, Routes to Facebook event location and cheapest gas stations

Table 10. Proprietary Traveler Application Pro and Con Evaluation (continued)

Application	Pros	Cons	Comments
INRIX	1. Accurate traffic information 2. Great for trip planning 3. Large fonts are used 4. Detects your location (either home or work) and directs you to the appropriate destination (either work or home)	1. No turn-by-turn nav. 2. User can only have 2 saved destinations (Home and Work) or else it costs $24.99 for lifetime subscription 3. No option to send/share a destination to another app that has navigation	- This is simply a traffic app - They embed Google Maps
MapQuest	1. Customizable with multi-stop directions	1. Too much effort for user to choose voice input for directions from current location 2. "the app functions poorly with Talkback accessibility, making it hard to use by the blind" (Google reviewer) 3. Users struggle to get layer options to function smoothly	- This app is pretty basic and comparable to other traffic apps

2.3. State 511 and Proprietary Traveler Application Summary

The dichotomy between state-funded 511 travel information applications and proprietary traveler information applications is primarily determined by the features each contains. By examining the common features included in the proprietary traveler information applications today, we hope to provide insight into where opportunities may lie for future iterations of MN 511 mobile applications. The standards for 511 traveler information sharing are changing, as evidenced by the shift from phone-only systems to mobile-based applications in the past decade. We can continue to help improve the MN 511 application by incorporating certain features from the proprietary applications, such as voice commands, route guidance, saved places, and travel time estimates, while taking into account cognitive workload and visual distraction.

Chapter 3. Human Factors Issues

Chapter 3 provides an extensive review of the literature pertaining to the human factors issues which arise from users interacting with traveler information systems both stationary and while driving. Little research exists regarding the use of 511 smartphone applications while driving. The recent development of en-route notifications (e.g. knowledge cones presenting verbal alerts regarding events in the vicinity of the drivers direction of travel) provided by 511 applications have even smaller presence in the literature, providing little insight into their impact on driving performance. An alternative source of information can be pulled from the vast pool of literature examining how navigation systems impact driving performance. These sources of information are a logical addition to this discussion because they provide insight into how visual and auditory information should be presented to drivers while en-route and to what degree drivers are distracted from their use. Furthermore, it is important to examine how accurate route and destination information may best assist drivers by providing relevant information which reduces rather than increases cognitive workload.

The review describes the obstacles to good usability and safety for applications. Additionally, the cognitive and attentional limitations of users are described to highlight the importance of human factors testing of application interfaces for roadway safety. The intent of this work is to inform the design of Minnesota's MN 511 traveler application to maximize user satisfaction and, most importantly, limit the distraction potential of the application for users who opt to access the information while driving.

3.1. Usability issues

Usability issues are often not considered until later in the design cycle, after many technological decisions have been made and implementation of system change has become too difficult and expensive—this often results in a less than satisfactory design because users must adapt to the system which can be a sore experience. It is best to begin any usability discussion with a summary of what basic design elements are needed to achieve "good design".

3.1.1. What Makes a Good Design?

A proper interface design should allow its users to forget that they are using a computer and focus on the information and task at hand. With a good interface, there should be a fit between the user's needs and the service which the system provides—this can be achieved through the following design principles:

1. Feedback: Timely acknowledgement of user's input through the use of visual and auditory feedback to instill confidence and permit correction of detected error.
2. Error recovery: Explicit messaging to help users recognize and correct the error
3. Grouping: The organization and presentation of display elements or controls takes into account the psychological capabilities of the user. Users tend to perceive objects as belonging together if they are in close proximity or if they share a common visual feature, such as orientation, color, size, or shape. Inappropriate organization of screen information leads to wasted time in interpretation.
4. Flexibility: Provide users control and freedom so that incorrect actions can be undone and allow them to get out of a place they entered by mistake by putting them back to the previous screen
5. Visibility: Controls/displays should be visible across different lighting conditions (e.g. bright sunlight, night time). Size, luminance, colour, and contrast with background all help to minimise the time required to search and find the control/display. The time taken to see an object is directly proportional to its size (Baumann and Thomas, 2001). In low signal-to

background brightness contrast, red would be the easiest to detect, followed by green, yellow, and white, in their respective orders (Sanders and McCormick, 1993).

6. Identification: Before the users operate a control, they should have a good idea of what will happen. Control should be marked with a label or an easily interpretable symbol to help users identify its function (Bhise, 2012).

3.1.2. Usability Issues for Pre-trip Planning and En-route Assessment

Pre-trip planning and en-route assessment and adjustment are two decision-making processes that occur during travel. Pre-trip planning is a static process whereby the driver makes a decision on the mode, route, and departure time that will best match his established set of goals, typically carried out before departing for the trip. En-route switching is a dynamic process whereby the driver realizes that his travel goals will not be met by continuing on the current path and is motivated to switch paths (Adler et al., 1998). The following sections will introduce usability issues that typically arise during each of the aforementioned processes and measures that will address these issues and allow the users to focus on the information and task at hand.

3.1.1.1 Pre-trip Planning Usability

Key design elements that can increase a traveler information application's usability during "pre-trip planning" are provided in the reference tables below. The main categories for consideration include: Displays and Controls (Table 9) and Destination Entry (Table 10).

Table 11. Display and controls design elements for pre-trip usability

Displays and Controls	
Ambiguous button labels	Button should include clear and valid labels for clear understanding. Nowakowski et al. (2003) found that users often had trouble interpreting abbreviations (e.g., POI) and vague terms (e.g., view).
Button location	Buttons should be displayed at the same location across screens—internal consistency is important to ensure that the users can easily and efficiently interact with the interface (Baumann and Thomas, 2001). Buttons displayed at the different locations across screens, especially those used in sequence, are known to lead to user frustration and poor usability (Nowakowski et al., 2003).
"Back" buttons	Nowakowski et al. (2003) found that users frequently asked, "*Will pressing the "back" button save my edits*?" Users generally did not believe that pressing the "back" or "cancel" button when exiting the screen would save the changes made. They believed that an "enter" or "Ok" button would save their edits (Nowakowski et al., 2003).
Organization of features	Users had trouble navigating through the interface because they could not find certain features which they felt were out of place (Nowakowski et al., 2003). When encountering a new product for the first time, users will bring their expectations of how it should work based on their previous experiences. To the extent that the system conforms to the users' expectations and information is presented in a natural and logical order, operation of the app should feel intuitive (Baumann and Thomas, 2001).

Table 12. Destination entry design elements for pre-trip usability

Destination Entry	
Confirmation of Destination	Nowakowski et al. (2003) found that at least half of the users wanted a route overview and to confirm their destination after entering it in. Users largely used electronic maps to do this as they found route summaries to be too dense. Although immediately switching over to route guidance may save some time, providing a route overview would permit correction of detected error, such as a wrongly selected destination (Kray et al., 2003).
Personalization	The in-vehicle system should be able to remember the user's routing choices and previous destinations (Adler et al., 1998).
Presenting alternative	Schaub (2012) suggests providing users with all the available alternative routes and all the necessary information that the users will need to weigh these alternatives. This will allow them to take part in the decision-making process. Indeed, Wu et al. (2009) found that users are not fixed to a certain route and would like information about other alternatives.

3.1.1.2 En-route guidance usability

Key design elements that can increase a traveler information application's usability during "en-route guidance" are provided in the reference tables below. Given that en-route guidance provides users with multiple and on-going information throughout a trip, the design elements under consideration are far more extensive. The main categories for consideration include: Beginning and ending guidance (Table 11), Auditory Directions (Table 12), Display (Table 13), and Rerouting (Table 14).

Table 13. Beginning and ending guidance design elements for en-route guidance

Beginning and Ending Guidance	
Identifying a starting location and direction	A frequent issue that arise in current in-vehicle navigation systems is that sufficient detail about the starting location, starting direction, and first road segment (e.g., street name, distance) is often not provided at the beginning of route guidance (Taylor et al., 2008).
Timing of ending guidance	Nowakowski et al. (2003) found that some systems present the ending guidance message when the driver is within a radius to the destination. In cases where the destination is on a corner or parallel road, the driver will be told that he has arrived at his destination before he actually does.
Left & right side destinations	Nowakowski et al. (2003) found that some systems give no indication as to whether the destination is on the left or right side of the road once the driver has reached his destination. Users often ask, "Is the destination on the left or right side of the road?"
Displaying target address	It is important to display the target address as the driver approaches a destination to assist search and recognition of a destination. Nowakowski et al. (2003) found that as users neared the destination, none of them could recall the target address, which proved to be an issue when the system does not display the destination address or display it only for a brief period of time.

Table 14. Auditory directions design elements for en-route guidance

Auditory Directions	
Ambiguous distance information	In-vehicle navigation systems often used ambiguous time-based words, such as "ahead," to present instructions relating to the next maneuver—drivers usually interpreted these vague terms to mean "turn straightaway," leading to them to make the wrong turns or last minute maneuvers (e.g., dangerous lane changes) 5 to 10 seconds following the voice command. Drivers preferred more concrete wording, such as "next right turn," or explicit metric information, such as "In 3 tenths of a mile, turn right on 5th Avenue" (Nowakowski et al., 2003). Concrete distance information will prove particularly useful when the driver is traversing down a lengthy road segment as it allows the driver to turn into the appropriate lane well in advance. Indeed, drivers navigate better and indicate higher levels of anticipation and satisfaction with the auditory guidance when concrete wording was used (Taylor et al., 2008).
Length of directions	Green (2000) found that simple turn-by-turn navigation directions, where the system provides directions relating to the location and direction of next maneuver, is the preferred option in the United States. This finding can be explained by two factors. Firstly, due to its largely verbal nature, turn-by-turn directions do not require the users to glance at the visual display, allowing them to keep their eyes on the road. Although current navigation systems typically couple auditory directions with guidance displays, users have the option to ignore what it presented on these guidance displays under cognitively demanding situations (Burnett, 2000). Secondly, turn-by-turn directions present only action commands that are relevant to the next maneuver (Taylor et al., 2008). Providing directions for maneuvers that are beyond the oncoming one is ill-advised as it is unnecessary and necessitates the driver to expend extra cognitive resources filtering out irrelevant information (Dingus, 1993). Additionally, people can only maintain four pieces of information in their working memory at any given time. This suggests that verbal navigation directions should not include more than a) distance to next turn, b) direction of that turn, c) street to turn onto, and d) landmark that signals the turn (Tijerina et al., 2000).
Timing of directions	Drivers like to be informed about the oncoming turn within a few seconds after completing a turn so that they can adequately prepare for it (e.g., attend to street signs, change lanes), and avoid making last minute corrections (Taylor et al., 2008; Nowakowski et al., 2003; Chittaro, 2004). For vehicles traveling at 40 mph, Green and colleagues (1995) recommends delivering turning directions approximately 450 m before a turn has to be made—adjustments will need to be made for other traveling speeds (15 feet for each mile per hour) and direction of turn (left turns necessitates a more advanced warning). For situations in which the driver is required to make two successive turns within 10 seconds, Verwey et al. (1993) recommends delivering the two messages together just before the first turn.

Table 15. Display design elements for en-route guidance

Display	
Text size and comprehension	Nowakowski et al. (2003) found that systems often displayed texts that were too small to read. Brooks and Green (1998) suggested using 18-point font size when less than 6 streets are labeled and 12-point font size when more than 6 streets are labeled. Tijerina et al. (2000) found that when a given sentence is broken up into several lines, people could understand it better when the end of each line corresponded to the end of a phrase.
Clutter: Layering	Clutter increases search time and users are more likely to misread or miss items as well. A method of eliminating clutter is to hide information irrelevant to the current task by layering the interface (Stewart, 1976). Clutter can be an issue if a driver entering a city had previously turned on the extra labels (e.g., ATM's) while traveling through a less urbanized area (Nowakowski et al., 2003).
Clutter: 3D maps	Compared to 2D maps, 3D maps allow people to navigate better in cities because visualizations of landmarks on the maps match better to their true form and thus allowing the driver to recognize these landmarks more easily in his driving environment (Taylor et al., 2008). However, 3D views add to map clutter because they compress symbols and street names towards the top of the display. 3D maps also increases loading time which increases frustration on the users' end (Chittaro, 2004). Burns (2000) found that frustration caused by having to wait for the information to load can increase the risk of crashing.
Clutter: Labeling Streets	Brooks and Green (1998) recommend having the street names run parallel with the streets. Although it is important to label streets that are important for navigation, Brooks and Green (1998) recommends labeling no more than 12 streets to minimize error, response time, and clutter (See "Selection" section).
Presenting spatial information visually	Taylor et al. (2008) suggests delivering action procedures verbally and spatial information visually. Although drivers can navigate successfully using auditory guidance alone, it is by no means their familiar or preferred method for navigation (Green, 2000). Indeed, Nowakowski et al. (2003) found that drivers preferred turn arrows to texts, e.g. "Turn right." Most of the current navigation systems supplement auditory turn-by-turn directions with guidance display screens, i.e., map, turn-by-turn displays, and maneuver lists (Taylor et al., 2008). The inclusion of these different display formats into the navigation system is useful to support the different tasks that might be performed (Dingus, 1993). Compared to electronic route map with and without auditory and turn-by-turn guidance, turn-by-turn guidance screens with auditory guidance was the more usable method for navigation which produced shorter glance duration and less braking errors, lane deviations, abrupt braking, and cognitive workload (Young, 2007). However, electronic maps are especially useful in presenting alternative routes and nearby attractions and providing the driver with a general sense of where he is located (Taylor et al., 2008).
Syncing up visual display with auditory guidance	Given that users always look towards the display after an auditory alert (Brooks, 1999), it is imperative that the auditory directions is consistent with the visual display so as to not cause any confusion on the driver's end or lead the driver to make the wrong turn (Nowakowski et al., 2003).

Table 16. Rerouting design elements for en-route guidance

Destination Entry	
Dynamic traffic information	Although it is useful for the system to inform the driver of the traffic block that lies ahead and suggest a possible detour, the driver may be reluctant to follow the system's recommendations. To successfully convince the driver to change routes, the system needs to make apparent the benefits of the suggested detour (e.g., time and distance saved) and provide enough information so that its relevance and accuracy can be verified by for the driver himself. However, measures should be taken to minimize the number of choices and amount of information presented to the driver as research has shown that if too much information is presented on the display, drivers may not be able to process all the variables, leading to reduced accuracy of judgment (Blanco, 2006). Additionally, loading time increases with the amount of information presented. Longer loading time creates frustration which increases the risk of crashing (Burns, 2000). Schaub (2012) suggests presenting just the relevant information first, and upon the driver's request, provide additional information.
Wrong Turns	Nowakowski et al., (2003) found that in situations where the users cannot be confident that they have turned into the right street, they will typically realize their slip-up within 4-7 seconds. If the system does not reroute the users within 30 seconds, the users will assume it is broken. If the system *does* automatically reroute the driver after a wrong turn, but provides little to no feedback, the driver will typically not realize that he has made a mistake and become confused when he notices deviation from the pre-specified route. There may be cases where the driver makes deliberate detours to stop by the gas station, try out a short cut they think they might know, or avoid traffic. Usually, the system reacts by rerouting the driver or providing instructions to take the driver back to the pre-specified route (Hipp et al., 2010). The system output assumes the role of either noise or signal depending on the though process the role of either noise or signal depending on the thought process and needs of the user at that particular moment (Baumann and Thomas, 2001). Given that the driver had made the deliberate decision to take the detour, these messages will likely be annoying to the driver, particularly if they occur repeatedly (Hipp et al., 2010). Indeed, Nowakowski et al., (2003) found that if the system gave too much output (e.g., repeatedly telling the driver to turn around), the users grew hostile towards the system. Schaub (2012) suggests permitting two-way communication between the driver and the system so that the driver can make his intentions clear to system.

3.1.2. Usability Issues Summary

With a good interface, there should be a fit between the user's needs and the service which the system provides—this can be achieved by providing users with a) controls and displays that are highly visible and easily interpretable, b) internal consistency, c) an interface that is consistent with their convention and previous experiences, d) timely visual and auditory feedback, e) explicit messaging to help users recognize and correct the error, and f) control and freedom to undo incorrect actions.

Features that improve usability and user's trust in a system during pre-trip planning include presenting a route overview after destination entry, the ability to remember the user's routing choices and previous destinations, and providing users with all the available alternative routes and all the necessary information that the users will need to weigh these alternative.

For the purpose of en-route guidance, the inclusion of different display formats (i.e., electronic map, turn-by-turn displays, maneuver lists) into the navigation system is useful to support the different tasks that might be performed; however, turn-by-turn guidance screens with auditory guidance may the more useable method for navigation. A large benefit of navigation based systems is that the driver's route and destination is known by the system and thus alerts can be filtered and limited to only those relevant to the driver. A limitation of existing public information applications which provide verbal alerts regarding upcoming events is that the exact route and destination is unknown so the filtering of event information is poorly refined. Drivers are likely to be presented with non-relevant event warnings which could result in increased workload and, over time, result in distrust in the system.

Usability and user's trust in a system can be increased by providing users with a) sufficient detail about the starting location/direction at beginning of route guidance, b) the target address and an indication of whether the destination is on the left of right side of the road as driver approaches the destination, c) precise distance information, d) timely, brief and concise auditory turn-by-turn directions, e) auditory directions that are synced up with the visual display, f) a clutter free interface through layering, use of 2D maps as opposed to 3D maps, and having the street names run parallel with the streets, g) the benefits of a suggested detour, and e) timely rerouting guidance.

3.2 Distraction Issues

The study of human factors in driver safety largely focuses on drivers' cognitive abilities and limitations. Drivers can often successfully divide their attention between driving and performing secondary tasks, such as navigation, without putting their safety at risk; however, there are limits in the extent to which drivers are able to distribute their attention and cognitive resources across multiple tasks. Driver distractions occur when the driver's attention is diverted away from the primary task of driving, toward performing secondary tasks such as navigation, to the degree that their driving performance is negatively affected. The potential for any given secondary task to cause distraction is dependent on task complexity, driving demand, driver's decision to engage in the secondary task, driver experience, and driver age. Indeed, research has shown that older drivers are less capable of multi-tasking due to their reduced cognitive and visual capacity and thus engaging in a secondary task while driving may produce larger decrements in driving performance for older drivers versus younger drivers (Bolstad, 2001; Endsley, 2000; Endsley & Kaber, 1999). In a similar vein, compared to experienced drivers, novice drivers are more susceptible to effects of distraction because they often cannot operate a vehicle without expending most of their attentional resources (Young et al., 2007).

3.2.1. Visual and Cognitive Distractions

Driving is predominately a visual-motor task. Because we have only one foveal resource, extracting visual information from an in-vehicle display while driving would require the driver to look away from the forward view (Blanco, 2006). Off-road glance associated with visual tasks produce frequent and large lane variance (Liang et al., 2010) and the risk of accidents increases with eyes-off-road time (Nees et al., 2011).

Because of the inherent risks associated with visual displays, designers have looked to using speech-based systems, i.e. text-to-speech, to more safely convey information to the drivers. Speech-based systems present information to the users and allow users to communicate with the system through spoken speech. Proponents of speech based systems had thought that auditory displays would allow the drivers to focus their visual attention on the road ahead and thereby eliminating any risks associated with in-vehicle device use. Indeed, visual secondary task and, to a lesser degree, combined visual and auditory secondary task do produce longer and more frequent off-road glances and poorer lateral control compared to auditory secondary task alone (Liang et al., 2010). Speech-based interfaces, however, have been found to produce cognitive distraction (Lalande et al., 2004) which occurs when the tasks taps into the same cognitive resources required for driving. Cognitively distracted drivers tend to concentrate their fixations to the center of the road, which improves their lane keeping performance, but degrades the drivers' situation awareness and their ability to detect targets across the entire driving scene. The ability to perceive relevant cues, such as traffic density or behavior of leading vehicle, is essential for the driver to anticipate what will happen next and respond accordingly (e.g., braking in time to avoid rear-ending the lead vehicle). Compared to baseline levels, cognitive distractions also lead to slower saccadic eye movements, which impairs scanning performance across the driving scene (Liang et al., 2010). Gaze concentration and slow saccades are also observed with visual distraction and combined visual and cognitive distraction once the driver's eyes return to the road (Liang et al., 2010).

Evidence suggests that drivers engage in compensatory behavior at either a conscious or subconscious level when dual tasking. Jamson et al. (2005) found that visual distraction and, to a lesser degree, cognitive distraction both lead drivers to reduce their driving speed. The reduction in driving speed may reflect impaired responsiveness due to increased competition for drivers' resources during dual tasking. It is also possible that this reduction in driving speed is a result of the drivers' conscious effort to maintain a safe headway to the lead vehicle. Regardless, this speed reduction may not be sufficient to mitigate the effects of distraction as Jamson et al. (2005) found that for both cognitive and visual tasks, an increase in demand was associated with reduced time-to-collision in situations where the lead vehicle braked suddenly.

In general, visual distractions produce a larger decrement in driving performance than cognitive distractions. When both types of distraction are combined, the impact on driving performance (i.e., lateral control and off-road glances) is smaller compared to that produced by visual distraction alone. These findings suggest that efforts should be channeled towards reducing visual demand, and to a lesser degree, auditory demand during the design of an in-vehicle system.

3.2.1.1. Countermeasures for Visual Distractions

Presenting visual information on the in-vehicle system proves a tough challenge for designers because the size of the display constrains the amount of information that can be presented without overtaxing the driver perceptually. This section will present visual distraction countermeasures that will reduce the number of glances and fixations times and consequently risk of crashing. The key areas to consider when designing an interface is to minimize visual distraction are: fixation time and number of glances, menu structure and scrolling, color, orientation, reducing clutter, scaling, abstraction, selection, highlighting, and search asymmetry.

Recommended limit for fixation time and number of glances

Eyes-off-road time shorter than 2 seconds has negligible effects on driving performance; however, durations more than that dramatically increase crash risk (Nees et al., 2011). Therefore, researchers suggest that glances at in-vehicle system should not exceed 2 seconds, and average eyes-off-road time should be within 1.2 seconds (Nees et al., 2011). In fact, drivers are reluctant to look away from the driving scene for more than 2 seconds.

Green (1999) found that when the number of glances is less than 2-2.5, zero incidents of lane departure was observed. This finding is consistent with VICS Promotion Council's report which suggested an average of 2.7 glances to complete a task with the in-vehicle system will allow one to drive safely at 30 km/h (Lee et al., 2005).

Menu structure and scrolling style

Humans are capable of resuming visual search fairly quickly following brief interruptions. Identification of a resumption point becomes more difficult, however, if additional visuospatial tasks are carried out during this interruption, as in the case of time-sharing between driving and a secondary task.

Because items' relative lengths and locations are more distinguishable in list-style menu structures compared to grid-style menu structures, list-style menu structures provide users with more discriminative cues to help the users hold in mind the spatial representation of visited item locations during the interruptions. Displaying information in a format that facilitates spatial representation leads to less attention capture effects (e.g. a banner advertisement capturing attention) and less digression to already visited items, which translates to better, faster, and less variable scan patterns. Indeed, compared to grid-style menu structures, list-style menu structures produced smaller variance in glance durations (Kujala et al., 2011).

Kinetic touch screen scrolling may delay recognition of the resumption point after an interruption if the list keeps on scrolling after the driver has diverted his attention toward the road, in which case the driver's spatial representation of item locations will not match the display when he looks back to the display. Kujala et al. (2011) found that kinetic touch screen scrolling produced more variable in-vehicle glance durations compared to touch screen row-by-row scrolling with up and down arrow buttons.

Color

Lavie (2013) found that map colors or graphic style have negligible impact on performance times, provided that the cursor is clearly distinguishable from the rest of the information on the map. However, the “green realistic” style, which depicted the green terrain in the environment, produced the highest ratings in aesthetics and usability.

Orientation

North-up displays provide drivers with a consistent map orientation but such displays require the driver to mentally transform the vehicle’s orientation. Track-up displays, on the other hand, rotate so that the cursor representing the vehicle is always pointing towards the top of the map and thus does not require mental rotations (Taylor et al., 2008).

Research has shown that track-up displays are preferred for route guidance during driving while north-up displays are preferred for route planning (Lee et al., 2007). Track-up displays may prove particularly useful in complex driving scenarios where mental rotations could possibly impair driving performance (Taylor et al., 2008). North-up displays can be used when the driver’s view direction is not known. If the driver’s view direction is not known, salient landmarks are especially important to orient the driver (Kray et al., 2003).

Landmarks

Street signs are often not visible from a distance. In such cases, reliable and salient landmarks can serve as powerful confirmation points that will allow the driver to affirm that he is on the right path and reorient himself should he get lost (Burnett, 2000). Indeed, supplementing standard auditory turn-by-turn directions (i.e., distance to next turn+ turn direction + street to turn onto) with landmarks reduced overall workload and improved navigation performance compared to standard turn-by-turn directions (Nees et al., 2011). Therefore, landmarks that correspond to decision points should be made an integral part of turn-by-turn directions.

Poor landmarks, such as those that are hard to find or identify, can confuse drivers, increase workload, and jeopardize driving safety. Effective cues for navigation include landmarks that are permanent, close to the road, visible from a distance and under various conditions, and easy to identify (Burnett, 2000).

Green et al. (1995) suggested that landmarks should be presented through both voice and graphics. Humans are quick to recognize symbols, especially in dense displays. Lavie (2013) found that symbols that are clear and do not require complex inferences can be presented at increased amounts without impairing the map’s usability or aesthetics.

Reducing clutter

The time it takes to search for a single element on a display increases linearly with the amount of clutter (Wickens et al., 2004). Techniques to reduce clutter include: a) scaling, b) abstraction, c) selection, d) highlighting, and e) search asymmetry:

Scaling

For route planning, Wu et al. (2009) recommend choosing a map scale that will allow users to clearly see the location of the origin and destination and also one that will allow users to easily see the alternative routes between the origin and destination. Accurately depiction of road lengths is relatively unimportant to the users. Therefore, for route following, Lee et al. (2007) recommends distorting the actual road length so that the road segments associated with the current and nearby turns are presented at an enlarged scale than those far ahead or behind. Scanning in-vehicle display for directions while driving is difficult without directing attention to inside the vehicle. One measure to reduce this visual demand is to present information that the driver currently needs (i.e., features associated with a) the current or next turn, b) the road segments between current position and the next turn, and c) the final destination of the route), at an enlarged scale (Lee et al., 2005).

Abstraction
Abstraction is the process of distorting or simplifying information to make it more distinguishable in a given context. Prior studies have shown that graphic generalization in maps reduces cognitive load and thus more cognitive resources are left to support information processing, resulting in an increased amount of information processed overall (Taylor et al., 2008). Indeed, Lavie (2013) found that users perceived vehicle navigation maps with the least amount of detail to be the most usable and aesthetic.

Given that the actual curvature of the road is relatively unimportant to the users (Lee et al., 2007), maps can be simplified by rendering curvy roads that are unimportant for successful navigation as straight roads (Lee et al., 2007; Lavie, 2013).

Selection
Selection is another technique used to support user's information processing. It is the process of placing more emphasis on certain features on the map—this could be done by depicting them with more prominent symbols (Lee et al., 2005). Lee et al. (2007) found that verbal labels produced the fastest reaction time, followed by number labels, simple symbols, and complex symbols, and thus suggested using semantic renditions (i.e., verbal and number labels) in important areas on the map to increase their salience while using symbolic renditions (i.e., symbols) in the less important areas on the map.

During route following, we mostly attend to features associated with the road segment we are currently travelling though. Because cross streets and landmarks become meaningful only when they can serve as confirmation points, Lee et al. (2007) recommend displaying decision points (e.g., cross streets) and street labels only when the vehicle is approaching them. Indeed, we are more likely to attend to the information display if we know that only relevant information is presented (Schaub, 2012).

Highlighting
One technique to reduce clutter is to highlight important and frequently used items—this segregates the highlighted items from the lowlighted items which can facilitate the search process because users will only need to search the group likely to contain the target. However, highlighted items should not be made too bright as this will distract the user if he is required to extract information from the dimmer group (Wickens et al., 2004).

Search asymmetry
A search asymmetry occurs when Type A target amongst Type B distractions are found more easily than Type B target amongst Type A distractors. Asymmetry can result when the favored target possesses features, such as tilt, curvature, or an intersecting segment, that the disfavored target does not. Asymmetry can also occur if the favored target is longer or of a higher contrast than the disfavored target. Search asymmetries also favor stimuli that are unfamiliar, of a higher contrast, or deviate from a prototype color (Yamani et al., 2011).

Search asymmetry persists in the presence of heavy clutter (i.e. geophysical images) (Yamani et al., 2011). Saiki et al. (2005) found that asymmetry is observed even in cases where the participant does not know which target to search for, suggesting that asymmetry can be used to capture attention in a bottom-up manner. The authors also found that the effect of search asymmetry increases with the target's retinal eccentricity, suggesting that asymmetry could be used to facilitate detection of targets in the peripheral vision.

Designers can aid the detection of important symbols amongst high clutter by designing the symbols to produce an asymmetry that favors the important symbols. Asymmetry may be used redundantly with other techniques to increase target salience or it can be used to increase the salience of certain items within a segregated group (Yamani et al., 2011).

3.2.1.2. Countermeasures for Cognitive Distractions

Just as reducing an in-vehicle display's visual demand proves to be challenging, minimizing the cognitive load that an in-vehicle system imposes on the user is an equally daunting task. In particular, a system's cognitive distraction potential is largely dependent on the experience and age of the driver, as well as their current cognitive state (e.g. stressed or fatigued) and external surroundings (e.g. familiar vs. unfamiliar). This section will present cognitive distraction countermeasures that will reduce the amount of processing required for drivers to receive, process, and respond to information presented. The key areas to consider when designing an interface to minimize cognitive distraction are: speech interface, implementation of a multimedia system, and user input.

3.2.1.2.1. Countermeasures: Speech Interface

Volume intensity and signal to noise ratio
The speech interface requires special consideration in design due to the many factors that could potentially impact the amount of cognitive capacity required to process speech including volume (intensity), signal to noise ratio and user characteristics.

Presbycusis is an age-related, predominately high frequency hearing loss that is prevalent among older adults (Tun, O'Kane, & Wingfield, 2002). Presbycusis impairs affected individual's ability to understand speech and thus auditory signal must be presented at an increased intensity to these individuals. Moreover, auditory intensity levels must be presented 10 dB higher to adults engaged in multiple tasks than typically done for young adults (Baldwin & Struckman-Johnson, 2002).

Further consideration relates to the amount of noise present in a vehicle. One-third of older adults experience increased difficulty following conversations and understanding speech in noise (Schneider, Daneman, & Pichora-Fuller, 2002). Speech stimuli presented to older drivers (60 years or older) should be approximately 16 dB higher than those presented to younger listeners in their 20s (Coren, 1994). Speech information should be presented at least 15 dB higher than background noise (i.e. +15 SNR) in the vehicle for good speech comprehension (Tun, 1998). Thankfully, modern vehicles have quieter interiors than previous decades; however, as seals degrade in a vehicle, the cabin noise may increase.

Sentence structure
The sentence structure of verbally announced information can dramatically impact cognitive distraction. Navigational messages should contain 3 or less sets of information given at one time (Barshi, 1997) and should be in a succinct, list form, e.g., road construction, 35 mph, 15 miles rather than in prose form, e.g., road construction with reduced speed to 35 mph is ahead 15 miles (Llaneras et al., 2000). Aurally presenting the street name as the driver approaches can reduce cognitive and visual attention demand (Dingus, Hulse, Mollenhauer, Fleischman, McGehee, & Manakkal, 1997). Finally, providing contextual information at the start of the message (e.g., Turn ahead: Left in 2 miles) is preferred to presenting it at the end, e.g., In 2 miles, turn left (Dingus et al., 1997).

Information relevance and accuracy
One-way communication information systems can help reduce travel time by providing drivers with real-time information on congestions, delays, and potential hazards; however, the responsibility falls upon the user to filter through the information pieces, make decisions about information relevance, and identify the information pieces that will help him achieve his navigational goal. This process overtaxes the working memory and leads to impaired navigational performance (Taylor et al., 2008).

Timely and accurate information is essential in fostering users' trust in the in-vehicle system. Indeed, Jonsson et al. (2008) found that reducing the accuracy of hazard warnings and traffic-related information decreases driving performance, users' trust in the system, and user satisfaction. Therefore, in designing an in-vehicle system, efforts should be made to cater to the user's specific needs and limit the amount of information provided to the user by presenting only those that are accurate and relevant to the user's current goal.

Synthetic vs. pre-recorded human voice
Systems can typically deliver speech output using either pre-recorded human voice or synthetic speech—synthetic speech is typically considered to be the more viable, cost and time effective option to deliver unpredictable, dynamic information. However, both male and female listeners tend to like human male and female speech better than synthetic male and female speech (Mullennix, 2003). Similarly, Lai et al. (2001) found that human voices are generally preferred over synthetic voices. Additionally, in comparison to human voices, synthetic voices are more difficult to understand and this increased difficulty is associated with lower accuracy rates and greater mental workload (Delogu et al., 1998; Lai et al., 2001). This increase in cognitive load can possibly cause distraction and impair driving (Lai et al., 2001). Therefore, it is recommended that interfaces, especially those used by older drivers, use digitized natural speech rather than synthetic speech (Liu et al., 2000). Nevertheless, Delogu et al. (1998) found that difficulty in comprehending synthetic speech does improve with exposure.

Synthetic speech and human speech—to mix or not to mix?
Many of the text-to-speech based systems on the market use synthetic voice exclusively. Others mix human voices with synthetic voices—the rationale behind this approach is to use the better option (i.e., human voice) as much as possible. Although the human voice is more pleasing to the ear and would make a better impression on the users, the inconsistency and interference introduced by mixing human with synthetic speech could impair users' speech and cognitive

processing, which could negatively impact task performance (Gong et al., 2003). Indeed, Gong et al. (2003) found that compared synthetic speech, mixed speech produced more negative ratings and worse task performance.

Synthetic speech—male or female voice?
Given that users can get easily annoyed by voices they do not like, it is imperative that measures are taken to increase the acceptance of synthetic speech (Kray et al., 2003). Women speech is typically of higher frequency than men speech and higher frequencies tend to cause annoyance (Nees et al., 2011). Approximately 40% of older adults aged 75 and older report difficulties detecting frequencies that are necessary for understanding speech (Tun & Wingfield, 1999). This may lead to poorer detection of the higher frequency fricative sounds (e.g. s, f, or th consonant sounds) produced by a woman's voice and cause older drivers to feel that the speaker is mumbling (Dougherty & Welsh, 1966). Indeed, people prefer male synthetic speech over female synthetic speech. Compared to synthetic female speakers, synthetic male speakers were more persuasive, taken more seriously, and perceived as more knowledgeable, powerful, friendlier, softer, and less squeaky (Naumann et al., 2009).

3.2.1.2.2. Countermeasures: Implementation of a Multimedia System

Auditory presentations are transient in nature; however, this drawback is somewhat compensated by human's ability to store auditory information in their mind for a longer time compared to visual information (Sarter, 2006). Visual displays, on the other hand, provide the means for drivers to refer back to a message however many times is required. However, drivers may have trouble reading messages on the display screen on sunny days (Cao et al., 2010).

Drivers can easily miss important information presented on the visual display if they happen to be attending to other things (Cao et al., 2010). Auditory presentations, on the other hand, can be picked up by the driver regardless of where he is facing. Auditory presentations, however, may be less effective in situations where the driver is engaging in a conversation with someone or listening to radio or loud music (Sarter, 2006).

For navigation systems, researchers recommend the use of auditory presentations for alerting functions that require an immediate response (e.g., signaling the upcoming turn), followed by visual display to present details of the turn and spatial information (e.g., information on surrounding area) (Kray et al., 2003). Indeed, Cao (2010) found that using both auditory and visual presentations to deliver navigational information produced better user satisfaction and driving and task performance compared to either modalities alone.

3.2.1.2.3. Countermeasures: User Input—Voice Recognition vs Manual Entry

Drivers can enter destinations into the navigation systems by manually typing in the address or using speech recognition. Although manual entry is more visually and cognitively demanding as it requires hand-eye coordination, it is nevertheless the most common method for destination entry (Young et al., 2007). Indeed, Baron et al. (2006) found that generally, drivers who used speech recognition to enter addresses had steadier speed, were better at lane-keeping, had less cognitive load, and spent more time looking at the driving scene in comparison to when they typed the addresses onto a touch-screen interface. Speech interface tend to produce better task performance (i.e. completion time and error rates) for most tasks, with exception to phone number entry—dialing a number manually was faster than speaking the telephone number. However, speech interface with a low recognition rate can significantly impair task performance (Burnett et al., 2004).

3.2.2. Visual and Cognitive Distractions Summary

This section highlights a) the potential for in-vehicle systems to cause distraction, impair driving performance, and ultimately increase the risk of crashing, and b) the importance of human factor testing to evaluate the visual and cognitive demands that the system may be imposing on the driver. In general, visual distractions produce a larger decrement in driving performance than cognitive distractions, suggesting that efforts should be channeled towards reducing visual demand, and to a lesser degree, auditory demand during the design of an in-vehicle system.

Countermeasures that could potentially reduce visual distraction include list-style menu structures, touch screen row-by-row scrolling with up and down arrow buttons, a clearly distinguishable cursor, and a "green realistic" (i.e. featuring green terrain) graphic style. Usability can also be increased by using track-up display for route guidance and north-up display for route planning, incorporating good landmarks (e.g., those that are permanent, close to the road, visible from a distance and under various conditions, and easy to identify) that correspond to decision points into route guidance, and reducing clutter through a) scaling, b) abstraction, c) selection, d) highlighting, and e) search asymmetry.

Cognitive distractions can be potentially reduced by taking into account user characteristics, the circumstances in which the in-vehicle system will operate, and sentence structure. Although human speech is easier to understand compared to synthetic speech, many of the current text-to-speech based systems on the market use synthetic voice because it is the more viable, cost and time effective option for delivering unpredictable, dynamic information. Therefore, it is imperative that efforts are channeled towards increasing the acceptance of synthetic speech by a) not mixing synthetic speech with human speech and b) using male rather than female synthetic speech.

Cognitive distraction can also be potentially reduced by implementing a) a multimedia system that uses auditory presentations for alerting functions and visual display to present details of the turn and spatial information and b) a speech interface with a high recognition rate.

Chapter 4. Cross-Reference and Recommendations

Chapter 4 provides a cross-reference to highlight the current MN 511 features and their implications relating to the human factors and usability issues highlighted in previous sections. The cross-reference summary is intended to provide recommendations and inform the design of future iterations of public traveler information applications, like MN 511, to create a highly usable application for safe road travel.

The next generation of nationwide in-vehicle traveler information applications is predicted to include complex interactive functions with relevant human factors principles in mind. MN 511 is a useful tool for gathering basic road information across the state of Minnesota, but in order to remain competitive with other states' traveler information applications and meet the needs of the modern traveler, there are multiple features that Minnesota may wish to consider when designing the next generation MN 511. Basic features like road conditions, accidents/incidents, construction, and traffic density are already included in the current MN 511 app, but other important features such as auditory alerts, customizable pre-trip routes, and history/saved places are not included. Integration with a low-distraction navigation system and converting to a text-to-speech based system are strongly suggested for future iterations of MN 511. By understanding human factors and usability principles, the resulting application will be more valuable to users and ensure lower-distraction. Various design strategies as well as challenges are discussed in the following sections.

4.1. Current shortcomings of MN 511

4.1.1. Usability Issues

Currently, the embedded map is organized in a manner that does not meet usability standards. Some of the problematic areas on the map include legend organization and display elements (e.g. clutter and text size). Furthermore, the general organization and presentation of information can be potentially distracting to drivers. Specific areas that can be improved or should be revised are reviewed in the following sections.

Clutter

The map appears cluttered when the application is launched as each roadway is highlighted by a color to indicate the road condition. The road condition highlighting function is a default setting, but the legend that defines each color is not automatically visible. Once the legend is opened, the color-coded icons are displayed horizontally and directly above the three default icons (search, legend, and layers) which are displayed across the bottom of the main screen. This layout creates clutter on the screen and does not create an asymmetry in favor of the color-coded icons (Saiki, 2005; Yamani et al., 2011). Providing the color-coded icons within the legend in a vertical list may provide the desired asymmetry and is just one alternative to the current layout.

Consistency

The lack of consistency across the icons in the application creates an additional usability issue. The three default icons (search, legend, and layers) appear horizontally in a static position on the bottom of the screen and each opens differently. Selecting the "search" icon launches a new screen with the option to manually enter a Minnesota highway or select a highway from a list of main Minnesota roads. Selecting the "legend" icon partially populates a list of the color-coded icons, which are displayed horizontally; however, in order to view the entire list of legend icons, the user must continue to scroll horizontally. The legend then disappears from view after 10 seconds. Selecting the "layers" icon populates a list of four features on a vertical list. The vertical list is helpful to the user because it provides asymmetry; however, the user is limited to only selecting two layers at a time. A re-design of the visual interface is necessary to improve the consistency of the screen layouts and to provide a cleaner interface that is likely to lead to fewer cognitive distractions.

Visual vs Verbal Information
One of the main limitations of the current MN 511 application is the current lack of multi-modal features, such as auditory alerts and an interactive map. The current system relies solely on visual presentation of information which is laborious for drivers to extract information and does not allow for short visual fixations or minimal glances. These subjects are discussed in further detail throughout the following sections. It is understood that future generations of MN 511 will include auditory alerts to drivers; however, it is difficult to ascertain the quality and usability of such features with the limited information which currently exists regarding its functions and, more importantly, without an examination of a functional prototype.

4.2. Opportunities for Future Deployment

Lowering distraction is a main goal for future iterations of the MN 511 application. It is also desired for users to have a satisfactory experience with the travel information application. It is important to consider both of these goals when identifying opportunities for changes in the current 511 application. General display options such as reducing clutter through the use of a better map scale with added clarity can help lower distraction while driving (Wu et al. 2009). Designing the system to incorporate text-to-speech commands and to provide auditory feedback that confirms requests made by the driver can also help lower distraction (Nowakowski et al., 2003).

Clutter reduction
There are multiple techniques used to reduce clutter on a map-based system. Highlighting and scaling are two methods that allow the driver to focus on important features first. By keeping tangential information off the default screen users are left with additional cognitive resources to put toward driving tasks. Either of these methods is especially useful when the user's location is known, either via GPS or A-GPS, by the system to allow the map to isolate the driver's position on the map and provide road conditions for their specific area instead of the entire state of Minnesota. This function should be available to users across all platforms (e.g. iOS and Android). It is recommended that if the user's location is unknown because their location settings have been turned off that the application prompts the user with an option to activate their location. This prompt would lessen the clutter presented to users who are presented the road conditions of the entire state rather than their surrounding road conditions. Providing users with an option to decline enabling their location and an option to prevent future prompts would satisfy those who do not wish to have their location tracked alleviating a potential security concern for users. Navigation applications like Google Maps and Garmin ® Navigation Premium are designed to launch with limited screen clutter as to allow ease of route selection from the user.

Button size, placement, and orientation require further attention in future iterations. Given that the current features of MN 511 are small and hard to find, the next generation of the application should strive for internal consistency (i.e. same button displayed at same location across screens) and buttons that are frequently used in sequence should be placed close together. This information, however, is best captured through human factors usability testing to determine how users most frequently interact with the application. The application should also highlight important information and include scaling, search asymmetry, and include organization of features to conform to user convention. The next MN 511 should use semantic renditions (i.e., verbal and number labels) in important areas on the map to increase their salience while using symbolic renditions (i.e., symbols) in the less important areas on the map.

Visual and Cognitive Distraction Reduction

There are multiple modifications that could be applied to the next generation of MN 511 which would address visual and cognitive distractions. An in-depth usability investigation is recommended, however, to determine the true extent that MN 511 has on driver distraction. This could be safely tested within a driving simulator to measure the usability of the interface and determine the impact on driving performance and safety.

Preliminarily, there are some solutions to address the existing visual distraction. It is recommended that more advanced layering be included to allow users to view all the desired information at once and reduce additional manipulations, eye glances, and fixation durations. Additionally, using 18-point font size when there are less than 6 streets labeled, applying list-style menu structure over grid-style, and considering abstraction (or simplifying information to make it more distinguishable in a given context) should be implemented.

There is a wealth of research in the area of text-to-speech based navigation systems examining the factors that could potentially reduce visual distraction. By presenting information to the drivers verbally, the system will allow users to keep their eyes on the road for longer periods of time; however, the auditory displays should be designed with special consideration to human factors principles as listed in previous sections (e.g. intensity, sentence structure, and natural speech). Presenting drivers with auditory alerts for incidents within their surrounding area (e.g. Knowledge Cone via TellMe), but are not on their route is not recommended because of the over-stimulation this causes drivers. Drivers who are presented with non-relevant information must cognitively filter such announcements by determining if they will affect their trip or not. This is expected to increase drivers' workload, especially older drivers or those unfamiliar to the area, and is likely to cause cognitive distraction and decrease overall safety.

An additional feature which should be approached with great hesitation is one that allows users to report incidents which they encounter on their route or confirm incidents which have already been detected. Previous research has well established that simple text entry (e.g. address), has negative effects on driving performance (Jensen, Skov &Thiruravichandran, 2010; Tsimhoni, Smith & Green, 2004) resulting in increased cognitive distraction and longer fixations away from the road (Fok, Frischmann, Sawyer, Robin, & Mouloua, 2001). Voice entry for user reporting also poses a serious risk for distraction. Recent research has demonstrated the voice-to-text programs result in significantly slower reaction times and consume more time than traditional manual input despite the fact that drivers feel safer when using such programs while driving (Yager, 2013). The navigation application Waze has received similar criticism for inciting unnecessary distraction upon drivers by granting the ability to input information into the system (Travers, 2012). Furthermore, drivers demonstrated high levels of visual demand when using voice-command interfaces while driving even through the task itself is not a visual one (Reimer, Mehler, Dobres, & Coughlin, 2013). An in-depth usability test of such functions is recommended to adequately determine the extent that such functions in a future MN 511 might have on driver distraction. Meanwhile, automated data extraction for slow downs, stopped traffic, and pothole detection is recommended over user reports to minimize distraction potential.

Customizability

Minnesota's neighboring state, North Dakota, has better user feedback ratings for their state's 511 mobile app, ND Roads. ND Roads users report that having the ability to "favorite" their route to school or work as well as save frequently viewed weather cameras are two key features that are especially useful. Mississippi's state 511 app, MDOTTraffic, is another state 511 app with higher ratings than Minnesota. MDOTTraffic allows users to access live streaming road cameras and provides push alerts via text or email about traffic alerts. North Dakota and Mississippi provide simple examples of improvements that could be made to the current Minnesota application.

Many of the public navigation applications we examined in this paper already meet usability standards and have accounted for lowering driver distraction. While public navigation applications have saturated the market, one downfall of these applications is that they are not equipped with up-to-date local road conditions like MN 511. Since the availability of a traveler information application with full navigation is not currently available, we predict that the demand would be high for this service. Designing the next generation of MN 511 with turn-by-turn navigation would place Minnesota at the forefront of state traveler information applications. A custom navigation system for Minnesota drivers would be able to capitalize on relevant usability and human factors principles related to navigation systems (e.g., timing of directions, length of directions, street labeling, and re-routing). Two options for executing this in the next generation MN 511 include hiring a software developer to build a turn-by-turn navigation system into the application or embedding an existing service (e.g. Google, Mapquest) into the next generation application. Cost is certainly the largest barrier to deployment of a user-friendly navigation system. One alternative is incorporating GPS/A-GPS into the traveler information application to provide users with a more personalized experience. Importantly, providing a text-to-speech based application with only *route-relevant* incidents and information for the next generation MN 511 is highly recommended as a countermeasure to reduce the cognitive and visual distraction of a visual display.

Integrating a navigation system into the MN 511 application could help users reduce travel time and alleviate the stress and anxiety involved with travel planning and wayfinding by providing them with a) dynamic route guidance based on actual or predicted road conditions, b) two-way communication between the user and the system to allow users to input destination and receive the most efficient route, c) intelligent mapping to allow for real-time vehicle tracking to alternatively ascertain road congestion, d) pre-programmed directories of major attractions, and e) customized and personalized travel assistance that allows users to select from one of several route choices. Integration of a highly usable real-time route guidance system into MN 511 could result in high fleet penetration, potentially resulting in a significant reduction in traffic congestion and fuel emissions for the state of Minnesota as a whole.

4.3. Recommendation Summary

MN 511 currently includes many features which enable it to be competitive with other states: road conditions, accidents/incidents, construction, and traffic density. However, MN 511 currently lacks more advanced features which today's technology savvy users come to expect: speech-to-text input and auditory alerts, customizable pre-trip routes, point of interest and address input, and history/saved places. Frequent comments from users include complaints that the application runs slowly, there is no apparent legend for colors, and hitting "back" puts users through all previous actions. Additionally, users dislike that once the traffic camera is viewed, the image is not updated after clicking and that they must re-open the application each time after closing it (i.e. doesn't run in the background and there is no default refresh rate).

Recommendations for improvement include clutter reduction, reduction in visual distractions, customizable features (e.g. points of interest, favorite routes, and history of addresses and locations) and inclusion of verbal information. Moving towards an intelligent text-to-speech based system is highly encouraged. A speech interface tends to produce better task performance (i.e. completion time and error rates) for most tasks. However, a speech interface with a poor recognition rate can significantly reduce task performance. Special considerations should include: a pre-recorded human voice over synthetic voice (although this is costly), male voice over female voice, not mixing synthetic with human voices, and route specific information only.

The overall recommendation, given the in-depth investigation into 511 and proprietary applications nationwide, is for Minnesota to integrate a low-distraction navigation system and to convert to a text-to-speech based system. Minnesota should consider adapting MN 511 into a multimedia navigation system. This system would include the use of auditory presentations for alerting functions that require an immediate response (e.g., signaling the upcoming turn), followed by visual display to present details of the turn and spatial information (e.g., information on surrounding area). Notably, such a system would not need to rely on a "knowledge cone" of presenting non-relevant event information within the driver's periphery but would be able to appropriately filter messages to limit the visual and cognitive distraction potential of the application. Auditory turn-by-turn directions with guidance display screens (i.e. electronic map, turn-by-turn displays, maneuver lists) would meet the needs of today's drivers and would result in higher user satisfaction.

References

Adler, J. L., & Blue, V. J. (1998). Toward the design of intelligent traveler information systems. *Transportation Research Part C: Emerging Technologies*,*6*(3), 157-172.

Baldwin, C. L., & Struckman-Johnson, D. (2002). Impact of speech presentation level on cognitive task performance. *Ergonomics, 45*, 61-74.

Barón, A., & Green, P. (2006). *Safety and usability of speech interfaces for in-vehicle tasks while driving: A brief literature review* (No. UMTRI-2006-5). University of Michigan, Transportation Research Institute.

Barshi, I. (1997). Effects of linguistic properties and message length on misunderstandings in aviation communication, Unpublished Doctoral Dissertation, University of Colorado, Boulder.

Bhise, Vivek. (2012). *Ergonomics in the automotive design process*. Boca Raton: Taylor & Francis.

Blanco, M., Biever, W. J., Gallagher, J. P., & Dingus, T. A. (2006). The impact of secondary task cognitive processing demand on driving performance.*Accident Analysis & Prevention*, *38*(5), 895-906.

Bolstad, C.A. (2001). Situation awareness: Does it change with age? 45th Meeting of the Human Factors and Ergonomics Society, St. Paul, Minneapolis, MN.

Brooks, A., & Green, P. (1998). *Map design: A simulator evaluation of the factors affecting the time to read electronic navigation displays* (No. UMTRI-98-7,).

Burnett, G. (2000). 'Turn right at the Traffic Lights': The Requirement for Landmarks in Vehicle Navigation Systems. *Journal of Navigation*, *53*(03), 499-510.

Burnett, G. E., Summerskill, S. J., & Porter, J. M. (2004). On-the-move destination entry for vehicle navigation systems: Unsafe by any means?.*Behaviour & Information Technology*, *23*(4), 265-272.

Burns, P. C., & Lansdown, T. C. (2000). E-distraction: the challenges for safe and usable internet services in vehicles. In *Internet Forum on the Safety Impact of Driver Distraction When Using In-Vehicle Technologies*.

Chittaro, L., & De Marco, L. (2004, June). Driver distraction caused by mobile devices: studying and reducing safety risks. In *Proceedings of the 1st Int'l Workshop Mobile Technologies and Health: Benefits and Risks (Udine, Italy, 2004)*.

Coren, S. (1994). Most comfortable listening level as a function of age. *Ergonomics, 37*, 1279-1274.

Delogu, C., Conte, S., & Sementina, C. (1998). Cognitive factors in the evaluation of synthetic speech. *Speech Communication*, *24*(2), 153-168.

Dingus, T. A., & Hulse, M. C. (1993). Some human factors design issues and recommendations for automobile navigation information systems. Transportation Research Part C: Emerging Technologies, 1(2), 119-131.

Dingus, T. A., Hulse, M . C., Mollenhauer, M . A ., Fleischman, R . N., McGehee, D. V., & Manakkal, N. (1997). Effects of age, system experience, and navigation technique on driving with and Advanced Traveler Information System, *Human Factors, 39,* 177-199.

Dougherty, J. D. & Welsh, O. L. (1966). Environmental hazards: Community noise and hearing loss. *New England Journal of Medicine, 275,* 759-765.

Endsley, M. (2000). Theoretical underpinnings of situation awareness: A critical review. In M. Endsley & D. Garland (Eds.), *Situation awareness: Analysis and Measurement* (p.3-32). Mahwah, NJ: Erlbaum.

Endsley, M.R., & Kaber, D.B. (1999). Level of automation effects on performance, situation awareness and workload in dynamic control task. *Ergonomics, 42*, 462-492.

Fok, A.W, Frischmann, T.B., Sawyer, B., Robin, M., & Mouloua, M. (2001). The impact of GPS interface design on driving and distraction. *Proceedings of the Human Factors Ergonomics Society Annual Meeting,* 55, 1755.

Horrey, W. J., & Wickens, C. D. (2004). Driving and side task performance: The effects of display clutter, separation, and modality. *Human Factors, 46*(4), 611-624.

Gong, L., & Lai, J. (2003). To mix or not to mix synthetic speech and human speech? Contrasting impact on judge-rated task performance versus self-rated performance and attitudinal responses. *International Journal of Speech Technology*, *6*(2), 123-131.

Green, P., & George, K. (1995). When should auditory guidance systems tell drivers to turn? *Proceedings of the Human Factors and Ergonomics Society 39th Annual Meeting,* (pp. 1072-1076). Santa Monica, CA: Human Factors and Ergonomics Society.

Green, P. (1999). *Visual and task demands of driver information systems* (No. UMTRI-98-16,).

Green, P. (2000). Crashes induced by driver information systems and what can be done to reduce them. Paper presented at the Sae Conference Proceedings p, 27-36.

Hamish Jamson, A., & Merat, N. (2005). Surrogate in-vehicle information systems and driver behaviour: Effects of visual and cognitive load in simulated rural driving. *Transportation Research Part F: Traffic Psychology and Behaviour,8*(2), 79-96.

Hipp, M., Schaub, F., Kargl, F., & Weber, M. (2010, November). Interaction weaknesses of personal navigation devices. In *Proceedings of the 2nd International Conference on Automotive User Interfaces and Interactive Vehicular Applications* (pp. 129-136). ACM.

Jensen, B. S., Skov, M. B., & Thiruravichandran, N. (2010). Studying driver attention and behaviour for three configurations of GPS navigation in real traffic driving. In *Proceedings of the 28th international conference on Human factors in computing systems - CHI '10* (p. 1271). Presented at the the 28th international conference, Atlanta, Georgia, USA.

Jonsson, I. M., Harris, H., & Nass, C. (2008, April). How accurate must an in-car information system be?: consequences of accurate and inaccurate information in cars. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (pp. 1665-1674). ACM.

Kelly, M.J., Stanley, L.M., Lassacher, S. (2005). Driver performance while using a cellular telephone interface to a traveler information system. Report prepared by Western Transportation Institute, Montana State University, for the Research and Innovative Technology Administration, USDOT, July 25.

Kray, C., Elting, C., Laakso, K., & Coors, V. (2003, January). Presenting route instructions on] mobile devices. In *Proceedings of the 8th international conference on Intelligent user interfaces* (pp. 117-124). ACM.

Kujala, T., & Saariluoma, P. (2011). Effects of menu structure and touch screen scrolling style on the variability of glance durations during in-vehicle visual search tasks. *Ergonomics*, *54*(8), 716-732.

Lai, J., Cheng, K., Green, P., & Tsimhoni, O. (2001, March). On the road and on the Web?:

comprehension of synthetic and human speech while driving. In*Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 206-212). ACM.

Liu, Y .-C., Schreiner, C. S. & Dingus, T. A. (2000). The effect of advanced traveler information display modality on driver performance, in *Proceedings of the International Ergonomics and the Human Factors and Ergonomics Society Joint Congress* 2000, August 2000, Santa Monica, CA (Santa Barbara, CA: HFES), 3-234-3-237.

Lalande, S., & Harbluk, J. L. Speech-based interfaces for use while driving: The impact of email speech output. *Proceedings of CMRSC-XIV*, 27-30.

Llaneras, R., Lerner, N., Dingus, T. & Moyer, J. (2000). Attention demand of IVIS auditory displays: an on-road study under freeway environments, in *Proceedings of the International Ergonomics and the Human Factors and Ergonomics Society Joint Congress* 2000, August 2000, Santa Monica, CA (Santa Barbara, CA: HFES), 3-238-3-241.

Lavie, T., & Oron-Gilad, T. (2013). Perceptions of electronic navigation displays.*Behaviour & Information Technology*, *32*(8), 800-823.

Lee, J., Forlizzi, J., & Hudson, S. E. (2005, April). Studying the effectiveness of MOVE: a contextually optimized in-vehicle navigation system. In *Proceedings of the SIGCHI conference on Human factors in computing systems* (pp. 571-580). ACM.

Lee, J., Forlizzi, J., & Hudson, S. E. (2008). Iterative design of MOVE: A situationally appropriate vehicle navigation system. *International Journal of Human-Computer Studies*, *66*(3), 198-215.

Liang, Y., & Lee, J. D. (2010). Combining cognitive and visual distraction: Less than the sum of its parts. *Accident Analysis & Prevention*, *42*(3), 881-890.

McQueen, B., Schuman, R., Chen, K. and Halstead, G. (2002) Advanced Traveler Information Systems. Artech House.

Mullennix, J. W., Stern, S. E., Wilson, S. J., & Dyson, C. L. (2003). Social perception of male and female computer synthesized speech. *Computers in Human Behavior*, *19*(4), 407-424.

Naumann, A., Wechsung, I., & Hurtienne, J. (2009). Multimodality, inclusive design, and intuitive use. *Is Prior Experience the Same as Intuition in the Context of Inclusive Design*.

Nees, M. A., & Walker, B. N. (2011). Auditory displays for in-vehicle technologies. *Reviews of Human Factors and Ergonomics*, *7*(1), 58-99.

Radeborg, K., Briem, V., & Hedman, L. R. (1999). The effect of concurrent task difficulty on working memory during simulated driving. *Ergonomics, 42*(5), 767-777.

Rakauskas, M., Ward, N., Bernat, E., Cadwallader, M., de Waard, D. (2005). Driving performance during cell phone conversation and common in-vehicle tasks while sober and drunk. Mn/DOT and CTS contract 81655, work order 41. HumanFIRST Program, University of Minnesota.

Rakauskas, M., & Ward, N. (2007). Driving performance during 511 information retrieval. Mn/DOT and CTS contract 81655, work order 204. HumanFIRST Program, University of Minnesota.

Reimer, B., Mehler, B., Dobres, J., & Coughlin, J.F. (2013). *The effects of a production level "voice-command" interface on driver behavior: Reported workload, physiology, visual attention, and driving performance*. (Report No. 2013-17A). Cambridge: MIT AgeLab.

Saiki, J., Koike, T., Takahashi, K., & Inoue, T. (2005). Visual search asymmetry with uncertain

targets. *Journal of Experimental Psychology: Human Perception and Performance*, *31*(6), 1274.
Sanders, M. and McCormick, E. (1993). *Human factors in engineering and design*. USA: McGraw-Hill
Sarter, N. B. (2006). Multimodal information presentation: Design guidance and research challenges. *International journal of industrial ergonomics*, *36*(5), 439-445.
Schaub, F., Hipp, M., Kargl, F., & Weber, M. (2013). On credibility improvements for automotive navigation systems. *Personal and Ubiquitous Computing*, *17*(5), 803-813.
Schneider, B. A., Daneman, M., & Pichora-Fuller, M. K. (2002). Listening in aging adults: From discourse comprehension to psychoacoustics. *Canadian Journal of Experimental Psychology, 56,* 3, 139-152.
Strayer, D. L., Drews, F. A., & Johnston, W. A. (2003). Cell phone induced failures of visual attention during simulated driving. *Journal of Experimental Psychology: Applied, 9*, 23-52.
Taylor, H. A., Brunyé, T. T., & Taylor, S. T. (2008). Spatial mental representation: implications for navigation system design. *Reviews of human factors and ergonomics*, *4*(1), 1-40.
Tijerina, L., Johnston, S., Parmer, E., Winterbottom, M. D., & Goodman, M. (2000). *Driver distraction with wireless telecommunications and route guidance systems* (No. HS-809 069,).
Travers, J. (2012, May 11). Waze – Free navigation app with traffic and potential for unnecessary distraction. *Consumer Reports News*. Retrieved from http://www.consumerreports.org/cro/news/2012/05/waze-free-navigation-app-with-traffic-and-potential-for-unnecessary-distraction/index.htm
Tsimhoni, O., Smith, D., & Green, P. (2004). Address Entry While Driving: Speech Recognition Versus a Touch-Screen Keyboard. *Human Factors: The Journal of the Human Factors and Ergonomics Society, 46*(4), 600-610.
Tun, P. A. (1998). Fast noisy speech: Age differences in processing rapid speech with background noise. *Psychology and Aging 13*(3), 424-434.
Tun, P. A., O'Kane, G., & Wingfield, A. (2002). Distraction by competing speech in young and older adult listeners. *Psychology and Aging, 17,* 3, 453-467.
Tun, P. A. & Wingfield, A. (1999). One voice too many: Adult age differences in language with different types of distracting sounds. *The Journals of Gerontology, 54B,* 5, P317-467
Verwey, W. B., Alm, H., Groeger, J. A., Janssen, W. H., Kuiken, M. J., Schraagen, J. M., Schumann, J., van Winsum, W., &Wontorra, H. (1993). GIDS functions. In J. A. Michon (Ed.), *Generic intelligent driver support: A comprehensive report on GIDS* (pp. 113-144). London: Taylor & Francis.
Wickens, C. D., Ambinder, M. S., Alexander, A. L., & Martens, M. (2004, September). The role of highlighting in visual search through maps. In *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*(Vol. 48, No. 16, pp. 1895-1899). SAGE Publications.
Wu, A., & Zhang, X. (2009). Identifying proper scales on digital maps for in-vehicle navigation systems. In *Universal Access in Human-Computer Interaction. Applications and Services* (pp. 262-270). Springer Berlin Heidelberg.
Yager, C. (2013). An Evaluation of The effectivness of voice-to-text programs at reducing incidences of distracted driving. College Station, Texas: Texas A&M Transportation Institute.

Yamani, Y., & McCarley, J. S. (2011). Visual Search Asymmetries in Heavy Clutter Implications for Display Design. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *53*(3), 299-307.

Young, K. & Regan, M. (2007). Driver distraction: A review of the literature. In: I.J. Faulks, M. Regan, M. Stevenson, J. Brown, A. Porter & J.D. Irwin (Eds.). Distracted driving. Sydney, NSW: Australasian College of Road Safety. Pages 379-405.