Comparing the Effects of Integrated and Nomadic Navigation Systems on Road Traffic Safety: A Naturalistic Experiment.

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ABSTRACT

The real world problem that this master's thesis project addresses is the problem of distraction while navigation assisted driving. This study works with the following assumptions: (A) Traffic safety needs improvement. (B) Car navigation systems, like other information systems have the potential to cause dangerous distraction while driving. (C) Therefore optimizing navigation systems to minimize distraction will likely improve overall traffic safety. This study aims to provide empirical observations by quantitative experimental setup (n=30) on whether or not an integrated car navigation system causes less distraction (therefore be less detrimental to traffic safety) compared to a nomadic navigation system, such as a smartphone navigation app. This experiment is preceded by a requirements elicitation consisting literature review, a qualitative survey of 50 persons, traffic safety expert interviews and 10 field observation sessions. Requirements elicitation produces an analysis and a ranked set of indicators to road traffic safety, distraction and user interface design. Ultimately, this research will answer: (1) What are the specific distractions introduced by smartphone navigation systems that impact road safety? (2) What are the specific indicators of road safety that are relevant to the use of navigation systems? (3) How can these indicators be ranked in terms of their importance for evaluating the safety impacts of nomadic (smartphone) versus integrated car navigation systems? (4) How do nomadic (smartphone) navigation systems and integrated car navigation systems differ in terms of their impact on road safety indicators? (5) Is there a significant difference in road safety indicators between the use of smartphone navigation systems and integrated car navigation systems? (6) How can the results of this study be used to inform the design of future car navigation systems and regulations around their use to improve road safety? The project has a lead time from February until (and including) July 2023 and is dividable into three phases: (1) preparation, (2) requirements elicitation, (3) experiment phase and (4) finalization. The phases have a critical path, meaning each phase must be fully finalized before the next phase starts.

1 INTRODUCTION AND MOTIVATION

Recent years, progress of technology has brought smartphones and other extremely versatile devices to the dashboards of cars. These devices can be quite helpful, such as voice assistants and navigation systems. Applications may also have practical uses not related to driving, like messaging and dialing. Additionally, some applications have purely the function of entertainment. These developments have had an impact on the way people drive and subsequently the safety of driving and traffic as a whole. Most countries have a ban on non-handsfree telephone use while driving. Given almost 160-thousand violations of this ban in the Netherlands in 2021 [1], it can be established that many drivers have a tendency to get distracted by their phones while driving. Being distracted by for instance the car radio, intense emotions, or using a smartphone decreases the focus toward the rest of traffic, and increases the probability of disrupting traffic or causing an accident. A large scale 2019 naturalistic study in the USA by Dingus et al [2] reports a 3.5 odds ratio of getting into a car crash while using a cell phone, over a baseline of driving without distractions.

In a sense, the car has become an information unit. Traffic today without information distribution is nearly unthinkable. There are various data the driver needs, delivered by assistance and control systems. There are also data that the driver does not primarily need, but is nevertheless provisioned such as entertainment and communication. Car infotainment systems divided by Kandemir et al into Nomadic (external, such as smart phones) and integrated devices [3] consist a broad range of applications like messaging, radio and navigation. Modern cars contain a larger variety of infotainment systems. These systems by themselves change rapidly, for example further integration of smartphones with native car infotainment systems, adding to the variety, versatility and complexity of tasks related to these systems. Also the interactions themselves have changed. Notably, many existing or new functions of car infotainment systems are controlled by touch screen, where before this may have been done by knobs and buttons.

One issue that drivers encounter is the potential for an excess of information provided during certain stages of driving that may not be relevant or necessary for the task at hand. Studies have shown that drivers can become overwhelmed when presented with too much information, leading to increased stress, cognitive load, and ultimately reduced safety [4][5]. Navigation systems may have a positive effect on traffic safety as it prevents unnecessary searching and detours, but under condition that destination is entered into the system before starting to drive [6]. While navigation can be a necessary and useful tool to assist drivers in reaching their destination, the selection, presentation and timing of this information can be critical to avoid information overload and distraction. Therefore, finding the right balance between providing necessary information and avoiding unnecessary distractions is crucial for ensuring safe and efficient driving.

This study hypothesizes that the use of smartphones for navigation introduces numerous distractions, such as pop-ups and notifications, and these systems are not specifically designed with traffic safety in mind, posing greater danger to drivers compared to navigation systems that are integrated into the car. In this study, the impact of using an integrated navigation system on road safety will be investigated in comparison to using a smartphone for navigation while driving. The results of this study are expected to provide empirical grounding for future designs of car navigation systems and related regulations, ultimately to improve traffic safety. The following questions are formulated to which the answers provide these insights.

1. What are the specific distractions introduced by smartphone navigation systems that impact road safety?
2. What are the specific indicators of road safety that are relevant to the use of navigation systems?
3. How can these indicators be ranked in terms of their importance for evaluating the safety impacts of nomadic (smartphone) versus integrated car navigation systems?
4. Is there a statistically significant difference in specific road safety indicators between drivers using smartphone navigation systems versus those using integrated navigation systems?
5. How do nomadic (smartphone) navigation systems and integrated car navigation systems differ in terms of their impact on road safety indicators?
6. How can the results of this study be used to inform the design of future car navigation systems and regulations around their use to improve road safety?

Altogether this research will provide an answer to the following main research question: *What is the impact of smartphone navigation systems versus integrated car navigation systems on road safety, specifically in terms of the distractions they introduce, relevant indicators of road safety, differences in impact on road safety indicators, and implications for the design of future car navigation systems and regulations around their use?*

2 RELATED WORK

Use of navigation systems may introduce various types of distractions, classified by Ma, et al. (2022) as cognitive, visual, manual, and auditory [7], which can impact driving performance and road safety. This section aims to provide a overview of previous studies on navigation-assisted driving and its impact on road safety, including the types of distractions and interface design, as well as the indicators of road safety used in previous studies.

Grahn and Kujala conducted a study in 2020 that aimed to compare the degree of visual distraction caused by smartphone-based applications to that caused by a specialized application for cars (Carrio). According to their findings, the specialized application caused less visual distraction due to its specialized user interface design, the division of tasks into subtasks, and, to a lesser extent, the size of the screen [8].

Simulation studies are the most frequently used methodology in similar studies, followed by naturalistic studies as the second most common approach [9].

In an analysis of distraction by car infotainment systems, a team from University of Utah tested differences in cognitive load between various functions and interface components for car infotainment systems (IVIS) [10]. The research found significant differences between various applications (like navigation, entertainment, messaging or dialing) and various components of user interfaces with respect to driving performance.

2.1 Types of distractions

Multiple studies have identified navigation destination entry as highly demanding [11][12], and in at least two instances it was even identified by direct experiment as the most demanding secondary task [7][10] among other common tasks such as text messaging, dialing and radio volume adjustment.

Comprehensive literature review by Oviedo-Trespalacios, et al resulted in a extensive list of secondary in-vehicle tasks such as conversing, reaching, answering calls, dialling, browsing, reading, texting and typing [9]. These sorts of IVIS-related tasks can be considered unhelpful distractions, together with adjusting the radio, entertainment systems, dealing with irrelevant (navigation) data, and specifically to nomadic systems: popups and notifications by for instance social media or disruptions and interruptions of the navigation application.

Numerous of the reviewed articles focus on visual distraction, which tends to be measured in terms of glances/glance duration/ glance behavior, or similarly fixation count or duration [13][14][10][11][12][8][7][9][15].

2.2 Interface design and road safety

Grahn and Kujala studied in-car tasks and their distraction potential. They found that task structure, specifically how tasks are divided into subtasks, is important. People tend to switch tasks at subtask boundaries, such as between words, and this has implications for reducing distraction in car information systems [8].

Interaction modalities: Haptic feedback can help alleviate visual distraction and allow the driver to focus on the road [11]. Audio feedback, such as a "read aloud" feature, can also be helpful, although it may not be as effective in some situations and can still cause cognitive distraction [8]. Different input modalities for certain tasks, or different mixes of modalities are likely to have an effect on cognitive, visual or manual distraction. A 2022 study by Jun Ma et al suggests a well designed touch screen may be more suitable for certain complex secondary tasks, compared to knobs and buttons, despite the fact that knobs and buttons are by themselves more simple to operate [7].

2.3 Road safety indicators

Besides in-vehicle tasks, Oviedo-Trespalacios created an inventory of “Human Machine Systems (HMS) performance metrics: headway, lateral position (lane position), speed, crashes, and workload [9]. The mentioned metrics may be considered synonymous, or closely related to road traffic safety indicators.

The analysis reveals that the design of the IVIS interface affects driving speed. Engaging in activities such as conversing, dialing, or texting while driving leads to a decrease in driving speed and an increase in headways [9]. This is a well-known effect and named by Young and Regan as “compensatory or adaptive behavior” [12]. Lane position has been found to be impacted by visual and manual load. Also voice control that generates cognitive load has been found to affect departures from the lane center (more so than on speed control). Still voice control seems to distract less than operating a touch screen. [7].

The positive association between secondary tasks while driving and decreased driving performance seems to be moderated by environmental factors that impact the complexity of driving tasks [Regan]. Also minding the interdependencies of distraction variables, Kandemir, et al. propose the existence of “toxic” task combinations in which certain tasks, while not overly burdensome on their own, may surpass a certain threshold when performed in conjunction with more complex tasks, such as dialing while simultaneously braking at a red light [3]. In a similar sense, Oviedo-Trespalacios have approached what they called “Mobile Phone Distracted Driving” as a human-machine system. They have focused their observations not just on distractions by certain tasks, but also by conflicts that occur between combinations of tasks [Oviedo-Trespalacios].

3 METHODOLOGY

The data collection and analysis consists two main phases, the first being a requirements elicitation and the second an experiment.

Ethical considerations: Risks to participants, researcher and other traffic must be minimized. The researcher will explicitly request compliance with traffic laws at all times during driving sessions, and to always put safety first when making decisions while driving.

3.1 Requirements elicitation

Specific indicators of road safety relevant to the use of navigation systems will be identified through a comprehensive requirements elicitation process involving surveys, expert interviews, and field observations. By a triangulated approach that includes a survey, expert interviews and field observation, data is collected about behavior while navigation assisted driving, as well as variables or contextual factors that may influence the relation between distractions and driving performance.

Survey: An online survey is held among 50 random and anonymous car navigation system users (minimal 25 nomadic, 25 integrated) to observe the behavior around navigation assisted driving. The study aims to collect a cross section of all car drivers in the Netherlands. Respondents are recruited by distribution of flyers via fueling stations across the country. The respondents provide basic demographic data, and answer questions concerning: (1) their use or of navigation systems while driving (e.g. how, what for, preferences, frequency), (2) how they may or may not have found they were distracted by navigation systems, (3) how have they found those distractions to impact their driving performance, (4) how distractions may be linked to navigation user interface. The resulting raw qualitative data is the main source of indicators such as events, distractors and their perceived effects on safety.

Expert interviews: To the survey results are added the insights of experts such as traffic safety experts, to provide context to the survey results to add to, weigh and rank indicators identified from the survey results. Respondents are linked to institutions such as CBR or SVOV and have knowledge about road safety research or experience in the mentioned domain. Between two and four interviews are conducted using a semi-structured format with a pre-determined list of topics to guide the discussion. The interview topics concern: (A) what the expert observes in driving behavior and traffic incidents that is linked to information system use while driving, (B) what differences the expert may or may not observe between use of integrated and nomadic information systems regarding driving behavior and incidents, (C) what the experts say should be done in terms of information system design or regulation to improve traffic safety, with regard to navigation systems. After transcription, a summary is made which is sent to the respondent for review, to mitigate the risk of recall errors.

Observations: A sample of four car drivers is drawn: two persons who prefer a smartphone, two persons who prefer an integrated navigation system. Sessions are held in which the driver and a researcher drive for thirty minutes by navigation over any trajectory that is convenient. The researcher observes the participant’s device and the behavior of the driver, while making notes. The purpose is to cross reference the observations with the topics found earlier.

The data collected from the survey, expert interviews, and field observations will be analyzed to identify potential indicators of road traffic safety and navigation-assisted driving behavior. After each data collection step, qualitative results are edited and then coded, processed into a code book and content analysis takes place. After finishing the three data collection steps, a combined content analysis takes place and a narrative form analysis is written. Furthermore, based on a process of exclusion and ranking, the most important road safety indicators will be selected for further experimental study.

Exclusion: Several factors will restrict the feasibility of testing certain indicators, including the availability of resources, ethical concerns related to unacceptable risks in road traffic, and personal aspects that are too subjective and difficult to quantify. Based on such factors, certain indicators will be excluded from further experimental study.

Ranking: The importance of each indicator on road safety will be assessed using a weighted scoring system that takes into account both the severity and prevalence of the safety risk. The survey data is the most important source for determining the prevalence of safety risks, while severity is mostly determined by the outcome from the expert interviews.

3.2 Experiment
To answer question number four as stated in the introduction, a naturalistic experiment is conducted. 40 random participants are recruited by the same method as the previous survey, of which 20 commonly use smartphone navigation, and 20 commonly use integrated navigation. Each participant will drive a predetermined route while following navigation instructions. Road safety indicators will be measured through methods such as GPS logging. Ideally, to increase reliability of the results, multiple methods are used concurrently. It is hypothesized that the integrated navigation system group will show better road safety indicators compared to the smartphone navigation system group. If the results confirm the hypothesis, it provides grounds for future empirical study into how nomadic navigation systems may be improved. The collected data will be analyzed using statistical techniques, including descriptive statistics, t-test, and regression analysis, to compare the road safety indicators between the two groups. The statistical significance level will be set at $p < 0.05$.

H0: There is no significant difference in road safety indicators between using a smartphone navigation system and an integrated navigation system in a car.

The independent variable in this study is whether participants use a smartphone navigation system (A) or an integrated navigation system (B). The dependent variable is a specific road safety indicator or set of indicators that will be identified through the requirements elicitation process. It is important to note that while distraction is a possible mediating variable in the relationship between navigation system type and road safety, it is outside the scope of this study to measure distraction directly.

The lack of control over variables in this naturalistic study poses risks to both validity and reliability. These risks include bias through confounding variables and the presence of uncontrollable external factors.

4 PROJECT PLAN & RISK ASSESSMENT
The planning is represented visually in figure 1, which includes planning phases and their durations. A fixed period is reserved for the project, starting from February 6, with a final delivery on July 31, 2023 latest. The full project is divided into four phases: (1) preparations, (2) case study, (3) experiment, and (4) Finalizing. A critical path exists between each of the phases. Each phase must be completely finalized before the next phase can start. An overview of the deadlines is shown in the table below.

A	19-2-2023	Thesis design
B	19-3-2023	Draft Literature Review
C	21-4-2023	Draft Results Section Analysis and Results
D	18-5-2023	Draft Thesis
E	31-7-2023	Final delivery

4.1 Risk assessment
Potential risks to the thesis project are classified in terms of time, resources, and quality.

A real risk exists that the thesis is not delivered at the final delivery date of 31st July. It is a common problem with part-time students who have to balance work with studies. There may be problems allocating the necessary amount of time to complete the thesis tasks on time, leading to missed deadlines and delivery delays. This risk is mitigated by continuously reviewing thesis planning and taking steps to adapt. The researcher must keep setting realistic goals for completion of individual chapters and milestones. Additionally, the researcher should stay in contact with the thesis supervisor to discuss which steps should be taken to keep the project on track.

Besides time, a lack of resources could also turn out to become a problem. More specifically instruments to take measurements related to indicators of driving performance. Also a real risk exists there may not be enough participants, or that recruitment of actually random participants turns out to be too costly in terms of time and resources. As a result, efforts to achieve the desired measurements or sampling standards may not be met, causing wasted time and efforts and eventually delay. To mitigate these risks, driving performance measures may be excluded that are too costly or complicated to measure, during the ranking and exclusion process. Convenience sampling may be introduced to increase response rate, to reduce workload in the sampling process. Weaknesses in validity that this will inevitably introduce to the research would be acknowledged and analysed in the discussion.

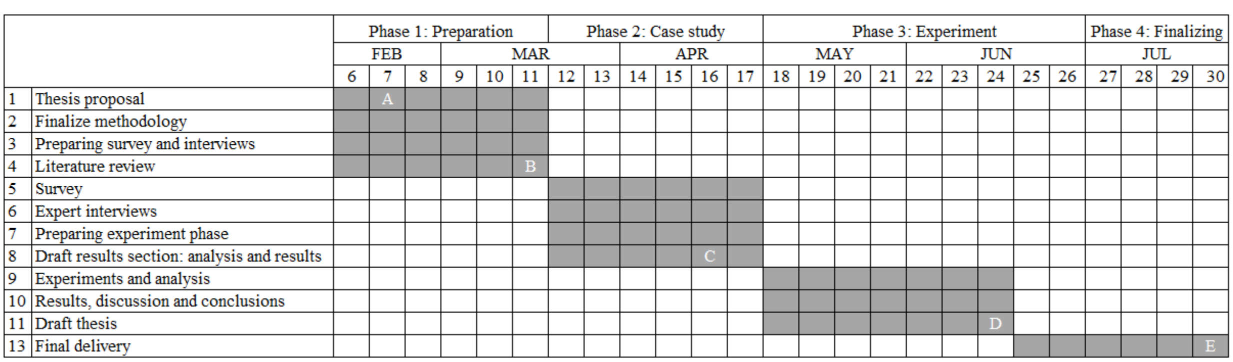

Figure 1: GANTT-chart showing phases with durations of the thesis project from start to end

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