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# Driver Behaviour in Highly Automated Driving

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An evaluation of the effects of traffic, time pressure, cognitive performance and driver attitudes on decision-making time using a web based testing platform

**The Institution for Computer and Information Science (IDA)  
Linköping University**

Supervisor: Daniel Västfjäll  
Supervisor: Katja Kircher  
Co-supervisor: Ignacio Solis Marcos,  
Examiner: Arne Jönsson  
Opponent: Fares El Ghoul  
LIU-IDA/KOGVET-A--14/001--SE

(IBL) Linköping University  
The Swedish National Road and Transport Research Institute  
The Swedish National Road and Transport Research Institute  
(IDA) Linköping University

## **Abstract**

Driverless cars are a hot topic in today's industry where several vehicle manufacturers try to create a reliable system for automated driving. The advantages of highly automated vehicles are many, safer roads and a lower environmental impact are some of the arguments for this technology. However, the notion of highly automated cars give rise to a large number of human factor issues regarding the safety and reliability of the automated system as well as concern about the driver's role in the system.

The purpose of this study was to explore the effects of systematic variations in traffic complexity and external time pressure on decision-making time in a simulated situation using a web-based testing platform. A secondary focus was to examine whether measures of cognitive performance and driver attitudes have an effect on decision-making time.

The results show that systematic variations in both time pressure and traffic complexity have an effect on decision-making time. This indicates that drivers are able to adapt their decision-making to facilitate the requirements of a certain situation. The results also indicate that intelligence; speed of processing and driver attitudes has an effect on decision-making time.

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# 1 Introduction

Driverless cars are a hot topic in today's industry where several vehicle manufacturers try to create a reliable system for automated driving. The advantages of highly automated vehicles are many, safer roads and a lower environmental impact are some of the arguments used for this technology. The Swedish car manufacturer Volvo in cooperation with the Swedish government just launched the Drive Me project whose aim is to deploy 100 highly automated cars in Gothenburg, Sweden by 2017 (Volvo Car Group, 2013).

The notion of highly automated cars give rise to a large number of human factor issues regarding the safety and reliability of the automated system as well as concern about the driver's role in the system.

For instance, studies have shown that drivers in automated vehicles are likely to end up 'out of the loop', meaning they are excluded from the control-loop of the driving task and thereby losing situation awareness. It is also possible that drivers could experience a decline in driving skills (Onnasch, Wickens, Li & Manzey, 2014). In the best of cases the driver would serve as an automation supervisor and thereby maintain some level of situation awareness, although, the supervisor role may lead to loss of vigilance, or to the shrinkage of available cognitive resources (Young & Stanton, 2002b) during long monotonous drives. Loss of vigilance may cause the driver to miss vital information about automation reliability (Norman, 2009 pp. 109, 114) as well as a loss in situation awareness.

When automated systems reach a high level of automation, in which both the lateral and the longitudinal control loop are automated, it is likely that drivers can engage in different in-car activities unrelated to the driving task, such as, watching a film on a screen, doing work on their tablet or computer, reading a newspaper or whatever the driver feel like doing (De Winter, Happee, Martens & Stanton, In press).

Situation awareness will most likely be adversely affected as driver attention is redirected from the road to other activities as shown in a meta-analysis of automated driving by De Winter et al. (in press). This in turn leads to increased response-times in comparison with manual driving in a situation where immediate attention is required as the driver actively has to gather information critical for the situation. This situation is very unlikely, however, there is no guarantee that an automated system will perform safely at all times. When automation failures arise it will most likely be with very short notice and without warning (Norman, 2013, pp. 213-214) hence, requiring a high driver vigilance state (Banks, Stanton & Harvey, 2014) or the driver would be likely to lose control of the situation and as a result, an accident could occur. This is an unlikely scenario as the automated system should be designed in a way that give the driver a heads up when the automation is approaching its operational boundaries, and thereby give the driver a chance to get back into the loop and make a safe transfer of control and avoid an accident (De Winter et al., In press).



## **1.1 Problem definition**

The problem with studying highly automated driving is that it is currently on a conceptual stage. This give rise to a number of issues when trying to introduce this concept to drivers, for example; what information is required to make safe transfers of control, how much time ahead does a driver need before a transfer of control can be made safely and how much time does a driver need to be able to orient him-/her-self in a situation where a transfer of control might be necessary. Given that the technology is quite far from being commercially available there is a lack of experience when it comes to highly automated driving.

In order to address these questions, a simple tool is needed to help examine the information needs in a highly automated vehicle. It is also important to try and discern in what time frame drivers can evaluate a situation in order to make a decision or initiate a transfer of control.

## **1.2 Purpose**

The main focus of this thesis is to find out whether and how different levels of time constraints and traffic complexity used in the study have an effect on the time it takes to evaluate the situation presented and make a decision (henceforth referred to as decision-making time) to ensure that the manipulations have an effect. The secondary area of focus is examine how and if measures of cognitive performance, demographical data and a measure of driver attitudes can account for any variance in decision-making time.

## **1.3 Research Questions**

- Are there any systematic differences in decision-making time between:
  - Different traffic complexity conditions?
  - Different time constraints?
- What factors could serve as predictors of decision-making time?
  - Are there any cognitive abilities that can serve as predictors of decision-making time?

## **1.4 Delimitations**

The scope of this study is delimited to examine how decision-making time is affected by time constraint and traffic complexity as well as how well decision-making time can be predicted by the cognitive tests. The actual decisions the drivers made will not be included in this study as the time frame does not allow for such an extensive analysis to be made.

## **2 Theoretical background**

Relevant background theories for the study are presented in the sub-chapters below.

### **2.1 Malleable Attentional Resources Theory**

The Malleable Attentional Resources Theory (MART) is an attentional resources theory suggested by Young and Stanton (2002a) as a way of explaining how attentional resources expand and shrink in relation to mental workload (MWL). This would mean that the attentional resources increase as MWL increases in complex, high workload situations (until a maximum level is reached) and the opposite would occur when in situations with low complexity and workload as the theory postulates that the attentional resources would shrink in relation to workload.

For example, according to the theory the attentional resources of the driver would shrink when driving in a highly automated vehicle due to a decrease in MWL caused by the lack of effort in performing the task. This would mean that the driver could suffer from mental underload (Young & Stanton, 2002b), meaning that the driver would have difficulties taking control of the vehicle if an emergency transfer of control would be necessary, as the driver has insufficient resources allocated to cope with the difficulty of the task. The implications of this ‘underload’ would, according to the authors (Young & Stanton, 2002a; Young & Stanton, 2002b) be equally bad, if not worse, than the more familiar concept of mental overload occurring in high workload conditions (Wickens, 2008). However, if the driver were preoccupied with a challenging task when in an automated vehicle, he would, in theory, have enough attentional resources allocated to safely handle a transfer of control if a sudden automation failure would occur.

### **2.2 Decision-making**

The following sections contain theoretical background of decision-making, in relation to cognitive abilities, relevant for the subsequent sub-chapters.

#### **2.2.1 Decisions and risk**

According to Kahneman and Tversky (1979) people underweigh outcomes that are probable in comparison with outcomes that are certain. This is called the certainty effect, which means that people generally avoid taking decisions resulting in uncertainty when there is an option resulting in a guaranteed gain and that people take decisions where the outcome is uncertain when the other option results in a guaranteed loss (Rabin & Weizäcker, 2007). People also seem to discard components of a decision, which is shared amongst the different options. This is called the isolation effect, which causes inconsistency in decision-making preferences when the same choice is presented in different forms. (Kahneman & Tversky, 1979; Tversky & Kahneman, 1981)

### 2.2.2 Choice bracketing

In a decision-making situation the decision maker can either “*broadly bracket*” or “*narrowly bracket*” their decision space. *Broad bracketing* essentially means that the decision maker takes all the available decisions into account, weighing them against each other to make the best decision given the available alternatives. The opposite stands for a *narrow bracketer*, a decision maker that uses *narrow bracketing* only considers the available options on their own. Hence, there is no comparison between available options. Consider the following example: A trivial decision such as having a cigarette would satisfy a person employing a narrow bracketing strategy because they only consider the short term pleasure of having a cigarette rather than to look at the long term effects of smoking. Whereas a broad bracketer would choose not to smoke because of the long-term effects caused by smoking. (Read, Loewenstein & Rabin, 1999; Rabin & Weizäcker 2007)

### 2.2.3 Choice bracketing in relation to cognitive ability

According to Dohmen, Falk, Huffman & Sunde (2010) there is a correlation between cognitive ability and risk aversion where willingness to take risks correlate with high cognitive ability. In relation to the decision bracketing theories by Read, Loewenstein & Rabin (1999) and Rabin & Weizäcker (2007) people with higher cognitive ability would, in theory, be prone to take risky decisions in the same manner as a *broad bracketer* would and hence, the decision maker should consider all available options and picking the one with the largest gain even though there is a risk that the choice will result in an unfavourable outcome. In theory it would also mean that people with low cognitive ability are more risk averse and will avoid taking decisions, which could result in an unfavourable outcome.

As well as correlating cognitive ability with risk averse behaviour Dohmen et al. (2010) found a correlation between patience and cognitive ability which indicates that people with high cognitive ability are more patient than people with low cognitive ability. This claim is also supported by Shane Frederick’s (2005) research on decision-making and cognitive reflection, stating that people with higher cognitive ability (or IQ) are able to suppress the response that first comes to mind and instead take more background factors into account before making a decision, weighing the advantages against disadvantages to take a favourable decision. In terms of decision-making this could indicate that people with high cognitive ability are willing to take long-term risky decisions such as investing in stocks. This could also, in theory mean that the time to make a decision would be higher in people with high cognitive ability than in people with lower cognitive ability as they spend more time weighing each option against the desired outcome.

Dohmen et al. (2010) suggests a simple way of testing an individual’s cognitive ability, which correlates with risk averse behaviour as well as patience. The test suggested is called a *symbol-number correspondence test*, the test has been controlled for personal characteristics, educational attainment, income and liquidity constraints as well as additional robustness checks which, according to the authors, makes the symbol-number correspondence test a reliable way of testing cognitive ability. The test itself is described in detail in chapter 2.4 below.

### 2.3 Trail-Making Test B

The Trail-Making Test B, henceforth referred to as TMT-B, is a widely used cognitive test to assess neurological impairment and brain damage. In the test the participant must connect 26 circles with alternating numbers and letters (i.e. 1-A, 2-B etc.). The test is scored on the time to complete the task (Oliveira-Souza et. al., 2000; Tombaugh, 2003; Betz & Fisher, 2009) and is sensitive on the following cognitive abilities: visual search, scanning, speed of processing, a visuospatial sequencing factor, cognitive set shifting, executive functioning and working memory (Oliveira-Souza et. al., 2000; Aributhnott & Frank, 2000; Tombaugh, 2003; Betz & Fisher, 2009; Salthouse, 2011; Sánchez-Coubillo, In press).

Oliveira-Souza et al. (2000) suggest that TMT-B performance could serve as a predictor of whether people are able to quickly adjust their behaviour depending on environmental changes. This could, in theory, serve as a tool to predict performance in automated driving i.e. where the driver goes from a sleeping state to a woken state where he/she is expected to take over control within a reasonable amount of time. This in combination with the fact that TMT-B seem to relate to a multitude of cognitive functions (mentioned earlier) it should be able to explain some of the variance between participants in the information preferences test.

### 2.4 Symbol-number Correspondence task

The Symbol-Number Correspondence (SNCT) task is a multifaceted cognitive test widely used in disability research. The multifaceted characteristics of the SNCT is both an asset as well as a failing since the score on the test is dependent on several factors that correlates highly with overall test performance, such factors are speed of processing and memory (Joy, Kaplan & Fein, 2004). Both Joy et al. (2004) and Crowe et al. (1998) showed that speed of processing could explain 50% of the variance in performance of the SNCT and that memory has a secondary role in performance as it only explains 5-7% or 14-15% of the variance depending on which test is used to assess the memory component (using either the *incidental learning tests* or the WMS-II indexes). Crowe et al. (1998) also showed that motor execution speed was able to predict a significant amount of variance in the SNCT. This should mean that there are more factors influencing the performance of the task, which should be taken in to consideration when using the task to assess speed of processing.

### 2.5 Tower of Hanoi

The *Tower of Hanoi* (TOH) is a “look ahead puzzle” in which a participant has to move a set of three discs from one “peg” to another utilizing a third peg in between the starting peg and the goal peg in as few moves as possible. Only one disc can be moved at a time and the participant can only place a smaller disc on top of a larger one. The difficulty in this task lies in breaking down the task in to sub task and solve these sub goals individually, which requires good planning skills (Shallice, 1982). The TOH is believed to assess some specific executive functions including planning, working memory, checking, monitoring and revising (Welsh, Satterlee-Cartmell & Stine, 1999). This also entails the ability to allocate cognitive resources to solve problems (Kafer & Hunter, 1997).

## 2.6 Driver Behaviour Questionnaire

The Driver Behaviour Questionnaire (DBQ) was originally developed by James Reason (1990) to be able to collect self-reported data from drivers when objective records of driving behaviour and traffic violations were unavailable. The original scale consists of 50 items and serves to give a score on the following three underlying factors: errors, violations and lapses. A meta-analysis of the DBQ by De Winter and Dodou (2010) showed that the original DBQ (Reason, 1990) or different modified versions (see Parker, Reason, Manstead & Stradling, 1995; Wells, Tong, Sexton, Grayson & Jones, 2008; Martinussen, Lajunen, Møller & Özkan, 2013; De Winter, 2013) of the DBQ have been used in 174 studies since its introduction. The study showed that the DBQ errors and violations factors are significant predictors of self reported accidents (De Winter & Dudo, 2010).

The DBQ used in this study is a modified shorter version of the DBQ by Wells et al (2008) created by De Winter (2013). The DBQ questions 1-7 were chosen as they, according to an exploratory factor analysis by De Winter (2013), loaded highly on the violations factor, the questions 8-10 were chosen as they loaded highly on the error factor and the questions 11-12 were chosen to capture lateral driving behaviour.

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### DBQ Questions

- 1 Sound your horn to indicate your annoyance with another road user
  - 2 Disregard the speed limit on a residential road
  - 3 Use a mobile phone without a hands free kit
  - 4 Become angered by a particular type of driver, and indicate your hostility by whatever means you can
  - 5 Race away from traffic lights with the intention of beating the driver next to you
  - 6 Drive so close to the car in front that it would be difficult to stop in an emergency
  - 7 Disregard the speed limit on a motorway
  - 8 Change into the wrong gear
  - 9 Forget to take the handbrake off before moving off
  - 10 Get into the wrong lane when approaching a roundabout or junction
  - 11 Incorrect steering so that you hit the curb
  - 12 Strayed from the middle of the lane into the verge or emergency lane
- 

**Table 1: DBQ questions from De Winter (2013)**

The DBQ has no formal scoring system (De Winter et. al, in press) and the factors of the different DBQ's are often assessed using a Principal Components analysis made by the researchers (De Winter, in press). This is not needed for this study as this study utilizes a DBQ version that is already assessed. The DBQ will be scored based on the mean score of the questions within each factor as well as an overall mean score.

### 3 Method

The test battery used in this experiment was divided into six parts, 3 cognitive tests, 2 questionnaires and the information preferences test. The different cognitive tests are described through chapters 2.3 to 2.5, the DBQ questionnaire are described in detail in chapter 2.6. Following these tests is an information preferences test devised and developed for the sake of this experiment. An illustration of the test structure is shown in Figure 1 and the test design is described in detail in the paragraphs following Figure 1.



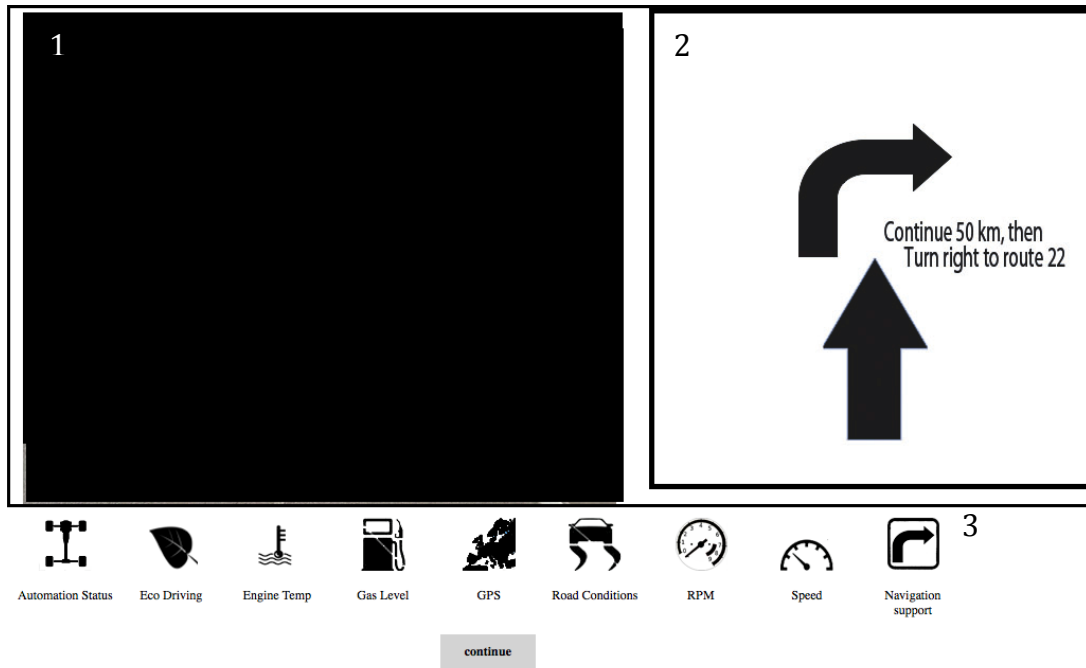
Figure 1: The structure and order of the test battery

#### 3.1 Test description

The information preferences interface has three main parts, the case image area (1), the information area (2) and the information selection area (3). A brief scenario text is displayed before starting each visual scenario (I.e. after a while without driving manually you feel like taking over the control of your car, what information do you need? The time for this task is limited to: 30 seconds). The participant continues to the visual scenario by pressing a button on the screen with the written scenario description. By pressing the button the participant moves to a visual scenario where an image was displayed along with different information types visible at the bottom of Figure 2. The participant then selects, via a click on the mouse, the information he/she prefers based (in theory) on the image displayed and the current time constraint. The information is displayed in the rightmost window (the turn by turn navigation in Figure 2).

When the participant is satisfied with his/her choices he/she may press the continue button to move to the next scenario information screen. If the participant does not click the continue button he/she will be transferred to the next scenario information screen when the time limit of the scenario is reached (15, 30 or 120-seconds). The measures collected from the information preferences task are:

- Time to first decision (which could be seen as a form of reaction time),
- First decision.
- The time the first decision window is open (i.e. the time it takes to register the information accessed and continue to the next scenario or choose a new set of information).
- What the second decision is and
- The time spent viewing the information of that particular information category.

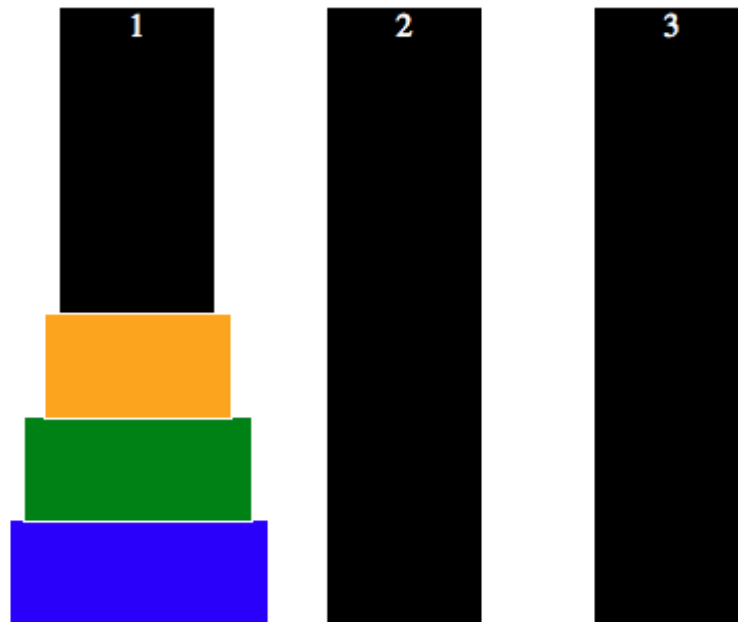


**Figure 2: The information preferences main screen (scenario image removed due to copyright reasons)**

### 3.1.1 Procedure

1. The test started with a screen informing the participant of the test as well as informing them about what the data was supposed to be used for. The information given is available in Appendix 1. They were then told that they are giving consent to the use of the data generated by their participation in the test by continuing to the actual test by pressing a “start test” button. The test then proceeds to a demographic questionnaire with questions regarding age, country, educational level, socioeconomical status, drivers license and annual mileage.
2. After completion of the demographic questionnaire the participant moved on to the first cognitive test in a series of three, *The Tower of Hanoi*, which is illustrated in Figure 3 and described in detail in chapter 2.5. The participant was given instructions about the test rules as well as the goal of the task before commencing to the actual test. *The TOH* task used in this was the three-disc version where the optimal solution requires 7 steps.

The participant's performance was assessed based on the total number of moves required to reach a solution as well as the time it took to complete the task. Data on the number of false moves (i.e. when the participant tried to place a larger disc on top of a smaller disc) were also collected as to be able to discern whether the participant had understood the limitations in the task.



**Figure 3: The Tower of Hanoi test screen**

3. The second cognitive test was the SNCT illustrated in Figure 4 and Figure 5 and described in detail in chapter 2.4. The participant received instructions about the task and the 90-second time constraint and that he/she would have a chance to see the all numbers and their corresponding symbols before the test with an unlimited time to memorize the symbol/number correspondences. The participant was also informed that the symbol/number correspondences would be visible throughout the test.

In the SNCT the participant had to enter the digit that corresponded to the symbol shown on the screen as fast as possible, when the interface registered a keystroke it immediately presented a new stimulus, saved the time between stimulus presentation and response and if the response was correct or not. The performance measures collected for this task were the average stimulus response time in milliseconds, the total number of responses, the number of correct responses as well as more detailed information in the form of the time in milliseconds for each individual stimuli response and whether the response was correct or not.



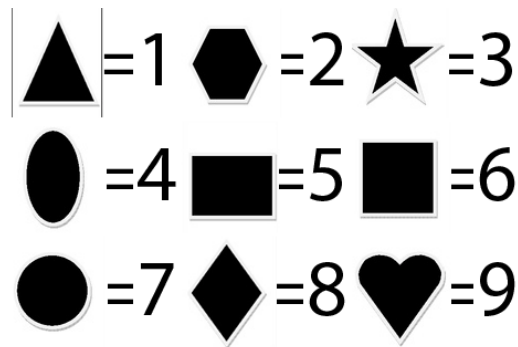


Figure 4: The symbol number correspondences displayed before the Symbol Number Correspondence Task

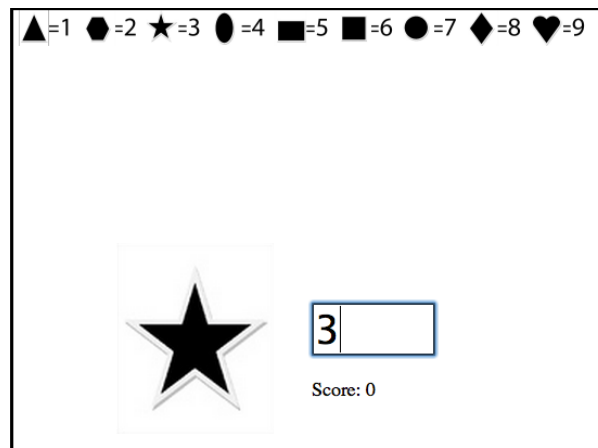
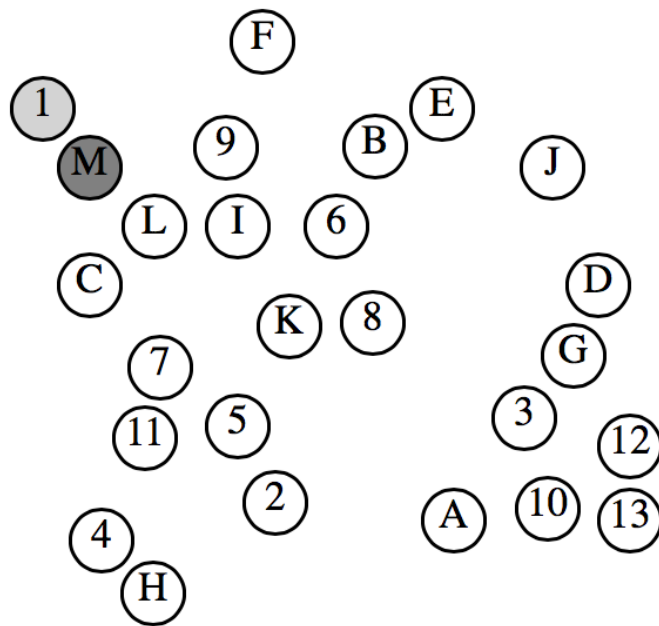


Figure 5: The Symbol Number Correspondence Task test screen. Symbol number associations at the top of the screen and the current symbol in the middle of the screen with an input field to the right.

4. The third cognitive test is the *TMT-B*, which is illustrated in Figure 6 and described in detail in chapter 2.3. In the *TMT-B* test the participant was supposed to work his/her way through a set of 26 circles in a set order based on the contents of the circle. Thirteen of the circles were numbered from 1-13 and the other thirteen had the letters A-M in them. The participant was instructed to click the circles in the following order: 1-A, 2-B, 3-C etc. The participant was also informed that the focus of the task was to complete it without making any errors, and that the first and last circle would be highlighted to make it easier for the participant to identify both the start and the end of the task. The data collected in this task were the total time of the task as well as the number of correct inputs and average time/input.



**Figure 6: The Trail Making Test-B test screen.**

5. After the TMT-B the participant was asked to fill out the second questionnaire, the DBQ. A detailed description of the DBQ can be found in chapter 2.6
6. The last part of the experiment was the information preferences test, which was designed as a tool to find out what information the participants preferred in certain situations. The information preferences test is subdivided into one training phase and one test phase.
  - a. The training phase consisted of 4 sub tasks where the two first tasks were without time constraint and the second two had the same time constraints used in the time limited sub-tasks of the main test as to make sure that the participants had a chance to familiarize themselves with the general layout and functions of the user interface in this test. The participants were instructed to take their time to familiarize themselves with the user interface before moving on to the main phase of the test as to make sure that confounding variables such as unfamiliarity with the interface etc. did not contribute to the variance in the data recorded in the main phase.
  - b. The main test phase consists of 9 sub tasks with different conditions generally described in Table 2; the exact time constraints are specified in chapter 3.2.4 for the pilot and main experiment. The order of stimuli was balanced using a randomization function to minimize the impact of order effects.

Task	Time limit	Traffic complexity
1	Short time limit	Low complexity
2	Medium time limit	Medium complexity
3	No time limit	High complexity
4	Short time limit	Medium complexity
5	Medium time limit	High complexity
6	No time limit	Low complexity
7	Short time limit	High complexity
8	Medium time limit	Low complexity
9	No time limit	Medium complexity

**Table 2: Experimental conditions for the information preferences test**

The experiment used a 3x3 design where all participants were presented with 9 different stimuli combining the 3 time conditions and the 3 complexity conditions. The different time related experimental manipulations in the sub tasks consisted of high vs. low time pressure to see whether time pressure had an effect on the information prioritization of the drivers. The no time pressure condition was used as a control to make sure the differences were due to time pressure and not caused by unknown confounding factors.

The different complexity related conditions consists of 3 levels of traffic complexity where high complexity was a situation where there were a lot of vehicles and signs. Medium complexity was where the traffic situation was somewhat less complex than in the high complexity condition with fewer cars and more headway. The low complexity condition had almost no traffic and a lot of headway. The low complexity condition served as a baseline condition as possible distractions were kept at a minimum.

### **3.1.2 Technical limitations**

All tests were developed for online use and was written in the following programming languages; PHP, JavaScript and HTML5 to facilitate smooth user interaction and an easy data collection process as the participants were free to use any computer with a high enough resolution (the resolution was limited to 1024x768 to make sure that no parts of the test disappeared outside of the screen area).

The use of mobile devices were considered but discarded as these users have an advantage over participants using regular means of computer interaction such as trackpad and mouse. An example of this advantage would be in the TMT-B test as the user of a touch screen enabled mobile device may be able to interact with the test in a smoother and faster way in comparison with a regular user.

By the use of a small script to detect mobile devices and screen resolution we were able to make sure users with low resolution screens or mobile devices were not able to participate in the test, these users were instead redirected to a dedicated error page stating the nature of the problem and encouraging the use of a regular computer or a computer with a higher resolution.

## 3.2 Pilot test

The following sub-chapter contains the design, procedure and results of the pilot test.

### 3.2.1 Purpose

The main purpose of the pilot study was to find adequate time restrictions for the time limits to be used in the main study. The reason for this is that it gives the larger study some increase in validity, as the time restriction is not an arbitrarily chosen number but based on actual data collected from a smaller sample prior to the larger study.

The times used in the larger study was based on the 80<sup>th</sup> percentile of the time spent before the participants ran out of time and were automatically transferred to the next sub-task or when the participants chose to move to the next sub task using the continue button.

### 3.2.2 Test description

The cognitive tests and the DBQ was excluded from the pilot study since the main objective of the pilot study was to find a suitable time restriction for the information preferences task, hence, the pilot study only contain the demographic questionnaire and the complete information preferences including the short training session. The time restrictions displayed in Table 3 for the pilot were chosen arbitrarily based on what the research team found plausible after a couple of unofficial trials.

Task	Time limit	Traffic complexity
1	15-seconds	Low complexity
2	30-seconds	Medium complexity
3	120-seconds	High complexity
4	15-seconds	Medium complexity
5	30-seconds	High complexity
6	120-seconds	Low complexity
7	15-seconds	High complexity
8	30-seconds	Low complexity
9	120-seconds	Medium complexity

Table 3: The different time constraints used for the pilot and main study

### 3.2.3 Participants

A small sample of 7 participants was collected for the sake of the pilot study. In the sample there were 5 males and 2 females.

### 3.2.4 Results

The time to the participants' first decision for each task was divided into the separate time constraint levels and the 80<sup>th</sup> percentile was extracted from each condition. The result from this analysis is displayed in Table 4

	<b>Constraint</b>	<b>Actual Time (in seconds)</b>	<b>N</b>
<b>Average:</b>	15-seconds	13.73	21
	30-seconds	18.32	21
	120-seconds	17.81	21
	All groups	16.62	63
<b>80<sup>th</sup> percentile:</b>	15-seconds	15.00	21
	30-seconds	29.97	21
	120-seconds	23.22	21
	All groups	22.74	63

**Table 4: Mean- and 80th percentile values of time spent to decision for the different time constraints**

The results from the pilot indicate that the arbitrarily chosen times for the pilot were a good approximation for the actual time spent completing the task, hence these time constraints were kept on the same levels for the main study; the 120-second time constraint was kept at the same level as the purpose of the higher constraint is to give participants enough time to decide and then move to the next task on their own without getting stuck.

### 3.3 Main study

The following sub-chapters contain demographical data of the participants in this study.

#### 3.3.1 Participants

The aim was to recruit as many participants as possible within a relatively short time frame. A total of 116 participants were recruited using the social network Facebook and more traditional means such as E-mailing lists. Eighty-one participants remained after removal of participants based on missing values and partial dropouts. The participants were between 19-71 years old with an annual mileage between 0-50 000 kilometres (mean, standard deviation and range is shown in Table 5). For detail demographical information see Table 6.

	<b>Mean</b>	<b>SD</b>	<b>Min</b>	<b>Max</b>
<b>Age</b>	28.56	10.94	19	71
<b>Annual mileage (Km)</b>	5377.75	9802.91	0	50000
<b>Annual income (SEK)</b>	190406.45	185130.39	0	765000

**Table 5: Descriptive statistics of Age, annual mileage in kilometres and annual income of the sample used**

	<b>N</b>
<b>Male</b>	49
<b>Female</b>	32
<b>Car License</b>	72
<b>Bus License</b>	1
<b>Motorcycle License</b>	5
<b>Truck license</b>	4
<b>High School</b>	5
<b>College</b>	12
<b>University</b>	60
<b>Post-graduate</b>	3

**Table 6: Sample distribution over a set of demographic factors**

In this study the data were analysed on an aggregated level meaning that there are no splits, other than by sex, based on the demographic data.

## **4 Analysis**

All analyses in this study were carried out using IBM SPSS 22. A significance level of  $\alpha = 0.1$  was used for all tests as this study was of an exploratory character.

However, if the p-value was below .05 it was marked as  $p < .05$ .

A bifactorial analysis of variance was carried out to assess whether there was a difference in decision-making time between the factors time constraint and traffic complexity. All post-hoc tests and pairwise comparisons were corrected for multiple testing using the Bonferroni correction for multiple comparisons.

A multiple linear regression was used to analyse the linear relationships between decision-making time and the other collected variables. The regression analysis used forced entry to enter the variables of interest in to the regression. The resulting model shows the predictors remaining after removal of insignificant predictors.

## 5 Results

The following sub-chapters contain the results from the bifactorial ANOVA and the regression used to evaluate the research questions proposed in this study.

### 5.1.1 Differences in decision time

A bifactorial ANOVA showed significant main effects between the different time constraints  $F(2, 720) = 13.91$   $p < .05$   $\eta^2 = 0.037$ , observed power = .999 and the different traffic complexity levels  $F(2, 720) = 7.97$ ,  $p < .05$ ,  $\eta^2 = .022$ , observed power = .978. The means of each main effect is illustrated in Figure 7 and Figure 8.

Post-hoc tests for the effect of time constraint on the time to first decision is shown in Table 7 and for the effect of traffic complexity on the time to first decision is shown in Table 8.

#### 5.1.1.1 Main effect of Time constraint

Time constraint	15-second	30-second	120-second
<b>Mean <math>\pm</math> SD</b>	5703.83 $\pm$ 4112.95	7840.66 $\pm$ 5034.30	7767.64 $\pm$ 5243.94
<b>Post-hoc</b>			
	<b>30-second</b>	$p = .000^*$	
	<b>120-second</b>	$p = .000^*$	$p = .986$

Table 7: Mean values and post-hoc tests of the main effect of time constraint in the time to decision variable. Significant values are marked by an asterix

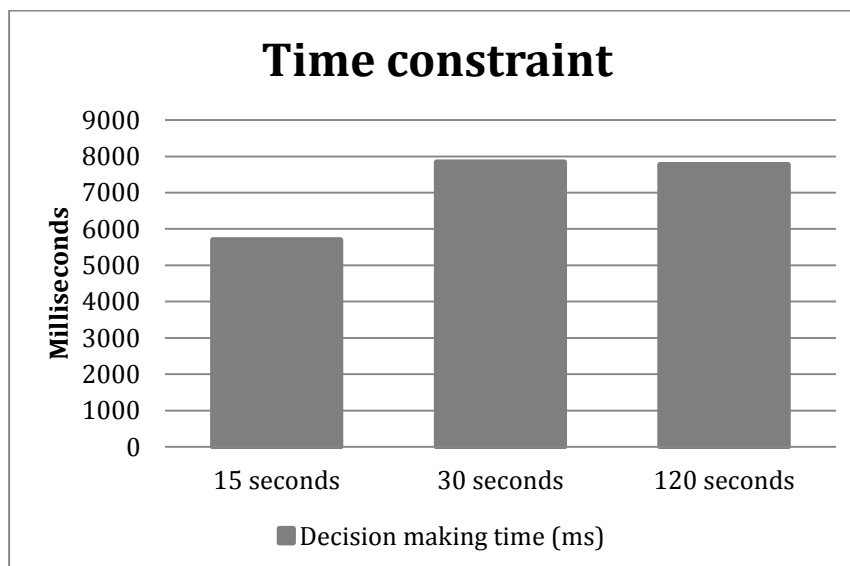


Figure 7: Mean values of the time to decision variable in the different time constraints



### 5.1.1.2 Main effect of Traffic complexity

Traffic complexity	High	Medium	Low
<b>Mean ± SD</b>	7263.10 ± 5143.39	7932.00 ± 5761.83	6117.00 ± 4621.73
<b>Post-hoc</b>			
	<b>Medium</b>	p=.439	
	<b>Low</b>	p = .039*	p=.000*

Table 8: Mean values and post-hoc tests of the main effect of Traffic complexity in the time to decision variable. Significant values are marked by an asterix

The post-hoc comparisons on the main effect of traffic complexity on decision-making time in Table 8 indicate that the time to decide increases as the complexity increases from low complexity to medium complexity, although there is no difference between the high and medium traffic complexity condition.

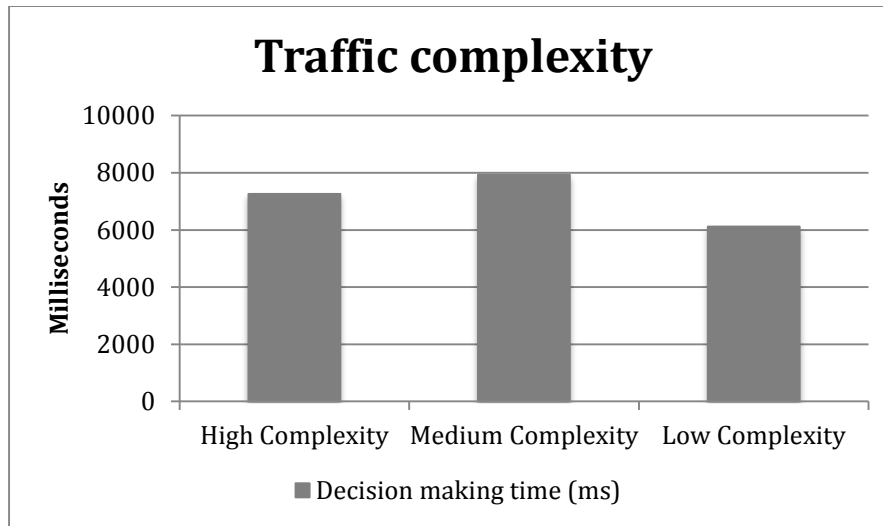


Figure 8: Mean values of the time to decision variable in the traffic complexity conditions.

There was a significant simple effect of time constraint within the high traffic complexity condition  $F(2, 720) = 9.08, p < .05, \eta^2 = .022$ , observed power = .979 and the medium traffic complexity condition  $F(2, 720) = 11.40, p < .05, \eta^2 = .031$ , observed power = .997. Pairwise comparisons are shown in Table 9.

High complexity	15-seconds	30-seconds	120-seconds
<b>Mean ± SD</b>	5677.23 ± 3170.36	7232.32 ± 4445.48	8879.72 ± 6709.52
<b>30-seconds</b>	p=.154		
<b>120-seconds</b>	p=.000*	p=.117	
Medium complexity	15-seconds	30-seconds	120-seconds
<b>Mean ± SD</b>	6190.42 ± 5639.79	9962.46 ± 5648.62	7643.21 ± 5420.50
<b>30-seconds</b>	p=.000*		
<b>120-seconds</b>	p=.206	p=.011*	

Table 9: Pairwise comparisons of the different conditions in the simple main effect of time constraint

There was also a significant simple effect of traffic complexity within the 30-second time constraint  $F(2, 720) = 11.29, p < .05, \eta^2 = .03$ , observed power = .997 and the “no time constraint” condition  $F(2, 720) = 3.51, p < .05, \eta^2 = .01$ , observed power = .763. Pairwise comparisons are shown in Table 10.

		Low complexity	Medium Complexity	High Complexity
30-seconds	Mean $\pm$ SD	6327.21 $\pm$ 4212.46	9962.46 $\pm$ 5648.62	7232.32 $\pm$ 4445.48
	Medium complexity	$p = .002^*$		
	High Complexity	$p = .769$	$p = .000^*$	
120-seconds	Mean $\pm$ SD	6780.00 $\pm$ 6066.78	7643.21 $\pm$ 5420.51	8879.72 $\pm$ 6709.52
	Medium Complexity	$p = .363$		
	High Complexity	$p = .026^*$	$p = .837$	

**Table 10: Pairwise comparisons of the different conditions in the simple main effect of traffic complexity**

There was also a significant interaction between the time constraint and the traffic complexity of the image,  $F(4,720) = 3.769, p < .05, \eta^2 = .021$ , observed power = .939. This effect indicates that the decision-making time was affected differently by the traffic complexity within the different time constraints (see Figure 9). Specifically, the decision-making time was significantly higher in the 120-second time constraint than in the 30-second time constraint (30-second,  $M = 7232$   $SD = 4445.48$ ; 120-second,  $M = 8879$ ,  $SD = 6709.52$ ) in the high traffic complexity condition. The decision-making time was significantly higher in the 120-second time constraint than in the 30-second time constraint (30-second,  $M = 7327.21$ ,  $SD = 4112.96$ ; 120-second,  $M = 6780$ ,  $SD = 4623.70$ ) for the low traffic complexity condition.

In the 120-second time constraint there is a significant increase in decision-making time between the high complexity condition and the low complexity condition. Looking at the mean values of the different complexities there is an increase in decision-making time as the complexity increases.

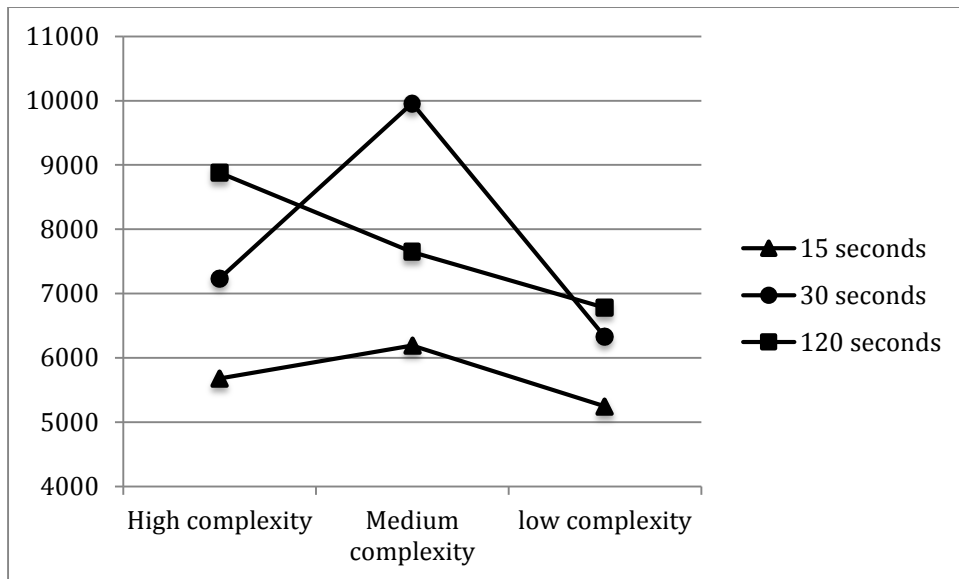


Figure 9: Interaction effect between the 30 and 120-second time constraint in the high and low complexity conditions

### 5.1.2 Predictors of decision-making time

A multiple linear regression analysis was made to assess what measures could serve as predictors of decision-making time. The initial predictors used for the regression are presented in Table 11. The regression resulted in a significant model able to predict ~11% of the variance in decision-making time ( $R^2 = 0.109$ ,  $F(10, 719) = 8.911$ ,  $p < .05$ ). A new model was then constructed using only the variables that were significant predictors of the variance. The second regression resulted in an improved model that could predict ~11% of the variance in decision-making time  $R^2 = 0.109$ ,  $F(7, 712) = 12.390$ ,  $p < .05$ . Significant model predictors are displayed in Table 11.

	B	Std. Error	$\beta$	t	p
Constant	4959.54	1351.16	-	3.671	$p=.000^{**}$
Age	50.68	18.97	0.106	2.671	$p=.008^{**}$
DBQ Errors	423.68	222.87	0.089	1.9	$p=.058^*$
DBQ Violations	-449.47	218.97	-0.096	-2.05	$p=.04^{**}$
SNCT correct	-57.49	18.61	-0.121	-3.08	$p=.002^{**}$
Tmt time	.01	.007	.060	1.5	$p=.134$
Toh moves	-7.9	38.87	-.012	.203	$p=.839$
Toh time	.003	.006	.026	.431	$p=.667$
Educational level	1355.11	305.93	0.16	4.43	$p=.000^{**}$
Traffic complexity	-603.84	226.87	-0.094	-2.66	$p=.008^{**}$
Time constraint	1012.1	226.87	0.158	4.461	$p=.000^{**}$

Table 11: Predictors of the time to decision variable. Significant values at the  $p < 0.1$  level are marked with one asterix (\*), significant values at the  $p < 0.05$  level are marked with two asterixes (\*\*). Unsignificant predictors entered in the original model are greyed out.

## 6 Discussion

The results and methodology is discussed in the following sub-chapters.

### 6.1 Results

**Are there any systematic differences in decision-making time between:**

- **Different traffic complexity conditions?**
- **Different time constraints?**

The results from the factorial ANOVA reliably (observed power of each effect exceeds .9) indicate that both time and traffic complexity on their own and in interaction had a significant effect on decision-making time.

It is clear that participants make faster decisions when under pressure in the high time constraint condition whereas there is no difference in decision making time between the medium and the no time constraint condition. This could mean that people make their decisions faster when under pressure but when the time constraint is above a certain level they spend equal time to make the decision, as they would have if they were not subject to any time pressure.

Similarly, complexity does not seem to have a linear, but rather a threshold effect. It looks like the traffic complexity affects decision-making time in situations where the complexity is above a certain level, whereas in situations with lower complexity the urgency to make a decision is likely to decline. Hence a situation with a complexity level above a certain limit might result in an increase in decision-making time compared to a low complexity situation.

There are significant differences between the 15-second time constraint and the 120-second time constraint in the high complexity condition. There is a continuous increase in decision-making time. It seem like the participants adapt their decision making time to the time restricted conditions and as the available time increases the participants spend more time considering their next action.

There was also a significant effect of time constraint in the medium complexity condition. There is a significantly higher time to decision in the 30-second time constraint in comparison with the 15-second time constraint and a significantly lower time to decision between the 30-second time constraint and the 120-second time constraint. These results looks like they are in line with the results in the high complexity condition since there is an overall increase in decision making time between each condition when looking at the mean as well as a substantial increase in decision making time from the 15 second time constraint to the 30 second time constraint. Even though the 120 second time constraint does not differ significantly from the 15 second time constraint there is still a difference of ~1.5 seconds when looking at the means which give more support to this hypothesis.

An alternative interpretation of the substantial increase in decision-making time between the 15-second constraint and the 30-second constraint is that the stimulus used for this combination of time constraint and traffic complexity deviates in some way from the other medium complexity stimulus. This would also explain why decision-making time decreases significantly between the 30-second time constraint and the 120-second time constraint. However, It is not certain that an individual image could be determined as the cause of this effect. Hence, the images used as stimulus in each complexity and time constraint should be completely randomized.

There are no differences in decision-making time between the different traffic complexities in the 15-second time constraint. However, the pairwise comparison of the significant simple main effects in Table 10 shows that there are significant differences between the low complexity condition and the medium complexity condition as well as a significant difference between medium and high complexity. The overall trend indicates an increase in decision time as the complexity level increases with a large increase in the medium complexity condition followed by an almost as large decrease. This result gives additional support that one of the stimuli deviate from the rest in some way.

Looking at these results, especially the increase in decision time as external time pressure and traffic complexity decreases it is fairly clear that people adapt to the situation at hand (i.e. making their decisions faster when external pressure is at the highest (high complexity and high time pressure)). This goes in line with the theories behind MART (Young & Stanton, 2002a; Young & Stanton, 2002b) stating that the allocation of attentional resources increase as MWL increases due to increased complexity or time pressure.

#### **What factors could serve as predictors of decision-making time?**

- **Are there any cognitive abilities that can serve as predictors of decision-making time?**

The final regression analysis resulted in a model that can predict ~11% of the variance in decision-making time. This is not a perfect model, however, there are some interesting predictor variables in the model. The DBQ measures show that an increase in the DBQ violations score is associated with a ~0.5 second decrease in decision time whereas an increase in DBQ errors has an opposite effect. It is possible that drivers who score high on the violations part makes more reckless decisions whereas drivers with high error score might be more careful since they are more self-conscious about their proneness to errors and therefore try to avoid making errors.

Age is also a significant predictor in the model, indicating that as age increases so does decision time. This is also supported by the SNCT correct variable as the symbol number correspondence task score usually declines with age.

The SNCT correct variable is showing a decrease in decision time as the score increases. This indicates that speed of processing has an impact on decision-making time. Since Dohmen et al (2010) suggested that the SNCT would be a good way of assessing cognitive ability; the individuals with a high score on this test would most likely have a higher cognitive ability. If cognitive ability is related to a decision making style as suggested by Dohmen et al. (2010) and Fredricks (2005) that involves substantial reasoning and weighing the utility of each available decision there should be an effect of education, age and the SNCT on the decision time.

In line with the decision-making theories age seem to have an effect on decision-making time as an increase in age cause an increase in decision-making time. There is also the possibility that age in this case indicates some sort of cognitive or visual decline, which in turn causes an increase in decision-making time. It is also interesting to see that educational level seems to have an effect on decision-making time, indicating that a higher education leads to longer decision-making times. Assuming that higher education equals higher IQ, this finding is in direct line with what Fredricks (2005) said about intelligence being related to decision-making.

It is also interesting to see that as the available time increased, the decision-making time increased, which also supports the results from the factorial ANOVA indicating an increase in decision-making time as the time constraint decreased. These results are also supported by the MART theory (Young & Stanton, 2002a) as it states that attentional resources most likely will increase as to facilitate the increased workload in a complex time restricted situation. The theory then states that as workload decreases so will the attentional resources invested in the task, hence leading to increased decision times. The same holds for traffic complexity, as the traffic complexity decreases the decision-making time increases, also in line with the results from the factorial ANOVA.

## **6.2 Methodology**

The method of data gathering used for this study made it very easy to reach a lot of people and recruit participants. However, there is always room for concern when conducting research outside a controlled setting. For instance, there is no way of knowing if some people made the test whilst attending a class or watching TV. There is also the problem of latency. There is no simple way of finding out whether participants used Safari, Chrome, Firefox or Opera as their browser. Different browsers might have different ways of calculating system time; hence, there is a possibility that there are discrepancies in time between participants using different browsers. There is also the problem with the computing power of the participants' computers. Even though the test is designed to perform well on ordinary computers there might be some participants using out-dated hardware, which might have an effect on the overall test performance.

Another thing that might affect performance on the tasks might be the participants internet connection as a slow connection makes the download of the images in the information preferences test load slowly, hence, giving rise to “lag” in the test, thus producing longer decision times than necessary.

Any issues with the instructions and descriptions in the test were hopefully avoided by doing the pilot test for feedback before the actual testing phase but it would be unwise to assume that every participant understood the instructions fully as there might be varying English skills as well as some terminology issues.

It would be desirable to do this test in a more controlled setting where it is possible to control for variance in computing power, browser usage and internet connection as well as making sure that all participants understand the instructions be able to provide help when they have problems understanding. Even though that would be desirable it would not be feasible as the overall purpose of doing a web based test was to be able to reach as many people as possible to make sure a demographically representative sample was collected, doing this the old fashioned way would result in large costs and the use of resources that would serve a better purpose elsewhere.

### **6.3 Future research**

The results clearly indicate that this test is able to discern differences in decision-making time in different traffic conditions and in different time constraints. It would therefore be recommended to collect more data to get a more representative sample of a larger population before proceeding to additional analyses. Further possible analyses should include the following;

- What was the first decision
- Are the decisions drivers make different depending on the situation
- Are the drivers decisions different depending on time pressure
- What other factors are involved in the decision

Furthermore it would be interesting to move this concept in to a driving simulator and try to assess what information people want in certain situation as well as how that information could be conveyed in different situations depending on the individual preferences of the driver.

## **7 Final conclusions**

Results from the factorial ANOVA clearly indicate that the experimental manipulations in this experiment were able to affect decision-making time, which supports the notion that this method is a promising way of exploring some aspects of highly automated driving.

The results also show that there are a number of factors that influence decision-making time apart from the experimental manipulations. Education is able to predict a significant portion of variance in the decision-making speed, which has good support in the literature. Driver attitudes and introspectiveness are also able to predict a significant portion of the variance, where “impulsivity”, as measured by the DBQ violations factor shows a decrease in decision-making time whereas the error proneness as measured by the DBQ errors shows an increased decision time as the score increases.

The symbol number correspondence task was also a significant predictor of decision-making time, this is not unexpected as speed of processing and the time it takes to assess a situation should go hand in hand. However, cognitive ability should be taken in to consideration when designing the automated vehicle as to fulfil the needs of both drivers with higher, and lower cognitive capabilities.

As decision-making time increases with aging, it should be considered when designing automated vehicles as a way of adapting the automation to the needs of the older drivers i.e. In terms of increased time before transfer of control initiates as to facilitate the increased time it would take to assess the situation at hand.

The findings in this study could be a good foundation for designing the in-vehicle environment in a way that makes the automation adapt to both the needs of the driver and the external requirements.



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## **9 Appendix 1: Pre-test information and consent**

Welcome to this study. This test is intended to measure your cognitive abilities in relation to your needs and the decisions you make in different driving contexts. The study is divided into different parts. You will be presented with two short questionnaires, cognitive tests, and visual scenarios of different traffic situations. The tasks are simple, and you will receive instructions throughout the whole test. Please, it's important that you try to perform as well as possible. The test takes no more than 20 minutes. Thank you for your participation!

By moving on to the test you accept that the data you provide can be used for scientific work and publications. The data will be presented at an aggregated level, such that it is impossible to identify which answers you have given. We guarantee that your data are treated with utmost care with respect to anonymity and personal integrity

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