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The influence of semi-autonomous car features on road safety in the Netherlands

Kelian van Pernis (5724961)
Bachelor in Artificial Intelligence
Utrecht University
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Supervisor: Leon Kenemans
Second supervisor: Chris Paffen

Abstract

Although the Netherlands has a very good road network there are still a lot of fatal accidents each year that involve cars. In this thesis, an evaluation is made of the potential safety benefits of more semi-autonomous cars on the road in the Netherlands. A classification is made of different types of accidents based on the literature on car accidents. After this, the concept of the schema and its causal relation to human error is applied to driver error. Lastly, the already existing semi-autonomous car features, as well as the features that are still in development are linked to the driver errors to determine if these features could prevent these errors. It was concluded that autonomous features that still require the driver to pay attention can prevent frequently occurring driver errors and with that prevent fatal accidents in the Netherlands. However, one of the pitfalls is that certain features and levels of automation can, in fact, cause new types of accidents because drivers could be confused about whether certain tasks are taken over by the car. It would thus be useful if further research would focus on finding a balance between tasks taken over by the car and tasks performed by the driver and try to determine whether or not there would be an efficient and safe way to transition from manually driven cars to fully autonomous cars.

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1. Introduction

For many households in the Netherlands it has become common to own at least one car. In the year 2018 there were over 8 million personal cars owned by citizens in the Netherlands (Centraal Bureau voor de Statistiek, 2019). In this same year there were a total of 233 fatal accidents with personal cars on the roads in the Netherlands (Centraal Bureau voor de Statistiek, 2019). In this context a “fatal accident” is an accident in which at least one passenger died. Although the statistics do not specify the cause of the accidents, research found that errors made by humans while driving contribute to 75% of all roadway crashes (Stanton & Salmon, 2009). A lot of these errors are linked to the concept of the schema. In this context the schema is referred to as an abstract entity in the brain that helps us decide which action to take based on our previous experiences and memory of similar or identical situations. There are a lot of different types of errors that humans make, but the underlying cause is usually misinterpretation of a situation, untimely activation of schemas or the faulty activation of schemas (Stanton & Salmon, 2009).

Chapanis (1999) wrote about how back in 1940 ideas started to develop about the significance of design error in relation to human error. He stated that throughout the years there has been an increasing interest in the ways in which improving design can lead to a reduction in human error (as cited in Stanton, Salmon, 2009, p. 227).

The awareness of human error contributing to (fatal) accidents and the potential benefits of smart designs in cars to reduce human error, has inspired researchers and big companies all over the world to look into the possibilities of semi-autonomous cars. A prime example of a company involved in the development of semi-autonomous cars is Tesla. This American car manufacturer focuses on self-driving technology. A recent move made by Tesla was the introduction of what they call the “autopilot system”. This system enables the car to stay within a lane, adjusting speed to that of the cars around it, change lanes, exit a freeway to move to another freeway and self-park when arriving at the destination. Tesla claims that these features have increased safety on the road and that the autopilot system is superior, in terms of safety, to human drivers (Rice, 2019, p. 137).

In this thesis an attempt will be made to link two concepts that have been studied a lot individually: human error in car-accidents and features of semi-autonomous cars. The research question will be: “Could an increase of semi-autonomous cars on the roads in the Netherlands lead to a decrease in fatal car-accidents?”. Sub-questions that will be discussed are: “How can different types of car accidents be categorized?”, “What causes these different types of car accidents?” and “Would semi-autonomous cars be able to prevent similar accidents?”. Based on the knowledge that Tesla, which is arguably the leading manufacturer of semi-autonomous cars, claims that self-driving car features make traffic safer, it is expected that more semi-autonomous cars on the roads in the Netherlands would lead to a reduction in fatal accidents.

1.1 Structure of this thesis

To try and find an answer to the main research question it will be necessary to look into the sub-questions in the order they were presented in the previous section. The first part will, therefore, be an attempt to classify different types of car-accidents. This will be done by generalizing types of car accidents described in the literature, as well as discuss driver errors made in these accidents. In the second part these categories of accidents and driver errors will be used to take a closer look at what the underlying causes were for the driver errors occurring in these accidents. The final part will be an analysis of different features of semi-autonomous cars and the effects these could have on the reduction of the number of fatal car accidents in the Netherlands. These features will be linked to the taxonomy for vehicle automation created by the Society of Automotive Engineers. This taxonomy consists of six levels, which indicate the extent to which the car takes over functions that are otherwise performed by the driver (Liu, Du, Xu, 2019). By looking at levels of automation and human error in relation to these features, a conclusion will be drawn on whether (part) of these features could contribute to the prevention of fatal car accidents and which level of automation would be optimal to achieve this goal.

1.2 Relevance to AI

The aim of this thesis is to determine whether intelligent features implemented in cars could prevent car accidents. A car that can make smart decisions based on intelligent analysis of the situation and that can learn from experience is a prime example of artificial intelligence. The (semi-)autonomous car is being developed further and further around the world. These developments predict its significance in the future. It is therefore relevant to investigate the benefits of this still-developing technology and think about the extent to which the autonomous features of a car can increase safety on the road in the Netherlands.

2. Categorizing car accidents

To determine whether accidents can be prevented by features offered by a semi-autonomous car, it is important to distinguish between different categories of car-accidents. Knowing what happens during certain types of car accidents can, along with information about mistakes made by the driver, help determine what could have prevented said accidents. In this part an answer will be formulated to the sub-question: “How can different types of car accidents be categorized?”.

There are a lot of possible scenarios when looking at car accidents. However, most of the car accidents can be placed in certain general categories. The first logical distinction to make is single-car accidents and multi-vehicle accidents. In the next chapter this distinction will allow for separately looking at mistakes made by people on their own and mistakes made by people who interacted with other people on the road. The subcategories of single-car accidents that will be discussed are rollovers and collisions with objects. The subcategories for multi-vehicle accidents that will be discussed are car-on-bicycle and car-on-car collisions.

Each accident type will be linked to at least one driver error based on the driver error taxonomy created by Stanton & Salmon (2009). Figure 1 shows this taxonomy. The column named “External error mode” states the different driver errors (Stanton & Salmon, 2009, p. 234). These driver errors simply state what went wrong during the accident and will be used in this chapter to clarify the physical actions drivers performed that caused accidents. Chapter 3 will discuss the underlying (psychological) causes of these errors. Accidents can also have causes that have to do with intentional violations. These types of errors cannot be prevented by features of a semi-autonomous car because drivers deliberately break the rules. This thesis focuses on unintentional errors and thus intentional violations will not be discussed.

Underlying psychological mechanism	External error mode	Taxonomy source	Example
Action errors			
Action execution	Fail to act	Tables 1, 4, 2, 8, 10	Fail to check rear view mirror
Action execution	Wrong action	Tables 2, 4–6, 8, 9	Press accelerator instead of brake
Action execution	Action mistimed	Tables 1 and 2	Brake too early or too late
Action execution	Action too much	Tables 5 and 6	Press the accelerator too much
Action execution	Action too little	Table 5	Fail to press the accelerator enough
Action execution	Action incomplete	Table 1	Fail to turn the steering wheel enough
Action execution	Right action on wrong object	Tables 1 and 2	Press accelerator instead of brake
Action execution, planning, and intention	Inappropriate action	Tables 1, 2, 4–6, 8, 9	Following too close, race for gap, risky overtaking, etc.
Cognitive and decision-making errors			
Perception	Perceptual failure	Table 2	Fail to see pedestrian crossing
Perception	Wrong assumption	Table 2	Wrongly assume a vehicle will not enter path
Attention	Inattention	Tables 5, 6, 8, 9	Nearly hit car in front when queuing
Attention	Distraction	Tables 4, 5, 8, 9	Distracted by secondary task e.g. mobile phone conversation
Situation assessment	Misjudgment	Tables 1, 4–6, 8–10	e.g. misjudged speed of oncoming vehicle, misjudge speed and distance, misjudge gap
Perception	Looked but failed to see	Tables 6 and 9	Looked at road ahead but failed to see pedestrian
Observation errors			
Memory and recall	Failed to observe	Tables 1, 2, 4, 5, 8, 9	Failed to observe area in front of vehicle
Memory	Observation incomplete	Tables 4, 6, 10	Failed to observe offside mirror when changing lanes
Situation assessment	Right Observation on Wrong Object	Tables 4 and 10	Failed to observe appropriate area
Memory and recall	Observation Mistimed	Tables 1 and 2	Looked in drivers side mirror too late when changing lane
Information retrieval errors			
Situation assessment	Misread information	Table 10	Misread road sign, traffic control device or road markings
Situation assessment	Misunderstood information	Tables 1 and 10	Perceive information correctly but misunderstand it
Situation assessment	Information retrieval incomplete	Table 10	Only retrieved part of information required
Situation assessment	Wrong information retrieved	Table 10	Read wrong information from road sign
Violations			
Action execution, planning, and intention	Intentional violation	Tables 4, 6, 8, 10	Overtake on the inside, knowingly speed
Action execution	Unintentional violation	Tables 4, 6, 8, 10	Unknowingly speed

Figure 1. Generic driver error taxonomy with underlying psychological mechanisms. Retrieved from [3]

2.1 Single-car crashes

In this section the focus will lie on crashes that happened to a single car without interaction with other vehicles. One important source in this section is a report about the mechanics behind rollover crashes (Cuerden, Cookson, Richards, 2009). This report provides information and statistics concerning car accidents in the United Kingdom. The Netherlands and the United Kingdom have a similar infrastructure. The Global Competitiveness Report of 2012 states that in the category of infrastructure the United Kingdom was ranked number 6 in the world and the Netherlands was ranked number 5. A significant part of the infrastructure ranking is based on the quality of the road network. Therefore, the information will be representative of similar types of accidents in the Netherlands (Schwab, 2012).

2.1.1 Rollovers

One type of single-car accident is a car rollover. The report mentioned in the previous section discussed details on what happened prior to the rollover accidents that were investigated. One aspect was the maneuver prior to the rollover. In most of the cases the car was moving either to the left or the right and was sliding, indicating a loss of control over the vehicle. Concerning the specific initiation of the roll without hitting an object, common influences were transitioning from a hard surface to a softer surface like grass or earth, driving up or down a hill or making a sharp turn (Cuerden, Cookson & Richards, 2009). Another important factor is the weather. Heavy rainfall can, especially when followed by a dry period, have an impact on the number of car accidents. More specifically, the friction between the tires of the car and the surface of the road is diminished after heavy rainfall and thus cars will slip faster, which can cause drivers to lose control of the car and potentially roll over (Brodsky, Hakkert, 1988). The driver error that causes this loss of control is thus a swaying movement to the left or the right which places the car outside of the lines that form the lanes on the road. This corresponds to the "Action too much" error category in the driver error taxonomy, because the steering wheel is turned too much in these situations (Stanton & Salmon, 2009).

2.1.2 Collisions with objects

In addition to car rollovers, collisions with objects are a common occurrence with single-car accidents. Collisions, too, often involve a loss of control of the car prior to the collision. This means that with most of the collisions the car had already lost control and gone off track before hitting the object. Common objects that get collided with are curbs, fences, safety barriers, and trees. Rollovers are also related to collisions with objects in the way that rollovers often happen either prior to a collision or after a collision. Especially with curbs, the chance of a sideways rollover is significant because curbs are very low and usually cause a bump of one side of the car (Cuerden, Cookson & Richards, 2009). Two types of driver errors occur in these types of accidents. The first error is the same error that was discussed with rollovers; swaying to the left or the right and moving out of the lane, thus an "Action too much" error. The second error is following the wrong lane. This could be a "Distraction" error or an "Inattention" error. The driver could follow the wrong lane due to a distraction like an incoming call. He could also miss the sign that indicates it is the wrong lane due to not paying attention to the road (Stanton & Salmon, 2009).

2.2 Multi-vehicle collisions

This category will focus on accidents between two vehicles. The division in this category will be car-on-bicycle and car-on-car collisions. This distinction is made because in the Netherlands the cyclists are almost always on a bicycle road, which creates different types of accidents compared to car-on-car accidents that happen on the same type of road.

2.2.1 Car-on-car collisions

This category consists of accidents involving car-on-car collisions. A study was done in Sweden on the category of car-on-car collisions with several variables. The data were divided into 6 categories: Type of crash, Urban area or not, Light conditions, Speed limit, Road conditions, and Car model year. About 50% of the accidents were in urban areas, where the most common collisions were a car turning on a lane or a car driving into the rear-end of another car. The accidents that were not in urban areas often were accidents that involved a car turning at a large intersection or a head-on collision (Hasselberg, Laflamme, 2009).

Another study was done in the United States on the driver, crash and car characteristics and the number of fatalities in car crashes. It was found that roughly 65% of severe car crashes were frontal impacts. This group represented the most fatal type of car collision. The category that represented the second largest source of fatalities was that of left-side collisions, which can be explained by the fact that the driver sits on the left side in the United States. Concerning the speed, data on drivers younger than 20 years showed that 25% of these drivers fatally crashed while not driving faster than 56 kph. For drivers that were older than 79 about 49% were fatally injured in severe crashes involving speeds of at most 56 kph. This statistic indicates the important fact that even accidents in urban areas, where cars drive slower, can , in fact, result in fatalities (Bedard, Guyatt, Stones & Hirdes, 2002).

Frontal or side crashes are thus more common outside urban areas. These types of accidents are also more likely to be fatal because the speed limit is higher outside urban areas. The data in these two studies also indicated that rear-end collisions happen more often in urban areas. The driver error with these crashes could be “Perceptual failure”, meaning the driver failed to see for instance a wrong way driver, or a car crossing at an intersection. It could also be a “Speeding” error. This type of error can follow from an “Inattention” error or a “Distraction” error (Stanton & Salmon, 2007). A driver could be driving too fast in an urban area due to inattention or distraction and collide with another vehicle. It is important to note that a distraction like looking at a phone can also cause inattention to the road. Inattention can however also happen without a distraction, which means it is still relevant to separate these two types of errors.

2.2.2 Car-on-bicycle collisions

When looking at accidents with cars it is relevant to also look at the accidents involving bicycles. This relevance lies in the fact that in the Netherlands riding a bicycle is incredibly common. In 2018 228 people died while riding a bicycle (Centraal Bureau voor de Statistiek, 2019). Part of these accidents involved cars. In an article written by Isaksson-Hellman and Werneke (2017) insurance claims from bicycle and passenger car collisions are analyzed to get a better understanding of how these collisions came to be. The analysis resulted in a distribution of different crossing scenarios that caused the collisions. Figure 2 shows the details of these scenarios. It is clear that most of the accidents involve a bicycle lane that lies perpendicular to the car. This is the case in scenarios S1 and S2 as seen in Figure 2. In these scenarios the cyclist tries to cross the road from the left or the right when the car hits the cyclist. It is clear that when the cyclist is crossing from left to right or vice versa on the opposite side of the road, the car is less likely to hit the cyclist. This makes sense because the car driver first must cross the intersection and therefore has more time to notice the cyclist. Scenarios S4 up to S8 all involve the car making a right or left turn with the cyclist going forward on the bicycle lane that lies parallel to the car lane. These last four scenarios don’t stand out as happening very often compared to scenarios S1 and S2.

In general, this research showed that in 78.1% of the crashes the bicycle and car crossed each other’s paths. Only 10% of the crashes involved a bicycle and car moving in the same or opposite direction. The data also showed that when the bicycle and car crossed paths only roughly 25% of the time the driver saw the cyclist, whereas with the scenarios in which the car and bicycle moved in the same or opposite direction the car driver saw the cyclist before the collision in about 50% of the cases. The main causes of collisions thus seem to be that the driver often does not see the cyclist coming or sees the cyclist too late to react adequately (Isaksson-Hellman, Werneke, 2017). This indicates several

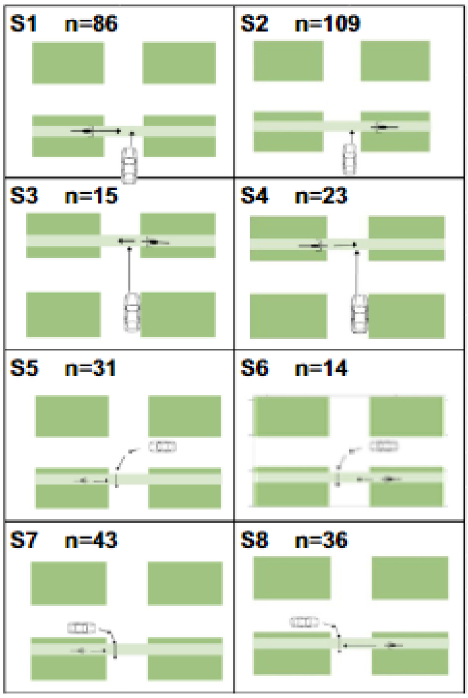

Figure 2. Road crossing scenarios with the cyclist travelling along a bicycle path. Retrieved from [9]

driver errors that relate to these types of accidents. The “Perceptual failure” error applies to the incidents in which the driver overlooked the cyclist altogether. The “Inattention”, “Distraction” and “Speeding” errors apply to the incidents in which the driver noticed the cyclist too late because these errors all decrease the time the driver has to react to a crossing cyclist.

3 Human error in car accidents

As mentioned in the introduction of this thesis, research has indicated that up to 75% of all roadway crashes are caused by driver errors. The driver errors from Salmon and Stanton's (2009) error taxonomy that related to the types of accidents discussed in chapter 2 were the "Attention too much", "Speeding", "Perceptual Failure", "Distraction" and "Inattention" errors. It is important to note that inattention and distraction are often factors that have a causal relation with the other three types of errors. These errors are not the only errors that could possibly occur, but the studies mentioned in chapter 2 indicated that these driver errors were the most frequently occurring in the types of accidents that were discussed. In this section an attempt will be made to look at the different approaches to human error to give a clear view of the ways in which human error can be categorized. While looking at the different types of human error the link will be made to the types of accidents and corresponding driver errors discussed in chapter 2, which will contribute to answering the sub-question that was introduced at the start of this thesis: "What causes these different types of accidents?".

3.1 The schema theory

When looking at the aspect of human error in relation to driving it is logical to look at the category of action errors. Human drivers perform certain actions that sometimes result in car crashes. Norman (1981) did research on the different types of errors by analyzing 1000 incidents. His research was based on the schema theory. The schema is argued to be a knowledge structure in the brain that triggers certain actions in certain situations. Norman argued that these schemas are structured as a hierarchy and that the specific conditions of the situation determine the type of action a person takes. The hierarchical structure means that schemas can activate other schemas that are "beneath" them in the hierarchy. The schema at the top is called a parent schema and this schema holds information on more general situations that involve more subconscious actions. The subschemas are called child schemas and these schemas hold information on more specific situations that also require more conscious actions. According to the error taxonomy created by Norman, human error can occur due to faulty activation of schemas, misinterpretation of the situation (mode errors) or activating a schema too early or too late (As cited in Stanton, Salmon, 2009). The next sections will discuss faulty activation of schemas as well as untimely activation of schemas. Mode errors are errors resulting from autonomous car features and will thus be discussed at the end of chapter 4.

3.2 Faulty activation of schemas

Based on Norman's theory the faulty activation of schemas can cause several different types of errors. One of them, that is applicable to driver errors, is called a capture error. Capture errors are the types of errors where an intended action is replaced by an action that is triggered due to a habit. The theory is that an intended action is based on a child schema, but the situation resembles the scenario that is linked to a parent schema, which is the schema that is linked to a habit (Norman, 1981). To clarify, this type of error can be applied to single-car collisions with objects. As discussed in chapter 2.1.2 crashes often happen due to a collision with for instance a safety barrier. The following example will elaborate on how a capture error works according to Norman's view on this type of error:

Imagine a man has driven to his workplace for the past 25 years and he has always taken the same route. In the Netherlands it is not unusual for a lane to be closed due to construction. At a certain highway junction this man is used to follow the left lane to get to his workplace, but this lane is now closed due to construction. If this man would see a warning sign above the road about the construction, a child schema would be activated that triggers the action of taking an alternate route. This schema was constructed because this is not the first time the man has to take an alternate route due to construction work. According to Norman's ideas on faulty activation of schemas, if this man would shift his attention to, for instance, an incoming call, it would be likely that the parent schema would be activated, which is the schema that triggers the action based on a habit, namely following the left lane. This parent schema would overrule the intended schema that would encourage taking an alternate route. This overruling process is the capture error. The potentially fatal accident that can follow is that the man stays on the lane he is used to driving on and that he eventually crashes into a safety barrier.

The accident described in this example can be linked to the “Inattention” and “Distraction” driver errors. The incoming call in this example is the distracting factor and causes the driver to lose attention on the road. This inattention causes the overruling process described in the example and this is what forms the capture error.

In a study done by Salmon, Young and Cornelissen (2013) the concept of the schema was used to shed light on the conflicts that occur between different groups of road-users. They found that car-drivers and cyclists activate conflicting schemas when interacting in traffic. The schema used by drivers puts the car central and thus makes drivers focus their attention on other cars. This focus on other cars, in turn, leads to a focus on the region in front of and behind the car. The right and left sides are not focused on as much (as cited in Briggs, Hole & Turner, 2018, p. 5). These findings can explain the driver errors made in car-on-bicycle accidents like the ones described in scenarios S1 and S2 in section 2.2.1. The focus on the region in front of and behind the car is an “Inattention” error that could cause the driver to overlook a cyclist crossing from the left or the right, which would be a “Perceptual failure” error.

3.3 Untimely activation of schemas

Neisser’s (1976) concept of schemas is similar to that of Norman. According to him, a schema guides us to collect information in certain environments and use that information to modify and update this same schema. Figure 3 shows how Neisser viewed this process. Neisser focusses more on what happens after activation, stating that schemas reinforce the use of an attentional set, which is a bias to search for information that is important to the task at hand and ignore information that is less important. This is illustrated in Figure 3 as “Environmental Information”. The circle divides the triangle, standing for the potential environmental information, into a section of the environment that is focused on and a section that is ignored. This means that when someone is driving the attentional set will encourage this person to focus on road signs rather than for instance signs of restaurants or shops. Besides Neisser’s study, several other studies have related the attentional set to traffic accidents.

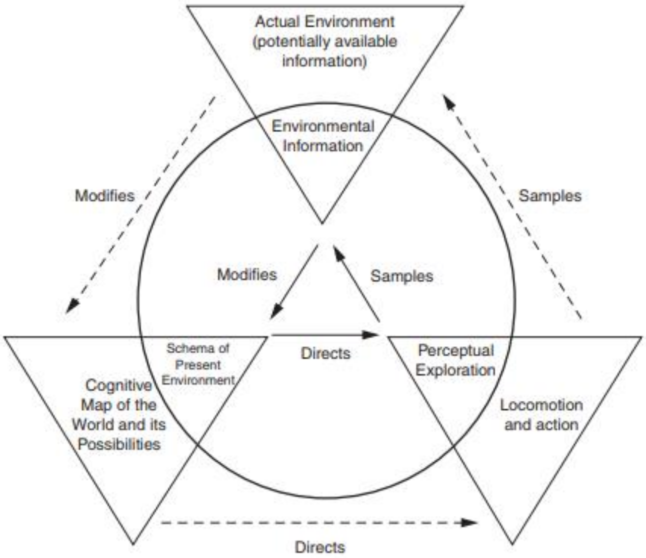

Figure 3. The perceptual cycle. Retrieved from [15]

A type of accident that could occur from a late activation of schemas is a collision between cars in an urban area. Once one of the before mentioned attentional sets is chosen there is a chance it is not frequently adjusted. This means that when a person is driving on a highway, the schema for that scenario is activated and the corresponding attentional set is selected. When this person moves from the highway to an urban area in a short period of time it could be that the attentional set is not adjusted fast enough. It has also been found that when a secondary task is introduced, which could be for instance navigating using a phone in the car, it is even more likely that a driver does not change his attentional set. This lack of adjustment of the attentional set would prevent the necessary schemas that correspond to driving in an urban area to be activated. A “Speeding” driver error could then occur meaning the driver would drive way too fast in the urban area. The driver also would not notice speed signs which can be seen as an “Inattention” error. The potentially fatal accident that could happen would be for instance a rear-end collision in the urban area with another car that is driving slower, or a side-end collision at an intersection (as cited in Briggs, Hole & Turner, 2018, p. 4).

A study by Hole and Tyrell (1995) also confirmed the idea that inappropriate attentional sets can cause accidents. When drivers were repeatedly exposed to images of traffic situations in which there were motor vehicles with bright headlights, they responded much slower to motor vehicles with unlit headlights. In some situations the participants did not notice the motor vehicle at all. This indicates that drivers tend to focus more on looking for headlights rather than looking for the actual motor vehicles (as cited in Briggs, Hole & Turner, 2018, p. 4). This shows that the schema-driven attentional set forces them to focus on vehicles with lit headlights, but they are often too slow in activating the schema appropriate for encountering vehicles with unlit headlights. Frontal collisions with, for instance, wrong way drivers could thus happen faster when a “Perceptual failure” error occurs because one of the cars does not use its headlights and is overlooked.

The attentional set is clearly an important factor in car accidents. Another study done by Most and Astur (2007) showed this importance by testing with a group of participants who were asked to focus on either blue or yellow signs while driving. At the tenth junction they encountered a motorcyclist that suddenly switched lanes and abruptly stopped in front of them. In the group of participants that encountered a motorcycle that had the same color as the signs they were asked to focus on, only 7% collided with the motorcycle. In the group of participants that encountered a motorcycle with a different color 36% of the participants collided with the motorcycle. This effect was attributed to the incongruency between the color that the attentional set forced the drivers to focus on and the actual color of the motorcycle. This study shows that in general schema-driven attention can cause accidents because situations can change or unexpected vehicles or objects can be encountered, and in these situations the appropriate schemas are often not activated fast enough. An example could be that in the Netherlands a driver is focusing on the signs above the road because he does not know the way. This means that the attentional set enforces the driver to look up at the signs a lot instead of focusing on staying in lane. This driver could then start swaying left or right and move outside of the lines that form the lane. As discussed in section 2.1, the “Action too much” error could occur if the driver would steer too much to the left or to the right. This could cause a fatal accident if the driver would lose control over the car. The car could roll over and/or collide with an object.

4. Autonomous car features

In this chapter the different types of driver errors (with their underlying causes) discussed in the previous chapters will be linked to some of the most important semi-autonomous features in an attempt to answer the sub-question introduced at the start of this thesis: “Would semi-autonomous cars be able to prevent similar accidents?”. As mentioned before, the SAE levels of automation will also be discussed. These levels indicate the division of labor between the driver and the car itself. One car could operate on different levels or in different modes, depending on the features used. Figure 4 shows details about the differences between the levels.

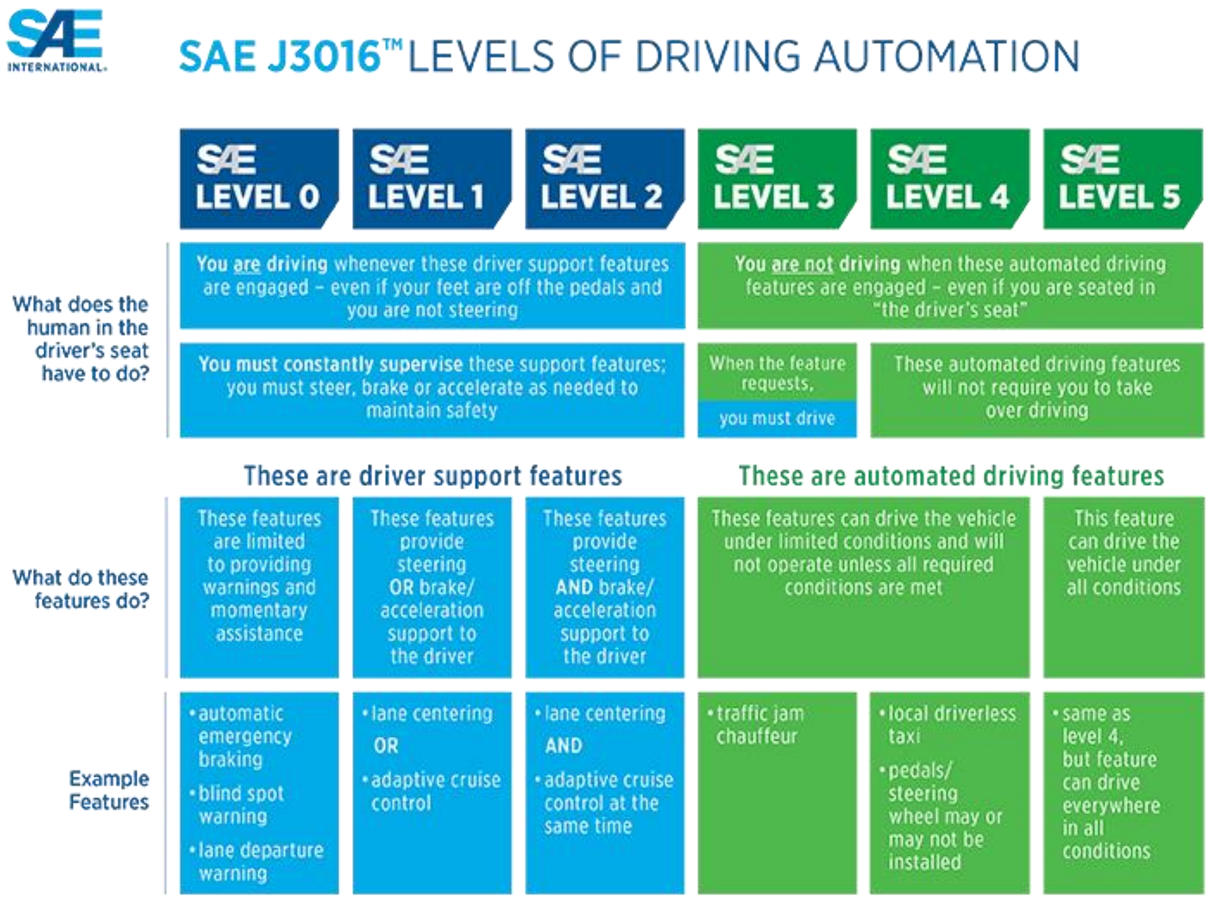

Figure 4. SAE J3016 Levels of driving automation. Retrieved from [15]

In total there are six levels, numbered from zero to five. Level 5 is not taken into consideration in this thesis. This level stands for fully automated cars and seeing as many autonomous features are still fully in development it is safe to assume that this stage of autonomous driving is still far away, making it more relevant to look at the partial automation levels.

Due to the fact that more automation can also cause new errors and with that new accidents it is important to investigate the number of added features and the types of features with which the positive effects outweigh the negative effects. Each feature discussed in the next sections will be linked to the SAE levels to eventually try and determine the level(s) at which more semi-autonomous cars could make the roads in the Netherlands safer.

4.1 The (adaptive) cruise control

From 1995 onward cars started to come out with a built-in function of adaptive cruise control (ACC). This function involves maintaining a certain speed without having to press the gas pedal, as well as adjusting the speed of the driver's car to the speed of the car in front of the driver. This particular feature can assist in preventing car-on-car collisions. The example in section 3.3 about a driver moving from the highway to an urban area without adjusting his speed indicates the usefulness of this feature. The ACC system could prevent this "Speeding" error by decelerating when the car gets too close to the car in front of it. It could also play a role in preventing "Distraction" and "Inattention" errors made on the highway. Drivers could get distracted and lose attention to the road ahead. If they would get too close to the car in front of them the ACC system would make the car decelerate, preventing a rear-end collision. The ACC system lowers the speed of the car compared to the car in front of it, which means it is limited to preventing rear-end collisions. The SAE level corresponding to this system is level 1 because it involves braking or accelerating, but no steering or any other feature.

4.2 Forward Collision Warning System

The FCWS or forward collision warning system is a feature of semi-autonomous cars that is designed to try and prevent collisions in any situation by using sensors to warn drivers when obstacles are detected. Obstacles could be objects or vehicles in front of the semi-autonomous car. Studies have already shown that this feature assisted drivers well by showing that drivers adopted longer and therefore safer headways and that drivers had faster braking reactions after the warning from this feature. One particular study by Ben-Yaacov et al. (2002) showed that people would ensure safe headways while using this feature, but even when turning it off after a couple of months they still ensured keeping a safe distance from other cars at all times (as cited in Bueno, Fabrigoule, Ndiaye &

Fort, 2014). This shows that people had gotten used to activating certain schemas that ensure focusing attention on keeping a safe distance while driving. This is a good example of how errors based on activating the wrong schema can be prevented by using features in semi-autonomous cars that encourage the use of the appropriate schemas. This collision prevention system is also important in relation to the idea discussed in section 3.3 about how “Perception failure” errors can occur because drivers look for headlights instead of cars. This feature would have sensors that could detect the car that has its headlights off before the driver could, potentially preventing a collision. Just like the ACC system, this system could prevent accidents caused by “Speeding” errors. The example that was referred to in the section on ACC also applies to this feature. The driver is speeding in an urban area and could collide with another car, but this system would warn the driver, and this could prevent the collision. The FCWS system also has the ability to prevent car-on-bicycle collisions. It could prevent “Perceptual failure” errors by notifying the car driver of the cyclist if the driver overlooks the cyclist. The “Inattention” and “Distraction” errors can also be prevented by sending a warning signal to a distracted driver to make them focus on the road again and potentially prevent a collision. This feature thus has the ability to prevent collisions with objects, bicycles and other cars. It could in theory also prevent rollovers that result from colliding with objects. This feature would fit in SAE level 1 because it only assists with decelerating/braking.

4.3 Lane-keeping assistance

Another relatively new technology is the lane keeping assistance feature. This system has the function of preventing the car to drive outside of the lines marked on the road. This is done by sensor tracking the vehicle’s position in relation to the road. This system has several options to assist the driver. A visual or auditive warning could be given to the driver, but the system could also intervene with light steering adjustments and/or light braking (Eichelberger, McCartt, 2016). To link this back to the previous chapter, this type of assistance is especially useful when the driver is focusing his or her attention on the wrong aspect of driving. As described in the previous chapter, faulty schemas can be activated forcing an inappropriate attentional set. This could cause the driver to lose focus on whether the car is staying in its lane. As we saw in chapter 2.1 single-car crashes often resulted from “Action too much" errors in the form of steering too fast to the left or right. Chapter 3 showed that this could be caused by the attentional set forcing a focus on the signs above the road instead of the road itself. These errors can result in the car moving from a hard surface (the road in between the lines) to a softer surface (for instance grass on the side of the road, outside the lines) as well as hitting curbs after swaying to the left or right. This technology would ensure the car stays within the lane. It would thus be able to prevent this error and with that single-car crashes. Due to the fact that this feature can assist with steering as well as braking, it would be placed in SAE level 2.

4.4 Vehicle to vehicle communication system

In the future the semi-autonomous cars will get more and more features implemented in them. This, in turn, means that these systems will acquire more and more information on the world around them. This creates possibilities for another technological innovation: the vehicle-to-vehicle communication system. This system has the purpose of sharing information on the surroundings of a car with other vehicles that are close by. Figure 5 illustrates a random scenario at an intersection. It shows the views of the cars and illustrates that the sensors of these cars have mapped the area that is colored either red or blue. The cone shows the direction in which the car is pointing (Ozguner, Stiller, Redmill, 2007).

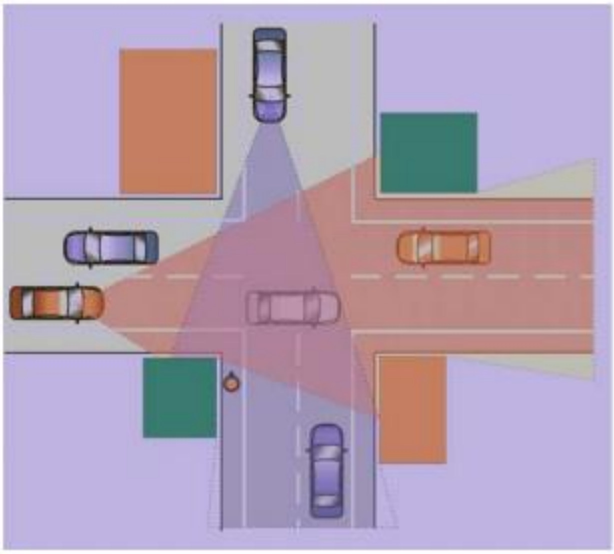

Figure 5. Sensor network to improve perception. Retrieved from [17]

When looking at Figure 5 it is clear that not the entire road is mapped by the cars there, but a significant part of it is. Some of the red and blue areas overlap which means several cars can share information on that area. More importantly, however, is the area that is either red or blue. This area contains information that could be shared with other cars that do not have this information.

When looking at the type of error caused by a lack of adjustment of the driver's attentional set, as described in section 3.3, the late activation of a new schema (new as in appropriate for the new situation) could cause a "Speeding" error causing the driver to drive too fast when entering an urban area shortly after driving on the highway. When applying this to the scenario of Figure 5, the leftmost red car could be this driver. The driver would cross the intersection and overlook the blue car at the bottom due to his high speed. Normally a collision would be imminent, but with this new communication system the blue car at the top would have established the presence of both the red and blue vehicles mentioned and could send a warning signal to both of them to try and prevent the collision. The drivers would see the warning and most likely slow down or stop altogether.

One very important aspect of this new technology is the fact that this system works better if more cars implement it. More cars with this feature mean that a larger area at for instance intersections is mapped and this increases the chance that information will be shared that prevents a collision. This new technology would fit best into SAE level 2 or level 3. The idea now is that a warning would be given to the driver, thus expecting intervention which would place this system in level 3 at most. However, because the driver has to respond quickly to the warning it would be wise to keep monitoring the driving environment, which would place this feature in level 2.

4.5 Combining features

In these previous four sections different features of autonomous cars were described and at the end, it was determined which level of automation corresponded to that feature. However, the levels of automation above 1 are often a combination of features. All four of the mentioned features could potentially be integrated into the same car. The ACC system could be used to keep a distance with other cars, but if this system would fail for some reason, the forward collision warning system could prevent a rear-end collision. The vehicle to vehicle communication system could benefit from this combination of features as well because all the information collected by these different systems in the car can be shared with other cars creating a huge network of information between different cars. Combining the features mentioned in the previous sections into one car also means that the car can potentially prevent all the driver errors that the individual features were theoretically able to prevent.

These features can however also cause new problems. A study done by de Winter, Happee, Martens and Stanton (2014) focused on the effect of ACC and highly automated driving (HAD) on situation awareness compared to manual driving. The collective summaries of several sections of their study show that HAD resulted in a deteriorated situational awareness due to drivers engaging in non-driving tasks. It also showed that ACC could have the negative effect of slower responses to critical situations. If automation would fail their study showed that most drivers would crash unless a clear warning was given beforehand that the driver had to take over (de Winter, Happee, Marten & Stanton, 2014).

As mentioned in the introduction, the most recent and advanced combination of several semi-autonomous car features is the autopilot system created by Tesla. Their system doesn't require the driver to pay attention to the environment at all times, but drivers need to react promptly to warnings if they are given. The technology would thus allow the car drive to drive on SAE level 3. This level has, however, shown to cause complications. Several severe accidents have occurred in the United States with Tesla cars driving in semi-autonomous modes. The first example involves a man named Joshua Brown who drove his Tesla Model S on the highway in Florida early 2016. When a tractor-trailer suddenly switched lanes in front of him the driver reacted too late and a fatal collision followed. The car was driving in a mode in which the driver was expected to step in and press the brakes if necessary, but the driver was not paying attention and thus crashed (Rice, 2019).

The second example concerns a man named Walter Huang who drove a Tesla Model X on route 101 in California early 2018. The car was operating in autopilot mode and thus the driver was focused on secondary tasks. When a car got really close the system warned about this short distance between the Tesla and the car in front and "asked" the driver to put his hands on the wheel. The Tesla started to slow down because of the ACC system but crashed into a highway barrier when the driver in front switched lanes. It was found that the driver did not have his hands on the wheel for 6 seconds prior to the crash, which means he had not reacted to the warning given by the car (Rice, 2019).

The last example involves a driver of a Tesla Model 3 who had engaged the autopilot function and struck a fire truck that stopped in front of her. The driver luckily survived the crash, even though she was on her phone the entire time leading up to the crash (Rice, 2019).

These accidents indicate that any level above level 2 causes problems because the drivers don’t react adequately to problems on the road due to them not focusing on the driver environment. This reconfirms the assumption made in the previous paragraphs that it would be wise to wait for further developments in this technology before implementing and using SAE levels higher than 2. The results of a study done by Seppelt and Victor (2016) also support this claim. In their paper they argued that driving on SAE level 3 could result in out-of-the-loop unfamiliarity, which was a term used to describe the inability to detect errors in the system of a car and react to failures promptly. They argued that this inability could result in for instance delayed response time, increased uptake of secondary tasks and mode errors. They even argued that a potential solution to these challenges would be to focus on either SAE level 2 or level 4 and forget about level 3, because level 3 has too many negative side-effects (Seppelt, Victor, 2016).

4.6 Mode errors

When misinterpreting a situation, it could be that a wrong schema is activated. This type of error is called a mode error and is specifically interesting in the context of semi-autonomous cars. Driving a semi-autonomous car means that the driver has access to automation systems like the cruise control system. This system allows the driver to set a certain speed after which the car will stay driving with that speed. Driving with cruise control is one of the actual modes the car can use. The mode error that could occur would be that a person would assume he is in cruise control mode and therefore take his foot off the gas. If cruise control is not on this means he will slow down drastically and potentially cause a collision. The adaptive cruise control discussed in section 4.1 can also cause mode errors. A mode error that could occur would be that the driver thinks this function is turned on, but, in fact, only the “regular” cruise control is turned on. Rear-end collisions on the highway could very well be caused by errors like these and could result in fatalities.

The mode error or mode confusion often occurs in cars with automation systems when control shifts from the system to the user or vice versa due to changes in the environment. In their paper Janssen, Boyle, Kun, Ju and Chuang (2019) argue that there are three important scenarios in which context changes have a significant effect on what they call mode confusion. The first situation is when the driver must take over control of the car all of a sudden due to an unexpected influence, which could, for instance, be heavy rainfall or snow. The car might not have a system that deals with slippery surfaces and might not take into account that making sharp turns of shifting lanes too fast could cause accidents, which might require the driver to take over. However, it could very well be that the driver does not have enough time to take over the control of the car and this could cause the car to lose grip and roll over or crash into an object or another car.

The second scenario is where the automated car's sensors could for instance not work as well as they should. This could be due to natural causes like fog, or when sudden changes have been made to roads or sections of roads because of construction work or accidents. The changes in the traffic patterns might require the driver to step in when he doesn't expect he has to. This could lead to for instance collisions with safety barriers in construction areas.

The third scenario described is a more general idea about the fact that in semi-autonomous cars more and more tasks are taken over by the car. This means that the driver will start to create a certain feeling of ease and will lose attention on important aspects of driving. In this case, the relevant aspect being the fact that changes in the driving mode could go unnoticed by the driver and this could cause accidents (Janssen, Boyle, Kun, Ju & Chuang, 2019).

5. Conclusion

In this thesis an attempt was made to find out whether more semi-autonomous cars on the roads in the Netherlands could lead to a reduction of fatal accidents. To try and answer this question three sub-questions were formulated. The first sub-question was “What types of accidents are there?”. Based on the literature on car accidents, a classification was made that divided accidents into single- and multi-vehicle accidents and driver errors that frequently occurred in these accidents were identified. The second and third sub-questions were “What causes these types of accidents?” and “Could semi-autonomous cars prevent similar accidents?”. These questions were looked at by applying a human error taxonomy based on the concept of schemas and linking these errors to semi-autonomous car features.

The results of this literature review have indicated that the expectation, that more semi-autonomous cars on the roads in the Netherlands could reduce the number of fatal accidents, was correct. Each feature discussed in chapter 4 was linked to human errors occurring while driving. It can be concluded that each of these features shows an ability to assist the driver in the early stages of faulty or untimely activation of schemas to prevent errors following this activation, as well as prevent mode errors if the right type of system is used and the driver is given warnings and signs that clearly show the mode in which the car is driving.

The results indicated that not all SAE levels of automation could reduce the number of fatal accidents. All features discussed shared one important common characteristic, which was the fact that all these features required the driver to be paying attention to the driver’s environment at all times in order to work optimally. Figure 4 shows that given that the driver has to pay attention to the environment, the SAE level would be 2. Based on the analysis of the literature, the SAE level that could actually prevent fatal accidents would be level 2. The literature also indicated that level 3 would not be an efficient mode, not now and not in the future. This is due to the fact that at this level the car takes over all aspects of driving, leaving the driver distracted and focused on secondary tasks, but still requires the driver to step in if necessary. Level 4 did actually show promise for the future, based on the knowledge that systems like the vehicle to vehicle communication system benefit from more cars on the road that share the same feature. This indicates that if the plan were to be to introduce cars that operate at level 4, it would be wise to introduce these cars on a large scale to prevent problems occurring due to the combination of manually driven cars and highly automated cars on the roads. At this point in time, where most cars don’t go further than SAE level 1, it would be an improvement to the safety on the roads in the Netherlands to introduce more cars that operate on SAE level 2; skip level 3 altogether, and proceed to SAE level 4 only collectively.

6. Discussion and further research

This literature review has resulted in a better understanding of the potential benefits of semi-autonomous car features for reducing the number of fatal accidents on the Dutch roads. It was concluded that SAE level 2 would be an improvement in terms of road safety, but higher modes of automation could cause new problems and it would therefore be unwise to increase the number of cars that operate on SAE level 3 or higher.

When looking back at the methods used in this thesis there are some points that need to be taken into consideration when looking at the overall conclusions. First of all, the studies on accidents were mainly based on data from other countries than the Netherlands. Although countries can have similar road networks the conclusions would be more reliable if the accidents that the human error taxonomy was applied to actually happened in the Netherlands. Secondly, section 4.5 focused on accidents that occurred with semi-autonomous cars. These accidents are significant because they shed light on the defects of the new semi-autonomous cars. It is important, however, to realize that these cars are a stage in the development of self-driving cars, which means that defects can be solved with new innovations and solutions. Besides this, it is also the case that new technology gets a lot of attention and thus these accidents are magnified, even though it could be that a lot of other accidents have been prevented with the introduction of these cars. Lastly, not all types of accidents were looked at, like accidents between cars and pedestrians. To really determine the safety benefits of semi-autonomous cars all types of accidents that involve cars should be investigated.

Two aspects of the conclusions raised some questions. The first one being the fact that it is difficult to predict what introducing a large number of cars that can operate on SAE level 4 would mean for the safety on the Dutch roads. This is because the literature mainly focused on the interaction between manual driven cars and semi-autonomous cars and showed that this would cause problems. However, as discussed in chapter 4.5, the semi-autonomous cars would really benefit from more other semi-autonomous cars, because the systems implemented could ‘communicate’ with each other and exchange critical information on the driving environment. Thus, it would, in theory, be best to swap most if not all manually driven cars for semi-autonomous cars all at once. However, this would probably have serious implications for the Dutch economy.

The second aspect is that mode errors are resulting from the fact that a car can drive on different levels of automation. Keeping the car at SAE level 2 would allow for managing mode errors by adding warnings and signs that make it clear to the driver what parts of driving are being taken over by the car. In order to move forward, though, somewhere in the future cars will arrive that drive on SAE level 4 or higher. This means these cars will have more enhanced features, but more features also mean a higher risk of mode errors. It thus seems like the increase of features would go paired with an increase in the number of mode errors.

The fact that semi-autonomous cars are still fully in development leaves room for a lot of further research on whether semi-autonomous cars could make traffic safer in the Netherlands. It would be relevant for this research to focus on all the different types of accidents that specifically happen in the Netherlands. This thesis focused on what errors could be solved by semi-autonomous car features, so the main focus of further research should lie on investigating what negative effects new automation features could have by testing them in several scenarios. Considering the fact that studies have already shown the existence of negative effects of semi-autonomous cars on road safety, the main goal should be to determine whether or not there would be an efficient and safe way to transition from manually driven cars to fully autonomous cars.

7. References

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