Cars that go their own way

liability for autonomous behaviour of cars

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1. Introduction and problem statement

A year ago several reports emerged of Toyota Priuses running amok. It was claimed that the car could suddenly started to accelerate and while doing so hardly responded to the brakes. This is notable because the car contains quite some autonomous functions. Driven by the hybrid drive unit of the Prius the controls of the car only look like normal brake pedals and accelerators. In conventional cars the pedals control the car mechanically. On the Prius they are input devices for an engine management system that optimizes the battery and gas mileage. Immediately the suspicion arose that a design or coding error caused the system to go haywire in certain circumstances[1]. Even former Apple great Steve Wozniak chimed in with his opinion on the software quality aspects of the Prius[2].

This is just an example of the increasing complexity present in current automobiles. In the offerings of the car manufacturers quite a few options are available that, at least partly, take over tasks of driving the car. This can be understood against the background of the development of more and more autonomous behaviour of cars[3] [4]. Part of this innovation has been driven by the car manufacturers themselves, part of it is stimulated by the military in search of autonomous capability. The military organized the DARPA challenges. In the latest version entrants had to come up with a car that was able 'to interact with both manned and unmanned vehicle traffic in an urban environment'[5]. Another part of the development is academic research, also resulting in a challenge, this time of land robots[6]. Recently Google announced a project to further develop a solution for automated driving[7]. This project is lead by a former winner of the 2005 DARPA challenge. All this shows that already today it is technically possible to create a car that can drive autonomously. The state of the art is such than a prototype can be built than can safely manoever in traffic.

The more difficult tasks to be performed by these system invariably lead to more complex designs. This again leads to more possible failure modes, which might be hard to detect by the user. In a convential car mechanical failures will be clear to the driver, a malfuntioning in the controlling software of an autonomous car will be far less obvious. In this thesis I will investigate the implications for liability of these developments. Who is responsible for damage resulting from design failures? What is the responsibility of the

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[1] http://www.zdnet.com/blog/hardware/toyotas-prius-problems-software-hardware-and-the-future-of-motoring/7164, visisted 31-05-2011
[2] http://news.cnet.com/8301-13924_3-10445564-64.html?tag=mantle_skin;content, visited 31-05-2011
[3] http://www.motortrend.com/features/auto_news/2011/1106_autonomous_car_technology_lurches_forward/timeline.html, visited 01-06-2011
[4] http://www.idsia.ch/~juergen/robotcars.html, visited 01-06-2011
[5] http://archive.darpa.mil/grandchallenge/index.asp, visited 01-06-2011
[6] http://www.elrob.org/celrob/celrob2011.html, visited 01-06-2011
[7] http://www.nytimes.com/2010/10/10/science/10google.html, visited 01-06-2011

user when using the automated functions? Even more precise: how does knowledge of possible problems by the user affect his liability. The question I want to answer in this thesis is how liability of the user of these new generation of cars is affected by his knowledge of possible malfunctions. This is to be compared with the criteria currently used for conventional cars. To put it simply: I know that I should not drive my car if the brakes are defective. But, if I am made aware of possible problems with my Toyota Prius by the media, what are the legal implications with respect to liability when the car is used?

Liability for devices has been discussed extensively in the literature. Lehman-Wilzig[8] proposed a series of incremental steps. The scale goes from product liability via dangerous animals to children and finally to independent persons. A fully autonomous car falls, at best, in the second step, the dangerous animal. He recounts that most juridictions have strict liability (i.e. liability for the owner without any other requirements of wrongdoing) for dangerous animals like wolves. For normally harmless animals the defendant should 'know or have reason to know of a dangerous propensity of the animal' for liability to arise. The legal status of a fully autonomous car is unclear. Calo discusses a first effort of the Nevada authorities to define a framework[9]. The New York Times reports that this is in part result of lobbying by Google[10]. In the European certification process I could not find an equivalent effort[11] [12]. For this investigation I use a definition of autonomous behaviour that consists of two parts. The first part: *any control of the car, done in parallel or taken over from drivers' operation of the car.* The second is complementary to the first: *any processing of (a combination of) data used in the control.* This definition allows for a gradual scale, as we see it in the current cars. For example, the input to the car or driver can be automated, part of a task of driving can be automated probably with limitations in the context, as well as fully independent performance of a task.

To answer the question raised above in the next chapter I will first investigate the grounds for liability in traffic situations under Dutch law. In the third chapter I will try to detail how in case law the questions of knowledge of (possible) dangers in relation to liability is answered. The fourth chapter examines various examples of autonomous behaviour in cars and their failure modes. In the fifth chapter I will try to synthesize the findings of the previous chapters to answer the question how knowledge of errors of complex systems affects liability. The final chapter summarizes the findings of my investigation.

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[8] S.N. Lehman-Wilzig, *'Frankenstein unbound: towards a legal definiton of Artificial Intelligence',* Futures, 1981, *p442*
[9] http://cyberlaw.stanford.edu/node/6663, visited 01-06-2011
[10] http://www.nytimes.com/2011/05/11/science/11drive.html, visited, 31-07-2011
[11] http://ec.europa.eu/enterprise/sectors/automotive/documents/directives/index_en.htm, visited 01-06-2011
[12] http://www.rdw.nl/tgk/nl/tgk/typegoedkeuring/Pages/default.aspx, visited 01-06-2011

2. General legal framework for traffic liability and own fault

2.1 Grounds for liability

In this section I will briefly review on what grounds liability can arise when using a car. The subject of liability fills a library on its own; I will try to limit myself to pointing out the basis of the legal system. For reasons of readability I will use several variants of car related accidents in covering the various grounds of liability. For more extensive treatments on liability in general I refer to the standard textbooks like the ones of Brahn/Reehuis[13], Hijma *et al.*[14] and the Asser series[15].

In Dutch law liability in traffic accidents can be based on several articles. First of all the general liability clause for tort of art. 6:162 of the Dutch civil code (BW). Closely related is the liability for the use of faulty goods as given by art 6:173 BW. Furthermore one finds in art. 185 Wegen Verkeers Wet (WVW) the special case of liability for damage of unmotorized traffic participants caused by cars. Moreover, the distribution of liability can also be affected by product liability as it is covered in art. 6:185 BW. After assessing liability based on either of these articles, the final distribution of damages can be affected by various degrees of 'own guilt' cf. art. 6:101 BW. In this section I will follow the line of reasoning as one would use it in resolving a case. First I will describe the articles on which liability can be founded. After establishing the grounds for liability I will cover the distribution of damages and the role 'own guilt' plays in this.

First consider an accident where a car crashes into another one because one of the drivers did not give way, as would be required by traffic rules. A variant of this is that the car collides with a car standing on the side of the road because the driver noticed the other car too late and could not avoid the collision anymore. For these accidents liability can be based on Art. 6:162 sub 1 BW, the corner stone of Dutch liability law. In translation it reads[16]: '*A person who commits a tort against another which is attributable to him, must repair the damage suffered by the other in consequence thereof*'.

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[13] *Zwaartepunten van het vermogensrecht,* Prof. mr. O.K. Brahn, bewerkt door Prof, mr. W.H.M. Reehuis, Kluwer, 7e druk, Deventer 2002.

[14] *Verbintenissen uit de wet en Schadevergoeding,* Studiereeks Burgerlijk Recht deel 5, Prof. mr. J. Spier, Prof. mr. T. Hartlief, Prof. mr. G.E. van Maanen and Prof. mr. R.D. Vriesendorp, Kluwer, 3e druk, Deventer 2003.

[15] *Mr. C. Assers Handleiding tot de beoefening van het Nederlands Burgerlijk Recht, De verbintenis in het algemeen, tweede gedeelte,* ed. mr. A.S. Hartkamp and mr. drs. C.H. Sieburgh, 13e druk, Kluwer, Deventer 2008.

[16] Translations of articles from the Dutch Civil Code are taken from: *The Civil Code of the Netherlands,* Hans Warendorf, Richard Thomas and Ian Curry-Sumner, Wolters Kluwer, Alphen aan de Rijn, 2009. Translations of other Dutch references are translated by the author.

One can distinguish the elements that constitute a tort: a) an actor, b) a tortious act, and c) causality and d) attributability of the actor. Upon establishing these, the actor is liable for damages. The tortious act is further specified under sub 2: *'… the violation of a right and an act or omission breaching a duty imposed by law or a rule of unwritten law pertaining to proper social conduct'.* Especially the last open norm gives flexibility to assign liability for all kinds of improper behaviour. On the other hand this will give legal uncertainty, which needs to be resolved by more detailed rules derived from case law. Indeed, case law on this article is abundant.

The definition of attributability is given under sub 3 of art 6:162 BW. The first ground for attributability is responsibility for a fault. Furthermore there is accountability by law or by generally accepted principles. The first norm can lead to strict liability where just operating a car generates a liability, we will encounter this extensively later on. The last open norm will again need further clarification in case-law.

Applying this to the simple cases above: the driver of the car is the actor, the tortious act is the collision causing the damage. In the example of not giving way the attributability is based on the violation of the traffic laws. In the case of crashing into a car due to negligence attributability can be based on violation of a norm of proper social conduct: one is expected to act carefully so that other people and their belongings do not come to harm. Proper social conduct could also imply that one should not use a car of suspicious technical quality.

A variation of the case is where the driver crashes into a car because his brakes did not function properly. He did notice the car ahead and wanted to avoid it, but a technical failure prevented him to do so. In this example he is liable because he used a faulty good. This type of liability is found in art. 6:173 BW. Under sub 1 the owner is liable for *'a movable thing which is known to constitute a special danger for persons or things if it does not meet the standards which, in the given circumstances, may be set for such thing…'.* This article makes the owner of a car responsible for damage caused by failing brakes. It is clear that properly functioning brakes are part of the mentioned standards applicable for a car. Moreover, failing brakes will constitute a danger. Under sub 2 an explicit reference is made to art 6:185 which covers product liability: in case the defect did not exist at the time the product was brought to the market or arose at a later date the owner is still liable. I will treat this more extensively below.

For completeness I mention that the car owner might be able to shift (part of) the liability to the seller of the car. Art 7:24 BW stipulates that the buyer of a movable thing that does not have the properties one expects based on the agreement can hold the seller liable for damages based on breach of contract via art 6:74 BW. The second clause of art 7:24 BW regulates how the liability of the producer and the seller are separated.

Now consider the case where the careless driver collides with a pedestrian that crosses the road. Both did not pay attention to other traffic participants. The case of unequal traffic participants, more specifically motorized versus unmotorized, defines a special category of accidents covered by art 185 WVW. It is applicable to accidents involving motorized vehicles on one hand and unmotorized participants on the other, the philosophy being that the latter category is a weaker party in need of additional protection. Under sub 1 liability is given for the damage caused by a motorized vehicle to other participants. Either the owner or holder of the vehicle is liable; the actual driver is not the subject of this article. Only force majeure can prevent liability. Barring this exception, the car owner will be liable without further requirements for the damage caused by the accident. Even when he had payed attention, he would still have been liable had the accident occurred. Careless behaviour on the side of the pedestrian is no ground for force majeure. Note however that this does not imply that the car owner will always be liable for the full amount of the damage. This can be corrected later in the process by application of art. 6:101 BW, which I discuss in section 2.2.

The fact that the owner/holder of the vehicle is required by law to have a minimum insurance against liability[17] leads to a system where in almost all cases a financially capable party will cover the cost of an accident. Bloembergen phrases this as:
'the system comes down to a national insurance against traffic accidents financed by motorized traffic'[18]. Given the wide distribution of car ownership one can argue that this is a pragmatic solution to both the problem of distributing the costs of accidents and the problem of large damages which cannot be recovered by the injured party.

Changing the case again to where the driver crashes his new car into another one due to defective brakes. This time it can be shown that the cabling broke because it was way to light for the task: the brakes were improperly designed, unfit for the task. This example introduces liability for a third party, the manufacturer of the car. Product liability is based on art 6:185 BW. In principle it applies to all the damage of all parties involved. While the driver of the car causing the accident can be liable for damage to the other party, the producer can be also liable for the damage of the driver. Sub 1 introduces a strict liability for a defect in the product in a negative way: the producer is liable unless one of a set of specific exceptions applies. Under b) we find the mirror of 6:173 sub 2 BW: in case the fault did not exist when the product was put into circulation or the defect came into being afterwards the producer is not liable. For this thesis the exception listed under e is also of importance: the state of scientific and technical knowledge was not such as to enable the existence of the defect to be discovered. Again, if the brakes of the car fail due to a manufacturing fault or design error the producer will be liable. In such a case the exception under e) might be applicable. However, the European High Court has set a high standard[19] in stating that the reference is the most advanced knowledge available at the time of bringing the product into circulation. It will be very difficult to succesfully claim this exception.

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[17] Wet Aansprakelijkheid Motorrijtuigen
[18] *Eigen schuld bij onrechtmatige daad*, Prof. mr A.J.O. baron van Wassenaer van Catwijck, mr A.R. Bloembergen, prof. mr J. Spier, mr H.A. Bouman, prof. mr J.H. Nieuwenhuis, mw mr C.J.M. Klaassen, prof. mr J.H. Wansink, introduction by mr F.B. Falkena, Koninklijke Vermande, Lelystad, 1997, *p10*
[19] HvJ EG 29 may 1997, NJ 1998, 522 (Cie EG/Verenigd Koninkrijk)

Art 185 sub 2 reduces or extinguishes the liability of the producer in case the damage was also caused by a fault of the injured person. As already noted above, the injured person can also be the driver causing the accident. In the literature it is assumed[20] that this correction is applied according to the regime of 6:101 BW. This regime will be discussed in section 2.2. In parlementary deliberations[21] the example was given of a driver running into a tree while he had discovered that his brakes were failing.

In art 186 sub 1 BW a defective product is further specified. Of importance are the presentation of the product, warnings for erroneous use, the reasonable use and the time when the product was put into circulation. The latter is elaborated sub 2, which states that a product is not defective for the sole reason that a better product has been put into circulation at a later date. A limit to reasonable use is found in the term unreasonable abuse. Spier cites the example of a dentist drilling teeth with a Dremel[22]. On the other hand, in case law one finds that a producer cannot count on all safety measures being fully applied by the user.

An important limitation is given in art 6:190 BW. Liability only exists for damage arising from death or personal injury (sub a) or damage done to goods usually intended for private use or consumption.

A recognized failure of a design can lead to warnings issued by the producer or even a product recall to replace the improperly designed part. Spier discussus the various aspects briefly[23].

As a final case consider a crash where the driver payed attention to the road, his car was in fine order but the road had a nasty hidden turn, hard to see in the fading light. In these cases the owner of the road can be liable. This is based on the liability for buildings and structures as given by art 6:174 BW. The wording follows to a large extent art 6:173:, '*…does not meet the standards which, given the circumstances, may be set for it, and thereby constitutes a danger for persons or things, is liable if this danger materializes…*'. In the case of traffic accidents this can be of importance when the owner of the road (municipalities or other parts of the government) fail to properly maintain the road or by a dangerous setup or layout of the road itself. This can be of interest for this thesis in cases where one has to decide whether the user of the road should have acted upon the dangerous situation.

In case law we will also encounter distribution of liability between employer and employee. Two articles are of importance: the general duty to care of both employer and employee as given in art 7:611 BW and the duty of the employer to provide a safe working environment as found in art 7:658 BW sub 1. The latter article provides almost a strict liability, sub 2 states that the employer is liable for any loss unless he fullfilled the

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[20] *Verbintenissen uit de wet en Schadevergoeding*, *p133*
[21] Memorie van Toelichting, Kamerstukken II 1987/1988, 19636-6
[22] *Verbintenissen uit de wet en Schadevergoeding*, *p130*
[23] *Verbintenissen uit de wet en Schadevergoeding*, *p141*

obligations of sub 1 or that the loss was to a large extent the result of intent or deliberate recklessness on the part of the employee. Especially the area where the danger is common, well known as a fact of life, and the employee should have prevented the loss based on his own knowledge provides cases which are of interest for the current discussion.

2.2 Distribution of damages: own fault

After establishing the liabilities for a certain case the actual distribution of damages can be affected by art 6:101 BW. This article states that '*where circumstances which can be attributed to the person suffering the loss have contributed to the damage, the obligation to repair the damage is reduced by apportioning the damage between the person suffering the loss and the person who must repair the damage, in proportion to the degree in which the circumstances which can be attributed to each of them have contributed to the damage …'.* We encounter, as in art 6:162 BW and 6:98 BW, the term attributable. This can be both due to guilt (as the consequence of a consious decision), responsibility (as the consequence of an act), or other circumstances. The mere use of a possibly dangerous thing like a car can give rise to attribution, often referred to as 'Betriebsgefahr'. The second part of the article provides a correction mechanism based on fairness of the result of the so-call causal distribution: '… *that a different apportionment shall be made or the obligation to repair the damage shall be extinguished in its entirety or maintained if is fair to do so on account of varying degrees of seriousness of the faults committed or any other circumstances in the case'.*

The scheme for applying art 6:101 BW consists of four steps[24]. First it needs to be established that the damage is also caused (increased is also relevant) by a circumstance attributable to the damaged party. This causal relation is to be interpreted with the *conditio sine qua non* criterium: the damage would not have occurred in case the damaged party behaved differently. Next it needs to be established if the circumstance is attributable to the damaged party. This can either be statutory or guilt. In the parliamentary history the latter was stated as 'behaving differently than a reasonable person in the given circumstance would do with this own interests in mind'[25]. The third step is the determination of the relative weights of the various attributable facts; this will give a percentage for distribution of the damage. In theory this is an objective number in the sense that only the causality should come into the reasoning. In the actual application this is much less clear. In the final step the percentage can be corrected in case the result does not provide a fair result.

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[24] *Mr. C. Assers Handleiding tot de beoefening van het Nederlands Burgerlijk Recht*, *p95*

[25] *Parlementaire geschiedenis van het nieuwe burgerlijk wetboek, parlementaire stukken systematisch gerangschikt en van noten voorzien Invoering boeken 3, 5 en 6, Boek 6 Algemeen gedeelte van het verbintenissenrecht,* ed. C.J. van Zeben, W.H.M. Reehuis, E.E. Slob, Kluwer, Deventer, 1990, *p351*

In Asser[26] it is already stated that this scheme is more a theoretical model than a regularly followed scheme in practical cases. In *Eigen schuld bij onrechtmatige daad* [27] several authors discuss the problems in the interpretation and application of this article. Spier states that judges often confuse the causal attribution with the fairness correction[28]. Judges tend to use the degree of seriousness already in the causal attribution whereas this should be done in the fairness correction. This leads to large variability in the outcome of comparable cases. Bouman is also critical on the interpretability of the fairness correction[29]: '*… the High Court gives oracle-like verdicts, sometimes even as a fixed rule'*. Later on he advocates more restraint in applying the fairness correction, as e.g. stated explicitly in art 6:258 BW. Note in case regress is taken by e.g. the insurer the High Court has ruled[30] that the fairness correction still has its place but '*usually will lead to a limited adjustment of the result of the weighing of causality factors' (r.o. 3.7).*

The legal framework described above can be summarized by describing the various steps in analyzing liability for a traffic accident. First one has to establish a ground for liability. As recounted above this can be based on art 6:162 BW for general tort, art 6:173 BW for using an unsafe movable good, art 6:174 for the maintainer of an unsafe road or the special case of art 185 WVW. The articles have various requirements to be met in order to establish liability. The next step is to check on possible exceptions. For this thesis the most interesting is the product liability of 6:185 BW where the producer is liable for supplying a faulty product to the market. The decision point is wether the fault existed at the moment the product was brought to the market. An exception to this occurs when the accident is also caused by an own fault of the user. In the final step the damage can be distributed over the various parties on basis of 6:101 BW based on the behaviour of the parties. This consists of four steps: the specific behaviour should have a sine-qua-non relation to the accident and it should be attributable to the party. Relative weights for all parties need to be determined, on these a fairness correction can be applied.

Knowingly using a car with bad brakes as an example of own fault as taken from parlementary history provides only a hint of guidance on how the more general question on how knowledge of defects affects liability is to be answered. In actual cases this question will be encountered in various forms. Analysis of case law should provide more detailed guidance on how to problem of own responsibility and liability is resolved.

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[26] *Mr. C. Assers Handleiding tot de beoefening van het Nederlands Burgerlijk Recht, De verbintenis in het algemeen, tweede gedeelte, p95*
[27] *Eigen schuld bij onrechtmatige daad*
[28] *Eigen schuld bij onrechtmatige daad, p20*
[29] *Eigen schuld bij onrechtmatige daad, p27*
[30] HR 05-12-1997, NJ 1998, 400.

3. On what knowledge should a user adapt his use of technology

To further clarify how the question of attribution of liability is resolved I now turn to the case-law. As can be expected, this is extensive. Several landmark cases in liability are discussed in the literature, which I will investigate for relevance to the question posed in this thesis.

To elaborate further on this I used two routes. First of all a search in the archives of case law as given by the public archive *www.rechtsspraak.nl*[31] and the annotated case-law of 'Nederlandse Jurisprudentie', accessible via the university library[32]. A naive search on the public archive on art 6:101 yields more than 1000 hits. Of course, by adding more key words the search can be refined to more manageable numbers. For example, combining the search with 'cars' or 'machines' the numbers reduce to a more accessible 200. Scanning the summary on possible relevance for this thesis provides a few interesting cases. As a criterium I used whether there possibly was objective knowledge of failures or dangers of cars, other material objects or dangerous constellations of such. A similar exercise was done on the NJ-archive.

A simple search on the own-responsibility article of product liability, 6:185 sub 2 BW, turns out to be improductive. Only a limited number of cases are found with no case being of particular interest to this thesis.

Second I checked published anthologies of case-law on liability. Especially the 'Jurisprudentie Aansprakelijkheidsrecht'[33] provides an accessible overview. Categorized by legal relevance it gives a short summary of each case. Again, this allows scanning for cases that might be of interest. Overlap with the results of the search described above gives some level of confidence that I did not miss out on relevant cases.

The case-law can be divided into two categories. On one hand the cases where the emphasis is on the responsibility of someone who created a danger and caused harm to others, on the other hand cases where the emphasis is on whether a harmed person should have been more careful. The latter are the ones of particular interest for this thesis.

I will order the discussion of case-law based on several demarcation lines one can identify. The emphasis is on identifying the argument used. This means that, especially

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[31] http://zoeken.rechtspraak.nl/default.aspx, visited 11-04-2011

[32] Kluwer Navigator on http://dbiref.uvt.nl/iPort?request=databases&dbgroup=alphabetGroup&language=eng#W, visited 11-04-2011

[33] *Jurisprudentie Aansprakelijkheidsrecht,* mr. K. Flanderhijn-van der Meer, M. Keijzer-de Korver en mr W.A. Luiten (red.), mr. K Baetsen, mr. M. Eijkelenboom, mr. L.K. de Haan, mr. J.C. Rous en mr, A.T. Stevens (auth.), 7th print, Staderman Luiten advocaten Rotterdam, 2010

for landmark cases, that the technology aspect of the case is not always dominant. Where possible I tried to find a more appropriate case that uses the same line of reasoning. As a start, from the obligation to warn for dangerous situations we can infer that there is a limit to the own responsibility of possible victims. This provides some criteria as to what the court assumes to be minimal knowledge and own responsibility of a possibly injured person. A limitation to this limitation is given by the *facts-of-life*, knowledge so ordinary that everyone is presumed to act on. A particulary important distinction for our problem is the difference between a knowledgeable professional and an ordinary consumer. Moreover, consumers come with flaws: even with proper warning and knowledge of dangers liability of other parties is not (fully) removed. Professionals are held to a higher standard, they are expected to closely follow the provided instructions. Well-recognized safety norm like lines on the road are expected to be closely followed. Also, in absence of knowledge of a created danger, a duty to investigate whether dangers are created might be present. Finally I will discuss a case where knowledge of inherent dangers was present.

In reviewing the case law one has to be aware of the ground for liability in question. For a strict liability the requirements to other parties will certainly differ from those for the open norm of art 6:162 BW.

3.1 Warning for dangerous situations

When a person creates a dangerous situation he cannot count on other people recognizing the danger in all circumstances and adapting their behaviour accordingly. This is the mirror-image of the situation I investigate in this thesis: instead of a need to act upon something one knows, one is now clearly not cognizant of a danger and needs to be warned to avoid damage. This provides something of a minimum standard for our problem: one cannot act upon knowledge that is not there.

A first landmark case for liability for creation of dangerous situations is the 'Kelderluik' ruling by the Dutch High Court[34]. In this case an employee of the Coca-Cola company left a hatch-cover open while providing a café with fresh supplies. In the meantime somebody else did not notice the opening on his way to the bathroom and fell into it, thereby severely injuring himself. The High Court distinguished four criteria for deciding when proper warning is needed: *- size and nature of the possible damage, - probability that the damage materializes, - the nature of the conduct and - the cost, time and effort to take precautionary measures*. Each individual criterium is to be judged on a scale: e.g. the more dangerous the created situation is, the more effort is required in precautionary measures. The behaviour of the damaged party is present in the *'nature of the conduct'*, in this case it is not further elaborated beyond that in this case where *'proper attention and carefulness are not a given'* there might be need for a warning. This ruling does not tell us much about the assumptions of the court on the knowledge or awareness of the damaged party (it was in a bar after all).

[34] HR 05-11-1965, NJ 1966, 136, *Kelderluik*

A more restrictive variant is failure to warn for a danger. In case a third party observes a danger a duty to warn can sometimes be assumed. Van Maanen[35] cites four criteria, which resemble the Kelderluik criteria: - *specific knowledge of the danger, - possibility of serious damage, - possibility and necessity to warn or help and - reasonable proportion between effort to warn and the danger.* In one case the High Court dismissed this duty on grounds that is crucial that the '*seriousness of the danger has entered the conciousness of the observer'*[36]. This case was about the children of 4 and 5 years old who while playing with a wire caused damage. Since they were small infants it is difficult to base a firm guideling on this case.

A relatively recent case on the obligation to warn, that has stirred quite some debate is the Jetblast ruling[37]. In this case Ms Hartmann sued the Arubean airport for damages after being hurt while watching departing aircraft at a road next to the airport. Although a warning sign with the text *'warning, low flying and departing aircraft blast can cause physical injury'* was present Ms Hartmann and as she claimed many others ignored the warning and were still watching. Ms Hartmann was caught by a strong jetblast, knocked backwards and came to harm. She sued, claiming the airport should have taken better precautionary measures and more stringent warnings. In r.o. 3.4.3. The High Court ruled that it is not enough to provide a warning such that the public can be aware of the danger but posed a more stringent criterium. Now the effectiveness of the warning should be taken into account as well: '*it is of crucial importance if it is to be expected that the warning will lead to acting or non-acting that will avoid the danger'*. Strictly read, this means that a warning is only sufficient when expected to be effective. The nuance might be found in *expected.* The requirement is that it has to be expected to be effective, not to be effective. Pape discusses the consequences of this ruling on warnings in relation to product liability[38]. In the view of Giessen this norm is way too strict[39], possibly leading to over-kill in warnings and thereby in the end reducing the effectiveness of warnings in general. It seems the High Court moves to almost a strict liability where only recklessness or gross neglicence can limit the liability. Giessen does not agree with this line, supported by Brunner who in his note in his usual terse style comments that the law is not meant to protect people who knowingly expose themselves to a danger. On the other hand Haake claims[40] that this type of protection of victims is part of modern social justice. Whatever one might think of the political choice underlying the ruling, as noted by Giessen[41], with the emphasis on the effect of the warning the High Court does seem to move into the cognitive psychological arena.

[35] *Verbintenissen uit de wet en Schadevergoeding, p51*
[36] HR 22-11-1974, NJ 1975, 149, *Heddema-De Coninck*
[37] HR 28-05-2004, NJ 2005, 105, *Jetblast*
[38] S.B. Pape, *De betekenis van het Jetblast-arrest voor de waarschuwing in het productaansprakelijkheidsrecht,* NTBR 2006, 374
[39] I. Giesen, *De psychologie achter de waarschuwing: Handle with care!*, AV&S 2006, 2
[40] K.F. Haak, *Gemankeerde rechters?*, NTBR 2006, 9
[41] I. Giessen, *op. cit.*

What are the implications of this ruling for our problem? The standard set by the High Court implies that a possible victim of an externally created dangerous situation needs to be made aware of the dangers before his own responsibility is taken into account. A possible relevance for our problem lies in product liability. If one requires that a product needs to warn about it's own malfunctioning it defines requirements for the effectiveness of the warning.

3.2 Professional vs average consumer

An additional differentiation applied by courts is the difference in knowledge and awareness of professionals on one side and consumers on the other. The professional is supposed to be knowledgeable and have a better judgement. This presumed experience can help to avoid liability: professionals are expected to sense dangers earlier. In the case were are lorry burnt out due to a failing drive shaft coupling the court in Utrecht presumed that the driver, who had several tens of years of experience, would have noticed that something was wrong. This was used to argue that the truck was properly maintained and found against the producer[42].

The court in Arnhem[43] used this distinction in finding liability for the professional. In a case that somewhat resembles our example of knowingly driving with failing brakes. The claimant's van broke down, during the provisional repair by the ANWB road patrol the mechanic noted that the brakes were worn down and should be serviced. Acting on this advice the claimant made an appointment with the shop and brought the van in for repairs. Unfortunately the shop didn't have the proper parts and returned the van unrepaired, to be serviced on a later date. The claimant started to use the van again although he obviously knew that the brakes were suspect and not repaired. On the same day as the van was returned, the claimant noted while driving the van that the brake was stuck. He could not get to the side of the road, had to stop, and switched on his emergency lights. While exiting the van it was struck by another car and the claimant had to be brought to the hospital. He claims damages from the owner of the shop, stating that the owner failed to warn him properly for the dismal state of the brakes. The shop owner refuted the claim. He states he thought it was dangerous to drive with the van and he would tell an ignorant customer not to use the van. However, he did not warn the claimant because he thought the claimant realized that is was dangerous to use the van. In section 6 the court rules that the shop owner should have warned the claimant, since he had inspected the brakes and had precise knowledge of the dismal state. However, under 10 the court also rules that the claimant was at fault: he knew the brakes were not good and not repaired. Both acts have a causal relation with the accident and are attributable to the claimant and shop owner respectively. Under 11 the court rules on basis of art 6:101 BW that a 50% division is representative for the causality distribution. This division is not further elaborated upon. In this case we see that a professional is measured against a higher standard: even the explicit knowledge of the claimant that his brakes were not

[42] Rechtbank Utrecht 07-04-2010, LJN BM0457
[43] Rechtbank Arnhem, 11-02-2004, LJN AO5077

good (he was told so by another professional party, the ANWB road patrol) did not extinguish the liability of the shop owner.

To summarize: the professional is supposed to know more and to notice more than the average consumer. This can work to his disadvantage in case he should have acted. It can work in his advantage in case it is presumed he will have noted something in disarray and acted upon it.

3.3 Average consumers making errors

A further nuance in the regime for warning others is that one has to take into account that people will make errors. In the landmark case on producer liability, in this particular case on a leaking hot-water bottle used to keep babies warm, the High Court ruled that foreseeable mis-use should be taken into account[44]. The court ruled that in determining the chance of accidents, the users who did not take all the precautionary measures should be taken into account. In this case the measure would amount to putting the bottle with the lid down on a absorbing surface to keep the baby as far a possible from leaking water[45]. The idea being that an intrinsically unsafe product should not be made safe by precautionary measures. Still, the annotator Bröring is not really satisfied with the results of this line of reasoning in this particular case. For such a simple product the producer should be allowed to count on diligence and common sense on the side of the user.

Another example is found in the ruling of the court in The Hague[46] in the case where a cyclist suffered a transverse myelitis when he crashed in the dark on an unclear section of a bike-path. The court ruled that the single fact that the cyclist used a led-light (a minimal light which hardly illuminates the surroundings) did not bring own guilt cf. art 6:101 BW into consideration. Liability for an intrinsically dangerous bike-path is not extinguished by the user having improper lighting.

As a final example I mention the case where a mountainbiker fell on a sheet of ice during an organized tour. The conditions where clearly treacherous (it had frozen during the night) and the cyclist increased the danger by riding closely together in a group although this was not dictated by the nature of the event. Using these arguments the court ruled[47] that the organizer should have put up proper warnings, the behaviour of the rider contributed to the damages but closely riding together was to be expected in these types of event. Finally the court distributed the damages in a 2:1 ratio between the organizing club and rider.

In the last two cases the presence of an insured party might have played a role. Especially in the first case, were the damage is large, courts tend to put the damage on the doorstep

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[44] HR 2-2-1973, NJ 1973, 315, *Lekkende Kruik I*

[45] *De Hoge Raad van Onderen,* Freek Bruinsma e.a., W.E.J. Tjeenk Willink, 2e druk, Deventer, 1999, *p152*

[46] Rechtbank ‘s Gravenhage, 13-3-2002, NJ 2003, 101.

[47] Hof Arnhem, 2-3-2010, RAV 2010, 56

of a financially sound party who can more easily distribute the damage. Compare Bloembergen's remark on the system of motorized traffic insurance.

3.4 Generally known facts

Another minimal standard, this time for knowledge that is presumed to be there, is found in the 'facts of life'. It is presumed that everybody will act on this and no additional warning is required. One often encounters this argument to find against the employee in the nearly strict liability regime of the safe working place of art 7:685 BW.

Take a case on Aruba, were a worker fell on a slippery floor. This was caused by heavy rainfall. The High Court agreed sub 3.4 with the lower court[48] that people familiar with the climate in Aruba are presumed to know that floors can be slippery after rainfall. From the duty of care of the employer it did not follow that he should place warning signs after a rainfall at possibly dangerous locations. The High Court deemed such a requirement unreasonable.

In the same regime of liability for a safe working place the High Court ruled that the employer of a worker who used an inappropriate small stepladder to reach for materials was not liable[49]. A proper stepladder was available; the worker should have made the sensible choice to use it.

An illustration from product liability is found in the ruling of the court in Amsterdam[50] in a case where a smoker sued the tobacco company for damages. Citing that an average consumer, especially the well educated claimant, ought to have been aware of the general danger involved in smoking the court declined the claim.

3.5 Violation of safety norms

The violation of a safety norm can also affect the distribution of the damages. A proper warning can be interpreted as a variant of a safety norm. The cyclist who slipped in a groove on a temporary bridge was attributed half of the damage since he had crossed a continuous line intended to keep cyclists away from that part of the bridge[51]. Compare this with the Jetblast case were ignoring a warning sign did not have consequences for the injured party because the warning was not adequate. This can be explained by reasoning that the continuous line, being part of the traffic code, is presumed to be a well-known safety norm.

3.6 Duty to investigate

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[48] HR 2-3-2007, NJ 2007, 143
[49] HR 7-12-2007, NJ 2007, 643, JA 2008 33
[50] Rechtbank Amsterdam, 17-12-2008, NJ 2009, 311
[51] Rechtbank Utrecht, 25-9-2002, NJ 2002, 591

If one is not aware of a danger one has created, to what extent does the duty to care imply a duty to investigate whether one has possibly created a danger? The baseline is given in the ‘Dorphuis Kamerik’ ruling[52]. Personell of ‘het Dorpshuis’ put a bucket with an unknown fluid on the side of the road to be taken away by the garbage collectors. While discharging this, one of the garbage men got some of the fluid in his eye. This turned out to be caustic soda and he was injured. The High Court ruled that ‘het Dorpshuis’ was liable since it violated its duty of care by not taking appropriate measures to counter the possibility of a created danger. One cannot put an unknown substance on the side of the road. Either one should have had good reason to know the substance was not dangerous, or explicitly warn for a possible danger. From this ruling it follows that knowing or not knowing about the possible danger makes no difference in liability for a danger one created.

Sometimes the High Court deviates from this baseline. In the ‘Taxusstruik’ ruling[53] liability for the death of a horse that ate from the waste clipping of the poisonous yew-bush was denied because the toxicity was not a well-known fact. Therefore the behaviour was judged not to be in violation of normal diligence. Brunner in his note disagrees; he sees no reason to not apply the norm of the Dorpshuis Kamerik case: ‘*Now it seems that urban ignorance is also the norm for civil diligence on the countryside’*. Dunné[54] spends an extensive treatise on the difficulties in reconciling these two rulings. One line of thinking, not supported by Dunné, is that different rules are applicable for natural materials as opposed to artificial goods. However, some later rulings could support this line of thinking. Both rulings concern natural waste that resulted in damage. The municipality of Rijnwaarden was not liable for the death of cattle when somebody, after consulting with the municipality stored cutting waste including taxus at a point where the cattle could eat it. The court ruled that the municipality did not have an obligation to know or investigate whether the cuttings posed a danger[55]. In another case the dumper of onions, which were to be eaten by sheep, which resulted in damage by infecting a nearby onion crop with a mould, was not liable. The High Court, explicitly referring to the Taxusstruik ruling, ruled that the dumper had no obligation to know or investigate the possible dangers of the dumping[56]. Clarity in this matter is hard to come by. Taking the Dorphuis Kamerik ruling as a starting point users of technology have a duty to investigate possible dangers. Ignorance does not extinguish liability.

3.7 No liability even with awareness of dangers

Finally I mention the case where a woman died as a consequence of a fall during skeeler lessons for beginners. The High Court agreed with the lower court in finding liability for

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[52] HR 8-1-1982, NJ 1982, 614, *Dorpshuis Kamerik*
[53] HR 22-4-1994, NJ 1994, 624, *Taxusstruik*
[54] *Verbintenissenrecht: onrechtmatige daad en overige verbintenissen,* J.M. van Dunné, Kluwer, Deventer, 2004, *p184ff*
[55] Hof Arnhem, 25-3-2003, NJ 2003, 577
[56] HR 7-4-2006, NJ 2006, 244

the organizer of the course since he did not oblige the participants to use a helmet[57]. Annotator Brunner states that the dangers of skeelering must have been clear to the woman, given the obligation to wear protective gear for wrists, knees and the like. However, there was no obligation to wear a helmet, although these were available if a participant wanted to use them. This was not enough for the High Court. Possibly the fact that the course leader did not wear a helmet played a role as well. Professional behaviour in a different guise, this time in the form of examplary behaviour. On the other hand, Brunner sees no need for an obligation to protect for accidents with such a remote chance. He thinks that the tragic circumstances, the woman was a mother of four young children and the damages were relatively low, amounted to the verdict. He also notes that the own-guilt defence by the organiser was not considered by the lower court for somewhat unclear reasons. An explicit consideration of the distribution of guilt is missing in this ruling.

3.8 Summary

For the investigation of this thesis some of the arguments listed above are of particular importance. As far as knowledge of severity of a malfunction goes, the most important is the difference between the professional and ordinary consumer. The case of the van with bad brakes serves as a good example. Although the owner, an ordinary consumer, knew his brakes were in a dubious state, he still was held only partly liable. The professional should have explicitly warned him. The ruling does not provide a detailed insight on which the judge bases his 50-50 distribution of damages.

Another element to consider is the duty to investigate. Ignorance of a danger does not extinguish liability. Clear boundaries for this duty are not given in the case-law. For example, it is not explicitly stated that a professional has a more extensive duty than the average consumer. Increasingly complex technology will complicate matters further. This is the subject of the next chapters.

Product liability can imply proper warnings. However, case law does not point to a duty to warn for possible failures in the car. If so, the established rulings on proper warnings will apply where the standard is that '… *it is to be expected that the warning will lead to acting or non-acting that will avoid the danger'*. A further nuance is give by the assertion that people will make errors. Trying to make a product safe by warnings only is discouraged.

Own responsibility is a given when the danger is so obvious that it can be classified as a fact of life.

[57] HR 25-11-2005, NJ 2007, 141

4. Failure modes in autonomous behaviour of cars

In this section I will investigate the failure modes in several examples of autonomous behaviour of cars. In the introduction I defined automous behaviour as having on of two possible aspects: *any control of the car, done in parallel or taken over from drivers' operation of the car* or *any processing of (a combination of) data used in the control.* For the analysis the examples are ordered by increasing complexity. After examining the conventional driver I will investigate the use of additional sensors, virtual controls, partly taking over control of the car and full control of the car. I will not list all available implementations as offered by the various car manufacturers, but will try to be complete in the different types of systems. Each example will be investigated on its error characteristics. I will use parts of the methodology of the Failure Mode Effect Analysis as known from failure and risk assesment[58]. In this method every component of a system is analyzed on its possible failure modes, the possibility of the failure, consequences of the failure and the detectability of the failure. Failure modes can then be ranked on a scale given by probability times effect times detectability. Analyzing a system in this fashion allows to systematically find errors with large consequences that are hard to detect and adjust the design accordingly.

In this investigation I am interested in the type of errors: are they due to physical failure, manufacturing errors or design flaws? Also the external characteristics of the errors are of interest: can they be detected by observations, and if so how? This is critical for answering the question how the user of the car can be aware of possible problems. Along with the error analysis some background is given in the state-of-the-art of solving the problems encountered.

4.1 Conventional Driver

The examples are presented graphically in a simple modelling scheme with three basic units. The scheme is not intended to be a rigorous scheme with all design details but as a method to indentify the critical components and data-flow. As a start, the model for the conventional driver is presented in Figure 1. The sentient driver, represented by a black ellipsoid, is the central piece in the model. He uses his own sensory input devices, eyes, ears, nose and skin, which are denoted by black squares. On top of that he uses mechanical sensors, represented by blue squares. The driver processes all the incoming information, combines this with his intentions with regard to speed, direction etcetera, and adjusts the actuators of the car accordingly. The actuators are depicted by red rounded squares. If he wants to go faster than the speed indicator tells him he will push the throttle. If he needs to go slower or change his direction to avoid a collision based on his own sensory input he will hit the brakes or use the steering wheel.

[58] http://en.wikipedia.org/wiki/Failure_mode_and_effects_analysis, visited 22-05-2011

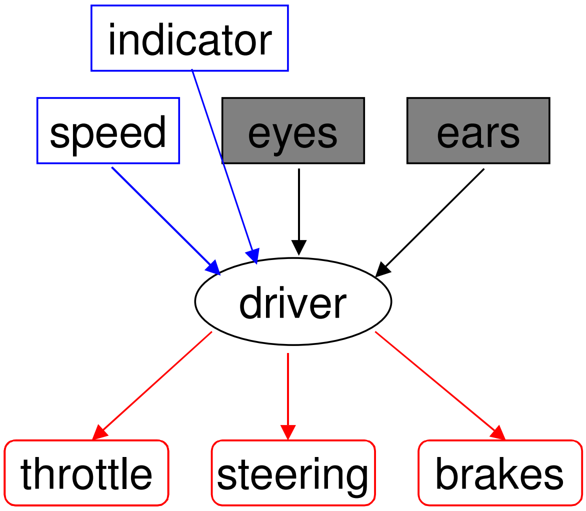

Figure 1: Model of the conventional driver. The sentient driver is denoted by the black ellipsoid. He processes the inputs that are represented by squares. The black shaded squares belong to the driver; the blue ones are mechanical sensors. The output controls/actuators of the car are depicted by red rounded squares.

This adaptive behaviour shows that the system contains a feedback loop: using the actuators leads to a change in the sensor readings which in their turn can lead the driver to change the actuators. This is not explicitly shown in the diagram. I will come back to the implication of this when (part of) the feedback is taken over by automated functions.

Error analysis

The errors in this system are relatively simple. When the actuators malfunction it will be clear to the driver: the engine does not react properly when pushing the throttle, the car fails to turn when rotating the steering wheel or the car does not stop when applying the brakes. Note that European regulations require a warning light for e.g. low brake-fluid level in a hydraulic brake systems[59]. Moreover, sensor failings will in most cases be obvious: the speed indicator can either show nothing or a less obvious misrepresentation of the speed. One can assume that most drivers will start to notice discrepancies of more than 25% in the given speed compared to the actual speed. Processing errors in the 'logic' of the driver can lead to accidents: e.g. the driver misjudges a priority on a crossing, fails to see a car on an adjacent lane and so on.

4.2 Additional sensors and Hidden Complexity

A more direct extension to the conventional driver model to be discussed is an additional sensor meant to help the driver in the execution of his tasks. An very common example is

[59] Commission Directive 98/12/EC of 27 January 1998 *adapting to technical progress Council Directive 71/320/EEC on the approximation of the laws of the Member States relating to the braking devices of certain categories of motor vehicles and their trailers,* section 2.2.1.12.2 and section 2.2.1.13

the navigation device, popular devices are offered by Garmin[60] or TomTom[61]. The system detects via GPS where the car is and based on routing information suggests directions to the driver.

An example of a sensor more involved in the actual driving of the care and offered by quite a few car manufacturers, is the clear-lane indicator. The intention of the sensor is to issue a warning in the event the driver wants to switch lanes while another car is oncoming. BMW, for example, offers the 'Spurwechselwarnung'[62]. It claims to scan 60 meters backwards using two radars. In case a car is coming it will warn with a light in the outside rearview mirror to either the left or right. On top of the warning signal, the steering wheel will start to vibrate when the drivers still tries to switch lanes just in front of oncoming traffic. Chevrolet offers a similar function, 'Side Blind Zone Alert'[63]; their version uses only a warning light in the mirror. This is quite similar to the 'Blind Spot Monitoring System' of Chrysler[64]. Finally, Ford has a more extensive system called BLIS (Blind Spot Information System)[65], this system also warns for traffic that is going to cross the drivers' path. In Ford's system warnings are issued in three ways: lights in the mirror, a warning sound and a signal in the messaging center.

A different type of additional sensor is offered by Peugot. It offers a lane departure warning system[66]. The system is stated to incorporate 6 infrared sensors that detect the lines on the side of the (lane of the) road. When the car unintentionally crosses the line one of the two vibrators incorporated in the driving seat warns the driver. The left or right vibrator indicates the direction of the stray movement. No further clarification is given how the system decides whether the movement was intentional or not.

These systems can be schematically depicted as shown in Figure 2. The additional sensor provides additional input, which helps the driver in his task. Although it does not take over any function it might supplant part of the drivers own actions. Instead of looking sideways properly the driver could rely more or less completely on the additional sensor to warn him in case of oncoming traffic. All implementations use a warning light in the outside rear-view mirror. This is the mirror a conventional driver should use in checking whether the lane he wants to go to is indeed free of traffic.

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[60] http://www.garmin.com/garmin/cms/site/us/ontheroad/, visited 05-06-2011
[61] http://www.tomtom.com/en_gb/products/car-navigation/, visited 05-06-2011
[62] http://www.bmw.de/de/de/insights/technology/innovations/lane_change_warning.html, visited 21-05-2011
[63] http://www.chevrolet.com/experience/vehicle-safety-prevention/?evar3=chevy_safety_safetybefore, under 'Side Blind Zone Alert', visited 21-05-2011
[64] http://www.chrysler.com/en/safety/, under 'Blind Spot Monitoring System', visited 21-05-2011
[65] http://www.ford.com/technology/, under Drive Assured, BLIS with Cross-Traffic Alert, visited 21-05-2011
[66] http://www.peugeot.com/en/innovation/safety/prevent.aspx, under LDWS, Lane Departure Warning System, visited 21-05-2011

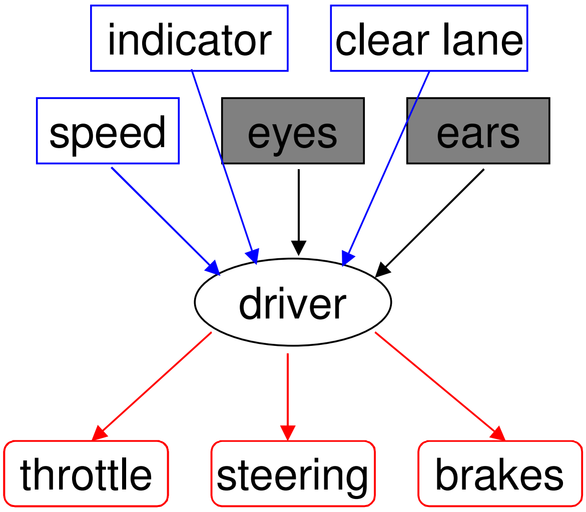

Figure 2: Additional Sensor. By introducing an additional sensor, here depicted in the 'clear lane' variant, the driver is supported in his task of driving the car.

A crucial property of the new sensors, which is not clear from this figure, is that the sensors have significant hidden complexity. Whereas the speed indicator in a conventional car is a simple representation of the rotation per minute of the wheels of the car, the clear lane indicator is a much more complicated device. It relies on the processing of data of multiple sensors of different types like radar, infrared or acoustic. It possibly includes a comparison with data stored in the system's memory. This is indicated in Figure 3. Obviously, hidden complexity can be layered: one of the input devices can have significant internal complexity as well.

QuickTime™ and a
decompressor
are needed to see this picture.

Figure 3: Hidden complexity. The 'clear lane' signal is the result of a processor activity based on several inputs: radar, InfraRed or acoustic sensors. Obviously, hidden complexity can be layered: one of the input devices can have significant internal complexity as well.

Error analysis

All warning systems described above have in common that they provide a positive warning: a warning is issued when the sensor determines there is an apparent danger. Absence of a warning is to be interpreted as no danger. However, a total failure of the system will have the same external appearance. This implies that at least some self-diagnosis should be present to warn the user that the system is not active to avoid the user interpreting the failure of the system as an absence of oncoming cars. This brings us to an important principle in safety design: system failures should as much as possible not arise due to a single point failure. For example, in case one of the input sensors breaks down the system should report it is not working properly. An example taken from the conventional car is the two-fold brake system. If one of the two systems fails, the car still has a reasonable breaking function. In this type of approach the system fails only when both the input sensor is broken and the reporting mechanism fails. Of course, to be effective it still needs to be noticed by the user (compare the case law on effective warnings). Whether a user that is totally accustomed to using his Spurwechselwarnung will adapt his behaviour based on e.g. a warning light on the dashboard stands to question. A similar reasoning applies to a failure in the indication devices of the sensor. A broken indicator light in one of the mirrors should not be interpreted as an indication of safety. In short: complicated sensors need to have a form of self-diagnostics with clear indications of failure to the user.

The real complexity of the system resides in the processor part. The processor executes an algorithm that determines, based on its input, memory and design parameters, whether an oncoming car is coming in the parallel lane or not. Three types of errors can arise. Most simply, the processor can be broken, for this the self-diagnosis reasoning of above applies. Obviously, this then has to be implemented in the central control of the car. Secondly the algorithm can be erroneously implemented, i.e. it does not behave according to the design. Finally the design could cointain errors: it does not cope properly with a certain set of input conditions. Both errors fall in the realm of software engineering. The fundamental problem one encounters here is that software of any reasonable complexity has for all practical purposes an infinite number of states. A theoretically complete testing of the code has to verify all possible states of the program. In reality, this is only possible for trivial programs. The real time aspects as present in the examples described above provide even more complexity. Slight differences in timing when an input-sensor reports to the processor can possibly have different outcomes of the algorithm. The software industry has developed several practices and tools to cope with the problem. The design can be tested in a simulation environment where a large range of input conditions can be presented to the central processor and verified if the response is according to the specification. Appropriate coding practices and code checking tools can counter coding errors[67]. Finally the testing of the final product is critical. Obviously all these are responsibilities of the manufacturer. Design or coding errors will lead to unpredictable signalling by the sensor. The user will (hopefully) notice that a car is indeed coming in the parallel lane while the sensor did not issue a warning. A single incident will probably not trigger the user that his system is failing. However if this

[67] *Safer C, Developing Software for High-integrity and Safety-critical Systems,* Les Hatton, McGraw-Hill, London reprinted 1997.

happens more often he will probably not trust the sensor anymore and report the defect to the dealer.

Still, even without errors the design and its parameters can give rise to a product that does not fully align with the user's interpretation. On the BMW implementation a user comments that the warning is a bit 'optimistic' and he drives more conservatively[68], thereby avoiding 'erhöhten Bremsbelagverschleiss beim Hintermann'.

The lane departure system as offered by Peugot can have an important error mode that cannot be linked to a programming or sensor failure. Given unreliable input, e.g. to unclear or missing lane markers it will be possible that the system 'loses track' of the lane and cannot issue a warning anymore. Again, to avoid that the driver relies on the system this needs to be brought to the attention of the driver. A simple and probably effective implementation would be to activate both vibration sensors.

In summary: sensor or processor failings should be brought to the attention of the user by a notification. The user will notice design or implementation errors because his observations do not align with the warnings of the sensor.

4.3 Virtual controls

Not so much a transfer of a task of driving but more a change in behaviour of the car is what I call 'virtual controls'. This describes a system where an actuator still has the external appearance of its conventional counterpart but hides other, more complex, functionality. In the airplane industry this is known as fly-by-wire. A prime example is the engine management system of the Toyota Prius. The brake pedal and the throttle are only input devices for this management system. Based on the status of the car, which includes speed, battery status and so on, applying the brake pedal will lead to either using the mechanical brakes or using the regenerative brakes to restore the charge of the battery. The same goes for the throttle. This is schematically depicted in Figure 4.

[68] http://www.motor-talk.de/forum/fahrerassistenzsysteme-hat-jemand-schon-praktische-erfahrungen-t2643966.html#post24010350, comment by wodkamelon, visited 22-05-2011

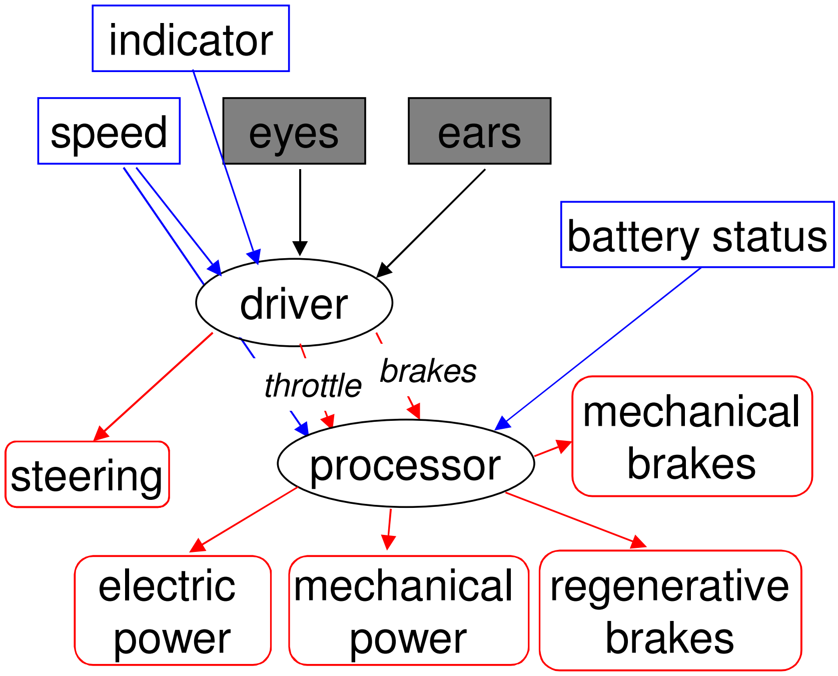

Figure 4: Virtual controls. The conventional control devices of the car are now input devices for a processor which decides, based on all input, how the physical actuators are used.

From this figure it is clear that the throttle and brake pedal are not the only input devices of the processor. Based on all input the processor decides how to use the physical devices to reach the engine or brake action intended by the driver.

Error analysis

Obviously, if the brake or throttle input device malfunction, so will the system. They are now electronic input devices; the failure modes will be different. A faulty contact is something else than a mechanical brake. If the additional input devices, battery status and speed input, are not correct the system will not reach an optimal distribution over the actuators. Assuming that all output devices are properly functioning in this case, the battery might not be charged while it was possible or needed, the mechanical engine might have been operating in a wasteful regime and so on. However, the functions of throttle and brakes will still be performed as intended. In case the output devices are malfunctioning, the effects are similar as in the conventional case. The design allows for some reporting of the processor to the user.

The most severe errors arise when the processor does not cope properly with the input due to a programming or design error. Strange things can happen; this was exactly the suspicion derived from the incidents with the Toyota Prius reported in the USA. The most problematic part of this failure is that the user has few options to correct it: the actuators to do so are the problem. Stopping a runaway car with the handbrake is not always possible.

4.4 Cruise control and its extensions

An extension that takes over part of the controls of the car has already existed for a long time: the cruise control. Its simplest incarnation is presented in Figure 5. The user sets his desired speed, either by dialing in an increase or decrease of the speed or by setting the current speed as the desired value. The processor will combine the readings of the speed

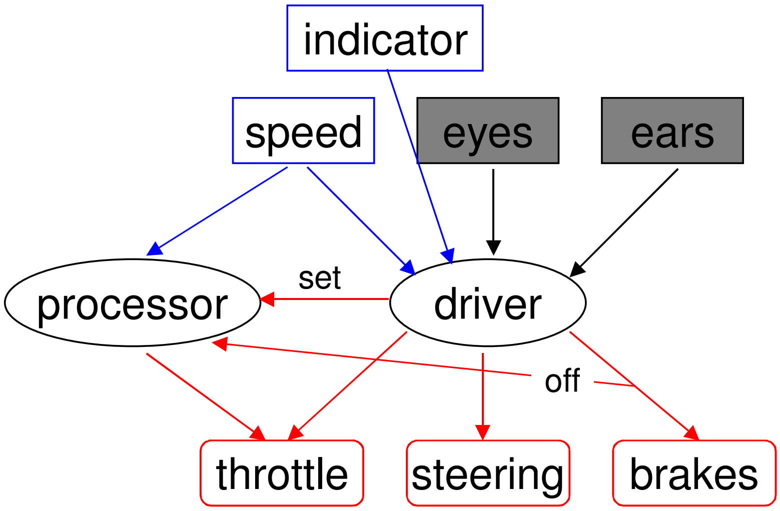

Figure 5: The conventional implementation of the cruise control. The driver sets his desired speed; the processor adjusts only the throttle to keep the speed constant. Any use of the brakes by the driver will switch off the cruise control.

sensor with the desired speed and adjust the throttle accordingly. The processor cannot use the brakes as an actuator; it can only control the engine of the car. Using the brakes acts as an interrupt: the cruise control will deactivate immediately. Of course the user can also switch off the control.

Before turning to the effects of errors let's first discuss an essential property of this system; the feedback control. Analysis of these types of systems is a field of study on its own, a thorough introduction can be found in the book of Franklin *et. al*[69]. Fig 1.3 of this reference shows a representation of the feedback loop of the cruise control, which is copied in Figure 6. In this picture the feedback character of the system is made explicit. The controller uses the throttle to control the engine, which affects the speed to reach the desired setpoint. However, the road grade (taken for simplicity, other disturbances are possible) also affects the speed. This will lead to a discrepancy between desired and actual speed on which the controller will react. The ratio with which the system reacts to differences of the actual speed and desired speed is called the gain. A low gain leads to a slower reacting, soft controller with larger tracking errors; a high gain gives a faster reacting hard controller with smaller tracking errors. The gain cannot be varied without cost: it is an essential parameter for the stability of the feedback loop. A badly designed

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[69] *Feedback Control of Dynamic Systems*, Gene F. Franklin, J. David Powell and Abbass Emami-Naeini, 6th edition, Pearson, Upper Saddle River, 2010.

feedback loop can overreact to input noise and become unstable. Squeeling of a sound-system is a well-known example.

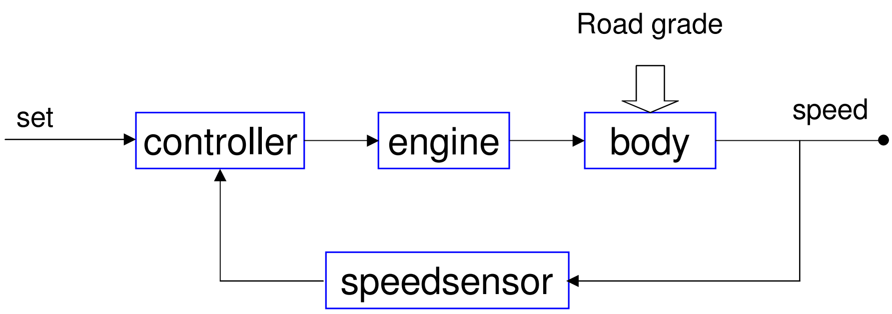

Figure 6: Component diagram of the cruise control. The essential part is the impact the road grade has on the body of the care and thus on the speed. These variations in the speed need to be acted upon by the controller.

Franklin mentions four performance criteria of a feedback controller[70]. First of all, for our discussion the most important, is that the system must be stable at all times. Secondly, the system must track the input signal: it should deliver what it is asked to do. Thirdly, the system should not respond too much to disturbance inputs. For example, a minor variation in external conditions should not lead to slowly damped oscillatory behaviour. Finally the controller needs to perform properly even when the (physical) model present in the controller is not completely accurate. The controller needs to be robust.

For a simple feedback system the stability requirements can be strictly mathematically formulated[71]. Given the design and its parameters stability can be proven. Robustness can be achieved by allowing sufficient margin in the choice of parameters to avoid instable regions. For more complex systems one has to rely on design methods and simulations.

In practical use some other boundary conditions enter: what should the controller do when the tracking error is too large for a long period of time. This could happen when the car is on a steep climb in the wrong gear or the motor is malfunctioning.

Extensions to the standard cruise control are, among others, offered by Lexus in the form of 'Adaptive Cruise Control'[72]. Instead of controlling only the speed, this system adapts the speed when it notices a car in front and keeps a minimal distance provided by the driver. When the car is gone, e.g. because of a lane change, the system resumes it original speed. The various states of the ACC are presented to the user with a display. It is packaged with the 'Pre-Crash Safety System'[73]. This system pre-charges the brakes for maximum effectiveness when it determines a crash is highly likely. It actively starts

[70] *Feedback Control of Dynamic Systems, p19 and p188ff*
[71] *Feedback Control of Dynamic Systems, p148ff*
[72] http://www.lexus.nl/range/is/key-features/safety/safety-adaptive-cruise-control.aspx?WT.ac=spotlight_Adaptive_Cruise_Control, visited 27-05-2011
[73] http://www.lexus.nl/range/is/key-features/safety/safety-pre-crash-safety.aspx, visited 27-05-2011

braking the car when it determines that a crash is unavoidable. Mercedes offers similar functionality under the name 'Distronic'[74]. The system is stated to work only at speeds between 30 and 180 km per hour, so it cannot be used in city-traffic. Mercedes also offers a crash intervention system called 'Pre-Safe brake'[75]. The latter has an escalation ladder to warn the driver that a crash might be imminent: it first warns the driver with acoustic and light signals, if no reaction follows it can start braking before finally performing an emergency brake. Ford offers 'Adaptive Cruise Control' and 'Plus Collision Warning'[76]. The latter only warns by showing braking lights in the heads-up display in the front window, it does not start breaking as is done by the Mercedes variant. Finally, Porsche has the 'Abstandsregeltempostat'[77].

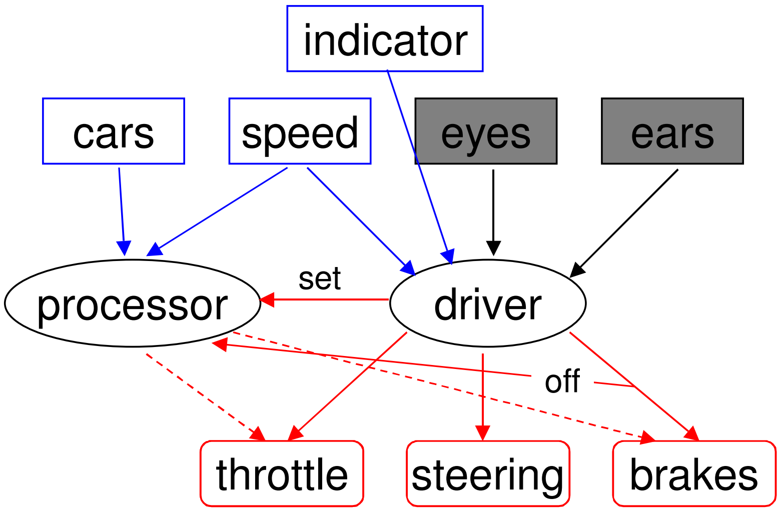

Figure 7: Adaptive Cruise Control and Brake assist. Using a feedback loop the processor controls speed and avoids cars. As an added function, in case of a threatening emergency it might autonomously decide to brake. The system controls a significant part of the car. The driver still has override capability indicated by the dashed lines.

In Figure 7 the schematic diagram of the adaptive cruise control system is shown. On top of the classis cruise control, the processor now also uses input from a sensor that can detect cars in its environment. For better control the processor now has access to the brakes, only using the throttle of the engine will not be enough to avoid a collision with a

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[74] http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passengercars/home/world/webspecials/techcenter.html#/distronic/details, visited 27-05-2011

[75] http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passengercars/home/world/webspecials/techcenter.html#/pre_safe_brake/details, visited 27-05-2011

[76] http://www.ford.com/technology/, under adaptive cruise control, visited 27-05-2011

[77] http://www.porsche.com/microsite/technology/default.aspx?pool=germany&ShowSingleTechterm=PTAbReTemp&Category=CATSic&Model=&SearchedString=&SelectedVariant=, visited 28-05-2011

car ahead at a slower speed. The dashed lines from processor to actuator indicate that the driver has the capability to override the settings of the controller.

A complementary function to the adaptive cruise control is offered by e.g. Volkswagen. They offer a ‘lane assist’ functionality that actively keeps the car in the lane[78], an active variant of what Peugot offers in a warning-only variant. As far as the scheme is concerned, it is slightly altered by now using the steering as an actuator instead of the brakes. Toyota has a ‘Lane Keeping Assist’ with the same functionality[79], it states that the system will not activate if road conditions do not allow it.

Error analysis

Failures in the sensors lead to erroneous input of the processor. In the previous section this lead to possibly false negatives (the system fails to detect an actual danger), now a failing speed sensor can lead to problems in the control loop. If the speed sensor gives a faulty reading the processor will adjust the throttle or brakes, which have nothing to do with the physical reality. Say the speed is underreported by a fraction of 10%, then the actual speed will be 10% higher. If the driver sets the speed to retain a value he reached himself this will be hardly problematic. In case the speed sensor fails intermittently, the controller will react intermittently as well, leading to large speed fluctuations. If it fails alltogether the controller will (in a naïve implementation) try to adopt by pushing the throttle. This will be without effect on the readings and the actual speed will keep increasing until the engine reaches its limit. This type of behaviour will be clearly noticeable to the driver; still the controller needs to react properly to this. If changing the controls has no effect on the readings it needs to stop after a certain timeframe to avoid damage. Failures in the car-detection sensor have similar consequences as in the previous section. If the driver does not interfere the car will drive into a leading car. Again, the controller needs to be notified or be aware of a failing sensor.

A similar analysis holds for failures in the actuators. The controller will behave erratically. In a proper design it needs to be notified and have appropriate logic to determine failures in the actuators. Of course, in case of a mechanical failure in the brakes or engine the driver will notice it himself.

I already discussed the design of controllers in some length above. The conventional cruise control needs to have a proven stability as given by the mathematical requirements. This can be achieved by using a well tested design adapted for the purpose, e.g. the PID controller[80]. It should also have a shut-off mechanism based on physical boundaries. For

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78 http://www.volkswagen.de/de/Volkswagen/InnovationTechnik/innovation_technikspecial.html, under Lane Assist, visited 28-05-2011

79 http://www.toyota-global.com/innovation/safety_technology_quality/safety_technology/technology_file/active/lka.html, visited 28-05-2011

80 *Feedback Control of Dynamic Systems, p204ff*

example, if the required throttle setting is maximal for an extended period of time the controller should disengage. One way to achieve a more stable design is to limit the settings the controller is allowed to give the actuators. Porsche states that the system can only apply brake forces up to 3.5/ms^2[81]. This obviously limits the range of input where the controller can have zero tracking error. In situations where stronger braking action is required the driver needs to supply this. For the more complicated adaptive cruise control, correctness of the design can to a large extent be shown by simulations specially suitable for control loops like Simulink[82]. The implementation should be tested in the same fashion as done for the sensor of the previous section. Given the increased complexity this will be more extensive.

The above applies in a similar fashion to the lane control devices. From what is shown on the respective web sites, the feedback loop is rather soft. The system will try to steer back, but has very limited range to what it is allowed to send to the actuator. This will also limit impact of design errors. Again, if the input or actuators are failing the system needs to be able to notice this and notify the driver.

For both devices the errors of the system fall between two extremes. On one side we have the 'functional' errors: the system does not perform as intended, but still operates within a reasonable margin. It fails to brake for a car, the control of the engine is unstable. The other side of the spectrum contains the 'actuator abuse' errors: wild excursions in the steering, maximum breaking, full throttle or the driver overrule does not function. Although parts of the tasks of driving are automated in this implementation, the driver still has direct active control over the car. One can expect the driver is able to correct for the functional errors, correcting the actuator abuse errors will be more problematic.

4.5 Automated parking

A final example of autonomous behaviour to be discussed is one where the car controls all actions. The driver follows the instructions of the car to achieve the task, in this example the parking of the car. By limiting the context of the activity, and thereby the range of possible inputs to the controlling device the control problem can be solved with sufficient safety. Another check is that the driver still has to follow the instructions and should judge whether it is proper to do so. Both Ford[83] and Volkswagen[84] offer an automated parking functionality under the '(active) Park Assist' moniker. Of course, one

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81 http://www.porsche.com/microsite/technology/default.aspx?pool=germany&ShowSingleTechterm=PTAbReTemp&Category=CATSic&Model=&SearchedString=&SelectedVariant=, visited 28-05-2011

82 http://www.mathworks.com/products/simulink/, visited 05-06-2011

83 http://www.ford.com/technology/, under Drive Assured | Active Park Assist, visited 30-05-2011

84 http://www.volkswagen.de/de/Volkswagen/InnovationTechnik/innovation_technikspecial.html, under Park Assist, visited 30-05-2011

cannot send the car away and let it find a parking spot on its own, but the final act of parallel parking is performed almost autonomously. The Volkswagen implementation uses ultrasound sensors; the driver has to drive along possible parking spaces until the system finds a spot large enough to park. The driver activates the parking assist, lets go of the steering wheel, follows the instructions of the processor with regard to gear and throttle and the car will be accurately parked. If needed the car will use multiple zig-zags. It can also park in a 90-degree angle. The system can also do the reverse trick: it can move out safely from a tight spot. A schematic representation is given in Figure 8.

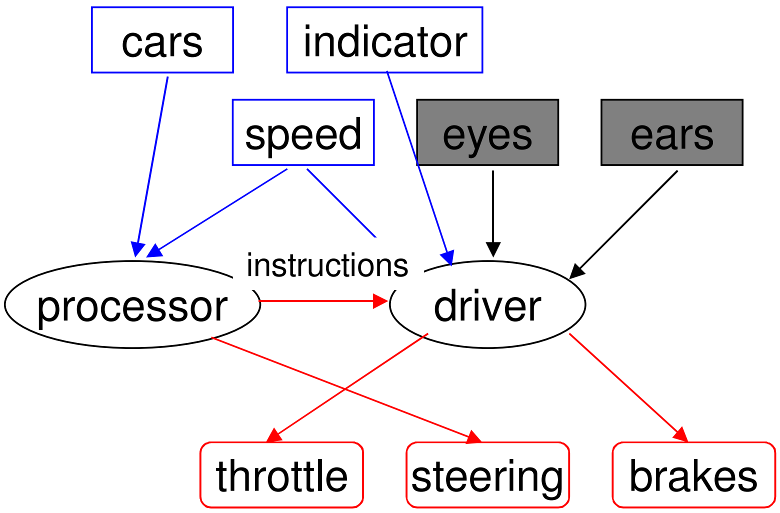

Figure 8: Automated parking. The processor controls all activities, the driver follows the instructions but still acts as a safety catch to avoid events outside the scope of the controller.

From this scheme it is clear that based on the input, the processor delivers instructions to the driver. He is still crucial in the safety of the system. For example, he still needs to check whether cars are oncoming when using the move-out function.

Error analysis

The failure modes are pretty much the same as we have seen above. If the input sensor fails the processor will happily instruct the driver to continue into an already parked car. This is improbable because the system first has to detect an open parking space before continuing to the actual parking maneuver. With failing sensors this will hardly be possible. The driver still controls the throttle and brakes, if the steering actuator does not work properly the parking maneuver will fail. In case the algorithm to determine the trajectory and steering output is not correct nothing more than a failed parking attempt will happen (assuming the sensors still work and give a warning) and the driver has to park using his own skills.

4.6 Summary

In the above I discussed several examples of autonomous behaviour of cars and their failure modes. In all examples the dominant feature is to avoid collisions and other accidents. Still, only in the virtual controls example the driver does not have the final responsibility for the safety of the car. In the schematic approach I used, errors can occur in three areas: the sensors, the controller and the actuators.

Failures in the sensors can lead to false negatives: the sensor does not give a warning because it is broken, not because it determined that there was no danger. This needs then to be corrected by the driver; even better he should be notified by the system that it is not working properly. A particular difficulty to cope with high-tech is that failures can be intermittent. This makes failures hard to pin down.

Apart from just breaking down, the design of the processor can contain flaws. Most elementary, a simple feedback loop should be designed to be mathematically stable. Design or production errors in more complicated systems will reveal themselves by erratic behaviour when certain input is provided. This behaviour needs to be corrected by the driver. In the case of virtual controls this can be problematic: he needs to correct the errors using the failing controls. Errors in the processor are prototypically intermittent. Since they heavily rely on details of the input, small variations might not trigger the problematic behaviour.

In most cases failing of the actuators is similar to what the driver experiences himself. A feedback loop might conclude, based on the lack of response, that the actuator is not working and report it to the driver. However, if e.g. the brakes fail mechanically, it will hardly help the driver that the advanced cruise control notifies him. He will find out himself as well when he tries to brake to avoid a collision. Still, the feedback loop might notice earlier that the response of the actuators is drifting and give a notification.

One aspect I did not discuss is the psychology of these safety systems. The safety models all have the driver still in charge. Given the ease of use, he might start to rely too much on the system and not be able to correct a failure when an emergency arises. Some possible answers might be found in case-law.

5. Mapping the current user-knowledge requirements on failure modes of autonomous cars

In the second chapter I discussed which parties can be liable in case of a traffic accident. Four possible parties were identified, the driver and/or owner of the car, the other parties involved in the accident, the manufacturer of the car and the owner of the road. In the final distribution of damages 'own guilt' as given by art 6:101 BW plays a central role. In this section I will confront the autonomous extensions of cars as discussed in the previous chapter with the distribution of liability.

In this investigation I focus on how knowledge of failures of a car affects liability. Note that the damage due to the accident is twofold: the damage of the third party and the damage of the owner of the car. The starting point is that the owner is liable for damage caused by failures of his car. This can change for various reasons. Obviously, behaviour of the third party, possibly even dangerous, that contributed to the occurance of the accident can affect the distribution. The state of the road might have contributed, leading to liability of the maintainer. The most important exception from the starting point for our investigation is liability of the manufacturer. He can be liable for all damage when the defect was due to a design or manufacturing error that already existed at the moment the car was brought on the market. Own guilt of the user can limit this liability.

The first extension I reviewed was the additional sensor, where the driver is warned of either oncoming traffic in the parallel lane or when he inadvertendly leaves his lane on the road. These sensors only support the driver in his decision making, he is still responsible for the operation of the car. Several failure modes were identified: a broken input or output sensor, a failing processor, a design/manufacturing error in the processor and tracking-loss.

The input or output sensors will have failed after the sale, this fact keeps the failure in the responsibility domain of the driver. Only when the failure is due to manufacturing or design errors the producer enters the picture again. One can argue that a system that is intended to enhance safety should have a maximally safe design. This would imply that the system should notify the user about malfunctionings as far as possible. Recall that European regulations already require notification of errors in a hydraulic brake system. The fact that for both systems lack of danger (i.e. no warning) has the same external appearance as failure adds weight to this argument. This line of reasoning would make the notification part of the product, and the warnings supplied to the user should be judged according to the requirements as developed in the case law for warnings. A failing of the processor should then be treated in the same way, the central processor of the car should alert the user that the sub-system is inactive.

A similar reasoning applies even more to the tracking-loss of the lane-departure device. When the system loses track of the lane due to the road conditions and thus stops detection of possible lane departures the user should be notified.

In the previous section I divided processor errors in functional errors and actuator abuse errors. The producer is clearly liable for the latter errors and its consequences. However, in the additional sensor example the system has no access to the actuators and consequently these errors do not exist.

The situation is less clear for the functional errors. By definition these errors cannot be detected by the system itself. The producer is still liable for the consequences of these errors. Still, liability for the failing of a supporting device does not imply liability for an accident in case the sensor malfunctioned: the driver is still the prime responsible person while driving the car. The own guilt clause of art 6:185 BW sub 2 will be of importance here. On one hand it is hard to argue that an accident is also caused by the failings of a supporting device for an observation the driver is primarily expected to make himself. On the other hand, what is the value of a safety device you cannot trust.

For the sake of the argument let's assume liability can at least partly be assigned to the producer of the device. This implies that the driver is allowed to base his decisions on the input of the device. At which point should the driver realise that he cannot use the device anymore. At this point liability would shift from the producer to the driver. Recall that in the discussion in parliament knowlingly using bad brakes was used as an example for such a shift in liability by applying art 6:185 BW sub 2. A lower limit is provided by the facts of life. In this example, not using a device being obviously broken would be a fact of life. A clear notification to the user of malfunction by the car would serve to signal this. An upper limit is found in the professional user. If the malfunctioning can only be clear to the professional user, lack of knowledge will not be attributed to the ordinary consumer.

However, as we have seen in the discussion of the case law, lack of knowledge of a danger does not preclude liability. There is a duty to investigate. Although the case law is not fully clear, it is safe to assume that for technical devices like a car this duty is present. This will be even more pressing when the user of the device has indications of malfunctioning. As a consequence of the duty to investigate the consumer could, upon suspicions of malfunctioning, consult a knowledgeable professional. In the case of 'bad brakes'[85] discussed above, liability was partly shifted to the professional who did not actively warn the driver not to use his car anymore before his brakes were repaired. In this case the driver knew his brakes were bad, to be compared with a suspicion that the system is not properly functioning. The professional might have knowledge of other malfunctionings. Of course, in case these malfunctionings happened on a large scale the producer will have acted with public warnings or even a product recall. Still, the 'bad brakes' case shows that if the professional makes an error, not all liability is transferred when the user has knowledge of the possible danger. Only when the professional declares that the system is fully sound the liability of the user will be fully absolved. The key question is of course when the indications of malfunctioning are so pressing that the customer needs to investigate. Given the tendency in the case law of forgiveness towards

[85] Rechtbank Arnhem, 11-02-2004, LJN AO5077

ordinary consumers (take e.g. the cases in the 'average consumers making errors') only a few instances of malfunctioning will probably not reduce liability of the producer.

In the virtual controls example much of the above applies. Failures of sensors will have happened after the sale of the car, putting the liability on the owner. Improper functioning of the primary sensors (throttle and brakes) will be clear to the user and he probably will have the car repaired. However, since the system is an integral part of the operation of the car the case for diagnostics as part of the design is much stronger. If the system detects a failure in one of the sensors the car is unsafe to drive and should prevent the user trying to do so.

Since the system is an integral part of the control of the car, both functional and actuator abuse failures of the processor now certainly create liability for the producer. Possible liability of the user will depend on the severity of the error and the reaction of the user on the errors. An actuator abuse error (if it did not lead to an accident already) will be completely obvious. Using the fact of life reasoning above, the user will be (partly) liable when he keeps using the car without further action. A single functional failure will not be enough, repeated failures within a short period of time probably will trigger a duty to investigate. Reiterating the statement on the additional sensor case above: if, after a few functional failures, the owner lets his car examine by a professional, case law suggests that liability of the producer will not be limited by own guilt of the driver.

The adaptive cruise control in its various incarnations combined with the lane assist feature allows for almost entirely automated driving on the high way. The driver is still in control, but he only needs to intervene when the braking force allowed by the settings of the system are not enough to avoid crashing into a car up front. As discussed in the previous chapter failure of input sensors and actuators can have various external consequences which will be noted by the user. These happened after the sale of the car and the driver is liable for consequences of the failure. As in the virtual controls example the case for diagnostics as part of a proper design for a safety feature is quite strong.

Because the driver has a supervisory role failures in the processor need not lead directly to liability for the producer. Actuator abuse errors will be hard to correct by the driver, leading to liability of the producer. For functional errors the reasoning as used in the additional sensor case is applicable. As in this case one might argue that the sale of a supporting safety device introduces possible liability if the system is badly designed. The large amount of control of the system over the car gives additional weight to this argument. Even more, the system is supposed to know its limits with respect to actuator control. When properly functioning it will warn the user to take over.

The presence of a feedback loop could aggravate malfunctioning of subsystems. Sensor error could lead to the feedback loop becoming unstable. This is a combination of design errors and failures after the sale. The liabity will be distributed over the driver and manfucturer. Again, one can argue that notification of the driver of sensor failures is part of a proper design, especially with the increased autonomy of this system. Also, the presence of the feedback loop with its available control error data allows for early warnings. The question if failures of the processor noticed by the driver reduce the liability for the manufacturer, if present, is again answered in the same terms as for the virtual controls.

In the park assist feature the car is in control of the motions, the driver operates the throttle and has to follow the instructions. In this way he still controls the motion of the car and acts as a safety catch. The discussion above on sensor and actuator errors in the adaptive cruise control and additional sensor scheme apply here as well. The user will get instructions from the car which do not fit his own observations: he is close to a car behind his back but is still instructed to continue. Processor errors can lead to either wrong steering output or false instructions to the user. The first will lead to an awkward final position, in the second case the user has to overrule the instructions to avoid collisions. The argument for assuming liability of the manufacturer is less strong here. The system only provides steering commands and instructions which the user can check before execution. One can interpret it as just a steering aide, if something is wrong with the steering output it will hardly lead to damage as long as the other sensors work properly. Assuming this liability, errors will be clear to the user and the liability of the manufacturer will be reduced.

The final remaining question to be answered is how to deal with the psychological problem. A user most probably will adapt his behaviour when using a safety device. Is he still able to function as a final safety check of the system and does that affect his liability? The philosophy of the Lekkende Kruik case[86] can be used. A manufacturer should anticipate on probably use of his product. Relying too much on safety by precautionary measurements of the user leads to liability of the producer. However, I have not been able to find an actual case using this reasoning.

5.1 Summary

The above can be summarized as follows. The driver of the car is liable for damage due to failing sensors or actuators, unless these were due to manufacturing errors. It can be argued that a proper design of a safety device includes diagnostics for these events. This is especially true when the failure mode is the same as an indication of lack of danger.

The producer is liable for damage caused by the actuator abuse variant of processor errors. The malfunction of the system will be so notable to an ordinary consumer that a follow-up action, like consulting an expert on the status of the device is required.

For functional errors the distinction has to be made for devices where the driver still has a supervisory role and for the virtual control system. For the first type the driver can still correct errors of the system. One can argue that the user should be able to trust the funtioning of a safety device. This distributes possible liability over both the user and the producer. Functional errors will have properties that make them hard to reproduce. After a few instances the user should notice something is wrong and consult an expert.

[86] HR 2-2-1973, NJ 1973, 315, *Lekkende Kruik I*

6. Conclusion and Outlook

In this thesis I investigated liability for autonomous behaviour of cars with an emphasis on how knowledge of the user of failures affects liability. The question to be answered was whether the developments in technology change the requirements to the knowledge of the user. I first reviewed the legal basis of liability for car accidents and how knowledge of the user of defects in the car affects the distribution of liability. The driver is liable for failures in his car. On the other hand the producer is liable for design and production errors. A key provision in the law is that product liability can be reduced when the consumer knows about the failure.

The norm given in the law is put in general terms. To apply it in a particular case several anchor points are used in case law. For my investigation two are of particular interest. First the level of technical knowledge of an ordinary consumer vs. a professional and secondly facts-of-life everybody is supposed to know. An additional point is that consumers need not be perfect. Lapses of judgement on the side of customers do not diminish product liability.

I investigated the failure modes of a series of currently available options on cars that facilitate autonomous behaviour. The failure modes range from obvious errors, where the autonomous system lets the car run amok, to errors where the failure has no direct dramatic consequences. In translating the failures to liablity the average consumer is still an essential point of reference. Thus the answer to the question posed in this thesis is that the requirements to the knowledge of the user change with the knowledge of the average consumer.

This solution allows for flexibility. In an increasingly technical society the average consumer will also be more proficient in technological matters. The application of the norm evolves along with the increasing proficiency. Still, no prescribed method exists for the creation of such a reference figure. It is a question of law-finding and law-creation since no direct definition is given in the law. These type of problems are studied in the field of legal theory studies from a general perspective. For an overview of this problem in the field of legal theory I refer to the book of Vranken[87]. Under nr. 88 *ff* he lists a typology of problematic cases that do not follow straightforward from existing case law. The second one is close to what I discuss: changes in the social norm to which the law refers. Vranken already notices that tort-law, driven as it is by case-law, will often yield cases that fall into this typology. A practical way to create this might be found in the comparison method of Wiarda[88]. In this method an answer is found by varying the case to find an upper and lower bound to the answer. By stating what is certainly not and what is

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[87] *Mr. C. Assers Handleiding tot de beoefening van het Nederlands Burgerlijk Recht, Algemeen deel 2,* mr. J.B.M. Vranken, 1e druk, Kluwer, Zwolle 1995

[88] *Drie typen van Rechtsvinding,* Mr. G.J. Wiarda, *ed.* Mr T. Koopmans, 4e druk, Tjeenk-Willink, Deventer 1999

certainly part of the knowledge and capability of the average consumer one could try to get a firmer grasp on the definition.

Although the user still has a supervisory role it is not clear to what extent he is allowed to rely on the supporting devices. Most of these are marketed as safety enhancing features, on can argue that one should be able to rely on their functioning. Legal arguments aside, the psychology of the driver will probably have him do so anyway. This can partly be resolved with strong requirements on self-diagnostics of the system and reporting of failures to the driver. European regulations already require this for brakes, extending this to the supporting devices seems natural.

Given the results of e.g. the DARPA challenge one can safely state that there are no technological hurdles for fully autonomous driving. Within a more limited context, like e.g. highway driving, it seems already possible with existing technology. Extending the adaptive cruise control with broader settings and combining it with a stronger lane assist should come pretty close. Mercedes-Benz claims to be using automated driving to allow more precise testing of its safety support systems[89]. At least two hurdles can be distinguished. First of all, the desire to invest in this direction needs to be present in the industry. Schmidhuber states that BMW and Mercedes-Benz show very limited drive to do so since it does not align with the driver experience these companies want to offer[90]. Things might be different in the USA. There the emphasis is much more on convenience of driving than on the experience. The difference in adaption rate of automatic gear boxes is an example of this difference in attitude. The second hurdle is liability. Fully autonomous driving would put the liability completely on the producer. Apart from the virtual controls, all examples I reviewed still have the driver in a supervisory control with the task to intervene when the supporting device does not live up to its intended funtionality or exceeds its implementation range.

The story of the Toyota Prius slowly faded away. After a long and thorough investigation it was concluded that the electronics and software were not to blame for the reported incidents[91]. In the end only mundane mechanical causes were found: sticky accelator pedals and interference of the floormat. The length of this investigation shows again how difficult it is to prove that a software controller functions properly.

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[89] http://www.autoblog.com/2010/05/16/mercedes-benz-inches-closer-to-fully-automated-driving, visited 22-06-2011

[90] http://www.idsia.ch/~juergen/robotcars.html, visited 22-06-2011

[91] http://www.nytimes.com/2011/02/09/business/09auto.html?ref=automobiles, visited 22-06-2011

Appendix: resources

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