Human Factors as Causes for Road Traffic Accidents in the Sultanate of Oman under Consideration of Road Construction Designs

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"Academic work needs to follow rules of good practice, but we should not confuse rigor with tediousness or objectivity with lack of personality. Academics are still '*human after all*' – to quote Daft Punk. And beyond the barren scientific facts that academics produce, they have a life, an upbringing, a cultural context they inhabit, with opinions and passions (Hassenzahl, 2010)."

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Executive summary

The Sultanate of Oman has one of the highest road traffic accident (RTA) related fatality rates worldwide (Al Lamki, 2010). Since Sultan Qaboos addressed this issue in a speech in October 2009, research institutions, ministries and NGOs alike have strengthened their efforts to cope with this public health burden. Yet, still little is known about the factors contributing to the high number of RTAs.

Evidence from research conducted in other countries suggests that the human factor and the interaction between the human factor and the road environment are among the most frequent contributors to the occurrence of RTAs. The ultimate goal of this thesis was therefore to provide recommendations on how to adjust the road design to the human factor. In order to meet this goal, two objectives were determined, namely *to identify the main human factors that contribute to the occurrence of RTAs in Oman* and *to investigate the human road interaction as a contributing factor to the occurrence of RTAs in Oman.*

A total of 296 in-depth interviews were conducted in three Omani hospitals with road users who were involved in RTAs. The data collection took place between April 2011 and May 2012. Road and environmental information were collected by visiting the RTA locations and using Google earth. In addition, road data for each RTA location was requested and provided from Muscat Municipality and the Directorate General of Road and Land Transport.

For the first objective, *identification of the main human factors that contribute to the occurrence of RTAs in Oman*, the study on human factors conducted by Gründl (2005) was replicated. The results revealed five human factors that significantly increase the risk of causing an RTA in Oman. These factors are according to the strength of their impact: (1) inappropriate speed, (2) fatigue, (3) unintended blindness, (4) annual mileage between 20.000 and 40.000 km and (5) having a conversation with the passenger.

The second objective, *investigation of the human road interaction as a contributing factor to the occurrence of RTAs in Oman*, was split into four specific objectives. These objectives addressed the extent to which roads in Oman can be considered self-explaining, the subjective perceived safety of roads, road design elements that affect driving speed and the prevalence of selected human factors according to road design elements.

For the first specific objective, the extent to which the Omani road design corresponds to the recommendation on self-explaining roads suggested by Matena (2006) was investigated. It was found

that none of three recommendations are met and concluded that this discrepancy may add to the occurrence of the human factor inappropriate speed.

For the second specific objective, a logistic regression analysis was calculated with the dependent variable subjectively perceived safety of a road and various design elements as independent variables. The results indicate that the number of carriageways is the only design element that predicts subjectively perceived safety of a road.

For the third specific objective, correlations and linear regression models were calculated with self-reported speed as a dependent variable and various road design elements as independent variables. It was found that speed is significantly higher in rural environments. The effects of lane and shoulder width on speed differ between rural and urban environments. Interestingly, driving speed did not correlate with the number of carriageways.

For the fourth specific objective, the prevalence of human factors according to various design elements was investigated using logistic regression models. Among others, the regression models revealed that the human factor fatigue occurs more frequently on roads with dual carriageway and that inappropriate speed occurs more frequently on curves without warning signs. Contrary to previous studies (Werneke & Vollrath, 2012), it was found that the human factor unintended blindness occurs more frequently at T-intersections characterized with a high traffic volume than at T-intersections with a low traffic volume.

Based on a discussion of the findings, the suggested recommendations focus on the following aspects:

- Applying basic design standards on road design.
- Considering dual carriageways and overtaking lanes.
- Capturing the road users' attention is insufficient for safe transitions.
- Reducing speed and restricting affordances at T-intersections.
- Improving visual guidance in curves.
- Marking roundabouts according to different categories.

This thesis is the first scientific work that has investigated the role of human factors and their interaction with the road environment in the causation of RTAs in a Gulf country. Although specific recommendations are suggested, this thesis is to be considered a source for future research rather than a design guideline

Part I: Introduction

1. The global burden of RTAs

Road traffic accidents (RTAs) are a global public health problem. Currently ranked ninth, RTAs are predicted to be the fifth leading cause of death in 2030. Every year, more than one million people die worldwide because of RTAs, more than 2500 deaths every day. 90 % of RTA related fatalities occur in low and middle income countries (WHO, 2004).

2. RTAs in Oman

Until recently, the Sultanate of Oman was listed as middle income country (WHO, 2009). Due to its oil and gas wealth, Oman has experienced rapid social and economic modernization within the last decades. This development included an increase in the motorization rate and a growing road network. In 1970, only 1016 vehicles were registered in Oman and only three km of the roads were paved. In 2009, the number of registered vehicles and the number of paved road km has grown to 755.000 and 53.000, respectively (Al-Maniri, Al-Reesi, Al-Zakwani, & Nasrullah, 2012). This growth was accompanied by an increase in the number of RTA related fatalities (Al-Reesi et al., 2013). With around 30 deaths per 100,000 persons, Oman has one of the highest RTA related fatality rates worldwide (Al Lamki, 2010). Although the number of fatalities decreased in 2010, it increased in 2012 by more than 30 % (*Figure 1.1*). Due to increasing employment and more people obtaining driving licenses, it is likely that the rate of RTA related fatalities will further increase.

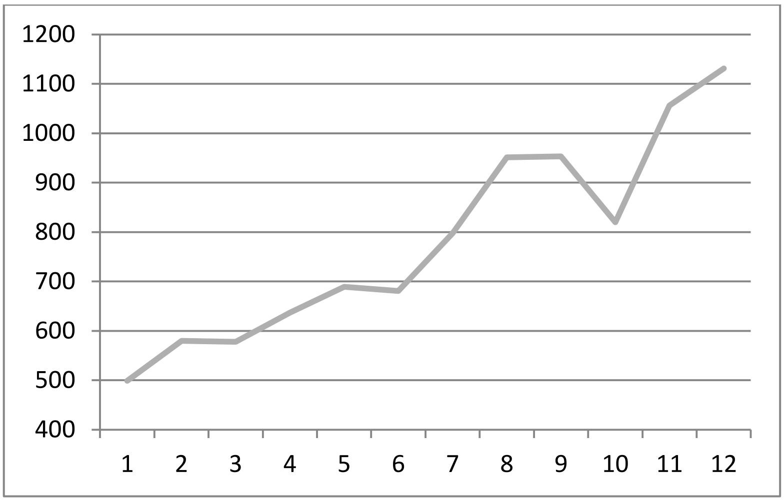

Figure 1.1. Number of road traffic deaths in Oman per year from 2001 – 2012. Note that Oman has only 2.7 Million inhabitants. Data from ROP (2012).

To date, only little is known about the factors underlying this high number of road traffic related deaths. According to the Royal Oman Police (ROP), the main contributing factors are risky driving behavior (e.g. speeding and overtaking), vehicle defects, road defects, weather condition and fatigue (Al-Maniri et al., 2012; ROP, 2012). A recent study conducted by Al-Reesi et al. (2013) has confirmed that risky driving in general and aggressive violation of traffic regulations in particular are major risk factors.

A road inventory survey carried out in 2005 (DGRLT) to assess the existing road network and to provide required improvement components for future planning revealed that only 49.3 % of the surveyed roads were in a good condition, 43.7 % were in a fair condition and 5.5 % and 1.5 % were in a bad and very bad condition, respectively. In addition, it was found that a portion of the road network lacked functional categorization. Black spots - road locations with a high RTA frequency - were identified as major contributor to RTAs in Oman. Insufficient shoulder width and poor pavement of some road sections were listed as further contributing factors.

In order to cope with this public health problem, an action plan was developed by the Omani authorities in 2010. In addition to that, road safety campaigns from both governmental and non-governmental organizations have been launched, a new Highway Design Standard has been published and an up-to-date RTA database is currently being developed. The number of recently published papers on this issue and the establishment of a research institute devoted to RTA related research indicate the ambitions of both governmental institutions and scientists to further understand the factors contributing to this burden. Despite these efforts much more research is needed, but what should the scope of this research be?

3. RTA research

Research on RTAs has a long tradition in Western countries (USA, Europe, and Australia). Basically, there has been research ever since there have been motorized vehicles. In low and middle income countries, road safety research is still in its infancy and researchers argue whether or not it is possible to apply road safety measures from Western high income countries in low and middle income countries (Bishai, Asiimwe, Abbas, Hyder, & Bazeyo, 2008; King, 2005). Despite cultural and developmental factors that need to be considered in this debate, there is little reason to doubt that it is not possible to refer to basic frameworks in order to improve road safety in low and middle income countries. Two well established frameworks are the system approach and the triple E approach (Enforcement, Engineering and Education).

3.1 The system approach

According to the system approach, the occurrence of RTAs can be ascribed to various contributing factors, namely the human, the vehicle and the road environment. As shown in *Figure 1.2*, the three factors (human, vehicle and road environment) as well as their interactions vary in the strengths of their contribution. The strongest factor is the human (95.4 %) (*Table 1.1*) followed by the environment (*Table 1.2*) and the human – road environment interaction (HRI) with 44.2 % and 34.8 %, respectively.

Since the human factor contributes to 90 % of all RTAs, one may conclude that revoking the driver's licenses from accident prone drivers would be an adequate measure to improve road safety. This measure would be in line with an approach known as the person approach (Reason, 2000) or the accident prone individual approach (Hacker, 2005). Both approaches, however, are controversial and won't lead to an improvement in road safety. First of all, there is statistical evidence that excluding accident prone drivers from road traffic wouldn't yield the desired outcome (Gründl, 2005; Hacker, 2005). Secondly, it would mean to isolate the human factor from the system context, thereby ignoring the remaining contributing factors (Reason, 2000). Yet, this is not to say that it would be unscientific to only investigate one of the three factors.

To better understand the difference between system and individual focused approaches, imagine the following situation. A driver is approaching an intersection. There is a bus-stop in close proximity to the intersection. The driver enters the intersection and collides with a vehicle coming from the right. When being questioned by the police, the driver reports that he or she thought he or she had the right of way. The police officer, however, points to a stop sign telling the driver that he or she should have seen the stop sign. Followers of the person (accident prone driver) approach would, most likely, argue that the road traffic collision occurred because the driver didn't pay attention to the scene ahead. Otherwise, he or she would have seen the stop sign. Followers of the system approach, on the other hand, would investigate the pre-crash phase of the collision. The first question they would most likely ask is why didn't the driver perceive the stop sign? It is well documented in human factor research that a driver's attention is often captured by those objects that pose the greatest threat at a given moment (e.g. Undeutsch, 1962). Recall that there was a bus stop in close proximity to the intersection. The driver might have paid attention to a bus parking at the bus stop, as the bus was perceived as a possible hazard. Consequently, the driver might not have perceived the stop sign. In this particular example, it can be argued that the road design was faulty. A bus stop should not be in close proximity to intersections. Hence, beside the human factor (attention), the factor environment contributed to the collision.

When talking about the system approach, a human factors researcher can't but refer to Reason and his famous Swiss Cheese model (Reason, 1997, 2000). According to Reason (2000), a system contains various safeguards and each safeguard can be thought of as a layer. With regard to the three factors the system road traffic consists of, each factor can be considered a potential safeguard (*Figure 1.3*). Ideally, each layer would be intact. If one of these layers is not intact (has a hole), a RTA is likely to occur. With regard to the previous mentioned example, the safety layers environment and human were not intact. The extent to which each layer was not intact requires a close examination of the situation that lead to the RTA.

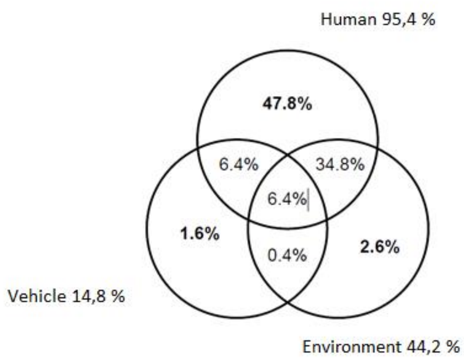

Figure 1.2. The distribution of how the three factors human, vehicle and (road) environment contribute to the occurrence of RTAs (Treat et al., 1977). The overlapping areas indicate the interaction of the three factors. Note that this distribution is based on North-American data. The percentages might be different in low and middle income countries.

3.2 Education, enforcement and engineering

This approach will simply be referred to as the triple E approach (Pease & Preston, 1967; Zimmermann, 2009). Education refers to road safety education and ranges from awareness campaigns to driver training and education. Enforcement requires that authorities like traffic police ensure that road users comply with traffic regulations. Engineering focuses on the road design, layout and maintenance. The triple E approach suggests that in order to decrease the number of RTA related fatalities, systematic improvements in each of the aforementioned areas is necessary. Akin to the system approach, the interactions of the three areas of the triple E approach need to be taken into account. This interaction is demonstrated in a study conducted by Mutto et al. (2002). The researchers investigated the effect of an overpass for pedestrians in Kampala (Uganda). The construction of the overpass didn’t lead to a reduction in the number of RTAs involving pedestrians. Whereas most pedestrians knew that the purpose of the overpass was to reduce the number of RTAs involving pedestrians, some people believed that the overpass was only meant to assist children and elderly. Although the majority of pedestrians were aware of the overpass's purpose, they refrained from using it because they argued that taking the overpass was too time consuming. This account clearly suggests that construction measures do not necessarily improve road safety unless they are accompanied by education and enforcement.

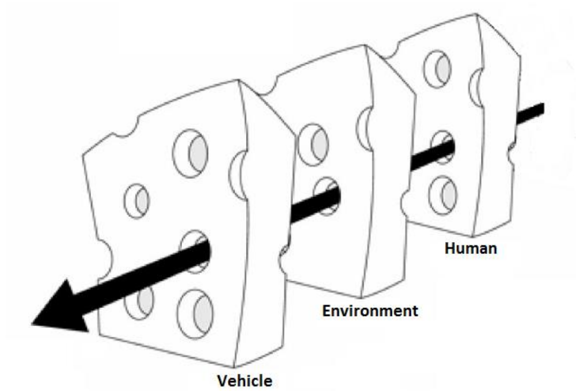

Figure 1.3. Reason's Swiss Cheese model adapted to the three factors human, vehicle and environment. The human factors could, for example, be errors in perception, vehicle factors could be break failure and environmental factors could be lack of traffic separation or incomprehensible road signs.

4. Objectives and structure

Which of the three contributing factors should be considered for research and which of the three areas from the tripe E approach should be covered? As the main contributing factor, it would be recommended to focus on human factors. Only few studies on human factors have been conducted in low and middle income countries in general and in Oman in particular (e.g. Al Reesi et al., 2013). When focusing on human factors it would be of high value to take into account a second factor. Such an approach would not only yield research results of two contributing factors, but also allow the investigation of the extent to which these factors interact.

Oman is a relatively rich country. However, large parts of the populations are not able to afford vehicles that comply with up to date safety standards, especially those living and working in rural areas. Consequently, the benefits of investigating the human – vehicle interaction which would result in recommendations on how to improve vehicle safety, would only be limited. Roads on the other hand are built and financed by the government. Focusing on the HRI and recommending methods to improve the road design in current and future layouts therefore appears to be the more valuable option. The importance of investigating road design as a contributing factor has also been emphasized by the road inventory survey carried out in 2005 and by a more recent unpublished survey carried out by the Muscat Municipality in 2012.

Table 1.1. Human factors according to different categories contributing to the occurrence to RTAs as identified in various studies. Note that the categories are interrelated. For example, cognitive factors such as emotions are associated with factors related to attention such as distraction.

Categories	General	Attention	Perception	Cognition
Examples	***Speed*** (Gründl, 2005; D. Shinar, McDonald, & Treat, 1978; Undeutsch, 1962; Vollrath, Briest, Schießl, Drewes, & Becker, 2006), ***Intoxication*** (D. Shinar et al., 1978; Undeutsch, 1962), ***Age*** (Undeutsch, 1962), ***Driver experience*** (D. Shinar et al., 1978; Staubach, 2009)	***Mental overload*** (distraction)(Hendricks, Fell, & Freedman, 2001; Otte & Kühnel, 1982; Undeutsch, 1962; Vollrath et al., 2006), ***Fatigue*** (D. Shinar et al., 1978) and / or ***Mental underload*** (Hendricks et al., 2001; Otte & Kühnel, 1982; Vollrath et al., 2006)	***Reduced vision*** (Hendricks et al., 2001; D. Shinar et al., 1978; Undeutsch, 1962), ***Time to collision (TTC)*** (Undeutsch, 1962), ***Wrong focus*** (Staubach, 2009), ***Stimulus masking*** (Staubach, 2009)	***Activation of wrong schema*** (Hendricks et al., 2001; Malaterre, 1990; Undeutsch, 1962), ***Emotions*** (D. Shinar et al., 1978), ***Impatience*** (D. Shinar et al., 1978), ***Navigation errors*** (Gründl, 2005)

Another argument that supports the decision to focus on HRI is that researchers and engineers alike generally agree that considering human factors in the design of roads leads to a significant improvement in road safety. The U.S. Transportation Research Board claims:

“Despite a widespread acknowledgement that traffic safety reflects the consideration and integration of three components - the roadway, the vehicle, and the roadway user - the information needs, limitations, and capabilities of roadway users are often neglected in traditional resources used by practitioners. In short, existing references applicable to road system design do not provide highway designers and traffic engineers with adequate guidance for incorporating road user needs, limitations, and capabilities when dealing with design and operational issues. (Campbell, Richard, & Graham, 2008, p. 1.1)"

The ultimate goal of this thesis is therefore to provide recommendations for engineers on how to adjust the road design to human factors, thereby systematically contributing to the engineering aspect of the triple E approach, or, using Reason's terminology, to improve the safety layer road. In order to meet this goal, two objectives are defined:

1. To identify the main human factors that contribute to the occurrence of RTAs in Oman.

2. To investigate HRI as contributing factor to the occurrence of RTAs in Oman.

The second objective is further structured into four specific objectives:

- ***To assess the degree to which roads in Oman can be considered self-explaining.***
- ***To identify predictors for the subjectively perceived safety of a road.***
- ***To identify road design elements that affect driving speed (for a definition of design element see part II, 2.5).***
- ***To identify possible relationships between the occurrence of main human factors and road design elements.***

This thesis is structured into five parts.

Part I: Introduction

Part II provides an extensive theoretical overview on human factors (e.g. *Table 1.1*), road design (e.g. *Table 1.2*) and HRI.

Part III provides the methodology and results of a study that was conducted to address objective one. This study is to a great extent based on a previous study on human factors conducted by Gründl (2005).

Part IV provides the methodology and results of a study that was conducted to address objective two. This study consists of four investigations each of which intended to address one of the four specific objectives.

Part V provides the discussion of the main findings and the design recommendations. An overview on road designs in which the human factor was not taken into account is provided in the Appendix. Furthermore, the limitations of this thesis will be discussed.

Table 1.2. Road and environmental factors that are associated with RTA risk as identified in three different studies.

Road and environmental factors	Jennings & Demetsky (1983)	Fildes et al. (1987)	Becher et al. (2006)
Curve radius	Yes	Yes	Yes
Road and lane width	Yes	Yes	Yes
Intersecting roadways or driveways	Yes	Yes	Yes
Road markings and delineators	Yes	Yes	Yes
Cognitive characterization of road	No	No	Yes
Transition from road to intersection	No	No	Yes
Urban or rural environment (Roadside development)	-	Yes	-
Sight distance	Yes	Yes	Yes
Roadsidedevelopment	Yes	Yes	Yes

Part II: Theory and literature review

1. The human factor

1.1 The driving task

Driving is a complex task. In order to understand how the human factor is associated with the occurrence of RTAs, it is necessary to understand this task. A well-established theoretical approach to distinguish between different aspects of the driving task is the synthesis of the task hierarchy model (Michon, 1985) and Rasmussen’s skill, rule and knowledge framework (Rasmussen, 1983, 1985).

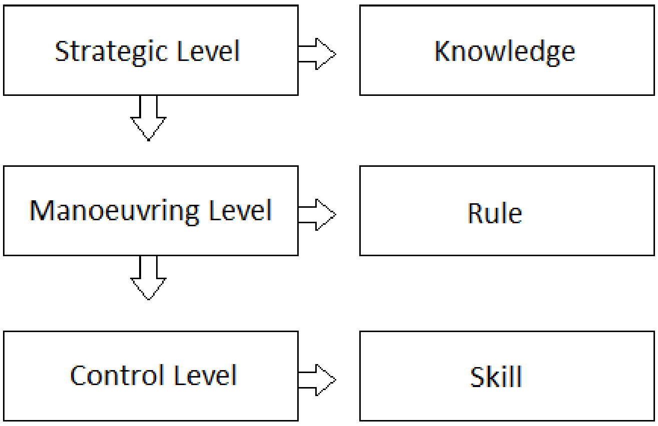

Figure 2.1. The association between task hierarchy model (Michon, 1985) and task performance (Rasmussen, 1983, 1985). See text for explanation.

According to the task hierarchy model, the driving task can be divided into three levels: strategic, manoeuvring and control level. The strategic level is the navigation level; strategic level tasks might involve planning the route including the trip goal (highway A or highway B, turning left or right at the next intersection) as well as problem solving (finding alternative routes) (Becher et al., 2006; Michon, 1985). At the manoeuvring level, gained behavior-sequences (schemata, see 1.4.2) are executed (Becher et al., 2006). Examples for the manoeuver level would be turning, responding to traffic signs or overtaking. A wrong analysis of the situation ahead could lead to the activation of a wrong schema. The lowest level, the control level, is responsible for automatized tasks such as maintaining stable vehicle control. The driver controls speed and the leading headway (longitudinal control) as well as the position in the lane (lateral control) through shifting, braking, steering, etc.

Each level can be attributed to the level of task performance (*Figure 2.1*) as proposed by Rasmussen in his skill, rule, and knowledge framework. The knowledge based level comes into play in new, unfamiliar situations. At the knowledge based level, actions have to be planned on-line (Reason, 1990). In this situation, the action is goal oriented. The person needs to analyze the environment in order to find ways and / or methods to reach his or her goal. The knowledge based level corresponds with the strategic level. The rule based level is controlled by stored rules. The rule or schema is "retrieved from memory simply on the basis of previous successful experience (Theeuwes, 2001, p. 244)". Although rule based behavior is also goal oriented, it is structured through "feed forward" control through a stored rule. The goal might not be formulated, but found in the situation releasing the stored rules (Rasmussen, 1983). Errors usually occur when the situation is misclassified. Rule based behavior corresponds with the manoeuver level. At the skill based level, behavior represents sensory-motor performance during activities which take place without conscious control. According to Rasmussen (1983), the main difference between rule based actions and skill based actions is that at the higher level, rule based behavior coordination is generally based on know-how and that the person is able to report the applied rules. Errors at the skill based level are associated with intrinsic variability of force, space or time coordination (Reason, 1990). Skill based behavior corresponds to tasks at the control level.

Driving tasks are not necessarily attributed to a specific level / behavior (*Table 2.1*) (Gründl, 2005). An experienced driver who is driving in an unfamiliar environment would perform tasks such as shifting at the control / skill based level and tasks such as turning at an intersection at the maneuver/rule based level. The more the driver gets familiar with the environment, the task turning at the intersection would move to the next lower level (control / skill level). Another example would be a novice driver who performs a task such as gear shifting at the knowledge based level, as he or she is not yet familiar with the gears. With increasing driving practice, the task will move to the next level.

Table 2.1. Relation between task hierarchy and the skill, rule, and knowledge framework (modified version from Gründl, 2005). The bold printed tasks are the most common tasks. Note that these are just examples. Whether or not one of the tasks can really be considered to be at a specific task and driving level depends on various factors, see also Hale et al. (1990).

	Knowledge based	**Rule based**	**Skill based**
Strategic level	**Navigation in unfamiliar environment**	Choosing between two familiar routes	Daily way to work
Maneuvering level	First time driving in the desert	**Overtaking of other vehicles**	Turning at a familiar intersection
Control level	First lesson in driving	Driving a new car	**Driving curves, shifting**

	school		

1.2 Driving and attention

Driving requires the driver's full attention. Generally, attention can be divided into mental overload and mental underload (Brookhuis & De Waard, 2010; De Waard & Brookhuis, 1991); the former leading to distraction, the latter to state of drowsiness.

1.2.1 Mental overload

Mental overload occurs when drivers have to attend to more one than one task. Any additional task has an adverse effect on driving. Various studies have for example demonstrated that a secondary task such as mobile phone usage or listening to the radio causes a decrease in brake reaction time (Brookhuis et al. 1994, Irwin et al. 2000, Consiglio et al. 2003). Consiglio et al. (2003) report that mean reaction time while using a mobile phone was 0,072 sec. higher when compared to the control condition (no mobile phone usage). Considering that every hundredth of a second can reduce stopping distance by 0,25 m at 90 km/h, (Warshavsky-Livne & Shinar, 2002), the interference (distraction) caused by a secondary task explains whether a driver is able to react in a timely fashion or not.

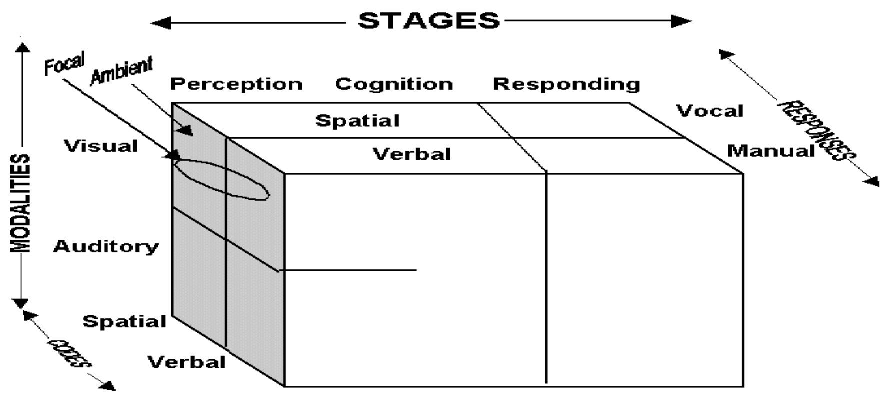

Figure 2.2. Multiple Resource Model (MRM) by Wickens (2002), modified version.

Wickens' Multiple Resource Model (MRM) (*Figure 2.2*) is a prominent model for explaining task interference (Wickens, 2002, 2003, 2008). Wickens assumes that human attentional capacity should be understood as multiple resource pools with dual task interference being greatest when tasks compete for similar processing resources and least when tasks draw from different resources (Matthews et al. 2008). The MRM consists of three dichotomous dimensions. The processing stages describe cognitive and perceptual activities (working memory, for example). The perceptual modalities are categorized into visual and auditory. The processing codes are divided into spatial and verbal processes. *Figure 2.3* illustrates the application of the MRM on the dual task driving and mobile phone usage.

According to a study conducted by the National Highway Safety Administration of the USA (2000), most RTAs that are associated with mobile phone usage occur due to the mental demand during the conversation and not due to the visual and motor processes like dialing or typing. Evidence to support these results can also be found by Consiglio et al. (2003). Interestingly, Consiglio et al. also found that the usage of hands-free phones deteriorates performance to the same extent as usual mobile phones. With reference to the MRM, these findings indicate that mobile phone usage and driving compete for mental resources rather than for the manual response. However, assuming that the mobile phone would be used for writing text messages, visual and motor processes would be required to a greater extent.

To which extent the driver is distracted depends on the driver him- or herself, how demanding the respective task is and the driver's willingness to engage in the task (Ranney et al. 2000). In other words, the proportion of mental capacity an operator is willing to allocate (Pauzié, 2009). The willingness or motivational factors to engage in a task is lacking in Wickens' model. He therefore recommends understanding what drives the allocation policy. In a laboratory, allocation policy is often driven by primary and secondary task instructions, but why someone would use a mobile phone while driving a car remains unclear (Wickens, 2008). Furthermore, the task level at which the driving task is executed should be considered. As skill and rule based behavior is less sensitive to secondary tasks, drivers might be more likely to engage in behavior that is detrimental for road safety.

Note that multiple resource theory and mental workload are two related concepts that are often confused. They overlap but are distinct (Wickens, 2008). With regard to this thesis, they have been introduced together for illustrative purposes.

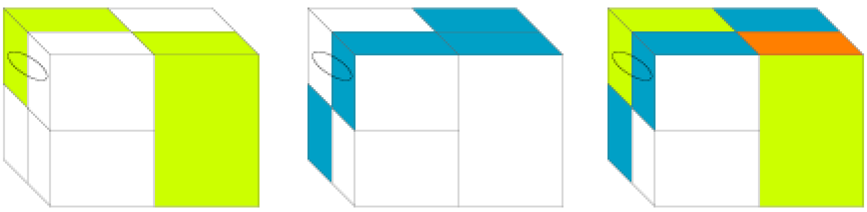

Figure 2.3. The green fields in the left cube illustrate the resources for the driving task. Visual perception is required, the coding is spatial and the responses are manual. The blue fields (center)

illustrate the resources required for the mobile phone usage. Auditory perception is required and the responses are vocal and manual, as the driver talks and holds the phone in his or her hand at the same time. The cube on the right side illustrates where both tasks interfere with each other. Mobile phone usage and driving compete for the same resource (Humboldt University Berlin, department for Engineering-Psychology). With permission.

1.2.2 Mental underload

A lack of mental demands can result in mental underload, which can be as detrimental to performance as overload (Branscome & Grynovicki, 2007). Mental underload is especially likely to occur when the driving environment is predictable. While safe handling of a car requires a sustained level of alertness, the aforementioned factor leads to the opposite (Mets et al., 2011).

Mental underload is associated with a phenomenon referred to as “highway hypnosis” (Tejero & Chóliz, 2002). The term highway hypnosis was first introduced by Williams (1963). Williams postulated that prolonged driving in a monotonous environment leads to a trance like state. This state, in turn, leads to drowsiness. He argues that mainly monotony as well as bright points of fixation are circumstances that have always been used to hypnotize people. Williams' assumptions were questioned years later by Wertheim (1978). Wertheim, however, didn't reject Williams' theory that there are other states than fatigue leading to drowsiness, but rather Williams' explanation. According to Wertheim, monotony is not easily measured and not necessarily a contributing factor to the phenomenon of highway hypnosis. He therefore proposed a different explanation for this phenomenon. Wertheim's starting point is the distinction between two different mechanisms of oculomotor control, namely attentive and intentive. “The attentive component refers to retinal feedback and the intentive component refers to the intention to move our eyes (Wertheim, 1978, p. 112).” Long prolonged driving in a predictable environment in which most of the present stimuli are not relevant to the driving task could lead to an increase of the intentive component at the expense of the attentive component. In a series of experiments, Wertheim demonstrated that an increase of the intentive component is associated with lowered alertness. As a consequence, a driver might no longer be able to detect changes in the lateral position of his or her vehicle. In short, Wertheim concludes that highway hypnosis is not induced by the degree of monotony, but rather by the degree of predictability: “A very monotonous road situation does not necessarily imply a very predictable one, as for example when driving in heavy fog. In that situation it is most unlikely that highway hypnosis develops (Wertheim, 1978, p. 128).” Another important aspect in Wertheim's argumentation is that highways are more predictable than secondary roads. Hence, highway hypnosis is less likely to occur on secondary roads. This assumption has partially been confirmed by

Cerezuela et al. (2004). For a more comprehensive overview on mental alertness and monotonous environments see Thiffault and Bergeron (2003).

The conclusion from the preceding sections can be summarized as follows:

- ⇨ Provide information on different attentional levels. For example, rumble strips are perceived haptically and thus relieve the visual attentional level.
- ⇨ Mental underload is associated with predictability rather than monotony.
- ⇨ The road environment affects the mental demand.

1.3 Driving and perception

1.3.1 Speed perception

Inappropriate speed is among the main RTA risk factors. Rigorous and smart law enforcement is one way to control speeding behavior (Zimmermann, 2009). Research, however, has demonstrated that there are other ways to affect the road users' speeding behavior by affecting the road users' perception.

How does a driver perceive the speed he or she is traveling at? It could be argued that a driver checks the speedometer more or less frequently. Recarte and Nunes (2002), however, provide some evidence that contradicts this notion. The two researchers demonstrated that drivers tend to choose an optimum preferred speed in order to minimize mental effort dedicated to speed control. If drivers don't refer to the speedometer to regulate their speed, how do they control their speed? There are three factors that determine the perception of ego-speed, namely Edge Rate, Global Optic Flow Rate (Chatziastros, 2003; François, Morice, Bootsma, & Montagne, 2011; Larish & Flach, 1990; Recarte & Nunes, 2002) as well as the Contrast and the Spatial Frequency in a scene (Blakemore & Snowden, 1999; Distler & Bülthoff, 1996; Johnston & Clifford, 1995; Pretto & Chatziastros, 2006; Stone & Thompson, 1992; P. Thompson, Brooks, & Hammett, 2006).

The Edge Rate "corresponds to the number of texture elements that pass by the observation point in a given visual direction in a unit of time and is expressed in edges per second (François et al., 2011, p. 215)," hence the name Edge Rate. If a driver is driving through an alley, the Edge Rate would correspond to the unit of time at which the driver passes a tree. The shorter the distance between the trees or the higher the speed the driver is travelling with, the higher the edge rate. Edge Rate thus depends on texture density, but it is independent from eye height (François et al., 2011). There are some studies in which the role of Edge Rate on road safety has been investigated. Fajen (2005a) for example reports that a decrease in texture density / Edge Rate has a negative effect on brake reaction time. Manser and Hancock (2007) modified the texture of tunnel walls by applying different visual patterns. The participants of their study decreased speed when decreasing width visual patterns were applied to the tunnel walls, but increased their speed under increasing width conditions. Manser and Hancock thus confirmed the results of a study conducted by Denton (1980) almost three decades earlier. Further studies on the effect of Edge Rate have been conducted by Anderson et al. (1999), Lewis-Evans and Charlton (2006) and Bing et al. (2008). Note, however, that despite these positive effects, Chatziastros (2003) points out that these effects might be temporary and that drivers return to their preferred speed as soon as they get familiar with the new situation.

In terms of the perception of ego-motion, the Edge Rate is similar to the effect of the Spatial and Contrast Frequency (Chatziastros, 2003). The difference is that the Edge Rate refers to salient objects in the environment with a high contrast. The effect of Spatial and Contrast Frequency on the perception of ego-speed tends to be stronger in the peripheral than in the foveal vision (Jamson, Lai, Jamson, Horrobin, & Carsten, 2008). Blakemore and Snowden (1999) found that a decrease in contrast leads to a decrease in perceived speed. Snowden et al. (1998) conducted an experiment in order to investigate how drivers perceive speed under foggy conditions. The participants increased their speed when the scene got foggier. The authors concluded that the drivers thought that they were driving slower due to the low contrast condition caused by the fog and therefore increased their speed. Pretto and Chatziastros (2006), however, argue that Snowden et al. produced unrealistic fog conditions in their driving simulator. Under real fog conditions, the contrast is exponentially reduced with distance which leads to higher perceived speeds. Pretto and Chatziastros (2006) were able to confirm this theory. They conducted an experiment in a driving simulator, in which the participants had to drive under normal and foggy conditions. Indeed, the participants reduced their speed under the foggy conditions. Pretto and Chatziastros concluded that fog masks distal portions of the scene, leaving only the proximal parts with higher angular velocity visible. The Global Optic Flow Rate will thus indicate a higher speed.

"The Global Optic Flow Rate is the optical velocity of ground surface texture elements in a given visual direction, and is proportional to observer speed assuming constant eye height (Fajen, 2005b, p. 740)" Unlike the Edge Rate, Global Optic Flow Rate depends on eye height. Yet, it is independent of texture density (François et al., 2011). This fact has some interesting implications for road traffic. Drivers of large vehicles such as SUVs or trucks perceive speed differently than drivers of saloon cars (Fajen, 2005a; Rudin-Brown, 2004). Furthermore, this effect of Global Optic Flow Rate could affect speed perception when driving on a bridge. The effect of eye height on speed perception when Global Optic Flow Rate is investigated depends on the angular velocity. The angular velocity of an object close to the center of the visual field is small, but the angular velocity of an object in the far periphery of the visual field is large. In the case where the driver's eye height above the road is reduced, the angular velocity in the peripheral visual field increases and indicates higher speeds (Jamson et al., 2008; Zimmermann, 2009). In other words, the closer the objects to a moving person, the higher the angular velocity and the higher the perceived speed.

It is difficult to say which of the three aforementioned factors has the strongest impact on the perception of ego-speed. Research results indicate that Edge Rate is the most important determinate (Chatziastros, 2003; Larish & Flach, 1990).

1.3.2 Time to collision

The time to collision (TTC) is defined as the time required for two vehicles to collide if they continue on the same path at their present speed (Hayward, 1972). For example, a vehicle traveling at 110 km/h and a second vehicle approaching from behind traveling at 130 km/h. Given that both vehicles maintain their current speed, they would eventually collide. The two vehicles would also collide if the second vehicle decelerates to 120 km/h and the first vehicle decelerates to 110 km/h. Hence, the driver of the second vehicle always has to adjust his or her speed to the speed of the preceding vehicle. Researchers have therefore attempted to investigate how drivers estimate TTC.

One of the most prominent models to investigate TTC is Lee's *tau dot* model. The *tau dot* model is a theory about the visual control of braking. The expansion rate of the retinal image of a stationary object that a driver is driving towards (the visual variable *tau*) specifies when the driver will collide with the object. By changing the speed, the driver can change the rate of expansion of the retinal image (*tau dot* = time derivative of *tau*) (Groeger, 2002; Lee, 1976). As long as the driver maintains tau dot within specific bounds, he or she is able of perform a controlled stop.

Hoffmann & Mortimer (1994) investigated the ability of a driver to estimate TTC when two vehicles are in motion. The participants in their study were presented with film segments that showed the driver's perspective in a car that was approaching a lead vehicle on a freeway. The participants were asked to indicate when the vehicle would have collided with the rear end of the lead vehicle. Special emphasis was given to the angular velocity. In order to judge TTC accurately, the angular velocity with which the visual angle subtended by the lead vehicle changes must exceed a threshold of 0.003 radians/sec (Hoffmann & Mortimer, 1994). If the angular velocity is above the threshold, short viewing times are sufficient in order to estimate TTC. Otherwise, the driver needs to detect spacing changes from which he or she can infer the speed of approach. In a tailgating situation, the distance between the two vehicles is rather short. Accordingly, TTC is low. Hoffmann & Mortimer have shown that at low TTC values, drivers usually underestimate TTC. Nevertheless, the authors reported only a small percentage of occasions in which the participants overestimated TTC. Overestimating TTC would eventually lead to rear end collisions.

Gratzer (2009), with reference to Harvey &Michon (1971) also investigated TTC. Gratzer's findings confirm the importance of the threshold as reported by Hoffmann and Mortimer. Additionally, Gratzer argues, correct estimates of TTC depend on the observation period which has to be at least 0,2 sec. This time span complies with the time between two saccades (fixation duration). Given that the threshold is exceeded and the driver is not visually distracted, he or she should be able to estimate TTC appropriately. Furthermore, Gratzer reports that the threshold of the angular velocity has to be higher when the distance to the other vehicle is shorter and the difference in speed between the two vehicles is smaller. Correct speed estimation depends on the speed variance. The lower the variance is, the higher the likelihood for correct estimations (Zimmermann, 2009).

Caird and Hancock (1994) investigated TTC at intersections. The authors conducted an experiment in which 48 participants had to estimate TTC of vehicles within a traffic intersection scene. The results revealed that participants generally underestimated TTC. Women had significantly lower values than men. However, men were significantly more accurate at estimating TTC of motorcycles and trucks. The researchers further report a significant main effect for distance. The closer the vehicles was, the more accurate TTC estimation.

1.3.3 The Useful field of view (UFOV)

The UFOV is defined as "the region of the visual field, from which information can be acquired without any movement of the eyes or the head (Ball, Beard, Roenker, Miller, & Griggs, 1988) and consists of the central and peripheral vision (Ball, Owsley, Sloane, Roenker, & Bruni, 1993). The size of the UFOV varies, as it depends on a multitude of factors like luminance level, light wavelengths, stimulus salience and the execution of secondary tasks.

Objects are most likely to be perceived when displayed within the center region of the UFOV (Dahmen-Zimmer & Zimmer, 1997). Factors that add to the detection probability will be described in 1.3.4. The peripheral region is also crucial to the driving task (Cohen, 2009). Peripheral vision has a sort of "alarm function". Objects can be detected in peripheral vision leading to an appropriate eye movement and a fixation of the object with the central (foveal) vision. Road characteristics such as road markings and lane width can be controlled by peripheral vision. Lastly, as elaborated in 1.3.1, peripheral vision is important for speed perception.

The UFOV deteriorates with age (Ball et al. 1990), when a secondary central task is added (Wood et al., 2006), under monotonous driving conditions (Rogé et al., 2004) and in addition to sleep deprivation (Rogé, Pébayle, Hannachi, & Muzet, 2003). The age related deficiencies can be compensated by experience or specific training up to the age of 75 (Cohen, 2009). The deterioration of the UFOV usually causes a "tunnel vision" (Rogé et al., 2003; Rogé, Pébayle, Kiehn, & Muzet, 2002) and is often considered a contributing factor for RTAs. Allahyari et al. (2007) conducted an experiment in which they investigated UFOV limitations in 90 drivers. They found that a 40 % reduction of the UFOV increased the risk of accident involvement regardless of age. Similar results are reported in a review conducted by Cohen (2009). Despite these seemingly dangerous reduction of the UFOV, Cohen argues in the same article that a deterioration of the UFOV can also be regarded as a useful selection process through which objects are only displayed on the fovea which allows a faster processing of the perceived information. In this regard, the UFOV limitation is a mechanism of avoiding "information overload".

1.3.4 Where do drivers look and what do they see?

It was argued in the previous section that the UFOV is the region of the visual field that can be acquired without any movement of the head or the eye. A person performing a task such as driving does not normally just stare ahead. In fact, humans scan the environment by moving their eyes. These eye movements are guided by attention. Only in few cases, attention is captured by stimuli perceived in the peripheral vision; a process that would lead to a head movement (Dahmen-Zimmer & Zimmer, 1997). The conditions that are required to attract the observer's attention are referred to as singularities. Singularities are stimulus configurations which are more salient than other stimuli in the environment (Braun & Sagi, 1990; Dahmen-Zimmer & Zimmer, 1997). According to Dahmen-Zimmer and Zimmer (1997), these singularities are:

- Dynamic singularities: Movements in front of a background that changes in accordance with the motion parallax.
- Geometric singularities: Stimulus configurations such as Y- or arrow-connections or semiotic singularities such as perceived curvature.
- Symbolic singularities: Symbol or text information (only perceived within 30 degrees left / right of the visual field).

A combination of these singularities would yield the best results in terms of detection probability (Dahmen-Zimmer & Zimmer, 1997). In addition to that, there is evidence that singularities can be perceived parallel to focal visual attention (Braun & Sagi, 1990). These assumptions suggest, for example, that human visual scanning behavior is not guided by conspicuous colors – an assumption that has been confirmed by Theeuwes and colleagues. The researchers (Theeuwes, Atchley, & Kramer, 2000) conducted a number of experiments in which they asked participants to find a red circle among green circles. Although the red circle was more conspicuous than the green circle, the participants started searching randomly. These results indicate that even conspicuous road signs can be overseen by road users unless they search for the respective sign. Findings supporting this conclusion were reported by Hughes and Cole (1984). The researchers also demonstrated that commercials attract the road users' attention more than traffic signs (Hughes & Cole, 1986). It thus appears that drivers don't perceive all elements of a traffic scene that might be necessary to drive safely.

There are two other phenomena confirming this notion. Firstly, Dahmen-Zimmer and Zimmer (1997) point out that movements are processed in relation to reference systems. They argue that a cyclist who is riding behind a parking vehicle might not be perceived as a moving object but rather as partial movement within a texture which is only perceived with peripheral vision (*Appendix A, Figure 1*). As a consequence, the cyclist doesn't constitute an attractor leading to an appropriate head movement. Secondly, some elements of a traffic scene might not be perceived by a driver - a phenomenon that is referred to as change blindness. "Change blindness is defined as the inability to detect changes made to an object or a scene during a saccade, flicker blink or movie cut...change blindness is especially pronounced when brief blank fields are placed between alternating displays of an original and modified scene (J. K. Caird, Edwards, Creaser, & Horrey, 2005, p. 236)." This technique is generally known as Flicker technique (Simons & Levin, 1997). A few studies have been conducted in which the flicker technique has been modified to investigate drivers' attentional capabilities at intersections (Batchelder, Rizzo, Vanderleest, & Vecera, 2003; J. K. Caird et al., 2005; Edwards, Caird, & Chisholm, 2008). In these experiments, participants are generally presented with a series of pictures. The first picture is grey. The second picture shows a traffic scene, usually an intersection. The third picture is grey and is meant to represent the saccade, etc. The fourth picture shows the traffic scene. Sometimes, however, this traffic scene has been modified. After being presented with the series of pictures, the participants have to make the decision whether they would turn or not. Research has shown that turn decision accuracy is associated with age (Batchelder et al., 2003; J. K. Caird et al., 2005), but not with experience. Novice drivers showed the same turn decision accuracy as experienced drivers (Edwards et al., 2008). It was also demonstrated that longer gaze duration are related to greater turn decision accuracy and that accuracy was greater when vehicles were the changing objects (Edwards et al., 2008). Edwards et al. (2008), however, believe that the detection of vehicles as changing objects is not related to the object size. It is possible that objects are rather detected because, unlike pedestrians, they pose a greater hazard (Undeutsch, 1962).

Thus far, it can be concluded that road users do perceive certain features unconsciously, while the majority of perceived information depends on the drivers' visual attention. Nevertheless, it is possible that important elements of a scene are not perceived. It is noteworthy that the perception of information depends to a great extent on driver experience (yet, as shown in the previous paragraph, there appears to be no relationship between driver experience and the effects of change blindness). Experienced drivers, for example, are more capable of keeping the vehicle in the lane when focal visual attention is not directed to the road markings than novice drivers (Heikki Summala, Nieminen, & Punto, 1996). The next paragraphs will provide more information on the drivers' gaze preferences.

Mourant & Rockwell (1970) investigated the effects of route familiarity and driving conditions (open road vs. car following) on visual scanning patterns of experienced drivers. Their results revealed that the driver's visual scanning systematically depends on the task to be performed. In the scenario where drivers were not familiar with the road, their fixations were widely dispersed and rather concentrated above and on the right side of the road, those sites where they were expecting road signs. As soon as the drivers were familiar with the road, their scanning behavior moved far down the road, "where drivers can obtain information with maximal lead time (Shinar, 2008: 381)". In a second study, Mourant & Rockwell (1972) compared visual screening patterns of novice drivers to screening patterns of experienced drivers. In contrast to experienced drivers, novice drivers' fixations were distributed on a much smaller part of the visual scene and mostly direct on the road in front of the car, on the right side of the road, as well as on road markings. Furthermore, novice drivers used rear and side mirrors less frequently than experienced drivers.

Research on visual behavior in curves has shown that drivers look at the tangent point (*Figure 2.4*) on the inside of the curve (Land, 2001; Land & Lee, 1994; Mars, 2008). "The tangent point is the point where the driver’s line of sight is tangential to the road edge or centre line, and it moves around the curve with the driver (Land, 2001, p. 227)". Drivers start searching for the tangent point about 1-2 seconds before entering the curve and return looking at it many times while passing through it. This visual strategy allows the driver to predict the curvature of the curve (Underwood, Chapman, Crudall, Cooper, & Wallen, 1999). Interestingly, the fixation of the tangent point takes more time in curves with high RTA frequency compared to curves with a low RTA frequency (*Appendix A, Figure 2*). Becher et al. (2006) conclude that the longer fixation period is associated with a higher mental demand. According to Land (2001), drivers behave differently to near and far regions of the road: "When only the far part of the simulated road was visible, drivers matched curvature well, but their lane keeping performance was poor; and when only the near part was visible lane keeping was better, but steering was unstable and jerky (p. 232)." Land concludes that the near and the far region provide different and complementary information. "The distance region (including tangent points where visible) supplies feed-forward information about the future curvature of the road, and the near region supplies feedback information about position in lane (p. 233)." The near and the wide region have also been taken into account by Kandil et al. (2010). The researchers argue that drivers tend to look at the end of the curve when they attempt to partially leave the lane (cut the curve). The amount of gazes to the tangent point further depended on openness (defined as sight distance at the start point of the curve segment) and curvature. The stronger the curvature or the lower the values of openness, the more often drivers looked at the tangent point. Lastly, the researchers demonstrated that road users tend to look more often at the tangent point in right-hand curves than in left-hand curves. Given the importance of tangent points for curve driving, this finding would explain why RTAs occur more frequently in left-hand curves than in right-hand curves. Curves will be further discussed in 2.6.3.

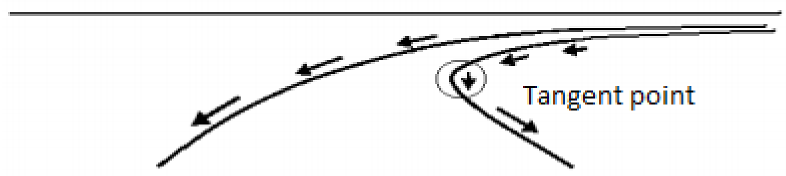

Figure 2.4. The tangent point, the point drivers tend to fixate when negotiating a curve. Modified version from Mestre (2001).

Werneke and Vollrath (2012) investigated the influence of intersection characteristics on visual attention. The authors found that the intersection characteristics have an effect on how drivers allocate their visual attention. For example, at intersections with a low traffic volume, drivers tend to gaze less often to the left before making a right turn compared to intersections with a high traffic volume. Werneke and Vollrath also found that since drivers pay more attention to the traffic at complex intersections, RTAs are more likely to occur at less complex intersections. Note, however, that the authors only considered a small number of independent variables. Intersections will be further discussed in 2.6.2.

A few important conclusions can be drawn from the aforementioned studies. The most important one is that visual screening patterns seem to be systematic depending on groups (e.g. novice vs. experienced drivers) and scenarios (e.g. straight road vs. intersection). Also, novice drivers apparently compensate their missing experience by referring to road markings and traffic signs (at the right side of the road). They also seem to be visually overloaded (Shinar, 2008). Experienced drivers, on the other hand, look further down the road to detect possible hazards in time. Both findings will be essential when discussing the role of road markings and traffic signs later on. It should be mentioned that although eye tracking systems have been improved within the last years, Mourant & Rockwell's results were confirmed by other studies. A good overview on their work and the replication of their findings is provided by Shinar (2008). Moreover, visual behavior in road traffic has occasionally been considered in design principles such as "do not place intersections on curves" (*Appendix A, Figure 3*). "The flow of visual information for drivers on a curve is at different speeds for the left and right eyes. On curve to the left, the flow of information is faster for the driver's right eye than for the left eye. As a result for this difference, drivers are less able to judge the relative speeds of cars on an intersecting road at the end of their curved path (Basacik, Luke, & Horberry, 2007, p. 17)."

The conclusion from the preceding section can be summarized as follows:

- ⇨ The road environment has a large impact on speeding behavior.
- ⇨ Certain features can be used to affect the drivers' speeding behavior.
- ⇨ In general, road users are able to correctly estimate TTC. This estimation, however, depends on various factors like secondary tasks or speed variance between two vehicles.
- ⇨ Road users are likely to oversee important elements of a traffic scene. Therefore, important elements have to be designed in a way that considers human limitations, captures the road users' attention and are in accordance with the road users' expectations (e.g. place a road sign where road users would expect it).
- ⇨ Avoid elements at the outer side of a curve that might capture the road users' attention. Note, however, single chevrons have a positive effect on both speed perception and guidance.
- ⇨ Consider differences in visual search behavior among different groups of road users.
- ⇨ Do not place intersections on curves.

1.4 Information processing

1.4.1 Bottom-up and top-down processing

The senses are the human's window to the world (Cohen, 2009). The most important sense for the driving task is vision. About 90 % of all information required for the driving task is perceived visually (Sivak, 1996). Yet, good vision isn't a sufficient condition for safe driving (Cohen, 2009). Perception can be divided into two processes, namely bottom-up and top-down processing. Bottom-up (stimulus driven) "processing refers to stimulus analysis driven by the input data alone (Matthews, Davies, Westerman, & Stammers, 2008, p. 27)". Top-down (goal directed) refers to sensory input that activates the person's relevant knowledge, motivation and expectations (Cohen, 2009; Weller, Schlag, Gatti, Jorna, & Van der Leur, 2006). Perception can be understood as an interaction between both processes. Weller et al. (2006) illustrate the role of both processes for the driving task by referring to the driver's speed choice when entering an unknown road. The speed the drivers choose can be assumed to be driven by top-down processes (e.g. the driver is motivated to go home as fast as possible as he or she doesn't want to miss the football match), while the minor adjustments he or she makes during driving are essentially bottom-up driven. In addition to motivational factors top-down processes are also driven by experience and expectations. A driver gains this experience during his or her driving career. It is these experiences that form the basis for the driver's expectations.

Driving experience and the interaction between top-down and bottom-up processes explains for example why older people are less frequently involved in RTAs than expected due to their age related deficiencies. Young drivers have fewer problems perceiving information, but older drivers are more capable of relating the input to their experience and thus able to make appropriate decisions (Cohen, 2009). If an older driver, however, doesn't have sufficient driving experience, he or she won't be able to compensate his or her age related deficiencies. This might be the case in Oman, where many people started driving a vehicle in their fifties or sixties.

1.4.2 Situation awareness and schemata

In terms of road safety, it is not only what we see that is important, but how we process and respond to perceived information (*Appendix A, Figure 4*). Imagine a driver who is driving on a straight rural road. He or she perceives a car parking on the shoulder of the road. Does the driver perceive this car as a possible hazard because the driver could suddenly pull out or does the driver ignore the car because he or she knows that he or she has the right of way? In either case the driver judges the situation. According to Malaterre (1990), 59 % of all RTAs occur due to misjudgment of the traffic situation. It is thus important to understand how a road user makes this judgement.

Human behavior is goal driven (Richetin, Conner, & Perugini, 2011; Theeuwes, 2001; Thomas L, 2007). A person tries to accomplish his or her goal. This goal can be divided into sub-goals and the sub-goals can be divided into sets of actions (Theeuwes, 2001). The will to accomplish this goal is synonymous to finding a desired state in a problem scenario (Newell, Rosenbloom, & Laird, 1987). The person has to take several steps to find the desired state. After each step, he or she compares the new state to the desired state and is thus able to control whether the desired state has already been found. The aforementioned processes have been described as mental models or, more recently, as situation awareness (Matthews et al., 2008).

Situation awareness is well known in the aviation field. The goal of this concept is basically to describe to which extent an operator is aware of what is going on. The higher the level of situation awareness the more likely it is for an operator to act appropriately. Since driving a vehicle and flying an aircraft are both tasks that depend on environmental input variables (Ma & Kaber, 2005) and also due to its success in aviation, situation awareness has become a popular approach in the field of road safety research (Baumann, Petzoldt, & Krems, 2006; Ma & Kaber, 2005; Sommer, 2012).

There are different approaches to situation awareness (e.g. Endsley, 1988; Regal, Rogers, & Boucek, 1988; Smith & Hancock, 1995). One of the most prominent approaches was presented by Endsley, who defined situation awareness as "the perception of elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future (Endsley, 1988, p. 97)". In this regard, situation awareness can be understood as a mental model of the current situation which provides the basis for the selection of actions. Drivers, for example, should form assumptions about the development of a traffic situation. Is this car going to stop, will the pedestrian cross the road, etc.? As every performed action affects the situation, the model has to be "refreshed". Situation awareness is therefore a state as well as a process (Baumann et al., 2006).

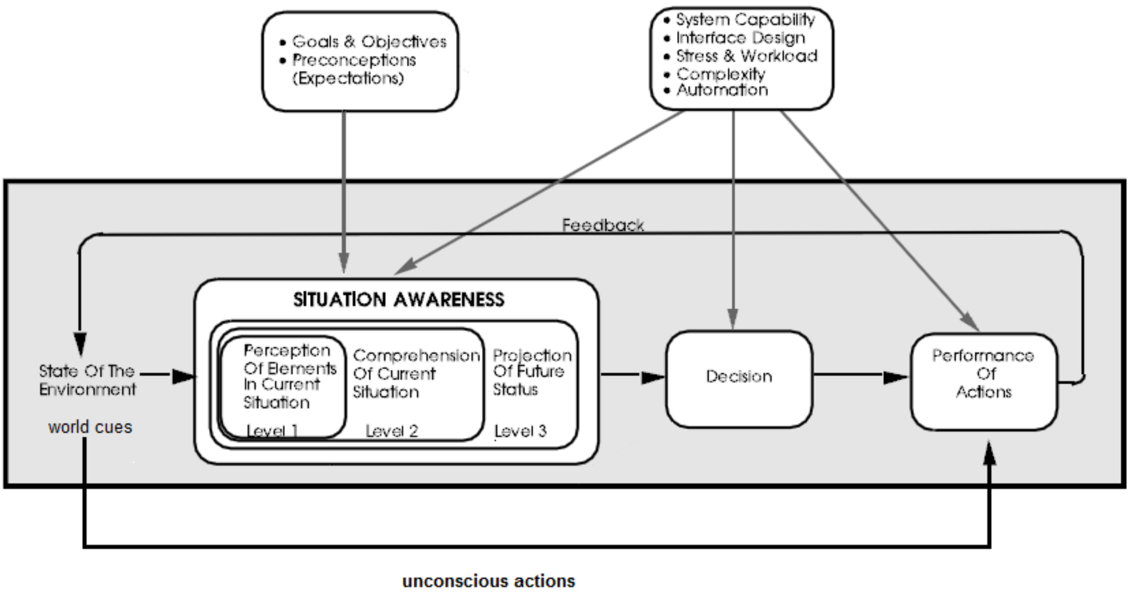

Figure 2.5. Situation awareness, modified version from Endsley (2000). For explanation see text.

Endsley (1995) identified three components of situation awareness: perception of elements in the environment (level one), comprehension of their meaning in relation to task goal (level two), and projection of their status in the near future (*Figure 2.5*). Level one is probably the most fundamental element of situation awareness. At the first stage, environmental cues are perceived. These cues can be overt like an alarm or subtle like a slight change in the hum of the engine (Weller et al., 2006). Some of the subtle cues may only be perceived unconsciously (Endsley, 2000). Not perceiving important cues in the environment would drastically increase the probability of forming a wrong picture of the situation and thus increasing the likelihood of causing a RTA. What kind of information is being perceived depends on the driver's behavior as well as the limitations of his or her sensory system. On a familiar route, the driver might not pay attention to road signs. It is therefore possible that he or she oversees important information (see also 1.3). Otte and Kühnel (1982) provided an interesting example to illustrate how easily important information can be overseen. A woman, who described herself as experienced driver, crashed into an oncoming car that was travelling on her lane. The problem was that this woman didn't notice a construction site and a warning sign indicating that one lane was closed. She reported that she always took this road on a daily basis and thus didn't expect any changes. If she would have perceived the warning sign, the RTA might not have had occurred. In other words, this woman had a very low level of situation awareness. Moreover, this characteristic of situational awareness indicates that even experienced drivers make mistakes, a view advocated by many known researchers on human factors like Reason (2000). At the second level, the perceived information is interpreted. Multiple pieces of information have to be integrated and determined as to their relevance to the person's goals (Endsley, 2000). The more information available, the more demanding the process is. Obviously, this makes the level vulnerable to additional tasks (e.g. conversations). The effect of additional tasks on situation awareness and how situation awareness is related to concepts of workload, working memory and long-term memory is described elsewhere (Endsley & Garland, 2000; Ma & Kaber, 2005). Based on the perceived information and their interpretation, the person forecasts future situations (level three).

What determines the selection of one action over the selection of another action? Baumann et al. (2006) and Baumann and Krems (2007) propose Norman and Shallice's (1986) theory on willed and automatic control of behavior to explain how actions are selected that seem most appropriate for performing a task in a certain situation. According to Norman and Shallice (1986), any given action sequence that is well learned is controlled by a set of schemata, with a source-schema serving as the highest order control. This source-schema activates sub-schemata. Norman and Shallice refer to the driving task as a possible source-schema. Once this schema is selected, the sub-schemata such as steering or braking get activated as well. Each sub-schema in turn serves as a new source for further sub-schemata. Furthermore, there are connections to functionally related schemata or schemata that are not compatible with other schemata, e.g. decelerating and accelerating when approaching a yellow traffic light (Baumann & Krems, 2007). Generally, a schema is connected to trigger conditions and activated once a given activation threshold is reached. A mechanism referred to as contention scheduling (Norman & Shallice, 1986). The more frequent a schema is applied, the lower the activation threshold. In Baumann and Krems' yellow traffic light example, however, the two schemata accelerate and decelerate would compete with each other for activation. In this case, further elements that are present in the given scene (level one situation awareness, e.g. perception of environmental cues) could affect the activation of both schemata. Other vehicles that are already slowing down could contribute to the activation of the deceleration schema (Baumann & Krems, 2007). On the other hand, if no other road users would be visible, the accelerating schema could receive more activation. The road environment thus, in part, determinates which schemata receive more activation. Sommer (2012) has recently demonstrated that elements on the road are more likely to be responded to than elements in the periphery. Concrete hazards such as the end of a traffic jam is more likely to trigger the schema decelerate than pedestrians on the sidewalk or speed limit signs. If a task is novel or complex and the required schema might not be available or if automatic action sequences need to be modified (Radeborg, Briem, & Hedman, 1999), an additional control structure is required: the Supervisory Attentional System (SAS) (Norman & Shallice, 1986). The SAS allows for voluntary, attentional control of performance and allows top-down influences in the action selection process (Baumann & Krems, 2007). Recall the example from 1.4.2. A driver is driving on a straight road and perceives a taxi (or any other car) driving slowly on the shoulder. The taxi driver indicates that he or she wants to enter the road. Like in the traffic light example, the driver of the other car would have several options for action, to decelerate letting the taxi enter before him or her, accelerating giving the taxi driver the option to enter quickly or maintaining the current speed not caring about the taxi driver. But, if all of these action sequences are available depends on the drivers experience with the current situation. The schema that has been chosen most frequently in the past is the schema with the lowest threshold and it is most likely to be activated (Norman & Shallice, 1986). However, recent experiences with taxis suddenly entering the road might activate different schemata or require new action sequences. In this case, the SAS would allow the driver to control which action sequence receives more activation. Another example to illustrate the importance of schemata and situation awareness would be a person who approaches a slow driving vehicle. Here, too, different options are available, overtaking or not overtaking. If the overtaking option is chosen, should the driver wait or should he or she just go ahead? In this case, it would be essential that the driver recognizes the complexity of the situation that might lead the SAS to carefully select the appropriate action. However, drivers who were interviewed for this thesis admitted that they would occasionally just overtake a vehicle without paying much attention to the situation ahead, especially under time pressure. Furthermore, some drivers admitted that they always overtake slower driving vehicles but were never involved in a head-on collision. These statements confirm the notion that schemata are more likely to be activated when they have been frequently and successfully activated in the past (see 1.1: “rule or schema retrieved from memory simply on the basis of previous successful experience”) and provide some evidence that contention scheduling is affected by various factors such as the road design (*Appendix A, Figure 5*), being in a hurry or maintaining the current traveling speed (see 1.3.1).

1.5 Driver behavior models

Driver behavior models are based on the assumption that drivers don't simply respond to stimuli, but also actively determine their driving behavior (Staubach, 2009). As such, driver behavior models add to the understanding of factors that explain both allocation policy of mental resources and the preference of one schema over another - two questions that have only been partially answered in the previous sections. Considering that road users actively determine their driving behavior, driving can be regarded as a self-paced task. Fuller (2007), who coined this notion, emphasizes that this self-pacing is associated with risky driving behavior. The extent to which a driver is willing to take risks, in turn, poses a strong mechanism that affects allocation policy of mental resources and the selection of particular schemata.

There are different models that propose theoretical foundations to comprehend risk taking behavior. According to Michon (1985), these models can be categorized into risk compensation, risk threshold and risk avoidance models. The three categories "differ primarily in the way in which they evaluate a perceived level of risk that is supposedly the control variable for the quality of driving performance (Michon, 1985, p. 501)". The most popular examples of these three categories will be briefly introduced in the following paragraphs. For a more detailed overview, refer to the references of each section. For an overview of recent models on driver behavior see also Cacciabue (2007).

1.5.1 Risk threshold models

Klebelsberg (1977) distinguishes between subjective and objective safety. The objective safety is constituted by the physical environment. The subjective safety is the safety perceived by the individual. At best, the subjective perceived safety should be lower than the objective safety. Safety improves if an increase in the objective safety is not paralleled by an increase in the subjective perceived safety (Dahmen-Zimmer & Zimmer, 1997). Michon (1985) describes Klebelsberg's model as follows. Klebelsberg postulates a control process that enables the driver to maintain a stable balance between subjective perceived safety (S) and objective safety (O). If the systems settles at a level where S = O, an ideal situation ensues. Individual road users, however, differ in their personal balance between S and O for various reasons such as mental, emotional and physiological. An equilibrium is dangerous where S > O. This situation occurs when the road user judges a situation safer than it actually is. On the other hand, S <O means a surplus safety margin.

Näätänen and Summala (1976), too, propose a threshold model. The road user's perceived risk depends on the subjective likelihood of the occurrence of a RTA as well as the consequences associated with the RTA. Under normal conditions, the road user does not assume that an RTA might occur, hence, there is no risk to compensate for (Dahmen-Zimmer & Zimmer, 1997). Näätänen and Summala's model is therefore often referred to as a "zero risk model". At first view, the notion that drivers don't expect a RTA to happen appears strange, but according to Summala, drivers have learned what to do or not to do in order to avoid RTAs. He further argues that driving has become a habitual activity based on largely automatized control of safety margins in partial tasks (Fuller, 2007). It is noteworthy, that, unlike Wilde's approach (1.5.2), Näätänen and Summala's model indicates that road safety campaigns, education or enforcement wouldn't be effective. Road safety could only be improved through better roads and vehicles (Michon, 1985). Rejecting the value of education and enforcement for road safety is contrary to many researchers' belief. It not only contradicts the triple E approach, but also contradicts empirical findings that both education and enforcements have a positive effect on road safety (Constant, Salmi, Lafont, Chiron, & Lagarde, 2008).

1.5.2 Compensation models

One of the most famous and highly disputed compensation models is Wilde's risk homeostasis theory (Wilde, 1988, 2001, 2002). Like Klebelsberg, Wilde argues that dangerous situations emerge if the objective risk is higher than the subjective risk. According to Wilde, drivers have a target level of risk - accepted risk - per unit time they try to maintain. As a consequence, drivers attempt to adjust the perceived risk to the accepted risk (Panou, Bekiaris, & Papakostopoulos, 2007). Additional safety features like ABS or wide roads wouldn't yield any benefits, because such features would lead to an increase in the perceived safety that deviates from the accepted risk. The drivers would compensate these additional safety features by engaging in more risky driving behavior. Any additional features will be compensated within two years (Sömen, 1993). In order to improve road safety, the accepted risk itself, which poses a personality trait, needs to be affected. Although Wilde has collected a great deal of evidence to support his theory, his approach has to be considered carefully. First of all, there is also a lot of data that contradicts the risk homeostasis theory (Dahmen-Zimmer & Zimmer, 1997) and secondly, it fails to specify the discriminative stimulus for risk and appears more like an economical than a psychological theory (Michon, 1985).

Wilde’s approach of changing the road users’ attitude towards risk is advocated by many researchers (Constant et al., 2008; Rundmo & Iversen, 2004). But even if everybody would drive responsibly, respecting traffic rules, conflicting situations could still occur. Wilde himself provided an example of such a situation by referring to the “psychological right of way” (2.2). The psychological right of way is based on Gestalt theory and indicates that some drivers perceive a road as the main road (having the right of way) based on “features such as pavement width, the amount of street lighting, the presence of shops, as well as by average daily traffic volume (Wilde, 1976, p. 481)”. As engineering measures would be required to alter such situations, there is little support to argue that engineering measures such as wider roads would not benefit road safety.

1.5.3 Risk avoidance models

Fuller (1984) proposes a model which incorporates most of the elements of the preceding models. Furthermore, this model is based on behavioral aspects in the sense that the road user is learning. In other words, the road users experience subjective risk and thus try to avoid it in future situations. Based on the driver's experience, a traffic situation generates a discriminative stimulus regarding possible hazards. How the driver responds to this stimulus depends on various factors such as expectations, motivations and utilities. A cautious driver is expected to eliminate the stimulus (e.g. slowing down) whereas the risky or offensive driver perceives the stimulus but doesn't adapt his driving behavior. Taking the motivations into account, driving behavior in certain situations could be predicted. Under certain circumstances, even a cautious driver could ignore the threatening stimulus.

Fuller further developed his approach and introduced a model known as the task capacity model (Fuller, 2000; Fuller & Santos, 2002). The task capability model focuses on task difficulty. Task difficulty arises due to the discrepancy between demands of the driving task and the driver's capability. If capability > task demand, the task is easy, if capability = task demands, the road user is operating at his or her limits. Every additional task (e.g. use of mobile phone) increases the demand and thus increases the risk for a RTA to occur. Other road users can rescue an unsafe situation. By anticipating the dangerous situation caused by a driver whose capabilities are lower than the actual task demands, a pedestrian, for example, could decide not to cross the road thereby changing the task demand for the driver (Fuller, 2005). Since Fuller claims his approach to be a step towards a general driver behavior theory, it is worth having a closer look (Fuller, 2005).

Fuller proposes to divide road traffic into four elements. The first element is the environment that consists of the roads, traffic signs etc., the second element are other road users, the third element is the vehicle and the fourth element is the driver. Driver capability depends on the driver's characteristics such as information processing capacity, reaction time, etc. These characteristics form the basis for knowledge and skills that have been acquired from training and experience. Based on his or her motivation, the driver decides how he or she allocates the mental resources.

Furthermore, Fuller describes two sub-elements that are under direct driver control, namely, speed and trajectory, where speed is considered the more important of the two sub-elements. Speed, for example, can be used as a method in order to increase the driver's level of arousal. The level of arousal is an important point in Fuller's model. Fuller argues that the level of arousal depends on the individual's circadian rhythm, but also on external stimuli. Especially in the case of extraverted people who have a rather low level of endogenous arousal and therefore seek external stimuli in order to achieve a higher level of arousal. According to Fuller, the driving task poses such an external stimulus. Consequently, some drivers might consciously seek a higher task demand in order to affect their level of arousal.

The aforementioned aspects affect task difficulty and for Fuller, these arguments are sufficient to claim that it is task difficulty that determines driver behavior and not other factors such as risk assessment. But how exactly is task difficulty associated with driving behavior? Fuller assumes that a driver, before he or she starts his or her journey, determines a range of task difficulty he or she is willing to accept. For example, if someone is in a hurry, he or she might be willing to accept a higher level of task difficulty as it is more important to arrive in time than safely. Speed choice is in this regard again the important aspect. The range of task difficulty is mostly determined by speed choice. Fuller demonstrated that task "difficulty is closely related to speed, throughout the speed range, but ratings of statistical risk remain at zero at lower speeds but increase fairly rapidly after the critical threshold is reached (Fuller, 2005, p. 469)". Also, drivers perceive speeds as dangerous when they are subjectively associated with an estimated risk of crashing.

2. Road design

2.1 The driving task and the road design

Engineering measures are the most costly method to improve road safety. Accordingly, it is important that these measures yield the desired effects. Taking into account the extent to which the HRI contributes to the occurrence of RTAs, it is crucial to design and modify roads under consideration of the human factor. Any modification has to aim at affecting the road user at the appropriate level (strategic, maneuver, control). "Just putting up a sign which indicates the driver should change lanes without actually providing lane markings on the road to guide the delineation maneuver would be an example of providing information at the wrong level. Signs to warn the driver that a delineation is coming up are important; yet, to let the driver negotiate the lane change maneuver at the appropriate level of the task hierarchy it is absolutely crucial to also provide information at the control level (i.e., by providing lane markings) (Theeuwes, 2001, p. 243).

The association between the road design and the task hierarchy levels will be discussed in the following paragraphs.

1. Strategic level: Theeuwes (2001) claims that the road design doesn't play an important role at the strategic level. With regard to aspects of the strategic level such as the goal of the trip (e.g. work vs. leisure), he argues that people might chose a route not because it is a fast route, but because it is a nice route. In such a case, the road user might spend more time observing the environment instead of the traffic scenes ahead. However, it is important to consider the performance level at which the strategic level tasks take place (*Table 2.1*). If the task takes place at the skill based level, it seems rather difficult to affect the driver behavior. Martens and Fox (2007) have demonstrated that although drivers glance at traffic signs that indicate a modification on familiar roads, they are likely not to adapt their driving behavior. On the other hand, drivers in unfamiliar environment do search for information (e.g. way signs) (the presence of way signs reduces the risk of RTAs (May & Ross, 2006; Yannis, Golias, & Papadimitriou, 2007)). In other words, the relevance of the strategic level for the HRI depends on the performance level. The more skilled a road user is / familiar with the environment, the less likely he or she is to refer to road signs. If the road user consciously searches for road signs, the sole presence of road sign is not a sufficient condition to provide the road user with valuable information.

2. Maneuvering level: The environment has a large impact on the maneuvering level (Theeuwes, 2001). Yet, as with the two other levels, this effect depends on the performance level at which the tasks at the maneuvering level takes place. More importantly, however, are the goals defined in the strategic level. Michon argues that the maneuvers executed at the strategic level "must meet the criteria derived from the general goals set at the strategic level (Michon, 1985, p. 399 f)". In other words, there is a great difference between a driver who is in a hurry and one who is not in a hurry. Generally, maneuvering level tasks are rule based, that is, schemata are executed based on the goal (e.g. go home as fast as possible) or the situation itself (Rasmussen, 1985). On a usual day driving home, a driver activates the schema "drive home" which subsequently activates other schemata. Since the way home is familiar, these schemata will follow a fixed procedure. If, however, the driver visits a friend and encounters a new road situation, available schemata will be activated. He or she might enter a road that according to the driver's expectations looks like a highway. As a consequence, the highway schemata will be activated and the driver might drive at high speeds. In

order to affect the driver at the maneuvering level it is therefore crucial to understand how the driver categorizes roads (2.2). These categorization processes have to be considered when designing roads so that the road design is in accordance with the drivers' categorization mechanism; an approach commonly known as the Self Explaining Road (SER) (2.3) (Theeuwes, 1998; Theeuwes & Diks, 1995; Weller, Schlag, Friedel, & Rammin, 2008). Another condition that needs to be fulfilled in this regard is driver education. A driver needs to learn that excessive speeds are not allowed and possible in certain environments. For German readers, for example, this might be trivial because every road user in Germany knows that the speed limit in built-up areas is 50 km/h. This, however, might not be the case in other countries (e.g. Oman).

3. Control level: The control level is the lowest level of the hierarchy. Since tasks at the control level are mostly performed unconsciously (Theeuwes, 2001) it seems difficult to affect the driver at this level. Nevertheless, the road design can have a positive effect on this level by the presence of certain design elements such as road markings. Summala et al. (1996) have demonstrated that experienced drivers are able to maintain stable vehicle control although focal attention is not directed to the road markings. In addition to that, the presence of objects can distract the driver. The literature on gaze direction in curve driving has revealed that drivers gaze at the tangent point of the curve, something we do unconsciously. If objects would be present at the outer side of the curve, visual attention could be distracted. The role of road markings will be elaborated in 2.5.4.

2.2 Road categorization

The first approaches on road categorization have been suggested by Undeutsch (1958, as cited in Dahmen-Zimmer & Zimmer, 1997). Based on Gestaltpsychology, Undeutsch defined principles (or laws) according to which road users intuitively categorize roads. These principles are:

1.The shape (e.g. road width, surface) of the road determines the right of way.

2. Roads with a high traffic density have the right of way.

3. As long as there is no obvious change in the rank of the roads (determined by the shape), no change in the right of way takes place.

4. Traffic that goes straight always has the right of way, as opposed to turning traffic.

A more recent model for road categorization which encompasses different approaches such as Gibson’s ecological approach and schema-theory has been proposed by Weller et al. (2008). The starting point of this model is the objective road geometry / situation (presence of design elements such as road width or sight distance). However, it is not the objective road situation that impacts driving behavior, but rather the perceived image and thus the subjective road situation. In this context, the properties of the situation gain importance. These properties are conveyed by affordances. Affordances were introduced by Gibson (1986). "According to Gibson, objects have properties which become affordances in relation to the properties of an individual...an affordance conveys a meaning to the onlooker in the sense of being...-able, for example being climbable...the element is drivable within a certain speed and attention range (Gibson, 1986, as cited in Weller et al., 2008, p. 1582)." Any road might thus convey the meaning of being drivable at different speeds. In addition to the affordances, the characteristics determining the road environment serve as discriminative stimuli indicating to the driver which consequences to expect when showing the respective behavior. As different "filters" might avoid the perception of single stimuli, Weller et al. refer to Fuller (1984) who proposes to understand the whole scene as one "integrated discriminative stimulus". In this context, the stimulus is referred to as "cue". Lastly, the drivers' knowledge and experience have to be taken into account, as these two factors are relevant for the level of task performance at which the behavior is executed. According to Weller and his colleagues, the cues as well as the affordances are the major aspects that need to be considered when defining road categories. Note that the authors stress the importance of further aspects that need to be considered in this model (e.g. risk perception). Furthermore, such models are difficult to apply for "driving fun" with is one of the major factors determining speed choice (Steyvers, Dekker, Brookhuis, & Jackson, 1994). The process of road categorization is illustrated in *Figure 2.6*.

2.3 The self-explaining road (SER)

The previous section theoretically explains how road users categorize roads. Road designers should design roads that meet the road users' expectations by taking their subjective categorization into account, an approach known as SER. The term SERs is thus applied to "those road designs which communicate to the driver what type of roads they are, or that can be easily categorized by drivers as requiring specific kinds of behavior (Dewar, 2002, p. 383)". For example, the road user enters a road, categorizes it as a highway and chooses the appropriate speed accordingly. There are a number of requirements associated with SER. According to Matena (2006), SERs need to be (more detailed requirements can be found in: Theeuwes & Godthelp, 1995):

1. Recognizable: Roads with the same function should look similar.

2. Distinguishable: Roads of different categories should have different layouts. There shouldn't be more than three to four different categories.

3. Easily interpretable: The desired driving behavior has to be clear. The measures used for differentiating should induce the desired behavior.

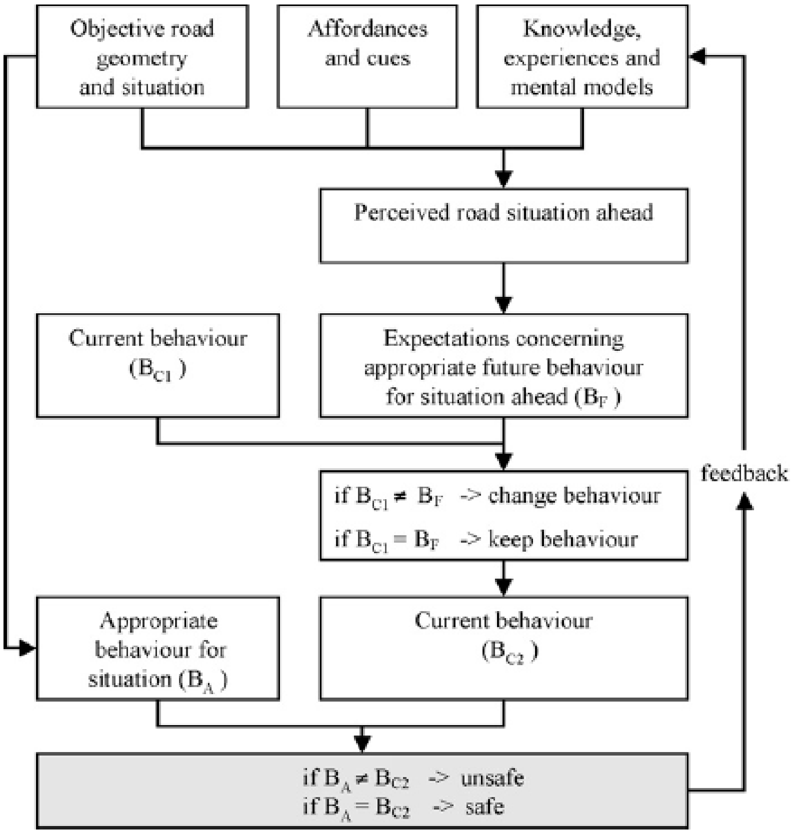

Figure 2.6. Subjective road categorization according to Weller et al. (2008), with permission from author. The driver forms expectations concerning the behavior for the situation ahead (Bf) based on the past and current situation, comparing the expected behavior for the situation ahead to the current behavior (Bc1). Should maintaining the current behavior result in a discrepancy to the expected behavior, the current behavior would be adjusted in an appropriate way. If the behavior that results from the comparison process (Bc2) deviates from the situation (Ba), the situation is considered potentially unsafe.

Which design elements determine road categorization has been investigated by a number of researchers. The results, however, are not always consistent. Goldenbeld and Van Schagen (2007) conducted a study in which they presented photos of different Dutch rural roads with a posted speed limit of 80 km/h to the participants. All roads differed in their design. The participants were asked about the speed they would choose when driving on these roads. The average chosen speed was about 8 km/h higher than the posted speed limit. With regard to the road design, the results revealed that high chosen speeds were associated with the absence of curves, buildings alongside the road, better than average sight distance, clarity of the situation, road width and the view to the right of the road. Kapstein et al. (2002) conducted a simulator study in order to investigate driving behavior on different kind of roads. The results are in line with Goldenbeld and Van Schagen's results. If houses or trees were present, the participants drove at lower speeds compared to roads that had no objects alongside the road or roads with dual carriageways. In an earlier study, Kapstein et al. found that center line marking (interrupted vs. continuous), road surface color (light vs. dark grey) and reflector posts (present vs. absent) don't affect driving speed. Road width (2 m vs. 3,6 m) and the presence of bicycle lanes had effects on driving speeds. Driving speeds were higher under the wide road condition as well as under the condition in which bicycle lanes were present. Interestingly, Riemersma (1988) reports that the probability of encountering other road users doesn't affect estimated driving speed. This notion clearly contradicts Kapstein et al. (1998) findings, who report higher estimated speeds for dual carriageways and lower estimated speeds when bicycle lanes are present. The negative effect of road width on driving speed is confirmed by Edquist et al. (2009) and Elvik et al. (2004). With reference to Van Schagen et al. (1999), Matena et al. (2006) also confirm that road width is used by road users to categorize the road and adjust their speed accordingly. Additionally, they argue that, among others, the number of carriageways / lanes, road condition, road environment as well as road markings affect subjective road categorization.

It was argued that there are different elements in the road design that are used to categorize roads. This categorization eventually affects driving behavior (estimated driving speed). With regard to these elements, Kapstein et al. (1998) demonstrated that road users seem to have difficulties in categorizing roads based on various elements (Kapstein et al. use the term dimension). They are able to refer to one or two elements to categorize a road but cannot learn new categories when three elements are present at the same time. For example, road users may refer to road width and presence of bicycle lane in order to learn a specific road category. The presence of a third element would impede the learning process.

Steyvers et al. (1994) investigated psychological aspects associated with the road environment. Steyvers and his colleagues developed a Road Environment Construct List (RECL) that consists of three factors, namely hedonic value, activational value and perceptual variation. Weller et al. (2008) applied the RECL on rural roads in Germany. A factor analysis with the RECL items was calculated. The factor analysis revealed three factors that explained almost 70% of the variance. The three factors were similar to Steyvers factors and named monotony, comfort and demand. The factor monotony describes a state of monotony mainly caused by underload. The second factor comfort represents a feeling of happiness when driving through a nice landscape whereas the third factor describes the necessity of constant alertness due to possible dangers caused by information overload. Interestingly, the third factor turned out to be insignificant in predicting speeding behavior.

The most important variables in predicting speeding behavior were the variables of the comfort factor. The authors conclude that the higher the comfort and monotony factor values are, the higher the selected speed is. This conclusion is in line with Fuller's task capacity model. If the road is associated with comfort, the driving task is most likely not demanding. Consequently, drivers would select high speeds. On monotonous roads, drivers would select high speed in order to increase their level of arousal.

Similar to the two previous approaches on how roads are categorized, Mazet and Dubois (1988, as cited in Theeuwes, 2001) argue that road users categorize roads based on the behavior each road displays. Roads that display the same behavior will be categorized into one type of road. This categorization, however, not only depends on the environment, but also on other road users' behavior, that is, if everybody drives 80 km/h in a residential area, road users might think that 80 km/h is the appropriate speed although the speed limit is 50 km/h (Theeuwes, 2001).

The reviewed literature suggests that road width and presence of possible hazards such as trees have the largest impact on road categorization. In other words, safe roads are perceived as categories that allow higher speeds. This notion is partially in line with Mazet and Dubois' (1988) theory on the display of specific behavior, as well as with affordances. Affordance play a crucial role, especially in environments that are rather "new" (modern roads can still be considered as something new in a country like Oman). The role of affordances can be illustrated by an example introduced by Norman (2002). Think about a pair of scissors. Since you are familiar with scissors you wouldn't think about how to use them and probably just use them more or less automatically. "Even if you have never seen or used them before, you can see that the number of possible actions is limited (Norman, 2002, p. 12)." The number of actions is limited, because a normal pair of scissors is well designed. However, despite the number of possible actions, it is well possible to use it for different actions like piercing. Now imagine a road with a bicycle lane. As previously mentioned the presence of bicycle lanes in the Netherlands leads to lower perceived speeds, most likely because the drivers respect the cyclers and are concerned with their safety. Wide lanes without bicycle lanes, on the other hand, lead to higher estimated speeds. The presence of bicycle lanes and cyclers is something normal in everyday road traffic in the Netherlands; but imagine a country in which cyclers are not common and where there are no bicycle lanes. The moment you introduce a bicycle lane in such a country, the total road width would increase (depending on the type of bicycle lane). Whereas a Dutch driver would most likely respect the bicycle lane as he or she knows it is reserved for cyclers, other drivers from this respective country might perceive the new road as a very wide road that affords (is for) high speeds. This notion is confirmed by other researches who argue: "The effect of road width on driver speed choice seems to depend on the amount of pavement the driver perceives as usable. (Edquist et al., 2009, p. 6)"

In general, it can be concluded that the concept of SER works, yet requires more research. In this regard, it should not be forgotten that this categorization also depends on individual / motivational factors as well as cultural factors that are very difficult to consider when investigating road categorization. Although it is difficult to name the factors determining subjective road categorization with certainty, researchers commonly agree that road users do refer to subjective categorization and that subjective road categorization often differs from the official categorization (Becher et al., 2006; Kapstein et al., 1998; Riemersma, 1988). Once again, the idea of the engineer who designs the road might differ to a great extent from how the road users actually perceive the roads.

2.4 The forgiving road

As described in the previous section, the idea behind the SER is that the road design itself induces a desired behavior. The goal is to reduce accident risk by preventing human error, "while a forgiving road design aims to reduce accident risk by correcting human error, and to mitigate accident consequence (Lu, Wevers, & Bekiaris, 2006, p. 4)". There are some designs that are characteristic for forgiving roads:

- "Median barriers to help prevent high severity head-on crashes.
- Roadside barriers to redirect out-of-control vehicles away from potential roadside hazards.
- Clear roadside areas (known as clear zones) where there are no obstacles, such as trees, that a vehicle could hit.
- Roadside slopes that enable a vehicle driver to either regain control or bring their vehicle to a safe stop. (NZTA, see also ETSC)"

Roads can be both self-explaining and forgiving, but recalling driver behavior, it should be kept in mind that forgiving roads "invite" drivers to more risky driving behavior. According to Fuller, for example, changes in the alignment (e.g. straight instead of curved) could lead to a decrease in task difficulty (Kanellaidis & Vardaki, 2010). As a consequence, road users might engage in risky behavior such as speeding, overtaking or writing text messages. Measures to improve safety should therefore be implemented in a way so that the "safety surplus" is not too obvious.

2.5 Design elements

(Road) design elements refer to all elements a road consists of. Design elements are for example speed, sight distance, radius, super-elevation or number of carriageways. Traffic signs are generally not considered as design elements, but will be treated as such within the framework of this thesis. Design elements such as lane width consist of properties. The properties of lane width would be the actual width in meters.

2.5.1 Design and posted speed

Speed is a major risk factor for RTAs (Elvik et al., 2004; Zimmermann, 2009). When talking about speeding, the author generally refers to a behavior that is related to an inappropriate speed choice for the prevailing conditions (e.g. driving too fast on a wet road or entering a curve at high speeds). Considering the various, well documented, human factors that contribute to speeding (e.g. Finn & Bragg, 1986; Schmid Mast, Sieverding, Esslen, Graber, & Jäncke, 2008; Whissell & Bigelow, 2003), it is crucial to investigate how speeding behavior is related to the road design. The section on SERs has already provided a good overview of the elements that affect speeding behavior. This section further discusses the relationship between roads and speed and focuses on the role of posted speeds (speed limits) and design speeds.

Table 2.2 shows the distribution of road types related to speeding related fatality rates in the USA in 2006. The majority of fatalities occurred on non-interstate roads (72 %); 43 % occurred on high speed non-interstate roads with a speed limit of 72 km/h or more whereas only 29 % occurred on low speed non-interstate roads with a speed limit of 64 km/h or less. These figures suggest a relationship between road type and speeding related RTAs. Some road characteristics for the same data are presented in *Table 2.3*

Table 2.2. Speeding RTAs by road type in the USA, 2006 (Neuman, 2009). 55 mp/h = 88 km/h, 40 mp/h = 64 km/h, 45 mp/h = 72 km/h

Road Type	Speed Limit	Speeding-Related Traffic Fatalities	Percentage of Total Speeding-Related Traffic Fatalities
Interstate	Greater than 55 mph	1,373	10%
	Less than or equal to 55 mph	371	3%
Non-Interstate	Low (40 mph or less)	3,969	29%
	High (45 mph or more)	5,793	43%
Unknown	Unknown/No Statutory Limit	2,037	15%
Total		13,543	100%

Table 2.3. Speeding related RTAs and road characterizations, USA, 2006, (Neuman, 2009).

Trafficway Flow	Speeding-Related Fatal Crashes on High-Speed Roads	Percentage by Trafficway Flow	Total Fatal Crashes on High-Speed Roads	Total Fatal Crashes on All Roads
Two-Way Undivided	4,916	62%	19%	13%
TWLTL	132	2%	0%	0%
Divide without Barrier	1,642	21%	6%	4%
Divide with Barrier	1,053	13%	4%	3%
One-Way	37	0%	0%	0%
Ramp	169	2%	1%	0%
Unknown	25	0%	0%	0%
Total*	7,974	100%	30%	21%

The data in *Table 2.2* and *2.3* is very interesting. The majority of speeding RTAs occurred on roads with two undivided lanes and most RTAs (71 %) were single vehicle RTAs (Neuman, 2009). The data clearly speaks in favor of forgiving roads. Although behavioral adaptations could have been expected, the overall safety effect of wide roads seems to be confirmed. Nevertheless, it is difficult to make statements as long as the circumstances for the RTAs are not known. According to the guidelines in the USA, an RTA is categorized as a speeding RTA as soon as the driver who was involved in the RTA exceeded the speed limit. This practice might bias the data that is necessary for the investigation of RTAs. According to the American Association of State Highway and Transportation Officials (AASHTO), it is common practice that the posted speed (speed limit) is about 8 km/h lower than the design speed (Neuman, 2009). If the design speed would be the maximum safe speed on a road section, it is unlikely that speeding contributed (as a main contributing factor) to the RTA if the driver didn't exceed the posted speed by more than 8 km/h. If he or she exceeded the posted speed by more than 8 km/h, speed would have been a contributing factor if the design speed is indeed the maximum safe speed. These thoughts require some clarification regarding design and posted speed.

Speeds are generally specified in the road design manuals published by the departments / ministries of transportation of countries or states (e.g. states of the USA). The most common speeds that are specified in road design manuals are design speed, operating speed, running speed and 85 percentile speed (V 85) (Fitzpatrick, Carlson, Brewer, Wooldridge, & Shaw-Pin, 2003). But even among different design manuals, the definitions of these speed categories are not consistent (EU, 2003; Fitzpatrick et al., 2003). A good overview on the different definitions of design speed can be found in Fitzpatrick et al. (2003) and Polus et al. (1995). In many guidelines (e.g. OHDS, 2010), the design speed is defined as the maximum safe speed on a road with respect to the design geometry of its horizontal and vertical alignments. This definition suggests that exceeding the design speed drastically increases the RTA risk. The term "safe" has also been included in the design speed definition of the AASHTO (1994). But experts of the AASHTO recognized that operating or posted speeds greater than the design speeds wouldn't necessarily compromise safety and thus removed the term "safe" from the definition in order to avoid the perception that speeds greater than the design speed were "unsafe" (Fitzpatrick et al., 2003). The recent definition of design speed as suggested by the AASHTO is a rather practical one: "Design speed is a selected speed used to determine the various geometric features of the roadway. The assumed design speed should be a logical one with respect to the topography, anticipated operating speed, the adjacent land use, and the functional classification of the highway" (USDT, 2007). An important aspect of this definition is the anticipated operating speed. It is the (anticipated) operating speed or 85th percentile speed that should determine the design speed and not the desired posted speed limit, unless the speed limit is based on the 85th percentile speed (AASHTO, 2004). The 85th percentile speed is the 85th percentile of the distribution of observed speeds at a point on the highway. Furthermore, the design speed has to take into account various factors such as the roadside environment, driver characteristics, familiarity with the road, etc. (AASHTO, 2004; USDT, 2007).

Although exceeding the design speed does not necessarily increase the RTA risk in a particular case, there is evidence that high speeds are generally associated with a high RTA risk (Elvik et al., 2004) and that posted speed limits considerably contribute to a decrease in RTAs. Lamm and Kloeckner (1984) investigated speeding behavior on a German highway section with no posted speed limits. About 90 % of the cars exceeded the design speed. After a 100 km/h speed limit was posted, the average speed decreased by 30 km/h and after the installation of speed cameras, the average speed decreased by another 20 %. Both measures, the speed limit and the surveillance, resulted in a 91 % reduction in RTAs on this highway section. One possible reason why the speed limit on the German highway led to a reduction in RTAs could be found in the negative consequences (e.g. fines) road users were expecting when exceeding the speed limit. The additional decrease in average speed as soon as cameras were installed might confirm this explanation. The need to enforce speed limits has often been emphasized and most researchers agree that speed limits without enforcement are not very effective (Zimmermann, 2009). If speed limits are not enforced, it is likely that they are ignored. According to Fuller, drivers choose a safe speed at which they travel to prevent an increase in task difficulty (see also preferred speed, 1.3.1). The chosen safe speed might be above the posted speed limits. The more familiar a road user is with the road, the more likely it is that he or she travels at high speeds. If speed limits are not enforced, why would he or she deviate from his or her preferred speed? Strict enforcement is therefore a necessary condition for posted speed limits to be effective.

There is no doubt that speed limits and their enforcement are among the most important factors to ensure road safety. But how are posted speed and design speed related to each other? Should the design speed always be greater than the posted speed as recommended by the AASHTO?

Generally, researchers argue that drivers adapt their speeding behavior to the behavior of the majority of road users (OECD, 2006). When entering a highway on which the majority of drivers are driving at 130 km/h, a driver would, unless he or she is in a hurry or thrill seeking, most likely adapt his or her driving speed to the speed of the other drivers and drive at 130 km/h. The lower the variance in speed, the less demanding the driving task is. This explanation is in line with Fullers task capacity model (Fuller, 2000). But what determines the speed of the majority of drivers? Why are they driving at 130 km/h and not at 150 km/h? Again, it could be argued with Fuller's approach that drivers are likely to choose the speed they find appropriate for the environment which affects task difficulty. If a road was designed for 130 km/h, this design would affect task difficulty. A driver might recognize that it is not possible (without experiencing an increase in task difficulty) to drive at speeds that are much greater than 130 km/h. In fact, there is evidence that drivers choose speeds they find to be appropriate with regard to the road and the environment (Edquist et al., 2009) (see also 2.3). Hence, posted speed limits should be in accordance with the driver’s idea of what the appropriate speed for a given road is. This requires that the environment (e.g. presence of trees) has to be considered as well. It was previously shown that drivers don't choose the same speed on two roads with the same road width if one road has trees alongside the road and the other does not. Having said that, it can be concluded that there shouldn't be a difference between design and posted speed; a conclusion that is confirmed by various studies (e.g. Archer, Fotheringha, Symmons, & Corben, 2008; Jongen, Brijs, Mollu, Brijs, & Wets, 2011; Wilmot & Khanal, 1999).

Another aspect that speaks in favor of posted speed limits that correspond to the design speed is speed variance. Speed variance is a high RTA risk factor (Elvik et al., 2004; Garber & Gadiraju, 1989). Considering two different kinds of road users, the law abiding citizen who always adheres to the speed limit and the citizen who would rather choose their speed based on the design of the road (design speed), adjusting the posted speed to the design speed would logically lead to a decrease in speed variance. Although some researchers (Garber & Gadiraju, 1989) argue that speed variance is lowest when the posted speed is 8 km/h to 16 km/h lower than the design speed, there is more evidence that speed variance won't decrease if the posted speed is lower than the design speed (McCarthy, 2001; Wilmot & Khanal, 1999). Note, however, that although posted speeds should be in accordance with the drivers' expectations and the design speed, speed limits should not be increased on a given section. The recommendation that posted speed and design speed should be identical should be considered in new designs. Increasing the speed limit on an already existing road section can lead to higher RTA risk (Baum, Lund, & Wells, 1989; Casey & Lund, 1992).

To summarize, the following aspects should be considered:

- ⇨ Posted speed should not be greater than design speed.
- ⇨ Posted speed and design speed should be equal.
- ⇨ Posted speed should be in accordance with the road drivers preferred speed choice (V 85).
- ⇨ The posted speed needs to consider the road design (e.g. road width, roadside development).
- ⇨ Roads with the same design (same category) need to have the same posted speed limits.
- ⇨ Speed limits do work, but have to be enforced.
- ⇨ Speed variance needs to be as low as possible.
- ⇨ Don't increase speed limits on already existing road sections, only consider the recommendations in new designs.

2.5.2 Sight distance

Many RTAs occur due to information errors (e.g. the view was obstructed by a tree or the driver didn't perceive the oncoming vehicle due to an incline). In order to minimize the likelihood that such errors occur "the sight distance must be sufficient for a driver to perceive potential hazards which may or may not be conspicuous (Basacik et al., 2007, p. 26)." Additionally, it must be ensured that the driver has enough time to process the perceived information and to make appropriate decisions. As a result, sight distance is a crucial aspect in highway engineering.

In highway engineering, the sight distance is determined by various factors such as the driver eye height (underlying values 3,5 ft / 1,07 m according to AASHTO), brake-reaction time (assumed value 2,5 sec according to AASHTO), and object height (2 ft / 0,61 m according to AASTHO) (Brockenbrough, 2009; CCG, 2007). It can be distinguished between different types of sight distances, namely stopping sight distance, passing sight distance, intersection sight distance and decision sight distance. Note that the underlying values vary among the different types of sight distance. It is worth mentioning that not all of them are necessarily considered in certain design manuals and / or the definitions of each type varies among different design manuals (TRIOS, 1997). The highway design manual of the State of New Jersey (USA) only distinguishes between stopping and passing sight distance (NJDOT), whereas the Omani Highway Design Standards distinguish between stopping, passing and decision sight distance (OHDS, 2010). The Texas Department of Transportation considers all of the aforementioned types of sight distances (TDOT).

Stopping sight distance

The stopping sight distance is the distance ahead that a driver should be able to see so that he or she can bring his or her vehicle to a safe halt short of an obstruction or object on the road. It is crucial to consider both the vertical as well as the horizontal stopping sight distance. In curves, the horizontal stopping sight distance might be restricted by crash barriers, bushes etc. In vertical curves, sight distance can be restricted due to inclines (Brockenbrough, 2009).

Passing sight distance

The passing sight distance is the minimum sight distance that allows a driver to pass another vehicle safely and comfortably, without conflicting an oncoming vehicle that travels at the design speed (NJDOT). Passing sight distance is generally applied on single carriageway roads only. It should be ensured that the passing sight distance is provided for as much of the road length as possible (Brockenbrough, 2009).

Intersection sight distance

A driver who waits at an intersection and wants to enter or cross a road needs to observe the traffic at a distance in order to find a gap that allows him or her to enter the road. The driver who has the right of way should have a clear view on the intersection. This includes all other vehicles that want to enter, cross or turn (Brockenbrough, 2009). A common method to provide enough sight distance at intersections is the application of "sight triangles". *Figure 2.7* shows a sight triangle. A indicates the waiting driver's position, B, the approaching driver's position and C, the intersection of the two paths, assuming that the waiting driver would drive straight ahead. The shaded area in Figure 2.7 should be free of objects that could obstruct the view of either the waiting or the approaching driver.

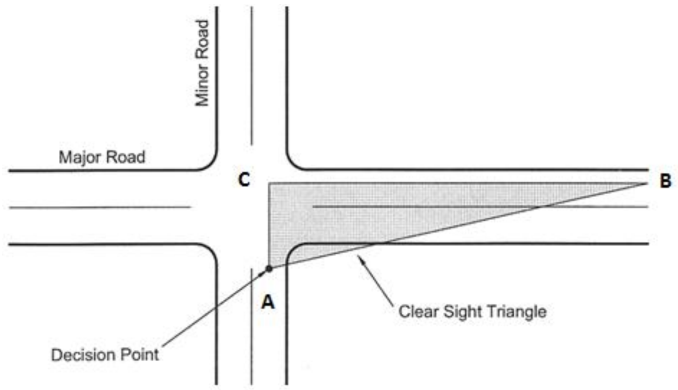

Figure 2.7. Sight triangle, modified version from Rodegaerdts et al. (2004). For explanation see text.

Decision sight distance

While stopping sight distance is considered to be the distance a competent driver requires to perform a hurried stop under normal circumstances (Brockenbrough, 2009), decision sight distances are required in situations where the driver needs to maneuver the vehicle into a particular lane (e.g. exit ramps, left turn lanes). Decision sight distances are thus greater than stopping sight distances.

If the different types of sight distances are considered in the road design, the design generally appears to be safe. In this regard, however, it must be ensured that any design elements (e.g. roadside development) considers the respective values for eye height, brake-reaction time and object height. For example, since the underlying object height is 0,61 m according to the AASHTO, crash barriers or bushes must not be greater than 0,61 m. But even though these values are considered, objects such as bushes can have an adverse effect on traffic safety (*Appendix A, Figure 1*). Another important aspect with regard to the human factor is the brake-reaction time. The AASHTO value for brake-reaction time is 2,5 sec. Studies have demonstrated that this value generally encompasses most of the driving population and is therefore an appropriate value for road design (Fambro, Koppa, Picha, & Fitzpatrick, 1998).

Table 2.4. Translated and modified version from Burg (2009). The different steps of reaction time in the context of the driving task.

Perception	Time from the occurrence of stimulus (signal) to visual or auditory perception.
Detection (Processing)	Time from perception to the awareness that the situation requires an appropriate action.
Decision	Time from awareness to decision on appropriate action.
Human motor activity	Saltatory conduction and muscle activation. 0,005 - 0,05 sec.
Implementation	Releasing the foot from the accelerator and first contact with the brake pedal. 0,15 - 0,3 sec.
Time initial response	Overcoming the play and the elasticity in the steering and brake system. 0,015 - 0,05 sec.
Build-up time	Building maximum pressure. 0,15 - 0,3 sec.

Nevertheless, it is worth having a closer look at the brake-reaction time. The brake-reaction time can be divided into several stages (*Table 2.4*). In general, reaction time can be understood as the timespan between the occurrence of a stimulus that requires an action and the first action that is executed in order to respond to this stimulus (Burg, 2009). When approaching an intersection, this stimulus could be a stop sign. According to Burg (2009), the time-span between the occurrence of the stimuli and the action (decelerating / braking) can be divided into stages as shown in *Table 2.4*. It is almost impossible to discriminate between perception and detection-time, as both processes depend on the driver's level of attention. Any additional tasks would have a negative effect on perception and detection-time. The decision-time depends on the possible options available (e.g. turning left, turning right). In other words, decision-time increases the more options are available (Burg, 2009). It can thus be concluded that not discriminating between stopping and decision sight distance is detrimental for road safety.

Summala (2000) conducted a literature review on brake-reaction time. He came to the conclusion that research on brake-reaction time requires more real-life data on driver reactions. Fambro et al. (1998) who confirmed that 2,5 sec. is sufficient carried out their experiments under real driving conditions. However, Summala points out that situational and driver-centered variables are generally not considered sufficiently. To consider these aspects is not only important for brake-reaction time, but for sight distance in general. It could be argued that the required sight distance depends on the task level and the level of situation awareness. Imagine a driver who is driving on his or her daily route to work. He or she always crosses an un-signalized intersection. The sight distance is very good and nothing obstructs the view. The driver is coming from the minor road and intends to cross the major road. Since the sight distance is very good and the driver can observe the traffic on the major road from a distance, he or she might just glance to the right and the left before crossing the intersection instead of performing a full stop which would allow him or her to observe the traffic on the major road more carefully. Studies on sight distance at railway intersections have found that restricted visibility is not necessarily associated with crashes. Ward and Wilde argue that the evidence that restricted lateral visibility at railway crossings is hazardous has not been forthcoming in spite of its apparent plausibility (Ward & Wilde, 1996, as cited in Wallace et al. 2008). In this regard, the aspects of objective and subjective safety must also not be forgotten. The better the sight distance is, the higher the perceived subjective safety.

To summarize, the following aspects should be considered:

- ⇨ The values of the design guidelines (AASHTO) are generally sufficient.
- ⇨ Any modification to the road environment must not interfere with these values.
- ⇨ Despite these values, objects can still pose a hazard.
- ⇨ The present and future roadside development should be considered when implementing design guidelines regarding sight distances.
- ⇨ Considering driver behavior and risk perception, a good view may not necessarily increase safety.
- ⇨ Decision sight distance should consider any possible actions a driver might perform and the time he or she needs to perceive road signs and make decisions.
- ⇨ Design manuals should distinguish between decision and stopping sight distance.
- ⇨ Lastly, it should be considered that worn out tires have a negative effect on stopping distance (Alexander, Brieschke, Quijano, & Yip, 2006). In countries where many people don't change their tires as instructed by the tire companies, this problem should be considered when calculating the sight distances.

2.5.3 Road signs

"Reading traffic sign information correctly is crucial. It helps the transport operator (car driver, pilot or train driver) to anticipate future situations, make decisions, and start to carry out appropriate motor responses (Castro, Horberry, & Tornay, 2004, p. 50)." The question is, however, do road users refer to road signs and / or are road signs effective?

Johansson and Rumar (1966) attempted to answer this question by trying to find the number of road signs recorded by a driver during the course of a car journey under the most favorable conditions and to find to what degree road signs act as signals, e.g. affect driving behavior. Although some participants of the study conducted by Johansson and Rumar recorded 90 % of the signs, the authors conclude that drivers cannot be expected - even under optimal condition (e.g. no distraction) to record every sign. Interestingly, the factor "familiarity with the road" didn't affect the number of recorded road signs. With regard to the effect of road signs on driving behavior, Johannsson and Rumar found that compliance depends on the personnel risk associated with the sign. Signs like "speed zone warnings" and "police control signs" had the highest effect on driving behavior, whereas "pedestrians crossing signs" had the lowest effect. The researchers conclude that drivers comply with the road signs if they are afraid of the negative consequences. In other words, the possibility of getting fined is a greater incentive to slow down than the possibility of encountering a crossing pedestrian. Note that the study was conducted in Sweden. In 1967, Sweden changed from left-hand to right-hand traffic. This change was highly discussed and to a great extent against the will of the Swedish people. These events could have had an effect on the results of the study. Yet, similar results were reported by Sommer (2012). Although she didn’t focus exclusively on road signs, she demonstrated that information perceived by the driver is rated and responded to according to the relevance for the driver.

Summala and Näätänen (1974) report that drivers are able to recall most of the traffic signs they pass if they are motivated enough , whereas others report that memory for signs is very often poor (Fisher, 1992). The latter is associated with the limited capacity of the working memory. Items that are not repeated are no longer remembered after a time-span of approximately 30 sec. (Becher et al., 2006). Whether drivers pay attention to road signs depends on the driver. There are drivers who are actively searching for information and there are drivers who are not actively searching for information (Martens, 2000). According to Martens (2000), the former requires that road signs are conspicuous and the latter requires that the road sign's message needs to be significant. The relevance of conspicuity for the visual search has already been discussed in section 1.3.4. Furthermore, it has been argued that driving behavior is based on expectations (1.4.2) and consequently, road signs should be placed where the road users expect them (Borowsky, Shinar, & Parmet, 2008). The problem to be solved is, how can road signs affect drivers who are not actively searching for them? This is especially important for road users in familiar environments. Unlike Johannson and Rumar (1966), Martens and Fox (2007) demonstrated that drivers on familiar roads do perceive new road signs but don't respond to them.

Castro et al. (2004) suggest a few methods to improve the effectiveness of road signs. For the purpose of this thesis these methods shall be briefly introduced:

Using new signs

Renewing the design of road signs or creating new ones might attract the attention of drivers more than signs the drivers are familiar with. This hypothesis has been verified by a number of researchers (e.g. Goldhaber & DeTurck, 1988; Ward & Wilde, 1995). However, Castro et al. point out that the effectiveness of new or redesigned road signs declines with increased familiarity. Another possible negative effect could be that road users simply don't understand the message conveyed by the new signs. In addition, this method appears to be costly.

Repeating the sign

This method is strongly associated with priming. "Priming is a non-conscious form of memory in which an encounter with a stimulus influences the subsequent identification, production or classification of the same or a related stimulus (Schacter, Wig, & Stevens, 2007, p. 171)." It can further be distinguished between repetitive and semantic priming. The former indicates that the prime and target are identical (e.g. the word church followed by the word church) and the latter indicates that the prime can be associated with the target (e.g. the word cemetery followed by the word church) (Crundall & Underwood, 2001). Studies have demonstrated that repetitive priming has a stronger effect on the effectiveness of road signs (Castro, Horberry, & Gale, 1999; Crundall & Underwood, 2001; Koyuncu & Amado, 2008). Although most of the studies on priming have been conducted in simulators, the results are confirmed under real driving conditions. Milosevic and Gajic (1986) have shown that "the repeated presentation of the same sign in a short time interval considerably increased sign registration (Castro et al., 2004, p. 59)" (*Appendix A, Figure 6*). It is worth mentioning the factors that affect repetitive priming. The effectiveness of repetitive priming is higher for experienced drivers when compared to novice drivers (Crundall & Underwood, 2001). Speed has been reported as a negative effect on priming (Koyuncu & Amado, 2008).

Only one sign on a post

Castro and Martos (1995, as cited in Castro and Horberry, 2004) have demonstrated that response time is higher if only one traffic sign is mounted on the post. If, for some reason, two sign have to be on the same post, the more important one should be larger and mounted on the top.

Bordering the sign

Warning research suggests that people pay more attention to signs if they have a border (*Appendix A, Figure 7).* Additionally, different colors are often associated with different levels of danger. The extent to which people pay more attention to the words hazard, danger, caution, etc. should also be considered. A good overview on these aspects can be found in Parsons et al. (1999). Despite international standards, language and cultural effects can have a great impact on how warning signs in general (Smith-Jackson & Essuman-Johnson, 2002) and road signs in particular should be designed.

Reducing visual clutter

Hughes and Cole (1986) and Castro and Martos (1998, as cited in Castro and Horberry, 2004) have demonstrated that drivers pay more attention to advertisement than to road signs. As a consequence, many drivers don't perceive or respond to road signs that are in close proximity to an advertisement. When traffic signs are erected, it should be ensured that they are (a) not close to any possible sources of distraction and (b) placed where drivers would expect them (*Appendix A, Figure 6 and 8*). Considering the visual behavior of drivers, the likelihood of road signs to be detected should be investigated. However, in a familiar environment (e.g. daily trip to work), it is possible that drivers search for sources of distraction in order to make the journey more variable and interesting.

Before summarizing the findings of this section, one important aspect should be added with regard to the focus of this thesis: RTAs in Oman. Al-Madani (2004) investigated road sign comprehension in the Arab world and summarized that:

"In the Arab world drivers comprehend just over half of the signs posted along roadways. Knowledge of regulatory warning signs was 55 %...the signs best comprehended by drivers in the Arab world regardless of their exposure rates were found to be those indicating no right-turn, dual carriage with three lanes, no U-turn and slippery road (p. 160)."

Possibly, due to the fact that the rapid modernization (motorization) has not been paralleled by development in other relevant fields such as education including driver education (Ofosu, Abouammoh, & Bener, 1988).

To summarize, the following aspects should be considered for road signs:

- ⇨ Road signs should be placed where drivers expect them.
- ⇨ There shouldn't be any possible sources of visual distraction in proximity to the road signs.
- ⇨ The road signs should be repeated.
- ⇨ Only one road sign should be mounted to a post.
- ⇨ Road signs should be designed in a credible way (e.g. the color red shouldn’t be used to indicate parking).
- ⇨ Whether symbols or words are more appropriate depends on the situation and the country. Aspects such as language and culture should be considered.

- ⇨ It must be ensured that the message conveyed by the road sign attracts the driver's attention in the sense that he or she expects a negative consequence when not complying with the message.
- ⇨ The message of certain road signs (e.g. diversion) needs to be supported by road markings.
- ⇨ Very important signs can be oversized or double (on both sides of the road).

2.5.4 Road markings

Road markings are not only crucial for dividing a road into different lanes; they also assist the driver in maintaining lateral vehicle control, provide visual guidance (2.1) (*Appendix A, Figure 9*) and aid road categorization (2.2). There are numerous studies on road markings and their effects on driver behavior and it is not possible to provide an extensive literature review on road markings in this section, but there are a few aspects that are worth consideration. An excellent overview on road markings is provided by Rumar and Marsh (1998).

Schlag and Heger (2002) conducted a literature review on road markings and found that lateral distance from the edge of the road increases when drivers are driving by night and the edge line is not visible. This effect can be compensated by applying white edge lines with a width of 20 cm. Under daylight conditions, the lateral position moves 23 - 41 cm to the right if edge lines are applied and 11 - 28 cm to the left if center lines are applied. It is, however, difficult to argue the extent to which the presence and width of edge or center lines affect lateral position, since lateral position also depends on shoulder width and possible hazards alongside the roads such as trees (van Driel, Davidse, & van Maarseveen, 2004).

Daniels et al. (2010) investigated the effect of road markings on speeding behavior. The researchers could find neither a positive nor negative effect. Although some researchers argue that road markings lead to an increase in speed (Burdett, 2010; Edquist et al., 2009), a meta study conducted by Van Driel et al. (2004) revealed that road markings can lead to both, an increase and a decrease in speed. The authors conclude that applying an edge line to a road without applying a center line increases the speed, whereas replacing the center line with an edge line decreases the speed. The latter can be the case because drivers refer to the edge line as an orientation, but since they are driving close to the edge of the road, they are at risk of running off the road and subsequently decrease their speed. Although road markings might have a negative effect on speeding behavior, this behavior is not associated with a higher RTA risk. Becher et al. (2006) confirm that road markings increase speed, but they also conclude from their literature review that the observed speeds are more homogenous when road markings are present.

Center or edge line road markings can also be applied as rumble strips. Unlike in-lane rumble strips (2.6.1), center and edge line rumble strips have generally positive effects on safety. Especially on two lane roads, center line rumble strips are a good measure to reduce head on collisions (Persaud, Retting, & Lyon, 2004). Anund (2005) reports that center line rumble strips have a positive effect on speeding behavior and lane position. The majority of road users interviewed in this study received the rumble strips favorably and responded that they feel safer. According to many driver behavior theories (e.g. Wilde, see section 1.5.2), drivers might compensate this safety measure by selecting more risky driving styles. But since Anund reports that no such behavior could be observed, it appears that rumble strips are not susceptible to negative adaptations. Surprisingly, Anund observed no significant difference in overtaking behavior which contradicts the aforementioned study by Persaud et al. In a later study Anund et al. (2008) investigated how edge and center line rumble strips affect tired drivers. Although the researchers couldn't find a positive effect, no negative effects are reported. Porter et al. (2004) confirmed that edge line and center line rumble strips have a positive effect on lane position but no effect on speeding behavior. Räsänen (2005) investigated the effect of center line rumble strips on lane keeping in a curve. According to his findings, the positive effect was rather associated with the center lines than with the rumble strips.

Probably the most crucial aspect of road markings is visibility. Neis (1986), for example, argues that many road markings are not visible under certain conditions (e.g. rain, at night). In order to be visible by night, road markings should reflect the lights from vehicle headlamps. The visibility (amount of reflected light) is dependent on various factors such as the width of the marking, the number of lines and the color. Under wet road conditions, raised pavement markers could be an option. Raised pavement markers also have effects similar to rumble strips (Bahar et al., 2004). Although color is important, it is not the most crucial aspect of road markings. After an extensive review, Rumar and Marsh (1998) concluded that: "Color coding undoubtedly affects drivers' behavior by transmitting a specific message to the road user. However, every color returns less light than the corresponding white. Secondly, when luminances are reduced as distances increase, the driver's ability to recognize various colors is also reduced. Finally, some road users are color-deficient and their ability to understand the message of some colors may be reduced. Therefore we must not rely too much on color coding (p. 61)".

To summarize, the following aspects should be considered for road markings:

- ⇨ Road markings are essential to facilitate visual guidance and are crucial for road safety.
- ⇨ Road markings are necessary, but not sufficient alone to facilitate guidance, especially in curves.
- ⇨ Road markings should always be clear and not confuse the driver.

- ⇨ The visibility of road markings needs to be ensured under all possible conditions.
- ⇨ If road markings indicate a modification (e.g. diversion), they should be supplemented by road signs.
- ⇨ Edge and center line rumble strips have a small positive effect on road safety and are not susceptible to negative adaptations.
- ⇨ The utility of road markings to function as a boarder might depend on the road users. The driver behavior and attitude needs to be considered.

2.6 Road location elements

The term road location element is borrowed from the Human Factors Guidelines for Road Systems (Campbell et al., 2008). As opposed to design elements, this term refers to locations on a road segment. Each location element consists of various design elements.

2.6.1 Transitions

In this thesis, transitions are defined as sections that combine a straight section with either a curve, an intersection, a roundabout or any other section that requires a change in driving behavior. Therefore, a transition could also combine two straight sections if both sections belong to roads of different categories. Note, however, that research and guidelines generally suggest to provide such transitions at roundabouts (OHDS, 2010; Theeuwes, 2001; Theeuwes & Godthelp, 1995).

If a straight section is followed by a sharp curve, the drivers needs to suddenly change his or her behavior. This is not only uncomfortable, but also dangerous. As a consequence, the transition from the straight section to the curve needs to be designed in a way that helps the driver to adjust his or her driving behavior (e.g. by providing warnings). Other measures to provide a smooth transition would be transition curves which will be further discussed in a later section (2.6.3).

A general problem is that drivers often approach intersections or curves too fast and are consequently not able to decelerate in time. If driving takes place at the navigation level, drivers need to be informed as early as possible about the path (e.g. lane) they need to take to arrive at their destination. The same would apply for driving tasks at other levels if a routing change was implemented. In the following sections, methods to be considered when designing or modifying transitions will be discussed.

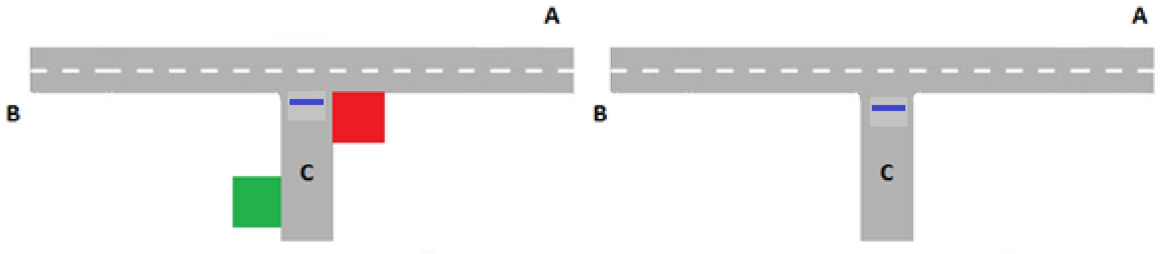

Figure 2.8. Sight distance and objects. Although the view is obstructed in the right image, this intersection is not necessarily to be considered dangerous.

Sight distance

In order to provide the driver with the necessary information he or she requires to adjust his or her driving behavior, it is crucial that the sight distance in sufficient. The different types of sight distances have already been discussed and it was concluded that although sight distance is important in order to provide the driver with information, a good view can have negative effects. In fact, studies that investigated the relationship between sight distance and RTA occurrence provide different results. It was already mentioned that Ward and Wilde (1996) argue that lateral sight distance is not associated with crashes, possibly because drivers approach such intersections carefully. Hancock and De Ridder (2003) investigated driver behavior when approaching intersections and inclines. They suggest that drivers identify possible hazards and respond with an "off the accelerator" action. However, this study was not conducted under real driving conditions and it didn't consider the aspect of familiarity. This aspect is crucial, as familiarity is associated with the driver's expectations. Lovegrove (1979, as cited in Sömen, 1993) argues that it is often not possible to avoid RTAs when the sight distance is insufficient. However, he also provided evidence that approach speed is affected by traffic density on the major road and not by sight distance. The speed of the vehicle coming from the minor road was high when the traffic density on the major road was low, and vice versa. Sömen (1993) considered Lovegrove's study along with various other studies in a review on risk perception and confirmed that driving behavior depends on the driver's expectation. If the driver knows that the intersection is dangerous he or she will behave accordingly. One conclusion that can be drawn is that driving behavior at transitions greatly depends on the driver. Although it is not possible to develop a road design that prevents a husband from distracting his wife by criticizing her driving style, it might be possible to help the driver make appropriate decisions.

Figure 2.8 shows two T-intersections. The white dashed line indicates the road that has the right of way. The left image shows two obstacles that obstruct the view. The red obstacle is at the edge of the major road. In order to see the traffic on the major road, the driver approaching the intersection (C) would have to enter the major road. The likelihood to collide with A or C would be quite high. The green obstacles on the other hand leaves C enough time to safely observe the traffic on the major road and allows A or B (given that the red obstacle is no longer present) to anticipate C's intention. The right image shows the same intersection without any obstacles and thus appears to be safer than the left intersection. However, the good view might prevent C from carefully observing the traffic (A and B). C might perceive A or B before he or she even comes close to the stop line (blue line). Since A and B have a good view on the intersecting road, they might assume that C has a good view as well. As a consequence they might not pay attention to the traffic coming from the minor road and drive at higher speeds compared to the left image condition. Recall that the higher the difference in speed is, the more difficult it is to estimate TTC accurately. Of course, A and B have the right of way and if a RTA would occur it wouldn't be their fault. Having the right of way might generally provide a feeling of safety, but referring to Damasio (1994), Vaa (2007) argues that if a dangerous situation is developing, a feeling of unpleasantness will enter the body and it would be a natural reaction for the body to gain control over the situation in order to avoid or anticipate any possible danger in time. In other words, it is more important to prevent the RTA than to insist on the right of way. Such a dangerous situation, however, is not shown on the right image. Even though the situation is clear and A, B, and C have a good view and feel safe, they are responsible to search for conflicting traffic, as are all other road users (Jenness, Lerner, Llaneras, Singer, & Huey, 2006). The road design should consider this responsibility as well. Even though C doesn't yield the right of way, an RTA could be prevented if A or B would anticipate C's actions. To summarize, the design that assists C in approaching the intersection carefully could also be implemented on the major road. How decision making can be affected will be discussed in the next section.

Decision making - positive guidance

In section 2.5.2 different types of sight distances were distinguished. One of these types is decision sight distance. Decision sight distance is generally applied when the driver needs to maneuver the vehicle into a particular lane. The idea is that the driver needs more time to adjust his or her behavior as he or she might have to search for more information than would be required if the driver simply has to stop the vehicle. In other words, the sight distance assists the drivers when he or she has to make decisions by providing the driver with a sufficient amount of time to make these decisions.

It was argued that drivers might approach intersections without carefully observing the traffic, relying on their right of way, and therefore don't pay sufficient attention to the driver who has to yield. In both cases, the drivers make decisions that increase the RTA risk. It is therefore important to investigate if the road design could assist the driver in making decisions that decreases the RTA risk. One method that helps the driver in anticipating hazards and making appropriate decisions is associated with the positive guidance model.

The positive guidance model (Jenness et al., 2006) is similar to the task hierarchy (*Figure 2.1*) The three levels of the positive guidance model are named control, guidance and navigation. They basically correspond to the three levels of the task hierarchy model. Positive guidance can be applied at transitions from straight sections to railroad crossings and describes different zones (Jenness et al., 2006; Wallace et al., 2008). The definition of these zones (Jenness et al., 2006) will be applied on a common intersection (*Figure 2.9*), not on a railroad crossing.

The advance zone - This zone is the area sufficiently in advance of the intersection. The driver doesn't need to deal with immediate decisions and actions about speed, path, visual search, etc. Few restrictions are required in the advance zone. Simple road signs could inform the driver about the coming intersections.

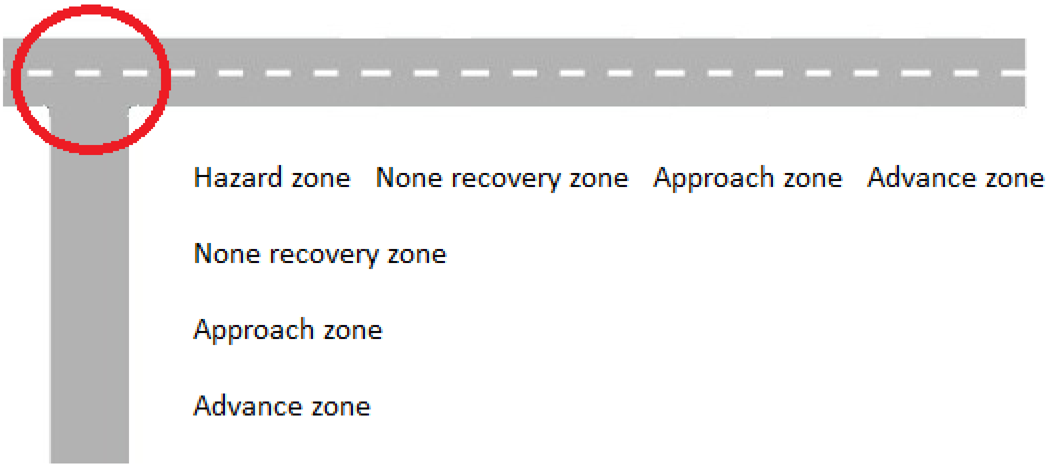

Figure 2.9.The Positive Guidance Model. For explanation see text.

The approach zone - This zone begins normally at the decision sight distance. It is the zone where the driver formulates and begins to execute the action needed to avoid hazards (e.g. visual search) and operates his or her vehicle in a controlled manner (e.g. adjusting speed). Since the driver must be planning relevant safety actions, relevant information should be limited to safety information. Warning signs can be applied together with rumble strips or similar measures that affect driving speed.

Non recovery zone - This zone begins normally at the stopping sight distance. The driver reaching this zone must quickly react to any potential hazard. It is therefore necessary to present high priority safety messages that require an immediate response.

Hazard zone - This is the zone where a stopped and an approaching vehicle could collide with each other. The left image in *Figure 2.8* is a good example. The view to the right is obstructed by the red object (e.g. a bush or a parked car). Consequently, C has to slowly enter the major road in order to observe the traffic coming from the right side. If A enters the hazard zone too fast, an RTA is very likely to occur. Therefore, the objective of the other three zones is to provide the driver with enough information and time to make appropriate decisions.

Of course, all measures that are supposed to affect the driver in the particular zone need to be investigated as well. These measures include, for example, rumble strips, speed humps, perceptual speed regulation as well as road signs and markings. The effectiveness of these measures will be discussed in the following pages.

Rumble strips and speed humps

"Rumble strips are either grooves or rows of raised pavement markers that are placed perpendicular to the direction of travel to alert drivers to an approaching change of road condition or hazard requiring substantial speed reduction. The intention of rumble strips is to provide both an auditory and physical (vibration) stimuli that can be felt by both the driver and vehicle occupants (Wallace et al., 2008, p. 42)". Rumble strips can be applied vertical (center line and edge line) or horizontal on the road (in-lane rumble strips). The effectiveness of rumble strips on edge or center lines will be discussed in a later section (2.6.4).

The effects of in-lane rumble strips are often discussed in the literature. Some studies report positive effects and others report none or even negative effects. Zaidel et al. (2006) report that rumble strips in front of an intersection lead to an average speed reduction of 40 %. The positive effects of the rumble strips could still be observed after one year. Fontaine and Carlson (2001) tested the effectiveness of portable rumble strips and confirmed the positive effect of rumble strips on speed reduction. However, their observations are less promising. Whereas the average speed reduction of trucks was 11,6 km/h, the average speed reduction of passenger cars was only 3,2 km/h. Similar results were reported by Thompson et al. (2006) who report a general speed reduction of not more than 1,6 km/h. Corkle et al. (2001) and Harwood (1993) argue that in-lane rumble strips can have negative effects on traffic safety. Drivers don't like the feeling when driving over rumble strips and sometimes believe that rumble strips can damage their vehicle. As a consequence, they try to avoid the rumble strips by driving on the shoulder or even the opposite lane (*Appendix A, Figure 10*).

Furthermore, drivers tend to brake faster when approaching a section with in-lane rumble strips, a behavior that increases the likelihood of rear end collisions. Harwood (1993), who has reviewed various studies on the effectiveness of rumble strips, further argues that most studies are based on small sample sizes or the researchers applied inadequate methods. More recently, Van der Horst and Bakker (2002) have considered in-lane rumble strips as a potential measure to reduce speed at transitions. The authors, however, concluded that "transversal rumble strips do not appear to work for reducing the speed of free-driving passenger cars, neither on 50 nor on 80 km/h roads. Cumulative speed-distributions did not differ significantly before and after installation of these rumble strips (p. 7)".

With regard to speed humps (sometimes called speed bumps), the literature provides similar results. According to some studies, speed humps are an efficient method to improve road safety (e.g. Afukaar, 2003; Tester, Rutherford, Wald, & Rutherford, 2004) whereas other studies are more critical towards the use of speed humps (e.g. Pau & Angius, 2001; Van der Horst & Bakker, 2002). By trend, however, more researchers seem to prefer speed humps over rumble strips. For a good comparison of both, as well as further information on how such measures should be implemented, see Van der Horst and Bakker (2002).

Intuitively, it is not surprising that both rumble strips and speed humps decrease the number of RTAs. Nevertheless, how these measures are applied and how rumble strips and speed humps are designed merit consideration (*Appendix A, Figure 11*). Furthermore, it is important to focus on risk adaptation and possible negative effects of these measures as mentioned in the previous paragraphs. In this regard, it must not be forgotten that rumble strips and speed humps might lead to a speed reduction at a particular section but due to the time loss the driver experiences, they might drive even faster between these sections. Becher et al. (2006) suppose that drivers choose higher speeds on sections between roundabouts compared to sections without roundabouts. In other words, on a 6 km long straight sections, drivers would drive at 80 km/h, for example. If this 6 km long section is divided by three roundabouts in three 2 km long sections, drivers would drive at around 100 km/h on these 2 km sections. The same effect can be applied to sections that are equipped with speed humps and followed by sections without speed humps.

The effect of speed humps on speeding behavior within a given section has been investigated by Clarke (2000). As can be seen in *Figure 2.10*, the 85th percentile speed was lower after the speed humps were installed. However, speed was also less consistent and a strong deceleration was observed before the speed humps and a strong acceleration was observed after the speed humps. Although the speed was lower when compared to the "before speed hump" condition, drivers accelerated before intersections instead of decelerating (*Figure 2.10*, intersections: Bloomington, Austin, Providence). This could have an adverse effect on the safety at the intersections.

Another important aspect is driver behavior in general. Speed humps, for example, might lead to lower speeds in urban areas. According to the reviewed literature it is well possible that drivers only drive at low speeds because of the speed humps (e.g. afraid to damage their cars) and not because they drive in an urban area where low speeds are essential in order to stop the car in time in the case of unexpected events (e.g. child suddenly runs into the road). As soon as the driver would enter an urban region without speed humps, it is likely that he or she will still drive at high speeds. Simply implementing speed humps in some urban areas and not applying them in other urban areas therefore seems to be unpromising.

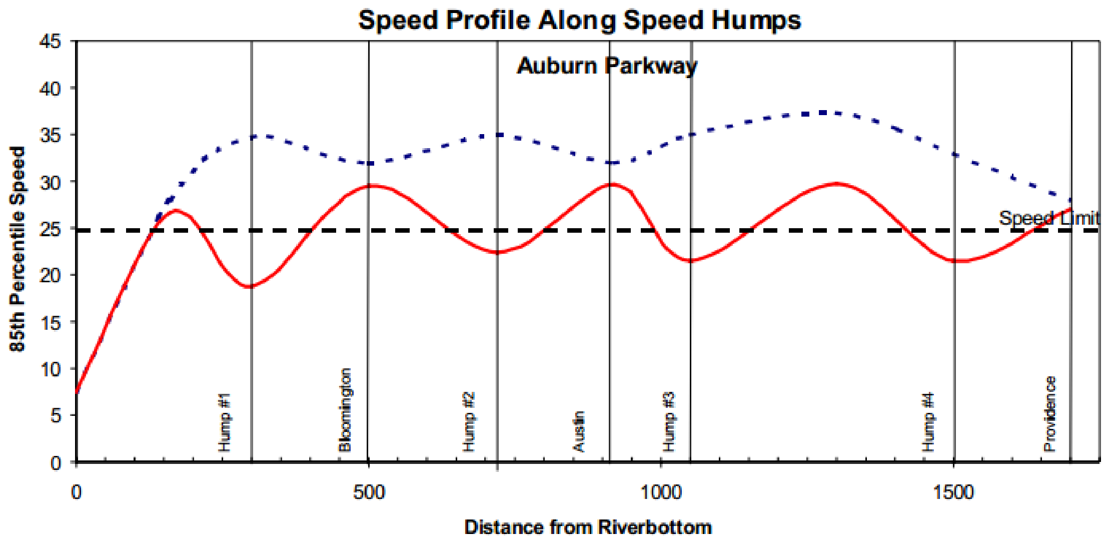

Figure 2.10.(D. E. Clarke, 2000). © 2000 Institute of Transportation Engineers, 1627 Eye Street, NW, Suite 600, Washington, DC 20006 USA, www.ite.org. Used by permission. Blue dashed line, before speed humps. Red line, after speed bumps. Drivers accelerated stronger before the intersection Bloomington, Austin and Providence after the installation of speed humps.

Perceptual speed regulation

The mechanisms underlying human speed perception have been discussed in detail in section 1.3.1. Affecting speed perception is a possible method to reduce driving speed. This method is sometimes referred to as perceptual speed regulation (Manser & Hancock, 2007) or optical speed bars (Godley, Triggs, & Fildes, 2000). Manser and Hancock (2007) investigated how driving speed could be affected in tunnels. They chose tunnels for their experiment "due to its ability to isolate visual factors and the fact that previous indications suggest speed perception could be manipulated successfully in this environment (p. 72)." The effect of four different visual patterns was investigated by applying different patterns in the different experimental conditions. These patterns were wide to thin (decreasing with), thin to wide (increasing width), baseline thin to thin and the control condition without patterns. The results showed that drivers decreased their speed under the wide to thin condition and increased their speed under the thin to wide condition. Allpress and Leland (2010) conducted a similar experiment. They placed evenly or decreasingly spaced cones at the entrance of a construction site and observed a speed reduction under both conditions. *Figure 2.11* shows another option to affect the driver's speed perception. Transverse stripes spaced at gradually decreasing distances are simple applied along the edge and the center liner of the road. Different studies have demonstrated that these markings can effectively reduce mean speeds, 85th percentile speed and speed variance (FHWA).

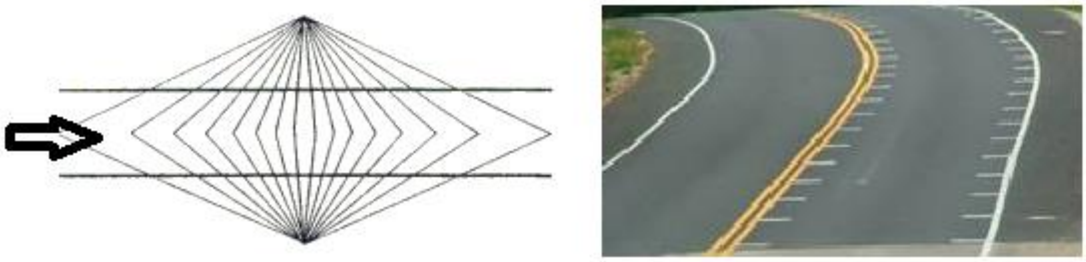

Figure 2.11. Left image: Hering illusion. Right Image: optical speed bars; modified version (FHWA). For further explanation see text.

Optical illusions are also a possibility to affect the driver's speed choice. The Hering illusion is probably the most famous one for this purpose (*Figure 2.11*). Two straight and parallel lines (e.g. edge lines of a road) look as if they were bowed inwards. In other words, the road appears to be narrow. Shinar et al. (1980) have investigated the effect of the Hering illusion by applying such an illusion on a transition from a straight section to a deceptive curve. The objective was to induce a speed reduction by visually narrowing the section before the curve. The results yielded a significant speed reduction for passenger cars. The speed reduction could still be observed after 30 days: "The mean speed reduction for passenger cars before the modification was 6,4 km/h, while immediately after the modification it was 11,7 km/h and thirty days later it was 13,8 km/h. (p. 271)".

Road signs and markings

It was previously argued that it is not sufficient to erect road signs to indicate a lane change as it would be an example of providing information at the wrong level. Lane changes should therefore always be indicated by the road markings. It should be ensured that road markings are always present and visible at any transition to assist the driver. With regards to road signs, several aspects have to be considered. In general, however, it seems that road signs are not very effective in warning drivers of an approaching intersection or curves (David Shinar et al., 1980).

To summarize, the following aspects should be considered for transitions:

- ⇨ A good view doesn't necessarily improve road safety at transitions.
- ⇨ Drivers should be given enough time to make the right decisions, even if the view is not good.
- ⇨ The concept of positive guidance could also be applied on roads that have the right of way, especially if visibility is poor.
- ⇨ Rumble strips are a method to induce speed reduction. However, they are also associated with negative effects that need to be carefully considered before implementing them.
- ⇨ Speed humps do reduce speed in a given section, but like rumble strips, they can have negative effects such as a strong acceleration after the speed humps.
- ⇨ Perceptual speed regulation provides a good method to induce speed reduction.
- ⇨ Road signs are unlikely to have a positive effect at transitions.
- ⇨ A combination of the aforementioned measures is likely to yield the best results, however, too many measures may confuse the driver.

2.6.2 Intersections

This section mainly focuses on unsignalized T-intersections (Y-intersection), as X-intersections and signalized intersections are not very common in Oman (except in the capital city). Furthermore, drivers who are involved in RTAs at signalized intersections often blame the traffic signals and not the road markings or other road related factors (Burg & Moser, 2009). A good overview on RTAs at signalized T-intersections can be found in Kumara and Chin (2003).

Both, T- and X-intersection are planned points of conflict in the road system. With different crossing and entering movements by both drivers and pedestrians, intersections are one of the most complex traffic situations that road users encounter (FHWA). If there are no traffic signals, intersections generally connect a major road to a minor road with the major road having the right of way. The most complex maneuvers at intersections are left-turns, as the driver has to pay attention to the traffic from both the left and the right direction.

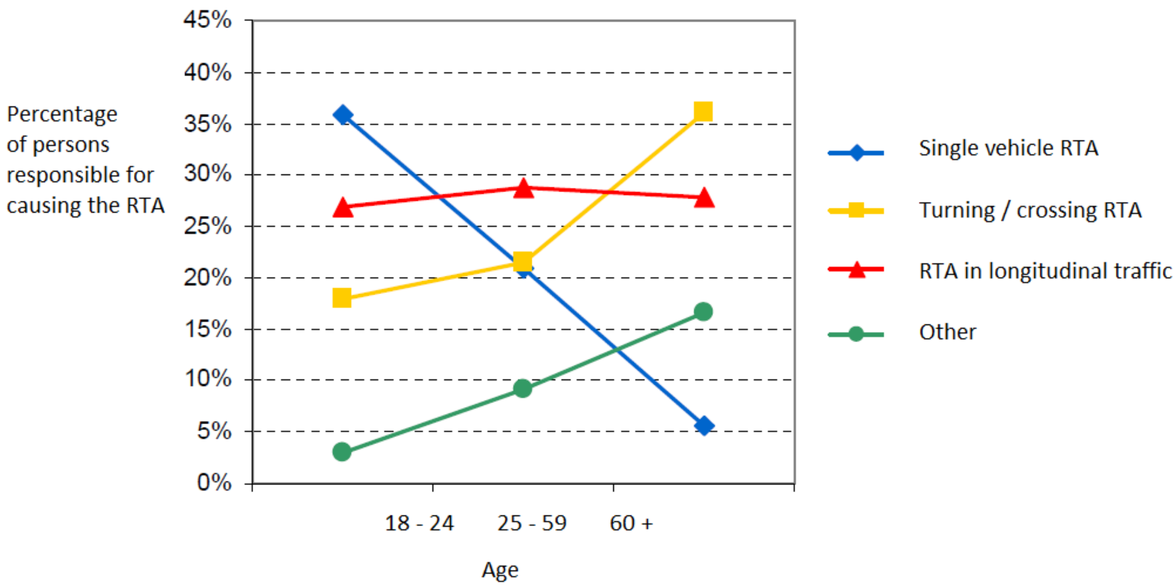

Figure 2.12. RTA type in relation to age and responsibility for causing the RTA. Modified version from Gründl (2005).

Due to the complexity of intersections, it is not surprising that RTAs at intersections are often associated with information errors. *Table 2.5* shows factors that were identified as contributing to RTAs at intersections in four different studies. These factors have been categorized into four different categories (right column, *Table 2.5*).

Category 1 includes only one factor: "look but didn't see". This factor is, for example, associated with the phenomenon of change blindness (1.3.4). Category 2 is related to RTAs that occurred because the driver who performed the turning-maneuver underestimated the time to collision (1.3.2). Category 3 describes visibility. The hazard (e.g. vehicle or pedestrian) was not visible because of lighting conditions or obstructed view. In driving, most of the information is perceived visually (Sivak, 1996). Measures such as sight-triangles (*Figure 2.7*) and sufficient road lighting, however, should ensure that the road users are able to perceive as much information as possible in order to safely perform a turn at an intersection. Road users, on the other hand, have to adjust their driving behavior to the prevalent condition by switching on the vehicle lights and driving more attentively. Category 4 comprises RTAs that took place due to inattentiveness, that is, the driver was either distracted, not paying enough attention to the action of other road users or didn't focus on other road users. In order to perform a turn safely, the driver has to pay attention to the objects (e.g. other road users, vehicles that might enter the road from a parking position, etc.) that are present at the intersection. This factor has already been investigated as a common factor contributing to RTAs five decades ago (Undeutsch, 1962). RTAs often occur because the driver is distracted by a secondary task such as mobile phone use. Since the human's mental resources are limited, drivers who are using the mobile phone while driving often decrease their speed in order for the driving task to become less demanding (Ma & Kaber, 2005). Furthermore, drivers are often only paying attention to those objects that seem relevant for his or her driving maneuver. In this regard, drivers tend to focus on those elements that pose a concrete danger (Undeutsch, 1962). For a driver, another vehicle obviously is more dangerous than a pedestrian. One should think that a driver generally is not only concerned about his or her wellbeing, but also about the wellbeing of other road users. But a study on the effectiveness of road signs has indicated that drivers are more likely to comply with road signs that are associated with concrete negative consequences for the driver (Johansson & Rumar, 1966). The participants reduced their speed when they encountered speed limit signs, but not when they encountered pedestrian crossing signs.

Table 2.5. Factors contributing to RTAs at intersections.

Study	Factors
Hendricks et al. (2001)	Look but didn't see
	Accepted inadequate gap between two vehicles
	Turned with obstructed view
	Driver's inattention
Larsen (2004)	Attention errors
	Misjudging the amount of time they had to complete the left turn
Vollrath et al. (2006)	Neglect (distance)
	Neglect (attention)
Staubach (2009)	Stimulus masking
	Distraction
	Wrong expectation
	Wrong focus of attention

Another problem associated with the complexity of intersections is that certain groups of road users are more likely to be involved in RTAs than others. As can be seen in *Figure 2.12*, the risk of causing a RTA at an intersection increases with age. The high RTA risk of older drivers is generally associated with age related deficiencies. However, a study conducted by Brilon et al. (2008) has revealed that the high RTA risk for older people at intersections is related to difficulties in interacting with other road users. The researchers conclude that it is rather difficult to affect these problems by modifying the road design.

Although it appears that the road design doesn't have a huge effect on intersection safety with regard to older drivers, there are many strategies that can be applied to improve overall intersection safety. These strategies have been summarized by the FHWA (2008a, 2008b):

- Improve compliance with traffic control devices and traffic laws (2.5.1).
- Reduce operating speeds on approaches (2.6.1).
- Guide motorists more effectively on approaches (2.6.1).
- Improve sight distance (2.5.2).
- Improve driver awareness on approaches (2.5.3).

Four strategies have not yet been discussed:

1. Reduce conflicts through geometric design improvements:

- Reduce or eliminate skew: Roads shouldn't intersect at skewed angles.
- Provide both (long) acceleration and left / right turn lanes.
- Implement turn restriction (to avoid that a vehicle entering the minor road collides with a vehicle entering the major road).
- Provide bypass lanes on shoulder.
- Provide offset at left and right turn lanes.

2. Improve availability of gaps in traffic and assist drivers in judging gaps:

There are certain measures like automatic gap detection advices (flashing beacons that signalize an appropriate gap) that assist the driver in finding appropriate gaps to enter the traffic on the intersection. However, a report on driver attitudes and behaviors has revealed that most road users tend not to trust such devices as they are concerned about their accuracy and prefer their own gap judgment (Krammes, 2006).

3. Improve management of access:

High RTA frequencies at unsignalized intersections are often related to driveways close to the intersection. According to the FHWA (2008b), driveways within 80 m of the intersection are of the greatest concern.

4. Choose appropriate intersection traffic control:

- Avoid signalizing through roads.
- Provide pavement markings with supplementary messages (2.2.1).

For recommendations on improving the road design at intersections refer to the strategies provided by the FHWA that were introduced in this section, as well as the recommendations on the sections on sight distances (2.5.2), transition (2.6.1), road signs (2.5.3) and road markings (2.5.4).

2.6.3 Horizontal curves

In many countries, about 25 % of all fatal RTAs occur along horizontal curves (Amjadi, 2009; Gründl, 2005). The underlying risk factors that contribute to RTAs along horizontal curves are manifold. Frequently mentioned risk factors are degree and length of curve, various measures of superelevation, lane and shoulder width, shoulder type, roadside hazard, pavement friction, vertical alignment, stopping sight distance, distance to adjacent curves, type of curve transition (e.g. spirals), number of access points on curve (e.g. intersection or driveways) and traffic control devices (e.g., striping, delineators, curve warning signs) (Zeeger, Stewart, Council, Reinfurt, & Hamilton, 1992). In addition to these "road" risk factors, the human factors include failure of driver attention, misperception of speed and curvature, as well as poor lane positioning (S. G. Charlton, 2007). Generally, it is an interplay of two or more aforementioned factors that lead to the occurrence of RTAs in curves (Mc Gee, Hughes, & Daily, 1995). Most researchers, for example, report a significant correlation between curve radius and RTA frequency (e.g. EU; Milton & Mannering, 1998; Zeeger et al., 1992). The sharper the curve, the more likely a RTA is to occur (*Figure 2.13*), a finding that is generally agreed upon. Yet, the role of confounding variables is less clear. Abdel-Aty and Radwan (2000) demonstrated that increasing shoulder and median width reduce RTA frequency in curves, whereas Stewart and Cludworth (1990) report no positive effect of lane width. However, it is difficult to consider all variables when conducting research on safety issues related to horizontal curves. Consequently, a few studies in which some of these variables are considered will be briefly reviewed in this section and some general findings will be derived.

Kallina and Zimmer (1974) modified traffic posts that were erected alongside a curve by mounting white reflectors and red reflectors to the posts on the left hand and the right hand side of the curve, respectively. A subsequent investigation revealed that curvature is much better perceived by night when road users are provided with visual stimuli of different colors. The benefits of supporting the road user in anticipating the curvature has been confirmed in more recent studies. Srinivasan and colleagues (2009) investigated the benefit of improved curve delineation by applying the following treatments: chevrons, horizontal arrows, advanced warning signs, post mounted delineators and the application of fluorescent colors. Numbers of injuries and fatalities were reduced by 18 %. The treatments turned out to be especially useful to prevent RTAs in sharp curves and RTAs that occur by night. Montello (2009) evaluated the safety effectiveness of measures aimed at improving horizontal curve delineation on 15 curves on a highway in Italy. He found that all the curves are characterized by low radius and high deflection angle, limited sight distance, and limited super elevation. Measures involved installations of chevron signs, curve warning signs, and sequential flashing beacons along the road. Total number of RTAs decreased by 39,4 percent. Räsänen (2005) has demonstrated that improved (re-painted) edge lines and vertically applied (on the edge line) rumble strips reduce the standard deviation of the vehicles lateral positions as well as lane departure. Charlton (2007) conducted a study that is similar to Shinar's (1980) study that has already been discussed in section 2.6.1 (also refer to this section in order to gain additional information on how to reduce approach speed before curves). Charlton, like Shinar, came to the conclusion that warning signs alone are not sufficient to warn the driver. The best results can be achieved when warning signs are erected in conjunction with chevrons (*Figure 2.14*) (*Appendix A, Figure 12*). Unlike Shinar, Charlton didn't invest the effect of the Hering illusion as a measure to reduce the drivers' approach speed, but as a measure to correct the drivers' lateral position when driving through the curve. Here, too, the Hering illusion turned out to be effective.

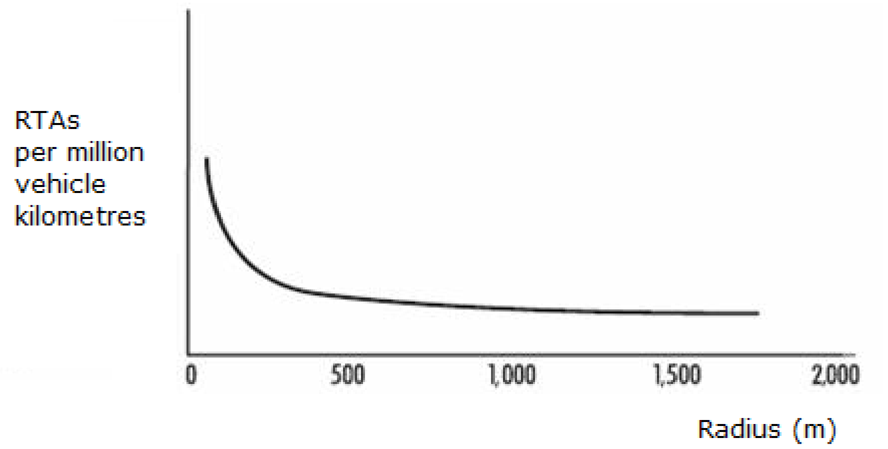

Figure 2.13. Number of RTAs increases when the radius decreases (Hauer, 2000, as cited in EU). The risk increases significantly for curves with radii less than 500 m.

Haynes et al. (2008) investigated whether the number of fatal RTAs in New Zealand is related to road curvature. RTAs in the period from 1996-2005 in which at least one death occurred were considered which resulted in a total of 4058 RTAs. Significant factors that caused a variation in RTAs were identified and held statically constant while the association with road curvature was analyzed. The authors came to the result that the main determinant of the number of RTAs was the volume of traffic flow. Neither a positive nor negative effect of road curvature on RTAs could be identified. Comparing the results of their study to a similar one conducted in England and Wales, Haynes et al.

conclude that there is limited support to the suggestion that "frequently occurring road bends might be protective (p. 843)". It is noteworthy that the study conducted in New Zealand yielded the same results as the study conducted in England / Wales in terms of the impact of road curvature on RTAs, as the geographical conditions of New Zealand differ from the conditions in England. New Zealand covers almost twice the land area of England and has more challenging topography and a lower density road network). Haynes el al. findings are "basically" in accordance with Becher et al. (2006) and EU's conclusions drawn from extensive literature reviews. According to the EU, the frequency of horizontal curves along the alignment is not only deemed "not protective" but also poses a serious risk. The more heterogeneous the curve radii are, the more dangerous the road.

Figure 2.14. Before (left) and after (right) the application of chevrons. Obviously, it was not possible for the driver to anticipate the curve before the chevrons were applied.

The reviewed studies clearly provide convincing evidence that horizontal curve safety can be improved on a "low-cost" basis, that is, without any costly measures such as widening the road or stretching (e.g. adding transition curves) the curve. These low-cost measures aim at providing visual guidance for the driver thereby assisting him or her in adjusting the approach speed and in negotiating the curve; in other words, making deceptive curves less deceptive. In this regard, chevrons and delineators play a crucial role as they also positively affect the drivers' speed perception (1.3.1, see also 1.3.4 for visual behavior in curves). Nevertheless, the role of curvature and curve frequency should be considered in both the design and investigation of RTAs.

To summarize, the following aspects should be considered for horizontal curve safety (for an excellent overview on treatments for horizontal curve safety see also Mc Gee et al. (2006):

- ⇨ Perceptual speed regulation is effective in moderating the approach speed as well as the speed in the curve (e.g. chevrons, Hering illusion, etc.).
- ⇨ Visual guidance is necessary for both moderating driving speed and correcting lateral position (e.g. road markings, delineators).
- ⇨ The combination of both aforementioned measures is likely to yield the best results.

- ⇨ The RTA risk increases for curves with radii less than 500 m.
- ⇨ Frequently occurring curves (especially with heterogeneous radii) increase the RTA risk.
- ⇨ Transition curves (allowing the driver to follow the curve by turning the wheel at a constant rate in the direction of the curve (EU) are recommended.

2.6.4 Straight sections

Common RTAs on straight sections are overtaking and run-off RTAs. In order to provide measures that prevent these RTAs, it makes sense to consider the underlying human factors and to discuss how these factors could be affected by road design. The respective contributing factors are shown in *Table 2.6*. Note that the factors in this table might be misleading, in the sense that these factors are not necessarily to be considered as sole factors, but interacting or causal factors. The latter might best be explained by a chain of events, for example, impatience precedes the failure to observe and fatigue precedes inattention.

Table 2.6. Some factors contributing to overtaking (left column) and run-off (right column) RTAs.

Factors contributing to overtaking RTAs	Factors contributing to run-off / departure RTAs
False interpretation of information (Vollrath et al., 2006).	Fatigue, inattention, drugs (Hendricks et al., 2001).
Poor observation, inexperience (D. D. Clarke, Ward, & Jones, 1998).	False decision (speed, safety distance) (Vollrath et al., 2006).
Recklessness, impatience, failure to observe, misjudgment (D. D. Clarke, Ward, & Jones, 1999).	
Distance to oncoming vehicle, misjudgment (Wilson & Best, 1982).	
Traffic flow (Sullivan & Troutbeck, 1997).	

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How is it possible to mitigate these factors by altering the road design? Although many possible measures have already been broadly discussed within the framework of this thesis (effect of lane and road width in section 2.2.3, rumble strips and speed humps in section 2.6.1, road markings in section 2.5.4), it is worth discussing some measures in a bit more detail, beginning with measures that aim at reducing overtaking RTAs. Dividing two carriageways by a median is most likely the most effective measure to prevent overtaking RTAs (*Appendix A, Figure 13*), yet, it is also the most costly measure. Further methods that are suggested to reduce the number of overtaking RTAs are the implication of passing lanes (S. Charlton, 2007; Frost & Morrall), as well as the widening and paving of shoulders (Ogden, 1997). In this regard, it is important to refer to the study conducted by Gross et al. (2009)

who demonstrated that it is not only a wide road or a paved shoulder, but rather the combination of both that is associated with lower RTAs numbers: "One significant departure from previous research is that the effects of lane and shoulder width should be considered together (Gross et al., 2009, p. 1)."

Overtaking RTAs not only occur due to insufficient shoulder or lane width, but also due to errors in perception and attention (*Table 6*). To ensure sufficient passing sight distance (2.5.2), as well as obvious warning signs (2.5.3) and road markings (2.5.4) to indicate sections (e.g. in front of curves) where overtaking is hazardous, is therefore crucial. The application of such measures could also contribute to the prevention of other RTAs types such as run-off road RTAs.

Summala (1980) conducted a study in which he temporarily introduced "no overtaking" sections. He reported that drivers increased their distance to the vehicle ahead most likely because they had no longer planned to overtake the vehicle. It goes without saying that the increased safety distance decreases the likelihood of rear-end RTAs. The positive effect of center lines to indicate "no overtaking" sections has also been confirmed more recently by Mackie and Baas (2007). Mackie and Baas, nevertheless, argue that the effect of rumble strip center lines might even be greater, as rumble strips provide an audio tactile response when driven over. However, according to two studies conducted in Finland (Ojala & Enberg, 2009; Tuovinen, Pahlman, & Enberg, 2005), rumble strips (milled) had no effect on overtaking rate. In contrast to the hypothesized safety benefits of rumble strips by Mackie and Baas; Hatfield and colleagues (2008) investigated if rumble strips are prone to behavioral adaptation. The researchers supposed that drivers might be more likely to drive tired knowing that rumple strips would alert them when accidently crossing the lane markings. The results of their questionnaire based study, however, revealed that drivers generally perceive roads equipped with rumple strip road markings as more safe, but that this safety surplus would not affect their driving behavior.

Another prominent factor contributing to overtaking RTAs is the overestimation of TTC (1.3.2).This factor might be associated with other factors such as impatience or recklessness. The overestimation of TTC might depend on the road environment. Recall that speed perception (1.3.1) is affected by the road environment. If there are no visual cues alongside the road, ego-speed is generally underestimated. Hence, it might be possible that the speed of oncoming vehicles and consequently TTC is also underestimated. However, to the best of the author's knowledge, there are no studies considering this hypothesis yet.

As previously mentioned, the implementation of overtaking lanes is another option to prevent overtaking RTAs. Charlton (2007) attempted to identify the most effective delineation treatments to guide the driver through the overtaking section. According to his findings, the most effective treatment (*Figure 2.15*) consists of "black and white warning signs (located 2 km and 200 m prior to diverge taper) and entry signs (15 m prior to diverge taper); a dashed white continuity line at the start of the diverge taper directing traffic to the left; a dashed white line ending at the start of the merge taper; an exit warning sign (200 m prior to the merge taper); and a hatched run out painted on the road shoulder at the end of the merge area tapering back to the standard shoulder width at 1 in 50. (S. Charlton, 2007, p. 155)" The results of his experiment have become the standard on New Zealand's roads. While testing various designs, Charlton found out that the majority of participants did perceive a change in warning signs, but didn't perceive a change in delineation. He remarks that unnoticed features of the situation often have a stronger effect on driver behavior than noticed features; a phenomenon that has already been observed in the investigation of curve negotiation. Note, however, that dashed white continuity lines are not the standard in all countries.

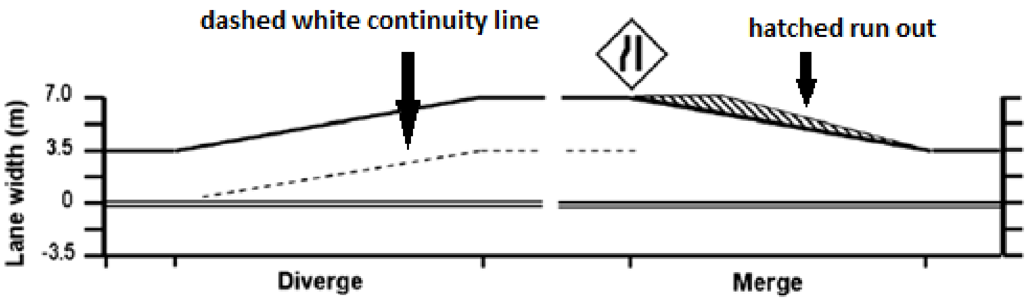


Figure 2.15. The overtaking lane as proposed by Charlton. Modified version from Charlton (2007). Note that New Zealand has left hand traffic.

Interestingly, the implementation of overtaking lanes doesn't prevent drivers from overtaking in "no-overtaking" sections. Generally, the extent to which drivers comply with traffic regulations depends on various factors (e.g. enforcement, education, driver characteristics). Discussing how each of these factors could be controlled would exceed the scope of this thesis. One measure to possibly address the "impatience" factor, however, shall be briefly discussed. Germany recently introduced "Smilies" (*Figure 2.16*) at construction sites. Different kinds of Smilies are erected at the beginning, middle, and end of a construction site to indicate to drivers the distance they have to drive before passing the construction site. The ultimate goal of the Smilies is to positively affect the drivers' emotions by reducing the drivers' aggression and increasing their attention (MSS, 2012). This approach could also be applied in order to indicate the distance before reaching an overtaking lane. Note that providing information on waiting time is also an established method to increase user satisfaction in human - computer interaction.

A discussion of how to affect the drivers' psychophysical state provides a good transition to run-off RTAs. According to *Table 2.6*, most RTAs of this type occur due to errors in attention. Attention errors can be of different kinds. They can be related to mental overload (distraction) or mental underload, a state that leads to inattention, drowsiness and trance (1.2.2) (*Appendix A, Figure 14*).

Figure 2.16. Smilies as seen on a German highway construction site. From left to right: The first red smiley indicates that the driver still has to travel a distance of 6 km (generally the length of the construction site) before passing the construction site, the second red smiley and yellow smiley indicate a distance of 4 km and 2 km, respectively. The green smiley indicates the end of the construction site (geschafft = done, Danke = thank you).

Possible countermeasures would be to increase the level of task difficulty (e.g. by increasing the unpredictability of the situation) or to apply common measures that warn the driver. These measures are similar to the measures suggested to prevent overtaking RTAs and include rumble strips, center and edge lines, as well as paved shoulders. According to Hegewald (2010), edge line rumble strips lead to a 43 % decrease of run-off RTAs on a German road section. As no adverse effects of edge line rumble strips were found in the literature, their installation is highly recommended. With regard to paved shoulders, the reader can refer to the section on overtaking RTAs.

Further measures that particularly aim at reducing run-off RTAs caused by mental underload (highway hypnosis) would be to attract the drivers' visual attention. The Smilies in *Figure 2.16* or any kind of commercial could be used in order to achieve this goal. In Denmark, highways are constructed in a way that prevents the driver from just staring ahead. This effect is achieved by introducing long curves through which the driver is always presented with different scenery. Providing the driver with different scenery on a desert road (as in Oman) is, unfortunately, almost impossible, or associated with high costs.

To summarize, the following aspects should be considered for straight sections:

- ⇨ The effect of lane / road / shoulder width on driving behavior is not clear. Research indicates, however, that drivers increase their speed when road width increases and that drivers move their lateral position closer to the lane edge (Lewis-Evans & Charlton, 2006).
- ⇨ Lane markings (lines) are crucial to guide the driver and assist him or her in maintaining lateral position. Driver behavior depends on the design of the markings (e.g. lane width, color).
- ⇨ There is evidence that the effect of road markings on driver behavior is unconscious and that road markings are more effective in affecting driver behavior than road signs. However, road markings should never be introduced without road signs or vice versa.
- ⇨ Center and edge line rumble strips are effective measures to prevent overtaking and run-off / departure RTAs. No adverse effect is known.
- ⇨ Roads shouldn't be too predictable. Long "monotonous" roads should be equipped with measures that assist the driver in maintaining visual attention.
- ⇨ Lane width and shoulder width are correlated and their effects should be considered jointly.

2.6.5 Roundabouts

Roundabouts are a popular alternative to intersections. Numerous studies have indicated that roundabouts are associated with lower RTA numbers and less severe injuries compared to T- or X-intersections (e.g. De Brabander, Nuyts, & Vereeck, 2005; Guichet, 1997; Retting, Persaud, Garder, & Lord, 2001). Despite these studies, it is not recommended to conclude that roundabouts are always the better option. Although a Meta study conducted by Elvik (2003) generally confirms this notion, Elvik points out that long term effects have not been considered by various authors. He further remarks that studies investigating the safety benefits of roundabouts provide little information on the design elements (e.g. speed limit, proportion of traffic entering from the minor road). The safety effect of roundabouts also depends on the situation before the conversion, that is, the safety effect for a conversion from an X-intersection to a roundabout is greater than the safety effect for a conversion from a T-intersection to a roundabout, and the safety effect of a conversion from an un-signalized intersections to a roundabout is greater than a conversion from a signalized intersection to a roundabout. Thus far, this thesis has provided safety recommendations for the design of intersections (2.6.2). Before convincingly arguing that roundabouts are generally safer than intersections, the safety of the intersection should be thoroughly evaluated.

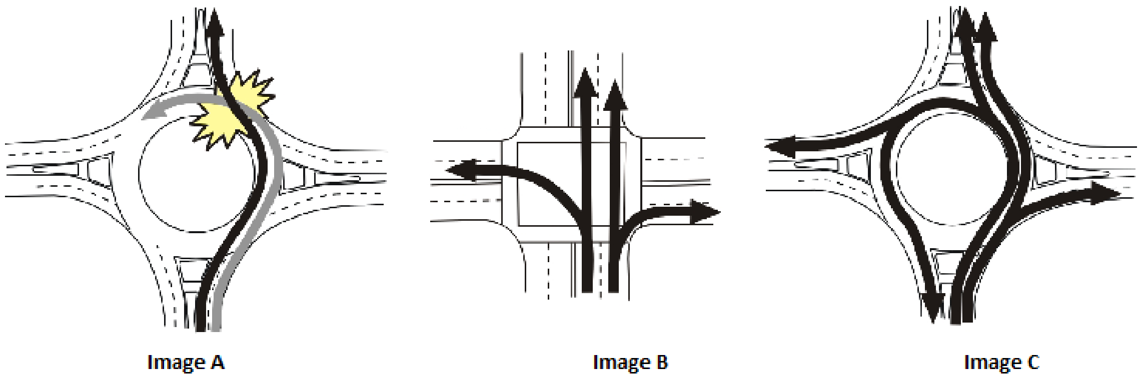


Figure 2.17. Modified version from Kinzel (2003). Image A: Possible conflict situation in roundabouts. Image B and C: Possible decisions a driver has to make when approaching intersections and roundabouts.

An important design aspect that is worth considering in greater detail is the roundabout size (diameter). The first roundabouts introduced in Germany, for example, were large in diameter and were generally associated with high RTA numbers. Consequently, most of these roundabouts were converted to signalized intersections. Due to the large success of roundabouts in Great Britain, roundabouts in Germany were reintroduced; their design elements, however, were revised. The results showed that small roundabouts have lower RTA numbers when compared to intersections (Brilon, 2005). Despite this success, small roundabouts are associated with one major problem, that is, they are difficult for large vehicles (such as trucks) to negotiate. Even at low speeds, trucks are at high risk for rollover RTAs at roundabouts (NZTA, 2007). In order to provide sufficient swept path for turning, it is necessary that either the circular road is wider than a normal lane or that the center island can be traversed (low curb) (Brilon, 2005).

Besides the diameter size of roundabouts as a potential factor that correlates with RTA frequency, the number of lanes and exits should be taken into account. In contrast to single-lane roundabouts, drivers approaching multilane roundabouts are confronted with complex decisions: “What lane should I use to enter the roundabout, can/should I change lanes while circulating, can I exit the roundabout from the lane in which I’m currently circulating? (Kinzel, 2003, p. 3)”. Of course, drivers approaching intersections also have to deal with these decisions. But as shown in image B and C (*Figure 2.17*), intersections are more self-explaining, in the sense that they allow fewer maneuvers. In order to provide measures that assist the driver in choosing the correct lane in roundabouts, several delineation methods and road signs are discussed in the literature. For a brief overview see Kinzel (2003) and Weber et al. (2005).

This brief section on roundabouts can be concluded by referring to Brilon's (2005) recommendations on roundabout safety:

Mini roundabouts:

- Application only in urban areas (maximum allowed speed = 50 km/h).
- Lateral slope 2,5 % inclined to the outside (to reduce speed).
- Central island with a maximum height of 12 cm (in the center) above the circle.
- Minimum curb height 3 cm.
- No flaring of the entries.
- Only single-lane entries and exits.

Additional recommendations for single-lane roundabouts:

- Intersection arms should be directed to the center of the roundabout in a manner rather rectangular to the circle. No tangential entries are allowed. This improves the visibility of the intersection for the approaching driver and causes reduced speeds.
- The circle lane should be inclined to the outside (2,5 %). This enables drainage, provides better visibility for the approaching driver, and reduces driving speeds on the circle.

Recommendations for two-lane roundabouts:

- Single- or two-lane entries.
- Single-lane exits only.
- No bicyclists are allowed on the circle lane.
- The design rule is: If capacity allows, only single-lane roundabouts should be built. If such a type does not match the required capacity, an enlargement should be tested in the sequence: (1) Bypass lanes (separate direct right-turn lanes), (2) Compact two-lane circle with single-lane entries and (3) Two-lane entries where necessary.

For further recommendations concerning the human factor, see the sections on transitions (2.6.1), road signs (2.5.3) and intersections (2.6.2).

Part III: Human factors

1. Methods

1.1 Data collection

Most of the data collection was done by the author himself. In ten out of the twelve months of data collection, all interviews at two out of three hospitals were conducted by the author. As all three hospitals are located in three different regions of Oman, the author drove approximately 30.000 km during the ten months of data collection. This distance doesn't include the assessment of RTA locations or any other task associated with data collection.

During this 30.000 km of driving, the author has almost been involved in a few RTAs and has witnessed many RTAs and near RTAs. In fact, the author has experienced almost every situation that leads or can lead to the RTAs that will be discussed in this thesis.

Since most of the interviews were conducted by the author, he was not only able to collect the data as required for this thesis but also to gain important additional information on RTAs and road safety in Oman by having conversations with the interviewees once the interviews were finished. Some of the additional information and comments will be incorporated into the data analysis as they provide an idea as to how some of the persons who were involved in RTAs perceive RTAs and road safety.

1.1.1 Ethical approval

Ethical approval was required for this study and granted by the Ethics Committee of the College of Medicine and Health Science at the Sultan Qaboos University (SQU). For Khoula hospital, a second ethical approval was required and granted from the Ethical Committee of the Directorate General of Khoula Hospital.

1.1.2 Participants and selection criteria

In order to cover only severe RTAs, road users who were admitted to a hospital due to their involvement in RTAs were interviewed. Further criteria included that the RTA did not occur more than one week prior to the date of the interview and that the respective patient was in a stable condition in which conversation was appropriate. Although the administrative staff ensured that it would have been possible to also interview female patients, the author refrained from doing so due to cultural aspects that prevail in Oman. Female drivers compromise less than 25 % of the Omani driving population.

A total of 296 road users of 292 RTAs were interviewed. The conducted interviews were questionnaire based. Each interview lasted between 30 and 45 minutes and was conducted in Arabic. On a few occasions, the English language of the interviewees was good enough to conduct the interview in English. If a conversation between the interviewer and the interviewee was not possible due to problems associated with language, a nurse acted as interpreter. If the patient neither spoke English nor Arabic and there was no one to translate, the interview could not be conducted.

1.1.3 Location and period of data collection

The interviews were conducted in three different governmental hospitals in Oman for the period of twelve months between 2011 and 2012. The three hospitals were:

Nizwa Hospital

Nizwa Hospital is located in Nizwa (Dakhiliya region) and is the largest hospital in this region. Nizwa Hospital not only receives patients from Nizwa, but also from other districts in the regions such as Bahla and Adam. On few occasions, patients from both the Sharqiya and the Dhahira region are directly transferred to Nizwa Hospital. Interviews were conducted by the author or a research assistant twice per week on Saturday and Tuesday at the male surgical ward. The data collection commenced in April 2011 and ended in April 2012. The research assistant only conducted the data collection in July and August 2012.

Ibra Hospital

Ibra Hospital is located in Ibra (Sharqiya region). Ibra Hospital mostly receives patients from the Sharqiya region. Interviews were also conducted at the male surgical ward every Saturday and Tuesday by a nurse who volunteered to conduct the interviews. She was briefed and instructed by the author. Data collection commenced in April 2011 and ended in March 2012.

Khoula Hospital

Khoula Hospital is the second largest hospital in Oman located in the capital city Muscat. Khoula Hospital receives patients from the capital city. Since Khoula is the only trauma center in Oman, the hospital also receives patients from all other regions of Oman. Interviews were conducted by the author and two research assistants. The interviews were conducted once a week every Monday.

Patients from the two male surgical wards and the general surgical ward were interviewed. Data collection commenced in May 2011 and ended in May 2012. The two research assistants only conducted the data collection in July and August 2012. The data collection did not start in April 2011 along with Nizwa and Ibra Hospital, as the administration of Khoula Hospital didn't accept SQU's ethical approval and required a separate ethical approval (1.1.1).

The three hospitals were chosen because they cover different regions and thus different environments. RTA data collected at Khoula Hospital covered mostly RTAs in the urban capital region, whereas RTA data collected at Nizwa and Ibra Hospital mostly covered RTAs in rural regions. The large proportion of rural roads in Oman is therefore partially considered.

Figure 3.1. A rough estimate of the areas covered by the three different hospitals. The areas covered by Khoula, Nizwa, and Ibra hospitals are indicated with green, red and blue, respectively. See also Figure 4.2.

1.1.4 The questionnaire based interview

A modified version of the questionnaire developed by Gründl (2005) was used for the interview (*Appendix C*). Initially, the questionnaire was designed to investigate the pre-crash phase of RTAs focusing on human error. The interview procedure is also similar to Gründl's approach.

The original version of Gründl's questionnaire is in German. For the purpose of this thesis, the questionnaire was translated into Arabic by a native Arabic speaker with very good German language skills and experience in quantitative research. The Arabic version was pretested before the actual data collection commenced.

The interviewer drove to the hospital on the dates indicated in the previous section. Prior to the interview, the interviewer would inquire at the nurse station about patients that have been admitted to the hospital due to their involvement in RTAs. The nurses were previously informed on the research project by the hospital's administration. The nurses checked the hospital database for RTA patients making sure that the RTA occurred within the last week. The nurse then checked whether or not the patient was able to be interviewed and if he was the driver. If the patient was in a good / stable condition, the researcher introduced himself, informed the patient about the purpose of the study and that all information would be treated confidentially. No personal information was collected and it is not possible to relate the data to a specific person.

At the beginning of the interview, the interviewee was asked where the RTA occurred and to reconstruct the circumstances: Try to reconstruct in your mind the context that surrounded the RTA, think about what the surrounding environment looked like at the scene, about your feeling and mentality, and posit yourself at the time the RTA happened (the cognitive interview, see Geiselman & Fisher, 1989).

The beginning questions of the questionnaires consisted of open and general questions, such as "how did the RTA happen" and "please describe what you have done or thought the last moments before the RTA occurred". The underlying idea was to engage the interviewee in a normal conversation and to get a brief overview of the events. The interviewee was asked to be complete and to not edit anything out of his report, even details he may think to be unimportant (Geiselman & Fisher, 1989).

Subsequently, specific questions were asked. These questions were grouped into the categories road design (e.g. road design, subjective road perception), perception (e.g. visibility, TTC estimation), attention (e.g. fatigue, distraction), cognition (e.g. navigation, risk perception) and other (e.g. age, driving experience). Note that Gründl didn’t consider the road design in his interview guideline. His category “motor function” was not considered within the framework of this thesis.

The questions addressing these categories were, if possible, phrased as "yes" or "no" questions to make the subsequent analysis easier. Such questions like "Did you use your phone?" were only asked if the interviewee didn’t mention it himself at the beginning of the interview.

At the end of each interview, the interviewer described the RTA based on the information acquired during the interview. The purpose was to assure that the interviewer understood the events correctly. Misunderstandings that might have been associated with the language could therefore be avoided.

1.1.5 Data handling

The data obtained from the interviews was prepared for analyses by putting the data into SPSS PASW 20 and by drafting reports for each RTA. Each RTA report was between a half and one page long (A4).

In order to avoid a subjective rater bias (Hoyt, 2000), a biased assessment of whether or not road factors that were not part of the interview might have contributed to the RTA or not, a random sample of 15 reports including photos of the location were sent to a road safety expert specialized in civil engineering, who commented on the reports. No major discrepancies between the author's assessment and the road safety expert's assessment were found.

1.2 Data analysis

In order to investigate the impact of the human factors on RTAs in Oman, a case-control design was selected. Case-control designs are a popular design in epidemiology and as such a useful and valid method for road safety research. A case-control study requires the identification of individuals with (cases) and without (controls) a particular condition. This condition is also referred to as the outcome. The exposure to certain factors is then measured in each group. If the exposure among cases and controls is different, it is possible to derive that the exposure is associated with an increased or decreased occurrence of the outcome (Santos Silva, 1999). The outcome and the factors correspond to dependent and independent variable, respectively.

A case-control design was also applied by Gründl (2005). As an outcome of interest, he selected legal responsibility for causing an RTA, with cases being those who caused the RTA and with controls being those who were involved in the RTA but didn't cause it in a legal sense. This method is also known as culpability analysis (Gründl, 2005; Smink, Egberts, Lusthof, Uges, & Gier, 2010). Epidemiologically, the culpability analysis can be described as case-control study (Bates & Blakely, 1999). The disadvantages of this analysis are discussed in part V, 4.3. Culpability analysis will also be applied for the investigation of human factors within the framework of this thesis. The outcome variable or dependent variable is labeled RES (for responsibility). Note that in most cases it was obvious whether or not a road user was responsible for causing the RTA in a legal sense (e.g. ignoring a stop sign, speeding). If it was not clear which party was at fault, the author contacted ROP traffic officers.

The factors that increase the risk of being responsible for causing an RTA (independent variables) are the human factors of the categories perception, attention and cognition as well as common human factors (e.g. speeding). Details on measurement and operationalization of these factors are provided in the next section. An overview on all variables considered in this thesis can also be found in *Appendix D*.

Statistical analysis was twofold. First, bivariate analysis was calculated for RES (responsible for causing the RTA; yes or no) and each human factor by applying the Chi² test and bivariate logistic regression analysis. If one or more cells of the contingency tables had expected counts of less than five, the *p*-value of the Likelihood ratio test and Fisher's exact probabilities were considered for samples larger than 30 and smaller than 30, respectively . The Likelihood ratio test is not a very common test in psychology (Hager, 2004). However, it was applied. As for large samples, the Likelihood ratio test is more precise than Fisher's exact probabilities and yields the same results as the Chi² test (Janssen & Laatz, 2007). Secondly, multiple logistic regression analysis was performed in order to investigate the extent to which each human factor contributes to the causation of an RTA. The inclusion criteria for a specific human factor to be considered in the multiple logistic regression was a significant association with RES with a *p*-value of <0.15 (Hosmer & Lemeshow, 1989). Some human factors were not considered despite a *p*-value of <0.15. The reasons for the exclusion are described in 2.5. All analysis was performed with SPSS PASW 20 and Microsoft Excel.

It is common to report various statistical values when working with logistic regression (e.g. standard error, Hosmer and Lemshow test, OR). But taking into account the frequent use of logistic regression in this thesis, only the *p*-value, OR and 95 CI (as well as Nagelkerkes R² for multiple analysis) are reported for the sake of readability. If a specific value gives reason for concern (e.g. Hosmer and Lemshow test *p*<0.05), this will be reported.

2. Results

2.1 General results

2.1.1 RTAs per months

Figure 3.2 depicts the number of investigated RTAs (N 292) per month. Each month, an average of 24 ± 3 RTAs was investigated. As can be seen, the majority of RTAs occurred in June, the hottest month per year with an average maximum temperature of 38 °C. This data indicates that the temperature affects the occurrence of RTAs in Oman. In order to support this assumption, the numbers of RTA that occurred in July and August should also be much higher when compared to the other months. Fewer RTAs in July and August could be associated with the data collection (see 1.1.3).

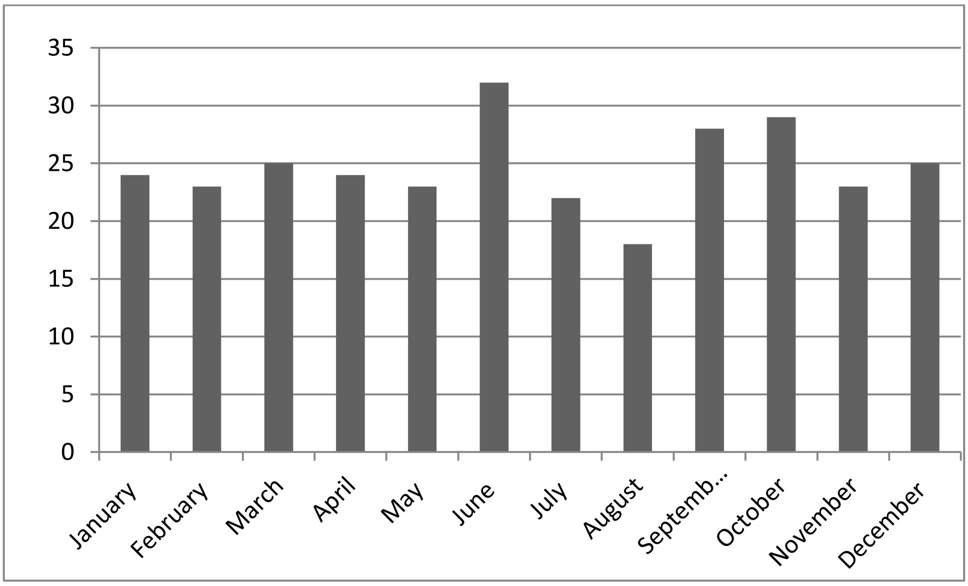


Figure 3.2. Interviewes and RTAs investigated according to month.

2.1.2 Road users

Constant and Lagarde (2010) criticize the fact that vulnerable road users such as cyclists and pedestrians are often not considered in RTA statistics. Although the focus of this thesis is primarily on drivers, all road users including pedestrians and cyclists were considered during the data collection. Generally, the number of cyclists and pedestrians should be much higher, but the majority of pedestrians or cyclists met in the hospitals during data collection were Indians, Pakistanis or Bengalis who neither spoke Arabic nor English. Conversation with these persons was therefore not possible. However, considering the importance of social determinants and road traffic injuries, the high number of Indian, Pakistani and Bengali vulnerable road users should be kept in mind and be a subject for future studies.

As shown in *Figure 3.3*, the majority of all interviewed road users were driving a passenger car at the time of the RTA (63.5 %), followed by SUVs and pick-up trucks with 7.8 % and 8.4 %, respectively. 7.1 % of the interviewed road users were pedestrians and cyclists. As mentioned in the previous paragraph, this number should be higher.

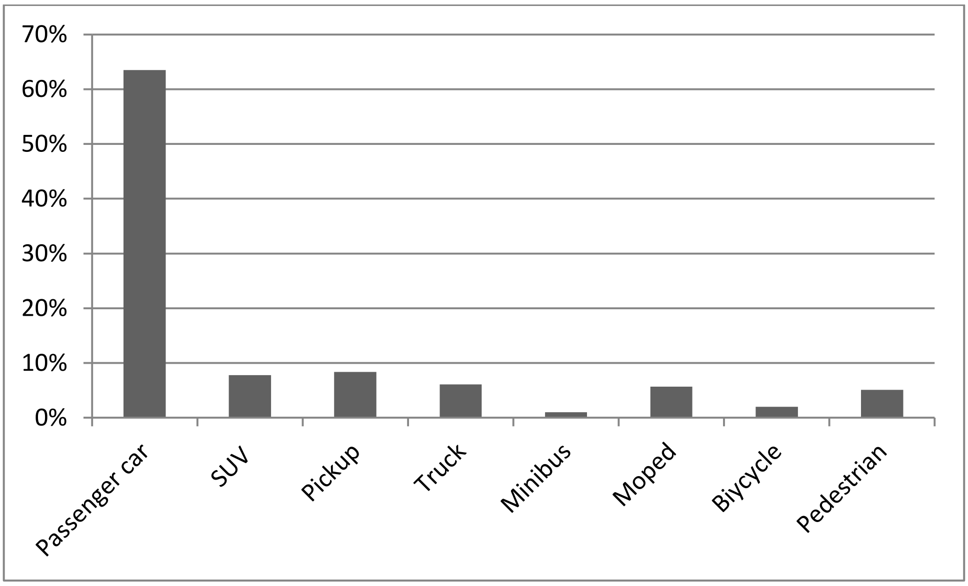


Figure 3.3. Frequency of means of transport used by the interviewees at the time of the RTA.

2.1.3 Nationalities

The majority of all interviewees were Omanis (84.8 %), followed by Asians (9.1 %, mostly Indians, Pakistanis, Bengalis and Philipino) and other Arabs (5.4 %, mostly Egyptians, Jordanians, Saudi Arabians). Only two Europeans (0.7 %) were among the interviewees. *Table 3.1* gives information on the association between the variable RES and the nationalities. As can be seen, the two Europeans were not responsible for the RTA. Not having met one Westerner who was responsible for causing an RTA during the year of data collection might indicate that most Westerners receive better driver training before obtaining a driver's license. Despite the notion advocated in this thesis that human error is not the monopoly of an unfortunate few; the available data suggests that good driver training can be considered a protective factor.

With regard to the Asian cyclists, the contrary seems to be the case. Almost all RTAs in which an Asian cyclist was involved occurred because the cyclists didn't respect traffic regulations like cycling on the right hand side; a classic case of RTAs caused by conflicting norm-systems (Factor, Mahalel, & Yair, 2007; Wilde, 1976).

Table 3.1. Frequency of RES according to nationality.

		Nationality		**Total**
		Yes	**No**	
RES	**Omani**	135 (45.6%)	116 (39.2%)	251 (84.8%)
	European	0 (0.0%)	2 (0.7%)	2 (0.7%)
	Asian	12 (4.1%)	15 (5.1%)	27 (9.1%)

	Arab	3 (1.0%)	13 (4.4%)	16 (5.4%)
Total		150 (50.7%)	146 (49.3%)	296 (100.0%)

2.2 RTA types

The RTAs were categorized into the following categories based on the New Jersey Department of Transportation's RTA type definition (NJDOT). The distribution of the RTA types is shown in *Figure 3.4.*

Run-off road

A vehicle crosses a painted or unpainted center or edge line, or otherwise departs from the traveled way. This type may occur on all road element locations and includes collisions with the crash barrier.

Head-on

Two vehicles approaching from opposite directions and collide in a frontal or angular manner as a result of one vehicle crossing the unpainted or painted centerline or the median. This type includes overtaking RTAs.

Collision with animal

A vehicle collides with an animal. The collision must have occurred on the road.

Collision with pedestrian

A vehicle collides with a person. The collision must have occurred on the road.

Red-light

Two vehicles collide with each other because one of them ignored the red light.

Rear-end

Two vehicles in a position of one behind the other collide, regardless of what movement either vehicle was making.

Turning

Two or more vehicles collide in a situation in which at least one of the vehicles was in the process of turning into a road or driveway, or crossing a road.

Sideswipe same direction

Two vehicles moving alongside each other and collide. This type would include a collision resulting from one of the vehicles making an improper turn such as a left from the right lane or vice-versa, or turning left from the shoulder onto the lane and striking a vehicle passing from this lane.

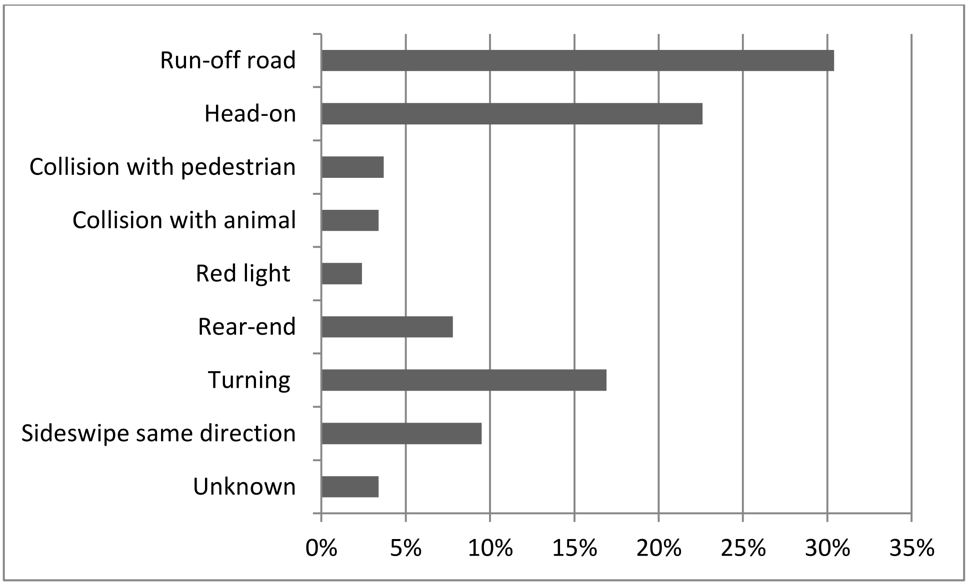


Figure 3.4. Distribution of RTA types. 3.4 % of the RTAs could not be categorized (unknown) as the circumstances were not clear.

As can be seen from *Figure 3.4*, the most frequent RTA types are run-off road RTAs with 30.4 %, followed by head-on and turning RTAs with 22.6 % and 16.9 %, respectively; 40 out of 67 head-on RTAs were caused by overtaking. Interestingly, there is an almost equal percentage of RTAs involving pedestrians (3.7 %) and animals (3.4 %). All red-light RTAs occurred at X-intersections. It is noteworthy that T-intersections are generally not signalized in Oman.

2.3 Technical factors

Initially, it was not intended to consider technical aspects as contributing factors. For the sake of completeness, however, technical factors that played a role in the causation of the RTAs investigated within the framework of this thesis will be briefly described.

Technical factors include any technical malfunction of the vehicle as well as bursting tires. Technical factors contributed to 10.8 % of all investigated RTAs. In other words, it is likely that one out of ten RTAs could have been prevented had no technical malfunction occurred.

The majority of the technical factors were bursting tires. Although ROP urges road users in Oman to frequently check their vehicle’s tires, especially in the summer, many road users refrain from doing so. Possible reasons could be monetary aspects as well as the underestimation of risks associated with tires. Many vehicles, especially trucks, are not equipped with tubeless tires which would decrease RTA risk. For the “bursting tire problem” in Gulf countries, see also Ratrout (2005).

Other technical malfunctions such as brake failure could be explained by non-professional repairs and service as well as driver error. Especially in rural areas, there are no professional garages. Even when there are professional garages, many Omanis in rural areas cannot afford professional servicing for their vehicles.

The following anecdote might illustrate the interplay between non-professional service and bursting tires: One road user deflated his tires in order to drive in the desert. Deflating the tire caused the tire pressure indicator to blink. When leaving the desert, this person drove to a small local garage and requested that the mechanic inflates all four wheels with 35 psi, the recommended pressure for the tires. After the stop, the tire pressure indicator stopped blinking indicating that the pressure was fine. After 200 km, the indicator started blinking again. When checking the tire pressure, the driver was quite surprised that all four tires were inflated with more than 70 psi which is twice as much as recommended. The probably only reason why the tires didn’t burst was their high quality and the fact that the driver changed them on a regular basis.

Technical malfunctions are also associated with driver error. In one investigated RTA, the driver came from the Amerat mountain road (N 23 32 07.59 E 58 26 05.64). Instead of using the engine brake, he pressed the clutch and used the normal brake. When approaching an intersection, he intended to brake, but the brake was overheated and no longer functional. In his attempt to avoid collision with other cars, he crashed against a wall. In another case, a truck was heavily overloaded. The brake power was reduced and the driver didn’t manage to stop the truck in time. The truck driver reported that the main reason for the RTA was the load, but he added that the truck’s brakes were old and haven’t been serviced or replaced for a long time.

2.4 Bivariate analysis

2.4.1 Common factors

This section comprises factors that have either been identified as major contributing factors in road safety related research (e.g. Valent et al., 2002; WHO, 2004) or are frequently listed as major contributing factors in RTA statistics (e.g. Destatis, 2011; WHO, 2004). Recall that gender has not been considered due to cultural aspects.

2.4.1.1 Age

The mean age of all 296 interviewed road users is 30.3 ± 10.6. The youngest road user was 14 years old. The oldest driver was 64 years old. The age categorization is threefold; young drivers (18-24 years old), middle-aged drivers (25-59 years old) and old drivers (60+ years old). The following table (*Table 3.2*) shows the distribution of RES in dependence of AGE. Persons under the age of 18 were not included, because it is not legal to drive a vehicle under the age of 18 in Oman. In total there were six persons under the age of 18.

Note that there were at least three more cases in which an RTA was caused by a minor driver. These drivers, however, were not admitted to hospital. It is worth considering this issue in a separate study.

Table 3.2. Frequency of RES according to AGE.

		AGE			Total
		18-24	**25-59**	**60+**	
RES	**Yes**	60 (21.6%)	79 (28.4%)	1 (0.4%)	140 (50.4%)
	No	46 (16.5%)	90 (32.4%)	2 (0.7%)	138 (49.6%)
Total		106 (38.1%)	169 (60.8%)	3 (1.1%)	278 (100.0%)

Only 1.1 % of all drivers were 60 years or older (*Table 3.2*), which is ten times less when compared to Gründl's study (2005) on RTAs in Germany. The finding of this study is in line with the WHO report on road safety, according to which the vast majority of RTA related injuries and fatalities in low and middle income countries are young adults (14-48 years) (WHO, 2004).

Due to the small number, the old drivers were excluded before further analysis. The association between RES and AGE is not significant (Chi^2 (DF=1, N=275), p=0.112). The histogram in *Figure 3.5* shows a trend that the younger the road user the more likely he is to cause an RTA. Road users in the youngest age group (18-22 years old), for example, seem to be three times more likely to cause an RTA than road users from the age group of 33-37 years old. These findings confirm the notion that young male drivers are more likely to engage in risky driving behavior. The odds for young drivers (18-24 years) to cause an RTA are 1.28 times higher when compared to middle aged drivers (25-59 years) (OR=1.28, 95%-CI [0.94; 1.73]).

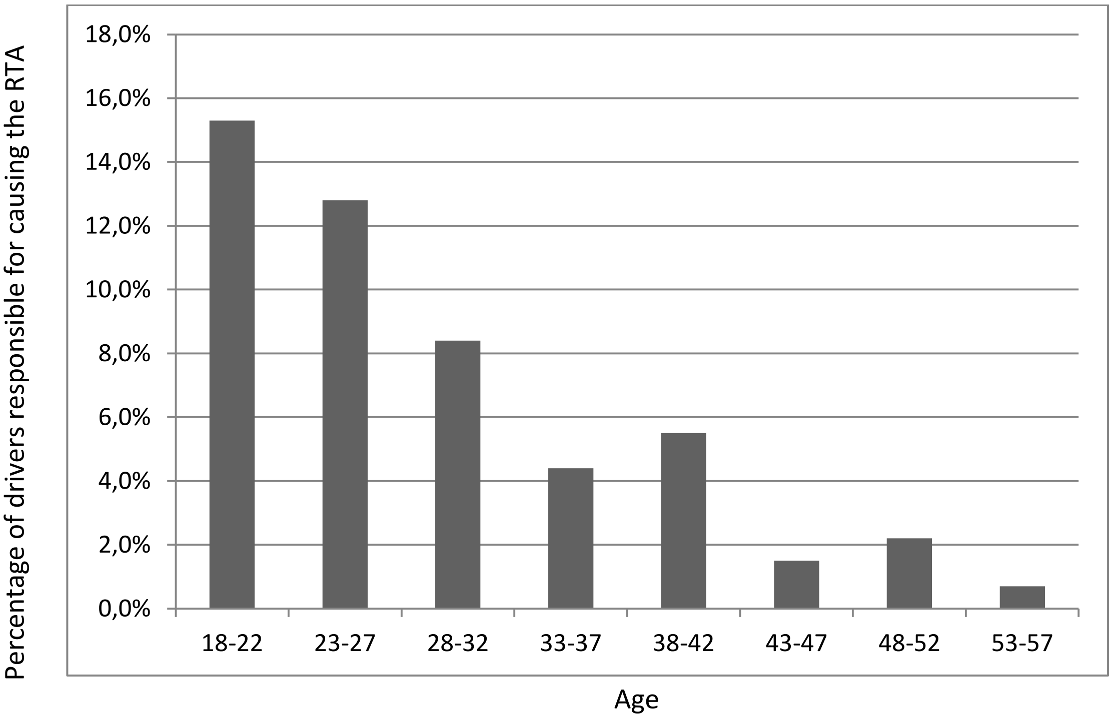


Figure 3.5. This figure shows the percentage of drivers responsible for causing the RTA in dependence of age group.

2.4.1.2 Intoxication

The dichotomous variable INTOX contains information on whether the road user was intoxicated (alcohol or drugs) at the time of the RTA or not. As police data was not available, there is no information on the extent of the intoxication (e.g. amount of blood alcohol). The interviewer did not ask the interviewee if he was intoxicated at the time of the RTA. This question would have been very inappropriate in an Islamic country. Whether or not the road user was intoxicated at the time of the RTA was reported by the nurse. On many occasions, however, there was no data available. One patient admitted (proudly) that he consumed various drugs before the RTA. It is not unlikely that there were more people among the interviewees who were intoxicated at the time of the RTA. Two interviewees reported that the other party was intoxicated but not admitted to the hospital. The data of these people is not available.

The distribution of RES and INTOX is shown in *Table 3.3*. As can be seen, only five out of 292 road users were intoxicated at the time of the RTA. This data is a strong contrast to similar data from other countries where intoxication is among the most frequent RTA risk factors. Considering that Oman is an Islamic country does not mean that no one drinks alcohol, but the number of those who do drink alcohol is most likely smaller when compared to non-Islamic countries.

The association between RES and INTOX is not significant (Likelihood ratio test, p=0.162). This is not to say that intoxication doesn't pose a risk factor. During the data collection, police officers assured that intoxication does pose a risk factor in Oman. Moreover, keeping in mind that there are Omanis who drink alcohol, that there are few public transportation options in Oman, and, most importantly, the social and religious norms that prevail in Oman, intoxication as an RTA risk factor should not be underestimated. The odds for an intoxicated road user to cause an RTA is four times higher when compared to non-intoxicated road users (OR=4.0, 95%-CI [0.45; 35.36]).

Table3.3. Frequency of RES according to INTOX.

		INTOX		**Total**
		Yes	**No**	
RES	**Yes**	4 (1.4%)	142 (48.6%)	146 (50.0%)
	No	1 (0.3%)	145 (49.7%)	146 (50.0%)
Total		5 (1.7%)	287 (98.3%)	292 (100.0%)

2.4.1.3 Inappropriate speed

Interviewees were asked to estimate their driving speed before the RTA. Speed (SPEED) was considered a risk factor when one of the following conditions was fulfilled:

1) The estimated speed was more than 10 km/h above the posted speed limit. In that case the driving speed would exceed the road's design speed limit, which is generally 10 km/h higher than the posted speed limit (OHDS, 2010). If the estimated driving speed was above the design speed limit, the RTA report was used in order to verify if speed actually might have contributed to the RTA. If, for example, a driver was driving with, say, 140 km/h on a straight road and fell asleep, it was not assumed that SPEED was a risk factor.
2) The estimated driving speed was not higher than the posted speed, but too high for the prevailing conditions, e.g. wet surface or sandstorm. Again, the RTA report was considered to evaluate the extent to which speed contributed to the RTA.

The association between RES and SPEED is highly significant (Likelihood ratio test, p=0.000). The odds for drivers who speed (according to the definitions above) are 12.23 times higher to cause an RTA than for drivers who don't speed (OR=12.23, 95%-CI [3.21; 32.82]).

Despite its high significance, SPEED should be considered very carefully due to the following reasons:

1) It is likely that drivers didn't remember their actual travelling speed and just reported the speed they believed to have traveled at.

2) Also, with regard to the above, drivers often reported that they didn't remember the speed, but reported that they didn't exceed the speed limit. Furthermore, drivers' speed estimates were often in accordance with the posted speed limit or below. Unfortunately, there is no police data or statistics based on speed measurements available. However, during 2011 / 2012, very few road users stuck to the speed limits in Oman. As a consequence, it is very likely that the number of people who actually exceeded the speed limit is much higher. Different numbers will, of course, affect the statistical analysis. Hence, it is important to consider if speed really contributed to the RTA and to keep in mind that this specific variable needs to be considered carefully.
3) From a methodological point of view, it needs to be taken into account that the investigation on whether or not SPEED was considered a risk factor in a particular RTA was mainly evaluated by the author. Although a sample of all reports was sent to a road safety specialist and no major discrepancies between the specialist's and the author's interpretation of the event was found, subjective rater bias cannot be totally excluded.
4) Even though ROP data on speed would have been available, such data also needed to be considered carefully. Most ROP officers are not specifically trained in the investigation of RTAs. In one case, a SUV went off the road on the 1000 km road between Salalah and Muscat. The driver and one passenger died on the spot and a third passenger lost consciousness. According to ROP, the RTA occurred due to fatigue and speed. According to the officers, the vehicle's speed was at least between 140 and 160 km/h (posted speed 120 km/h). However, an eye witness who drove in a vehicle behind the SUV reported that the SUV didn't exceed 120 km/h.

Table 3.4. Frequency of RES according to SPEED.

		SPEED		**Total**
		Yes	**No**	
RES	**Yes**	31 (10.7%)	114 (39.4%)	145 (50.2%)
	No	3 (1.0%)	141 (48.8%)	144 (49.8%)
Total		34 (11.8%)	255 (88.2%)	289 (100.0%)

Due to various reasons such as sensation seeking, young road users are generally more likely to be involved in RTAs in which excessive speed played a decisive role. This finding can be replicated in this study. The association between SPEED and AGE (old road users >59 excluded) is significant (Chi² (DF=1, N=272), *p*=0.045). The odds for drivers between the age of 18 and 24 are 1.5 times higher to be involved in speeding RTAs than for drivers of the middle aged group (25-59 years) (OR=1.50, 95%-CI [1.05; 2.14]). It is worth mentioning that many road users of the middle aged group mentioned during the interviews that they refrained from dangerous driving (e.g. speeding) the moment they started a family.

2.4.1.4 Insufficient safety distance

Insufficient safety distance (SAFEDIS) was measured by asking the interviewee if he was following another vehicle at the time of the RTA and if so, what was the distance between his and the preceding vehicle. Based on the self-reported speed and distance, it was determined whether or not the safety distance was adequate. If the distance was less than the travelling speed divided by two, safety distance was considered insufficient.

Insufficient safety distance is a factor that usually contributes to rear end crashes. There were 23 rear end crashes among all observed RTAs. Twelve out of these 23 rear end crashes were caused by inadequate safety distances. The mean speed reported for these twelve RTAs was 78.6 ± 33 km/h. The mean safety distance was 4.8 ± 0.6 m. The eleven remaining rear end crashes not caused by insufficient safety distance were mainly caused by the interaction of speed and inattention.

One rear end crash that was not caused by insufficient safety distance is worth mentioning. A driver was traveling from Izki to Ibra (N 22 39 15.67 E 58 35 39.87). After realizing that he missed his exit, he stopped his car and reversed. While reversing he crashed into an approaching car from behind.

14 out of the 23 drivers involved in rear end RTAs were responsible for the RTA. The nine remaining drivers were mainly involved in the rear end RTA because another vehicle hit them from behind and pushed them into the vehicle ahead. The association between RES and SAFEDIS is not significant (Fisher's exact probability test, p=0.344;). Yet, the odds for drivers who don't keep sufficient safety distances to be involved in a rear-end RTA are four times higher when compared to drivers who keep sufficient safety distance (OR=4.0, 95%-CI [0.38; 23.68]).

2.4.1.5 Driving experience

Driving experience is measured in both, annual mileage (ANMIL) and years of holding the driver's license (YDL). For the former, drivers were asked to estimate the number of km they travel per month and for the latter to report the number of years they have had a driver's license.

On average, every interviewed driver travels 4038 ± 4268 km per month. ANMIL, however, was initially not measured in km per month but in annual mileage. The monthly mileage was therefore simply multiplied by twelve and categorized into the four categories (1) < 10.000 km/year, (2) 10.000 – 20.000 km/year, (3) 20.000 – 40.000 km/year and (4) > 40.000 km/year.

The association between ANMIL and RES is marginal significant (Chi² (DF=3, N=247), *p*=0.054). As can be seen in *Figure 3*.6 there are almost as many very experienced drivers (> 40.000 km/year) responsible for the RTA as there are those who were not responsible. This finding is in line with what was reported by Gründl (2005) and contradicts the opinion that many experienced drivers don't cause RTAs. Interestingly, the bivariate logistic regression revealed only one significant effect. Drivers who drive between 20.000 and 40.000 km are more frequently responsible for causing the RTA when compared to the reference category < 10.000 km (OR=2.68, 95%-CI [1.23; 5.86]).

Another interesting finding is that the distribution of the relation between RES and ANMIL for the Omani data is similar to the German data. An obvious difference, however, is the number of drivers in category four. There are more than twice as many Omanis who travel more than 40.000 km per year than Germans. Considering this difference might add to the understanding of why there is such a high number of RTAs in Oman. The more people drive, the higher the likelihood of being involved in RTAs.

The number of km traveled per month reported by the Omanis should, however, be regarded carefully. Although the researcher has to rely on the oral reports, some interviewees seemed to exaggerate with regard to the km traveled per month. One interviewee, for example, reported to drive 50.000 km per month and few others reported to driver more than 30.000 km per month. Every reported monthly mileage that exceeded 20.000 km/month was not considered credible and excluded from the analysis.

Table 3.5. Frequency of RES according to ANMIL.

		ANMIL				**Total**
		< 10.000	**10.000 - 20.000**	**20.000 – 40.000**	**> 40.000**	
RES	**Yes**	23 (9.3%)	16 (6.5%)	37 (15%)	50 (20.2%)	126 (51%)
	No	29 (11.7%)	17 (6.9%)	18 (7.3)	57 (23.1%)	121 (49%)
Total		52 (21.1%)	33 (13.4%)	55 (22.3%)	107 (43.3%)	247 (100%)

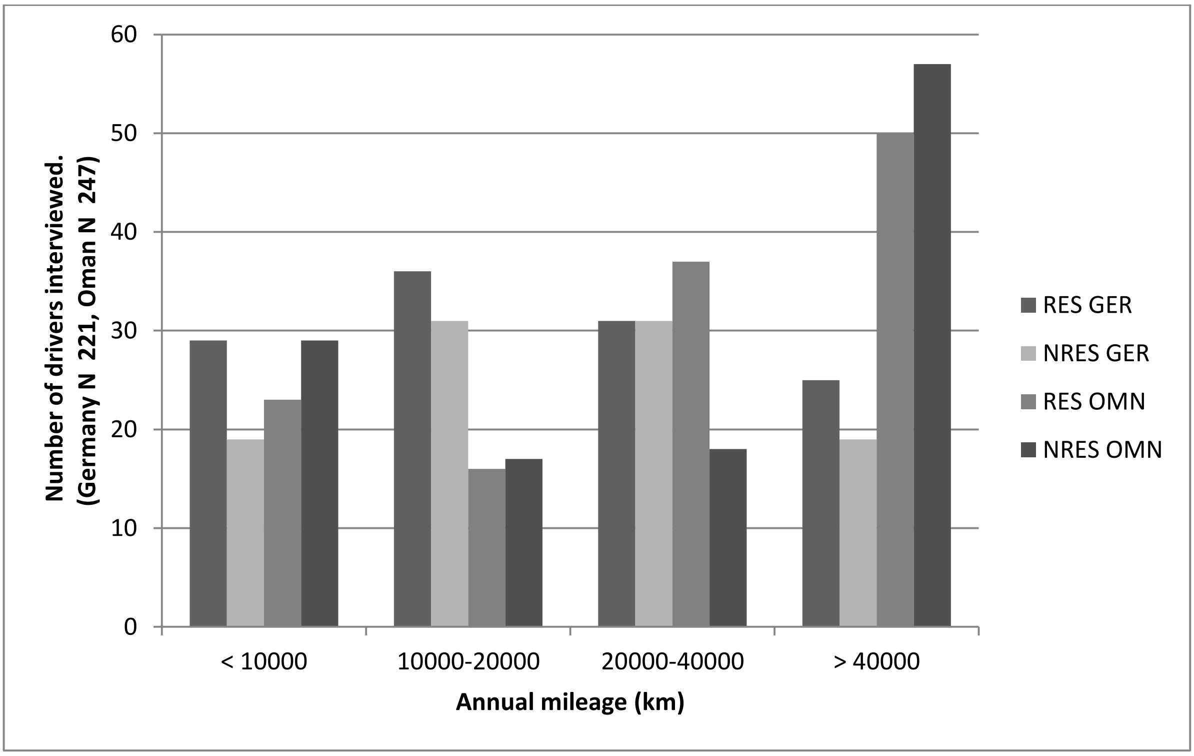


Figure 3.6. Number of drivers responsible (RES) and not responsible (NRES) for causing the RTA according to annual mileage (km) in Germany (GER) and (Oman). German data from Gründl (2005).

YDL was measured by asking the driver about how many years has he had a driver's license. The results were categorized into the categories (1) < 1 – 2 years, (2) 3 – 4 years, (3) 5 – 6 years, (4) > 6 years. The association between YDL and RES is significant (Chi² (DF=3, N=258), p=0.040). This result is not surprising; 50 % of drivers in category one (< 1 – 2 years) belong to the group of young drivers (18 – 24 years), who showed a tendency to be more likely to be responsible for causing an RTA.

Despite the significant association, YDL is not considered a valid indicator to measure driving performance in Oman. Many interviewees reported that it would be easier to get a driver's license in rural areas as opposed to the urban centers (especially in the capital city Muscat). Some interviewees even reported that they got their driver's license without driver training and many older people never attended driving school. Despite the efforts of the ROP to reduce the number of drivers without licenses, there are still many Omanis who drive without ever having received any professional instruction. Finally, there is reason to believe that driving schools in Oman are by no means comparable with driving schools in countries like Great Britain or Germany.

Table 3.6. Frequency of RES according to YDL.

	YDL				**Total**
	< 1 - 2	**3 - 4**	**5 - 6**	**> 6**	

RES	**Yes**	38 (14.7)	16 (6.2%)	25 (9.7%)	55 (21.3%)	134 (51.9%)
	No	19 (7.4%)	21 (8.1%)	19 (7.4%)	65 (25.2)	124 (48.1%)
Total		57 (25.1%)	37 (14.3%)	44 (17.1%)	120 (46.5%)	258 (100%)

2.4.2 Perception

2.4.2.1 Visibility

Interviewees were asked to rate the visibility at the time of the RTA. Most interviewees simply reported that visibility was either good or bad. In order to get more precise information, the interviewees were asked if one (or more) of the following factors affected their view at the time of the RTA:

DARKNESS: The RTA occurred at night and there was no or insufficient road lighting.

RAIN: Visibility was bad due to rain.

SAND: Visibility was bad due to sand (sandstorm).

SUN: Blinded by sunlight.

HEADLIGHT: Blinded by approaching headlight.

As can be seen in *Table 3.7*, the majority of drivers (87.7 %) reported that visibility at the time of the RTA was good. More than a third of all investigated RTAs occurred at night (N 107; 36.1 %). Out of these 107 RTAs, there were 30 RTAs in which there was no road lighting. These numbers suggest that many roads in Oman still lack road lighting. Indeed, 7.5 % of the interviewed road users reported that it was too dark to perceive the hazard in time. These findings confirm that conspicuity is a serious road safety issue in low and middle income countries and that increased and better road lighting is required (Constant & Lagarde, 2010).

Only eight out of 296 RTAs occurred under rainy conditions. It is thus not surprising that only 0.7 % reported that rain reduced visibility. One explanation for this small percentage may be that rain is not common in Oman. Another explanation could be that drivers adapt their driving behavior.

Unlike rain, sandstorms are quite often in Oman. Only 0.7 % reported sand as risk factor. Here too, it would be possible to assume that most Omanis adapt their driving behavior to the conditions and thus decrease the likelihood of an RTA to occur.

About 2.4 % could not perceive the hazard because they were blinded by the sun. The association between causing an RTA (RES) and SUN is significant (Likelihood ratio test, *p*=0.041). Note that all RTAs in which the driver was blinded by the sun don't include RTAs in which all involved parties could have been blinded (e.g. rear end crashes). When being blinded by the sun, the odds of causing an RTA is 6.13 times as high as causing a RTA when not being blinded by the sun (OR=6.13, 95%-CI [0.75; 50.23]).

Without protective factors the number of RTAs caused by SUN could be much higher. 25.6 % of all participants wore sunglasses at the time of the RTA and 34.5 % reported that their front windows were tinted. 2.2 % reported that they covered a large part of the windshield with an object (e.g. newspaper) to be protected from the sunlight.

However, these protective factors are associated with disadvantages. If a person always wears sunglasses while driving, his or her eyes will be very sensitive to sunlight when he or she drives without sunglasses. Tinted windows might affect speed perception and increase the likelihood of road rage due to the anonymity provided by tinted windows. Covering the windshield with objects reduces the driver's field of view.

Table 3.7. Frequency of RES according to VISIBIL.

		VISIBIL					**Total**
		GOODVIEW	**DARKNESS**	**RAIN**	**SAND**	**SUN**	
RES	**Yes**	120 (41.1%)	16 (5.5%)	3 (1.0%)	1 (0.3%)	6 (2.1%)	146 (50.0%)
	No	136 (46.6%)	6 (2.1%)	2 (0.7%)	1 (0.3%)	1 (0.3%)	146 (50.0%)
Total		256 (87.7%)	22 (7.5%)	5 (1.7%)	2 (0.7%)	7 (2.4%)	292 (100.0%)

The factor HEADLIGHT provides information on whether or not a driver was blinded by another vehicle's headlights. This factor is not included in *Table 3.7* as, in contrast to the factors DARKNESS, RAIN, SAND and SUN, HEADLIGHT is not a "natural factor". Considering the rather low coverage of road lighting in Oman, one could assume that drivers more frequently use their full beam which would increase the likelihood of accidentally blinding other road users. However, only 8.3 % reported to have used full beam headlights. 3.4 % of all drives were blinded by other cars. The association between causing an RTA (RES) and HEADLIGHT is not significant (Chi^2 (DF=1, N=288), *p*=0.982). Those road users who are being blinded by other vehicle's headlights are as likely to cause an RTA as those who are not blinded (OR=1.01, 95%-CI [0.3; 3.43]).

2.4.2.2 Obstructed view

In 29 out of 296 RTAs, the driver reported that he couldn't perceive the hazard because his view was obstructed. *Table 3.8* provides information on the causes for visual obstruction. The main causes are inclines (N 14) followed by other vehicles (N 5) and buildings (N 2). This factor will be elaborated in part IV, 2.3.2 and 2.4.2.1.

Table 3.8. Causes for visual obstruction as reported by the interviewees.

Bush or tree	Concrete crash barrier	Other vehicle	Building	Mountain	Incline	Construction site	Total
2	1	5	3	2	14	2	19

2.4.2.3 Unintended blindness

Especially at intersections, many RTAs occur because the driver underestimates the other vehicle's speed and thus the time to collision (TTC) or he or she is not paying sufficient attention to the scene ahead and fails to see other road users. For the latter, the underlying factors can be manifold and have been discussed in part II, 1.3.

When collecting RTA data (e.g. conducting the interview), it is not always possible to reconstruct the exact circumstances that eventually lead to the RTA. In other words, it is sometimes not possible to distinguish between the aforementioned factors. Assuming that a road user is not intending to commit suicide or kill someone, not perceiving the necessary information to prevent an RTA can be considered unintended.

A good example to illustrate this idea is TTC. According to the review on TTC in part II, 1.3.2, humans basically don't overestimate TTC (otherwise there would be much more than 3000 RTA related fatalities per day). Overestimating TTC is rather associated with other factors such as risk taking behavior, inattention or time pressure. As a consequence, perceptual errors that occurred under conditions in which the view was not obstructed were labeled "unintended blindness" (UIBLIND).

If UIBLIND contributed to the RTA was determined by analyzing the RTA reports. One interviewee for example reported: "I focused on the taxi at the taxi stop while turning left and didn't see the car approaching from the right". Another interviewee reported: "I was parking on the shoulder, when I entered the road. I collided with a car that was travelling on the road". "Did you check your side mirrors?" "Yes, I checked them and I didn't see this car." "Did you check the blind spot by looking to the left?" "No, I didn't. Yes, maybe it was my fault". The first example would generally be labeled "wrong focus of attention" or simply "inattention". In the second example, the RTA seems to have occurred because the driver failed to check the blind spot. Both examples and similar cases were included in the category UIBLIND.

As previously mentioned it is difficult to determine whether or not the RTA occurred due to a wrong focus of attention or change blindness, for example, but it is fairly easy to determine those RTAs that were caused by not checking the blind spot. Five out of 25 UIBLIND RTAs were caused by this factor. In all five cases the interviewees were not distracted or in a hurry. Not checking the blind spot could therefore be associated with inadequate driver training.

The association between UIBLIND and RES is significant (Chi² (DF=1, N=288), p=0.002). Road users who unintentionally do not perceive the hazard are at 3.89 times higher odds to be responsible for causing an RTA when compared to those who do perceive the hazard (OR=4.31, 95%-CI [1.57; 11.38]).

Table 3.9 Frequency of RES accoding to UIBLIND.

		UIBLIND		Total
		Yes	**No**	
RES	**Yes**	20 (6.9%)	126 (43.8%)	146 (50.7%)
	No	5 (1.7%)	137 (47.6%)	142 (49.3%)
Total		25 (8.7%)	263 (91.3%)	288 (100.0%)

2.4.3 Attention

2.4.3.1 Fatigue

Interviewees were asked if they felt tired before the RTA; they had the option to choose between four answers: very tired, tired, rather not tired, or not tired at all. Interviewees who reported that they fell asleep before the RTA occurred were categorized as "very tired". "Tired" and "very tired" were grouped as fatigue= yes, and "rather not tired" and "not tired at all" were grouped as fatigue= no. Fatigue= yes / no are the two categories of FATI. Note that there are different types of fatigue which couldn't be assessed within the framework of this thesis. For an excellent review of these types see Lal and Craig (2001).

FATI in dependence of RES can be seen in *Table 3.10*. The association between RES and FATI is highly significant (Chi² (DF=1, N=289), p=0.000). The odds of being responsible for causing an RTA while fatigue or asleep when compared to being awake are 8.16 times higher (OR=8.16, 95%-CI [3.32; 19.94].

Table 3.10. Frequency of RES according to FATI.

		FATI		Total
		Yes	No	
RES	**Yes**	36 (12.5%)	197 (37.0%)	143 (49.5%)
	No	7 (2.4%)	139 (48.1%)	146 (50.5%)
Total		43 (14.9%)	246 (85.1%)	289 (100.0%)

2.4.3.2 Distraction by technical device

Drivers are often distracted by technical devices. The use of mobile phones while driving has frequently been subject to research within the past years. Road users interviewed for this study were asked if they used some kind of technical device (e.g. mp3 player, mobile phone) or if they used or paid attention to technical devices inside the vehicle (e.g. radio, A/C, speedometer). If the interviewee reported to have done so, it was assumed that he was distracted, that is, he no longer had sufficient mental resources to pay attention to the traffic. The variable distraction by technical device (DTD) is therefore dichotomous, either distracted or not distracted by some kind of technical device.

As intuition suggests, there is a significant association between distraction and responsibility for causing an RTA (Chi^2 (DF=1, N=286), p=0.019). Road users who paid attention to a technical device are at higher risk to be responsible for causing an RTA (OR=3.44, 95%-CI [1.33; 8.90]) when compared to road users who didn't pay attention to a technical device.

As shown in *Table 3.11*, 25 interviewees reported to have used a technical device shortly before the RTA. 13 out of the 25 used their mobile phone, seven and five paid attention to the radio and the A/C, respectively. Eight out of the 13 mobile phone users wrote or read a text message and seven out of the 13 were talking to another person.

Table 3.11. Frequency of RES according to DTD.

		DTD		Total
		Yes	No	
RES	**Yes**	18 (6.3%)	124 (43.4%)	142 (49.7%)
	No	7 (2.4%)	137 (47.9%)	144 (50.3%)
Total		25 (8.7%)	261 (91.3%)	286 (100.0%)

2.4.3.3 Distraction by non-technical device

The variable distraction by non-technical device (DNTD) encompasses all non-technical factors that distracted the road user shortly before the RTA. Interviewees were asked if they looked at anything inside the vehicle or outside the vehicle shortly before the RTA. For the variable DNTD, only non-technical aspects were considered. If the driver reported to have looked at the mobile phone, it was considered as distraction by technical device (DTD).

As shown in *Table 3.12*, eight drivers were distracted by non-technical devices. In two cases, the drivers were distracted by tailgating vehicles. The drivers reported that they paid more attention to the rear mirror observing the tailgating vehicle than to the traffic ahead. In one case, the driver was distracted by two racing cars that kept on overtaking each other.

An interesting cause is “playing drums”. The driver reported that he was driving together with four friends from Sur to al-Kamil al-Wafi. He had a small drum between his legs, one hand used for steering and one for playing the drum. He and his friends were also singing. All of them must have been very engaged in singing as none of them perceived the camel that crossed the road in front of them. The young driver reported that they travelled at 60 km/h. The road between Sur and al-Kamil al-Wafi (22 17 05.13 N 59 16 18.19 E) is a straight paved road in a monotonous environment. Vehicles are generally travelling at much higher speeds than 60 km/h. As the driver was playing the drums he was engaged in a secondary task and had to allocate mental resources to this task. Consequently, he had fewer resources available for the driving task. Despite reducing the speed in order to make the driving task less demanding, his mental resources were insufficient to perceive the camel in time.

Strictly speaking the above described RTA not only occurred because the driver was distracted but because the passengers didn’t prevent the driver from playing the drums while driving. The same would apply for many other RTAs. Another example would be the RTA in which the driver was searching for something on the backseat. The passenger should have looked on the backseat, not the driver.

DNDT is significantly associated with RES (Likelihood ratio test, p=0.022). The odds of causing an RTA for someone who is distracted by non-technical devices when compared to someone who doesn’t are 7.2 times higher (OR=7.20, 95%-CI [0.89; 56.96]).

Table 3.12. Frequency of RES accoding to DNTD.

		DNTD		Total
		Yes	No	
RES	Yes	7 (2.4%)	136 (47.2%)	143 (49.7%)

	No	1 (0.3%)	144 (50.0%)	145 (50.3%)
Total		8 (2.8%)	280 (97.2%)	288 (100.0%)
Causes of distraction: 3 x road rage (tailgating x 2, racing cars x 1), 1 x playing drums, 1 x RTA on the other side of the road, 1 x friend on the other side of the road, 1 x children at a school, 1 x searching for something on the backseat.				

2.4.3.4 Conversation

Drivers are often distracted because they are engaged in conversation with the passenger(s). It should be clear from the previous factors related to distraction that any type of conversation prevents the driver from focusing his full attention on the traffic. Interviewees have therefore been asked if they were engaged in conversation (CON) before the RTA occurred. The results can be seen in *Table 3.13*.

The association between CON and RES is marginal significant (Chi² (DF=1, N=290), p=0.050). Road users who are engaged in conversation with a passenger have twice the risk to be responsible for causing an RTA (OR=2.03, 95%-CI [1.06; 3.19]) when compared to those who are not engaged in conversation.

Interviewees were also asked about the type of conversation (TYPCON) and whether they were talking or listening (TALKLIS). For the former, interviewees were asked if they were engaged in a normal conversation or in an emotional conversation (e.g. dispute, joking), and for the latter, whether they were talking or listening. No significant associations between TYPCON and RES (Chi² (DF=1, N=44), p=0.382) and TALKLIS and RES were found (Chi² (DF=1, N=43), p=0.408).

It should be noted that the significant association of CON and RES might be explained in terms of culture and driver education. It can frequently be observed that passengers, when engaging the driver in a conversation, or vice versa, turn to the person as it would be impolite not to establish eye contact when talking to someone. As a consequence, the driver would also be distracted visually thereby drastically increasing his or her risk of causing an RTA. Although this assumption requires more research, it emphasizes the conflict between deep cultural tradition and values on one hand, and the rather modern aspect of road safety on the other hand. In addition, when both the driver and passenger(s) are confident in the driver's skills, both might even be more likely to conform to cultural behaviors.

Table 3.13. Frequency of RES according to CON.

		CON		**Total**
		Yes	**No**	

RES	**Yes**	28 (9.7%)	117 (40.3%)	145 (50.0%)
	No	16 (5.5%)	129 (44.5%)	145 (50.0%)
Total		44 (15.2%)	246 (84.8%)	290 (100.0%)

2.4.3.5 Emotions

The emotional context is an essential part of the cognitive interview. It not only helps the interviewee recollect their memory but also to gain important information about the interviewees' emotional state at the time of the RTAs. As there is evidence that emotional state affects driving behavior (Mesken, 2001), it is worth taking the emotional state of a driver into account when examining human factors and how they are related to RTAs.

Besides the aspects concerning the mnemonics of the cognitive interview, road users have been asked whether they felt normal, sad, angry, happy, bored or experienced any other feeling before the RTA. As can be seen in *Table 3.14*, the majority of interviewees felt normal or happy. However, it should be mentioned that these two states are difficult to discriminate as most interviewees reported that they "normally" felt "happy". The discrimination simply stems from the subsequent question on whether the interviewee felt "normal" or "happy". As most interviewees didn't seem to make a clear distinction between the two feelings and, as no interviewee explicitly reported to have experienced an indescribable feeling of happiness and joy, the two feelings will be summarized as one category, labeled "normal", for the analysis. The other attribute of the dichotomous variable emotions (EMOS) consists of the remaining feelings (bored, angry and sad). The driver was either preoccupied with his feelings (angry or sad) or experienced a mental underload when feeling bored. In both instances, the emotional state could have affected driving behavior, either due to mental distraction or mental underload. However, no significant association between RES and EMOS was found (Chi^2 (DF=1, N=289), p=0.229). Drivers who experience a feeling other than what has been defined as normal aren't at higher risk of causing an RTA (OR=0.94, 95%-CI [0.86; 1.03]).

Table 3.14. Frequency of RES according to EMOS.

		EMOS		**Total**
		Normal	**Angry, sad or bored**	
RES	**Yes**	120 (41.5%)	24 (8.3%)	144 (49.8%)
	No	128 (44.3%)	17 (5.9%)	145 (50.2%)
Total		248 (85.8%)	41 (14.2%)	289 (100.0%)

2.4.4 Cognition

2.4.4.1 Self-assessment of driving skills

Self-assessment of driving skills (DRISKI) was measured by asking the interviewees to assess their driving skills (very good, good, bad, very bad). As only one interviewee assessed his driving skills as very bad, the two categories “bad” and “very bad” were merged. The results are shown in *Table 3.15*. There is no significant association between RES and DRISKI (Likelihood ratio test, p=0.475).

It might sound strange that more than 90 % of the drivers assessed their driving skills as either good or very good. This, however, appears to be a common phenomenon. Echterhoff (1991, as cited in Gründl, 2005) has demonstrated that drivers tend to rate their own driving skills as good or very good whereas they judge the skills of other road users as rather poor. In fact, 88.2 % of the interviewees were of the opinion that other road users in Oman drive dangerously.

Researchers maintain that young drivers are more likely to overestimate their driving skills (Deery, 1999; Tränkle, Gelau, & Metker, 1990). Consequently, one could expect a significant association between the dichotomous variable AGE and DRISKI. The association between both variables, however, is not significant (Likelihood ratio test, p=0.100).

Table 3.15. Frequency of RES according to DRISKI.

		DRISKI			Total
		Very good	**Good**	**Bad**	
RES	**Yes**	81 (29.8%)	52 (19.1%)	6 (2.2%)	139 (51.1%)
	No	85 (31.2%)	45 (16.6%)	3 (1.1%)	133 (48.9%)
Total		166 (61.0%)	97 (35.7%)	9 (3.3%)	272 (100.0%)

2.4.4.2 Safety of own car

According to risk homeostasis theory, drivers who perceive their car as safe would more likely engage in risky driving behavior. Risky driving behavior increases the risk of causing an RTA. Consequently, one might expect that those drivers who perceive their cars as safe are more likely to be responsible for causing an RTA.

Interviewees were asked to assess the safety of their vehicle as either “very good”, “good”, “bad” or “very bad”. Due to small numbers, the four categories were dichotomized (safe vs. unsafe). The variable was labeled CARSAFE.

A significant association for RES and CARSAFE was found (Chi² (DF=1, N=267), p=0.023). The results of the bivariate logistic regression contradict the assumption that drivers who perceive their cars as safe are at higher risk to be responsible for causing RTAs. Drivers who assess their own vehicle as safe are at lower risk of being responsible for causing an RTA (OR=0.32, 95%-CI [0.12; 0.90]).

It is worth mentioning that the interviewees' assessment of what is a safe car is somewhat biased. Many interviewees assessed the safety of their vehicle either based on the vehicle's physical size or the vehicle's age. Only two interviewees assessed their car as unsafe because they admitted that the brakes were no working properly or because the car was never checked by a professional mechanic.

Table 3.16. Frequency of RES according to CARSAFE.

		CARSAFE		**Total**
		Safe	**Unsafe**	
RES	**Yes**	124 (46.4%)	16 (6.0%)	140 (52.4%)
	No	122 (45.7%)	5 (1.9%)	127 (47.6%)
Total		246 (92.1%)	21 (7.9%)	267 (100.0%)

2.4.4.3 Route familiarity

Route familiarity provides information on the performance level at which the driving task is executed. On familiar routes (maneuvering level), the driving task would be executed at the rule based level. Schemata or rules determine driving behavior and drivers would be less likely to respond to traffic signs and might more often engage in dangerous driving maneuvers such as overtaking (part II, 1.4.2). If the driver is not familiar with the route (strategic level), the driving task is executed at the strategic level, which is very sensitive to secondary tasks.

Rout familiarity (ROUTFAM) was measured by asking the interviewees if they were familiar with the road. In almost all cases the route was very familiar, because it was the daily way to work or the way to the grocery store. The association between ROUTFAM and RES is highly significant (Likelihood ratio test, p=0.000). Whereas the proportion of drivers being responsible and not responsible for RTAs on familiar routes is balanced, there are 15 times more drivers who are responsible for causing the RTA on non-familiar routes than drivers who were not responsible for causing the RTA on non-familiar routes. If the driver is not familiar with the road, his odds are 16 times higher to be being responsible for the RTA when compared to drivers who are familiar with the route (OR=16.23, 95%-CI [2.12; 124.56]). Most drivers who caused an RTA on non-familiar routes reported to have searched for the way.

Table 3.17. Frequency of RES according to ROUTFAM.

		ROUTFAM		Total
		Yes	No	
RES	**Yes**	130 (44.7%)	15 (5.2%)	145 (49.8%)
	No	145 (49.8%)	1 (0.3%)	146 (50.2%)
Total		275 (94.5%)	16 (5.5%)	291 (100.0%)

2.4.4.4 Dangerous driving

Interviewees were not only asked to assess their driving skills (DRISKI) and the safety of their vehicle (CARSAFE), but also to assess whether they would consider their driving behavior to be dangerous for others or not (DANDRI).

As can be seen in *Table 3.18*; almost a third (28.5 %) of the interviewees admitted that their driving behavior posed a threat to other road users. The association between DANDRI and RES is significant (Chi^2 (DF=1, N=277), p=0.038). Drivers who admit that their driving behavior is dangerous are at 1.76 times higher odds to be responsible for causing an RTA when compared to drivers who don't admit to having a dangerous driving style (OR=1.76, 95%-CI [1.04; 2.99]).

In line with various findings on the association between risky driving behavior and age, there is a significant association between DANDRI and AGE (Chi^2 (DF=1, N=266), p=0.003). Young drivers (18-24 years) are at higher odds to admit to engage in risky driving behavior (OR=1.79, 95%-CI [1.22; 2.63]).

Table 3.18. Frequency of RES according to DANDRI.

		DANDRI		Total
		Yes	No	
RES	**Yes**	48 (17.3%)	93 (33.6%)	141 (50.9%)
	No	31 (11.2%)	105 (37.9%)	136 (49.1%)
Total		79 (28.5%)	198 (71.5%)	277 (100.0%)

2.4.4.5 Impatience

Personality traits such as impatience affect driving behavior (Jovanović, Lipovac, Stanojević, & Stanojević, 2011). Impatient drivers might be more likely to engage in dangerous maneuvers such as tailgating and overtaking, thereby increasing the likelihood of causing an RTA.

Impatience (IMPAT) was measured by asking the driver whether they would feel annoyed when following slowly driving vehicles (e.g. trucks). If the interviewees responded with yes, they were categorized as being impatient.

The association between IMPAT and RES is significant (Chi² (DF=1, N=273), *p*=0.007). Drivers who feel annoyed when following slowly driving vehicles indeed have a higher risk of being responsible for causing an RTA (RR=1.91, 95%-CI [1.18; 3.09]).

Table 3.19. Frequency of RES according to IMPAT.

		IMPAT		Total
		Yes	**No**	
RES	**Yes**	88 (32.2%)	51 (18.7%)	139 (50.9%)
	No	63 (23.1%)	71 (26.0%)	134 (49.1%)
Total		151 (55.3%)	122 (44.7%)	273 (100.0%)

2.4.4.6 RTA history

Intuitively, one would expect that drivers with an RTA history (RTAH) would be more alert in road traffic and less frequently involved in the causation of RTAs. But the available data (*Table 3.20*) contradicts this thought. Among those interviewees who were responsible for causing the RTA, the majority reported to have already been involved in an RTA (OR=1.68, 95%-CI [1.04; 2.73]). The association is marginal significant. (Chi² (DF=1, N=287), *p*=0.059).

Table 3.20. Frequency of RES according to RTAH.

		RTAH		Total
		Yes	**No**	
RES	**Yes**	59 (20.6%)	84 (29.3%)	143 (49.8%)
	No	44 (15.3%)	100 (34.8%)	144 (50.2%)
Total		103 (35.9%)	184 (64.1%)	287 (100.0%)

2.5 Multivariate analysis

In order to predict the strongest human factors contributing to RTAs in Oman, a stepwise backward multiple logistic regression analysis was performed. The dependent variable used in the regression RES is the same variable used in the bivariate analysis. The following variables were considered as independent variables, namely: SPEED, UIBLIND, FATI, DTD, AGE, DNTD, CON, DANDRI, ANMIL, INTOX, RTAH, CARSAFE and IMPAT. Despite meeting the inclusion criteria (*p*<0.15), the following factors were excluded: YDL, as it was argued that YDL is not a valid factor to measure driving experience. SUN, as the regression model also considers RTAs that occurred at night. ROUTFAM, as ROUTFAM strongly correlated with other independent variables.

Table 3.21 depicts the results of the regression analysis. The most significant human factors are FATI, SPEED and UIBLIND, followed by CON, ANMIL (20.000-40.000) and CARSAFE. These human factors will be referred to as main human factors. The overall model explains 40 % of the variance (Nagelkerke's $R^2 = 0.40$). According to Backhaus et al. (2006), this value is acceptable with a tendency towards good.

Drivers who don't choose the appropriate speed for the prevailing conditions in Oman are almost 22 times more at risk to be responsible for causing an RTA when compared to those who choose the appropriate speed. Drivers who are exposed to the factors fatigue and unintended blindness (e.g. not checking the blind spot, wrong focus of attention) are 17 and six times more likely to be responsible for causing an RTA, respectively. Drivers with an annual mileage between 20.000 and 40.000 km are three time more likely to be responsible for causing an RTA when compared to the reference category (10.000 – 20.000 km). Although the other human factors are controlled for, assessing one's own car as safe still decreases the risk for causing an RTA. It is possible that this risk factor is associated with another variable that has not been considered in the analysis, or, that the effect of this variable is modified by another variable. But due to extreme differences in the cell counts, the inclusion of interaction terms yielded extremely high standard errors. Lastly, however, it is worth mentioning that the final model provided in the backward regression is not necessarily the model that fits the data best. If there is no theoretical evidence that supports this model, the whole model or single variables can be ignored (Hosmer & Lemeshow, 1989). This could be the case in the present situation. Except for the effect of the independent variable assessing one's own vehicle as safe, the effects of all other independent variables are in line with theoretical evidence.

Table 3.21. Results of multiple logistic regression after backward stepwise elimination.

	Sig.	**OR**	**95 % CI**	
			Lower	**Upper**
UIBLIND	0.003	5.80	1.84	18.28
FATI	0.000	17.11	5.45	53.72
SPEED	0.000	21.56	4.69	99.21
CON	0.016	2.77	1.21	6.35
ANMIL (<10.000)	0.070			
ANMIL (10.000-20.000)	0.721	1.23	0.40	3.75
ANMIL (20.000-40.000)	0.019	3.27	1.22	8.80
ANMIL (>40.000)	0.604	1.26	0.530	2.98

CARSAFE	0.042	0.27	0.78	0.952
Constant	0.000	0.66		
Nagelkerke's R^2= 0.40; N = 225				

2.5 Main human factors and RTA types

Table 3.22 depicts four of the main human factors as identified in the multivariate analysis according to the different RTA types. Note that running the red light is not included due to the fact that only few intersections, mostly in the capital areas, are signalized.

*Table 3.22: Main human factors according to RTA type;**p< 0.01, *p< 0.05.*

	SPEED	FATI	UIBLIND	CON	Total
Unknown	1 (20%)	1 (20%)	0	3 (60%)	5 (100%)
Sideswipe same direction	2 (12.5%)	5 (31.3)	6 (37.5%)*	3 (18.7%)	16 (100%)
Turning	0	0	17 (68%)**	8 (32%)	25 (100%)
Rear-end	2 (25%)	3 (37.5%)	0	3 (37.5)	8 (100%)
Collision with animal	0	3 (50%)	0	3 (50%)	6 (100%)
Collision with person	0	1 (50%)	1 (50%)	0	2 (100%)
Head-on	1 (6.3%)**	3 (18.8%)*	1 (6.3%)*	11 (68.6%)	16 (100%)
Run-off road	28 (39.5%)**	28 (39.5%)**	0	15 (21%)	71 (100%)
Total	34	44	25	46	149

The most frequent RTA type is run-off road. The main contributing factors to this RTA type are SPEED and FATI with 39.5 % each. The second most frequent RTA type is turning RTAs which are mainly associated with the risk factors UIBLIND and CON. The third most frequent RTA types are head on and sideswipe same direction. The former is mainly associated with UIBLIND and FATI with 37.5 % and 31.3 %, respectively. Note that UIBLIND refers to the blind spot which has not been controlled by the driver before turning. The latter is mainly associated with the risk factor CON indicating that those drivers who were engaged in a conversation had difficulties in maintaining the vehicle's lateral position.

Part IV: Human road interaction

1. Methods

1.1. Data collection

1.1.2 Interview data and evaluation of RTA scene

Data on the road environment was collected along with data on human factors. At the end of each interview (described in detail in part III, 1.1) the interviewee was asked to make a sketch of the RTA and to draw a map of the location at which the RTA occurred (*Figure 4.1*). This information was used to identify the location on Google earth and to obtain the GPS location of the RTA. If the RTA occurred on a road with a length of several hundred km, the location was identified by referring to landmarks such as nearby towns or villages. In this event, a description like "on the way from Qarn al-Alam to Hayma, approximately 50 km behind Qarn al-Alam" was provided. Note that neither ROP nor any other governmental institution had any precise information on RTA locations. A database with GPS coordinates was not yet available at the time of the data collection.

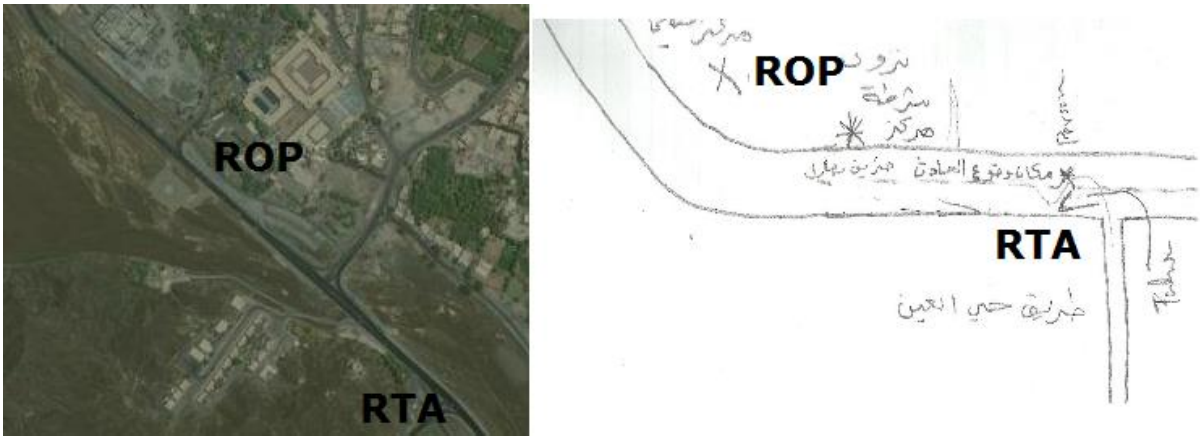


Figure 4.1. Right image shows the map of a RTA location as drawn by one of the interviewees. The left image shows a Google earth screenshot. RTA indicates the accident location and ROP indicates a ROP police station.

If possible, the author visited the locations. Some RTAs, however, occurred in Salalah and it was not possible to drive 1000 km to visit the RTA locations in this region. It is also worth mentioning that many RTAs occurred in rural areas where there are no settlements. These locations generally don't differ in their characteristics.

1.1.3 Muscat Municipality and Directorate General of Road and Land Transport data

The available GPS coordinates were sent to Muscat Municipality and the Directorate General of Road and Land Transport. The former is responsible for roads inside the capital area and the latter is responsible for roads outside the capital area. Both institutions provided further information on road design elements such as lane width, shoulder width, shoulder type, total carriageway width, number of carriageways and posted speed limits. In most cases, the requested data could only be provided for approximately two thirds of all 292 RTAs.

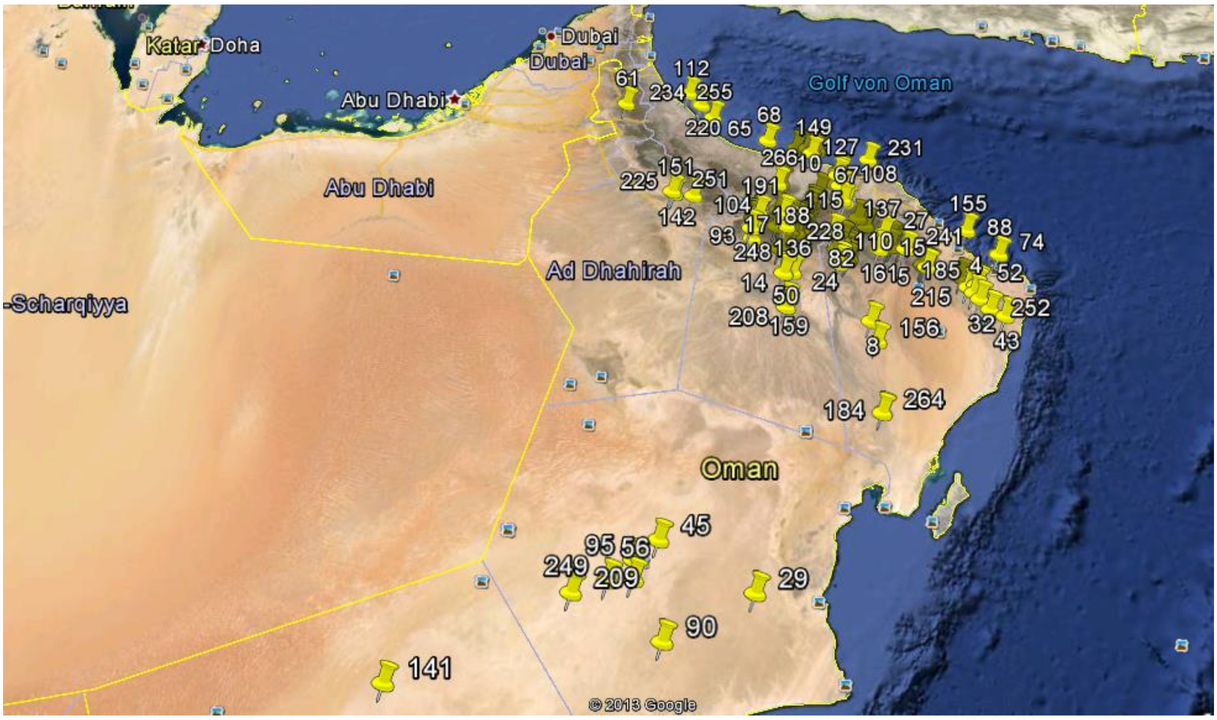


Figure 4.2. GPS locations of RTAs considered for this thesis. The locations are in accordance with the areas covered by the three hospitals in which the interviews were conducted, see Figure 3.1

1.1.4 Complementing missing data

It was not possible to get information on design elements for all road location elements (e.g. curve radius, roundabout diameter size). This gap was filled by estimates using Google Earth. Estimating design elements with Google Earth is not very precise, but a method that has been applied by other researchers as well (Kandil et al., 2010).

1.1.4.1 Curves

A common method to evaluate curve safety is to measure the effect of curve radius on RTA numbers. Since no curve radius is available, the openness of the curve will be considered in the analysis. The openness of a curve segment is “defined by the sight distance at the point on the road at which drivers enter the segment (Kandil et al., 2010, p. 2).” The sight distance in turn was measured using the path tool in Google Earth (*Figure 4.3).*The effect of the curve’s openness on road safety corresponds to the effect of curve radius on road safety. The lower the openness is, the sharper the curve (smaller the radius).

Figure 4.3: Estimating openness (sight distance) using Google Earth. The black arrow indicates the measured distance. The sharper the curve is, the lower the openness (sight distance).

1.1.4.2 Intersections

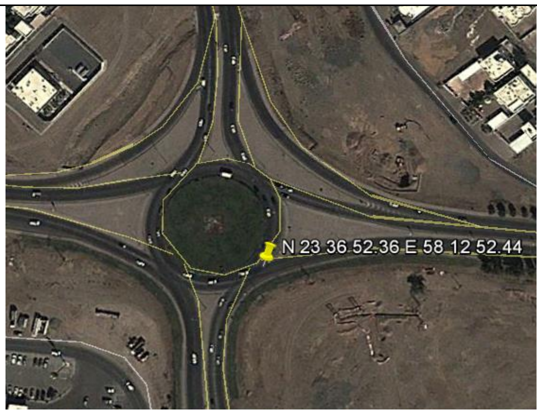
Specific intersection design elements to be included in the analysis are presence or absence of left-turn lanes and intersection sight distance. Data on the former was collected by using Google Earth and by visiting the RTA sites (if possible). Data on the latter was collected by drawing a sight triangle using the path tool on Google Earth (*Figure 4.4*). As can be seen in *Figure 4.3*, the angle between side C and B doesn’t indicate the driver’s waiting position. In this regard, this sight triangle is not in accordance with most design manuals. A design that assumes that a driver actually stops his or her vehicle and carefully observes the traffic before entering the major road maintains that the drivers’ behavior is in line with traffic regulations. However, the problem is that the drivers’ behavior is often not in line with traffic regulations. Many drivers don’t stop before turning because they observe the traffic while approaching the intersection. As a consequence, the length of side C should be greater when investigating intersection safety (positive guidance model). These thoughts are in line with the arguments provided in part II, 2.6.1 that are to a great extent based on railroad crossing research (e.g. Ward & Wilde, 1995).

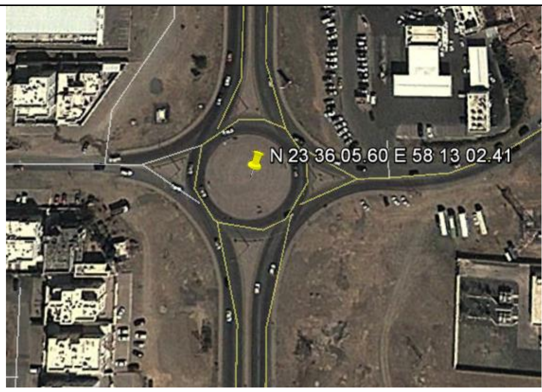
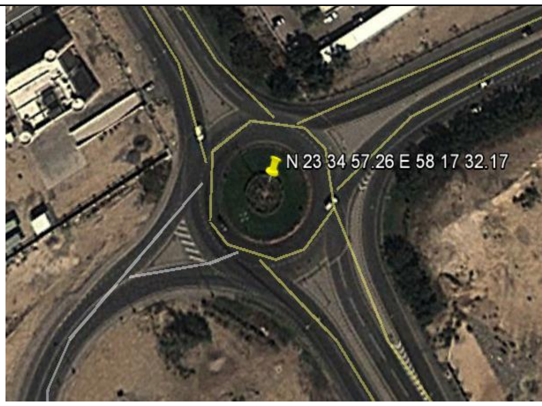
Figure 4.4. The sight triangle is illustrated by the black dashed lines. There shouldn't be any objects inside the area of this triangle. The lengths of the sides depend on the major road's design speed. For side A, a general value of 150 m and 220 m was chosen for all intersections with a design speed of up to 50 km/h and up to 120 km/h, respectively. Values were based on intersection sight distances as recommended in Brockenbrough (2009).

1.1.4.3 Roundabouts

Data on diameter size, number of lanes and carriageways were collected using Google Earth. It should be noted that the construction of two roundabouts was finished shortly before the RTAs occurred. These roundabouts are not yet visible on Google Earth. Furthermore, four roundabouts have oval islands. Consequently, it is not possible to estimate the diameter size. With regard to the number of carriageways that intersect at a roundabout, five different types were identified in *Figure 4.5*.

Figure 4.5. Five different kinds of roundabouts. The design varies primarily in the number of carriageways on each of the four legs of a roundabout.

Type 1: Four legs with dual carriageway on each leg (2222).	

<table>
<tr><td>Type 2: Four legs with single carriageway on each leg (1111).</td><td>
</td></tr>
<tr><td>Type 3: Four legs with dual carriageway on two legs and single carriageway on two legs (2211).</td><td>
</td></tr>
<tr><td>Type 4: Four legs with dual carriageway on one leg and single carriageway on three legs (2111).</td><td>
</td></tr>
<tr><td>Type 5: Four legs with dual carriageway on three legs and single carriageway on one leg (2221).</td><td>
</td></tr>
</table>

1.1.4.4 Roadside development (urban and rural roads)

Distinguishing between urban and rural areas in Oman is not easy. A major difference between rural and urban areas is traffic density and roadside development. The latter refers to objects such as buildings and trees alongside the road. It is these objects as well as the traffic density that affect driving behavior (e.g. speeding behavior). With regard to Oman, it would be possible to distinguish between major urban centers such as Muscat and rural areas such as, for example, Bidiya. But such a distinction would ignore the presence of major freeways in the capital area. These freeways have a high posted speed limit and no roadside development which could affect driving behavior. The presence of shops and conflicting traffic in rural Bidiya, on the other hand, would have a strong impact on driving behavior. A general distinction based on the location of the road, that is, urban center vs. rural area is therefore not recommended. The approach suggested here is to distinguish between rural (*Figure 4.6*) and urban (*Figure 4.7*) roads based on the level of roadside development. Four different levels of roadside development are proposed. Level one and two can be summarized as rural and level three and four can be summarized as urban.

Figure 4.6. Rural roads. Left image, category (1), no roadside development. Monotonous roads, mostly located in the desert. Right image, category (2), low level of roadside development. Road located in a desert area but small settlements are occasionally located alongside the road.

Figure 4.7. Urban roads. Right image, category (3), medium roadside development. Industrial area or freeways in urban centers. Left image, category (4). High roadside development. Shops and houses are located along both sides of the roads.

1.2 Data analysis

According to the four specific objectives identified in the introduction, the investigation of HRI is divided into four parts. Each part addresses one of the four specific objectives. All analysis is performed with SPSS PASW 20 and Microsoft Excel.

Specific objective one

The concept of SER has been introduced in detail in part II, 2.3. Briefly, SERs are associated with road categorization. It is assumed that traffic safety increases with the extent to which subjective and objective road categorization overlap.

General methods to investigate road categorization have also been introduced in the reviewed literature. These measures include the subjective evaluation of roads and statistical methods such as principal component analysis. The data collected within the framework of this thesis is basically inadequate for this kind of analysis. Yet, it is possible to evaluate the available road data with regard to the criteria identified by Matena (2006) that need to be fulfilled in order for a road network to be considered self-explaining. This evaluation will be descriptive. One may object that Chi² or Likelihood ratio tests should be used in order to provide more convincing evidence (if roads wouldn't be self-explaining, no significant association should be found between, for example, lane width and functional categorization). But considering that many cells of the contingency tables have zero cases, such an analysis was rejected.

Specific objective two

According to most driver behavior models, drivers adapt their driving behavior to subjectively perceived risk. Risk is associated with safety. A road that is perceived as safe is therefore more suitable for risky driving behavior such as high speeds.

It will be investigated which design elements predict subjectively perceived risk. Data from both, the interviews and Muscat Municipality / Directorate General of Road and Land Transport will be considered. Chi² tests and multiple logistic regression analysis will be applied. The inclusion criteria for the multiple regression analysis correspond to those applied in the human factors study (Part III, 1.2).

Specific objective three

Inappropriate speed (SPEED) was identified as a main human factor. Recall that excessive speed on a straight road section cannot be considered dangerous unless it is combined with another factor (e.g. presence of objects that obstruct the view such as parking cars or conflicting traffic, exceeding design speed). However, it is very unlikely that no such risk factor is present in a real traffic situation. It is therefore generally agreed upon that a reduction of mean speed on a given road section significantly decreases RTA risk. Anyone interested in road safety should therefore be interested in factors that affect the speed road users are travelling at.

In contrast to the variable SPEED defined as inappropriate speed for the prevailing conditions, the dependent variable in this case is the driving speed reported by the interviewees. This variable is therefore labeled self-reported speed (SRSPEED). Self-reported speed is used because there was no objective data on speed (e.g. measured with speed cameras) available.

Based on the reviewed literature, it will be investigated whether or not SRSPEED is affected by the level of roadside development, traffic density and road width parameters. These variables will be considered in a correlation matrix for the road location elements straight section, T-intersections and curves. Variables that significantly correlate with SRSPEED will be included in a multiple linear regression model. Note that lane and shoulder width are continuous in the linear regression whereas they are categorical in all logistic regression models.

Specific objective four

The association between the occurrence of the main human factors and road location elements will be investigated. The Main human factors are: SPEED, FATI, UIBLIND and CON. The road location elements are: Straight section, curves, T-intersections and roundabouts. The other main human factors as identified in study one are not considered. There is no evidence that the occurrence of the human factors ANMIL and CARSAFE are related to the road design.

If the prevalence of a particular main human factor at a particular road location element is equal or greater than 50 % (25 % for straight sections), the association between this main human factor and this road location element will be considered for analysis. The cutting point of 50 % (25 %) was chosen because it ensures that the number of cases for each investigation is still great enough to perform appropriate statistical analysis. The available number of RTAs that occurred on straight sections is comparatively large. Hence the lower cutting point.

In the subsequent analysis the association between the particular main human factor and each of the road location element specific design elements that are likely to contribute to the occurrence of the particular main human factor (*Table 4.1*) will be investigated using Chi² test (alternatively Likelihood ratio or Fisher's exact probabilities, see part III, 1.2) and bivariate logistic regression analysis. Similar to the study on human factors (part III, 1.2), road location element specific design elements that are associated with the occurrence of the main human factor with a level of $p>0.15$ will be included in a multiple logistic regression.

Despite the cutting point of 50 % (25 %) it may be that the number of cases for a particular variable is less than ten. Strictly speaking, this would violate a generally accepted rule of thumb regarding the required number of cases per variable in logistic regression analysis (Wilson VanVoorhis & Morgan, 2007). But recent research has indicated that deviating from this rule won't necessarily bias the results (Vittinghoff & McCulloch, 2007).

The selected study design corresponds to the design applied for objective one. As such, the design can be considered a case-control design with the cases being those drivers who engaged in the problem behavior (main human factor present) at the time the RTA occurred and the controls being those drivers who didn't engage in the problem behavior (main human factor not present) at the time the RTA occurred.

Recall that main human factors are defined as risk factors. Hence, the outcome of the case-control study itself is a risk factor. Generally, the outcome in case-control studies is a disease (or the occurrence of an RTA to be more specific in the context of road safety research) and the independent variables pose risk factors that contribute to the occurrence of the disease. In the present study, the independent variables are various design elements. The literature review has revealed that, for example, the geometric properties of a particular design element affect RTA risk. Properties of design elements might therefore be risk factors that contribute to the occurrence of RTAs. The literature review has also revealed that the environment affects the driving behavior and the behavior while driving. Recalling the role of the HRI in the causation of RTAs, it is likely that the frequency of the occurrence of a particular human factor depends on the road design. The following example might illustrate this thought:

In Part III, 2.4.3.4, it was argued that passengers, when engaging the driver in a conversation, or vice versa, turn to the person as it would be impolite not to establish eye contact when talking to someone. As a consequence, the driver would also be distracted visually, thereby drastically increasing his or her risk of causing an RTA. The more demanding a traffic situation is (e.g. narrow road, high traffic density), the less likely a driver would turn to the person he or she is having a conversation with. However, the extent of demand is associated with subjective and objective perceived risk. A driver might subjectively perceive a situation as not demanding (risky) and allocates more mental resources to the conversation. Objectively, however, the situation is demanding (risky) and requires more mental resources than the driver is willing to allocate. In other words, the environment does not necessarily contribute to whether or not the human factor conversation occurs, but (in this specific example) it can affect the amount of mental resources allocated to the human factor conversation. If the amount of mental resources required for the safe execution of the driving task is no longer sufficient, the RTA risk increases. Of course, the way the environment affects a particular human factor depends on the human factors and the design elements.

Now, given the case-control design, this study will yield insight into the extent to which a specific property (e.g. presence of hard shoulders) of a design element will increase the risk for another (human) risk factor to occur. Or, in other words, it informs about whether a particular human factor was more frequently present under condition A when compared to condition B among drivers who were involved in RTAs, with condition being properties of a particular design element.

This is contrary to objective one where the analysis revealed if a particular human factor increased the risk for causing an RTA (in a legal sense). The analysis in this study won't add to the understanding if the combination of a particular design element and a particular human factor increases the risk for causing an RTA.

Table 4.1. Design elements that are likely to affect the occurrence of main human factor at selected road location elements. The design elements have been selected based on the reviewed literature – a short introduction / review on the possible association will be provided before each analysis. It is assumed that driver demand depends on the properties of a particular design element. Driver demand, in turn, is associated with RTA risk.[1] Design speed data is only available for straight sections.

Road location element	**Main human factor**	**Design elements**
Straight sections (Tangents)	SPEED, FATI, UIBLIND, CON	Lane and shoulder width, shoulder type, roadside development, road markings, number of carriageways, design speed[1], traffic density
T-intersections	SPEED, FATI, UIBLIND, CON	Roadside development, presence of left-turn lane, sight triangle, obstructed view, traffic density
Curves	SPEED, FATI, UIBLIND, CON	Lane and shoulder width, shoulder type, roadside development, openness, presence of warning signs, road markings, traffic density, number of carriageways
Roundabouts	SPEED, FATI, UIBLIND, CON	Number of lanes / carriageways, diameter size, road markings, traffic density

1.3 Confounding and interaction

Confounding and interaction are two major issues that need to be considered in statistical analysis. In the field of road safety research with a focus on road design, possible confounders are lane width, shoulder width and daily traffic (Gross et al., 2009). No data on daily traffic is available. The subjectively reported variable traffic density (high or low) will be considered instead.

The model building strategy for multiple logistic regression is based on Hosmer and Lemshow's (1989) suggestions according to which the relevance for an independent variable to be included in the model depends on the significance of its associations with the dependent variable in a bivariate analysis. If an independent variable is not included in the model because it is not significantly associated with the dependent variable, it is unlikely that this variable was a possible confounder. For those variables that are included in the model, multiple logistic regression is a valid method to control for confounding (Hosmer & Lemeshow, 1989). The same applies for linear regression.

Possible interactions are to be expected between lane and shoulder with (Bonneson, Lord, Zimmermann, Fitzpatrick, & Pratt, 2007). Besides shoulder width, it is likely that the effect of lane width is modified by shoulder type (hard or soft). Interaction can be tested for by including interaction terms in both the multiple linear and logistic regression model. However, due to small sample sizes, it is not always possible to consider interaction effects. Therefore, despite strong theoretical evidence, the interaction terms "lane width x shoulder width" and "lane width x shoulder type" will only be considered when at least one of the design elements is significantly ($p>0.15$) associated with the dependent variable in the bivariate analysis.

The approach to control for interactions in linear regression is based on Aiken and West (1991) who recommend to center the variables (subtracting the mean from each independent variable) in order to reduce multicollinearity.

Note of course that there are many more factors that affect the dependent variables. Yet, the purpose of this research is to exclusively focus on the impact of design elements.

2. Results

2.1 Specific objective one

In order for roads to be considered self-explaining, the following criteria suggested by Matena et al. (2006) should be met.

1. Recognizable: Roads with the same function should look similar.

2. Distinguishable: Roads of different categories (classifications) should have different layouts. There shouldn't be more than three to four different categories.

3. Easily interpretable: The desired driving behavior has to be clear. The measures used for differentiating should induce the desired behavior.

According to the Omani Highway Design Standards (OHDS, 2010), roads in Oman can be categorized into five functional categories: national roads, arterial roads, secondary roads, distributor roads and access roads. Functional categorization is a way of grouping roads based on the character of service they provide (Brockenbrough, 2009). Each category is further categorized into sub-groups for different terrains (e.g. flat, mountainous, etc.), 84 % of the roads in Oman are flat. Each sub-group, in turn, consists of different design groups (*Table 4.2*). The design group and the respective design variables depend on the estimated traffic flow per year. For example, in the case where traffic flow for national routes is 2500 passenger cars / hour (one way), two carriageways would be required. Accordingly, design group A2 has to be chosen over design group A3.

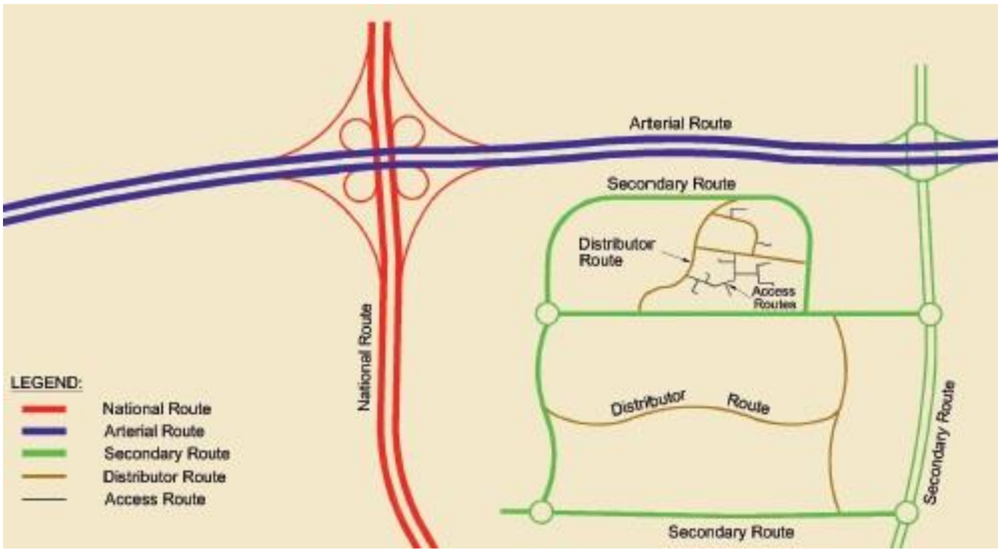


Figure 4.8: Road categories in Oman (OHDS, 2010). National routes are long distance high speed roads connecting the most important centers in Oman including ports and airports. Arterial routes connect the major centers in Oman, national routes and important links between national routes. Secondary routes form regional or area networks. They link towns with towns as well as towns with arterial routes. Distributor routes form local networks. They link villages and major villages as well as secondary or (exceptionally) arterial routes. Access routes are routes to small settlements, commercial centers or roadside developments.

At first view, the road hierarchy in Oman (*Table 4.2*) suggests that criteria one and two are partially met. However, a closer look at the design groups of the functional categories reveals that the design elements for design group A 3 and B 3 are basically identical. Hence, a road user would not be able to distinguish between the two categorizations based on the present design elements. These findings might be relevant for future layouts, but what about the present situation?

Table 4.2. Design elements according to the categories national routes and arterial routes (OHDS, 2010).

Route categorization terrain	Design group	Design speed	Posted speed	No of carriageways	No of lanes in each direction	Min lane width (m)	Desirable right shoulder width (m)	Possible curbside parking	Roadside development allowed
National rural / flat rolling	A1	130	120	2	3	3.75	3	No	No
	A2	130	120	2	2	3.75	3	No	No
	A3	110	100	1	1	3.65	3	No	No
Arterial rural, flat / rolling	B1	110	100	2	3	3.65	3	No	No
	B2	110	100	2	2	3.65	3	No	No
	B3	110	100	1	1	3.65	3	No	No

As reported in the road inventory survey (DGRLT, 2005) some roads of the Omani road network had no functional categorization. The categorization used in this report is different from the categorization used in the current Omani Highway Design Standards. Instead of national, arterial and secondary roads, the categories primary, secondary and local roads are used. These (obsolete) categorization types were also provided by the Directorate General of Road and Land Transport when the road design data was requested. Additionally, it should be noted that Muscat Municipality uses different road categorization, namely expressway, primary, secondary and tertiary roads. In order for the results to be comparable, the existing road categories in Oman will be evaluated based on the obsolete categorization system.

For evaluating the first criteria (recognizable: roads with the same function should look similar), it needs to be investigated whether or not roads of the same functional categorization are similar in their design.

Table 4.3 depicts three design elements (shoulder width, lane width, and shoulder type) according to functional categorization. In order to ensure comparability, the data has been limited to rural roads with single carriageways. As can been seen, all three categories vary in their design. About half of the primary and secondary roads are equipped with soft shoulders whereas the other half is equipped with hard shoulders. Lane and shoulder widths have differences of 0.25 m an 1.5 m, respectively. It can be concluded that roads of the same functional categorization are not similar in their design.

Table 4.3. Shoulder width, lane width and shoulder type according to functional categorization. The data is limited to rural roads with single carriageways.

	Shoulder width (m)						**Total**
	1	**1.5**	**2**	**2.25**	**2.4**	**2.5**	
Primary	6	2	21	2	4	6	41
Secondary	1	0	9	3	2	0	15
Local	0	1	5	0	2	0	8

	Lane width (m)			
	3.5	**3.65**	**3.75**	
Primary	19	1	22	42
Secondary	5	0	10	15
Local	5	0	3	8

	Shoulder type		
	Hard	**Soft**	
Primary	20	21	41
Secondary	5	10	15
Local	2	6	8

For evaluating the second criteria (distinguishable: roads of different categories should have different layouts. There shouldn't be more than three to four different categories), it needs to be investigated if there are obvious differences between the categories.

When comparing the lane width of rural roads from different functional categorization with single carriageways and 2 m hard shoulders, it can be found that the same lane widths have been applied on all three categories (*Table 4.4*). Not only are primary and local roads similar in the lane width, but also in other design elements that might assist road users in categorizing the road (e.g. shoulder type). Hence, there are no obvious differences between categories.

Table 4.4. Lane widths according to functional categorization. All roads are rural, single carriageways with 2 m hard shoulders.

	Lane widths (m)			**Total**
	3.5	**3.65**	**3.75**	

Primary	4	1	3	8
Secondary	0	0	4	4
Local	1	0	1	2
Total	5	1	8	14

In order to evaluate the third and last criteria (easily interpretable: the desired driving behavior has to be clear. The measures used for differentiating should induce the desired behavior), the credibility of posted speed limits could be evaluated. The literature review has revealed that the wider the roads are, the higher the observed speeds are. Consequently, speed limits should increase with road width. This is the case in the current Omani Highway Design Standards.

Table 4.5 shows the lane widths according to posted speed limits. In line with the recommended guidelines, the widest lanes have the highest speed limit of 120 km/h. With regard to 3.5 m and 3.65 m lane widths speed limit differences of up to 40 km/h exist. In other words, road users are not able to draw any conclusions about the speed limit based on design elements like lane width.

Although the latest version of the Omani Highway Designs Standards considers the demands associated with SERs, the findings suggest that the current Omani road network is not self-explaining.

Table 4.5. Posted speed limits according to lane widths, all roads are rural, single carriageways with 2 m hard shoulders.

	Lane widths (m)			**Total**
	3.5	**3.65**	**3.75**	
60 km/h	1	0	0	1
80 km/h	1	2	0	3
100 km/h	3	0	0	3
120 km/h	0	2	9	11
Total	5	4	9	18

2.2 Specific objective two

Interviewees were asked to assess whether or not they found the road on which the RTA occurred to be safe (yes or no). This variable is labeled SUBSAFE. But what are the predictors for a road to be perceived as safe? The following design elements are likely to be associated with the subjectively perceived safety of a road: Number of carriageways (NCW), roadside development (RD), shoulder type (ST) as well as lane (LW) and shoulder width (SW). The frequencies can be found in *Appendix B*.

NCW (Number of carriageways): NCW is significantly associated with SUBSAFE (Chi^2 (DF=1, N=213), p=0.000). Roads with dual carriageways are more frequently perceived as safe than roads with single carriageways (OR=6.38, 95% CI [2.84; 14.32]).

RD (Roadside development): RD is marginally significant in association with SUBSAFE (Chi² (DF=1, N=250), *p*=0.086). The odds for rural roads to be perceived as safe are higher when compared to urban roads (OR=1.57, 95% CI [0.94; 2.64]).

ST (Shoulder type): ST is significantly associated with SUBSAFE (Chi² (DF=1, N=197), *p*=0.009). The odds for roads that are equipped with hard shoulders to be perceived as safe are 2.22 times higher when compared to roads equipped with soft shoulders (OR=2.22, 95% CI [1.21; 4.05]).

LW (Lane width): LW is significantly associated with SUBSAFE (Chi² (DF=2, N=207), *p*=0.002). Roads with a lane width of 3.65 m (OR=4.47, 95% CI [1.89; 10.62]) and 3.75 m (OR=1.49, 95% CI [0.80; 2.70]) are more frequently perceived as safe when compared to the reference category (3.5 m).

SW (Shoulder width): SW is not significantly associated with SUBSAFE (Chi² (DF=1, N=198), *p*=0.307). Roads with a shoulder width of 2.1-3 m are more frequently perceived as safe when compared with roads with a shoulder width of 1-2 m (OR=1.36, 95% CI [0.75; 2.44]).

Multiple regression analysis: The aforementioned design elements that were significantly associated with SUBSAFE at a *p*<0.15 level were included in a multiple logistic regression analysis. Furthermore, the interaction terms LW x SW and LW x ST were included. A stepwise backward regression revealed only one significant effect (*p*<0.05) for NCW. Roads with dual carriageways (OR=6.73, 95% CI [2.98.; 15.26]) are more frequently perceived as safe when compared to roads with single carriageways controlling for roadside development, shoulder type, lane width and the interaction between lane width and shoulder width as well as lane width and shoulder type.

2.3 Specific objective three

Self-reported mean speed for all RTAs is 88.58 ± 36.54 km/h. For RTAs on straight roads, T-intersections and curves, self-reported mean speed is 97.02 ± 34.24 km/h, 92.44 ± 28.25 km/h and 70.42 ± 38.74 km/h, respectively.

2.3.1 Self-reported speed on straight sections

According to the literature review (part II, 2.0), the level of roadside development (RD), traffic density (TRAFD), number of carriageways (NCW), shoulder type (ST), lane (LW) and shoulder widths (SW affect driving speed (SRSPEED). A correlation matrix (*Table 4.6*) with these design elements reveals that only RD, SW and LW are significantly correlated with SRSPEED. In order to better control for the possible interaction of SW x LW, rural and urban roads will be considered in two different multiple linear regressions.

*Table 4.6. Correlation matrix for SRSEED on straight sections, T-intersections and curves with the design elements TRAFD (high or low), NCW (one or two), roadside development (rural or urban), ST (hard of soft), SW (measured in m) and LW (measured in m) **p*< 0.01*, *p<0.05.*

	TRAFD	NCW	RD	ST	SW	LW
Pearson's Correlation with SRSPEED on straight sections	0.105	0.116	-0.213*	0.193	0.208*	0.317**
N 139	275	106	122	99	99	102
Pearson's Correlation with SRSPEED at T-intersections	0.331*	-0.99	-0.251	-0.166	0.017	0.40
N 48	48	33	43	30	30	32
Pearson's Correlation with SRSPEED in curves	-0.107	0.190	0.060	-0.208	-0.077	-0.033
N 45	45	33	39	32	32	33

Mean self-reported speed on straight sections in rural environments is 104.08 ± 33.47. The multiple linear regression (*Table 4.7*) revealed a significant effect for LW on SRSPEED. The interaction is not significant. Yet, contrary to roads with wide LW, the scatter plot in *Figure 4.9* suggests a tendency for higher SRPSEED to occur on roads with narrow LW when they have a SW between 1 and 2 m.

Mean self-reported speed on straight sections in urban environments is 88.43 ± 30.89. With regard to the design elements that affect SRSPEED, the contrary can be observed (*Table 4.8*) when compared to the results from rural environments. Whereas LW has no significant effect on SRPSEED, the effects of SW and the interaction SW x LW are significant. The scatter plot (*Figure 4.10*) indicates that SRSPEED is only affected by LW when SW is between 2.1 and 3 m. For roads with a SW of 1-2 m, LW seems to have no effect on SRSPEED.

Table 4.7. Results of multiple linear regression for SRSPEED on rural roads and the dependent variables SW, LW and the interaction term SW x LW.

	B	Beta	Sig
Constant	103.268		0.000
SW centered	-4.326	0.051	0.768
LW centered	111.209	0.357	0.016
SW x LW centered	-16.429	0.020	0.886
			R^2 = 0.072, N=73

Table 4.8. Results of multiple linear regression for SRSPEED on urban roads and the dependent variables SW, LW and the interaction term SW x LW. Note that the whole model is only marginal significant; F(3,21)=2.552, p=0.083.

	B	Beta	Sig
Constant	80.494		0.000
SW centered	51.389	0.735	0.038
LW centered	33.224	0.101	0.647
SW x LW centered	395.677	0.636	0.047
			R^2 = 0.163, N=24

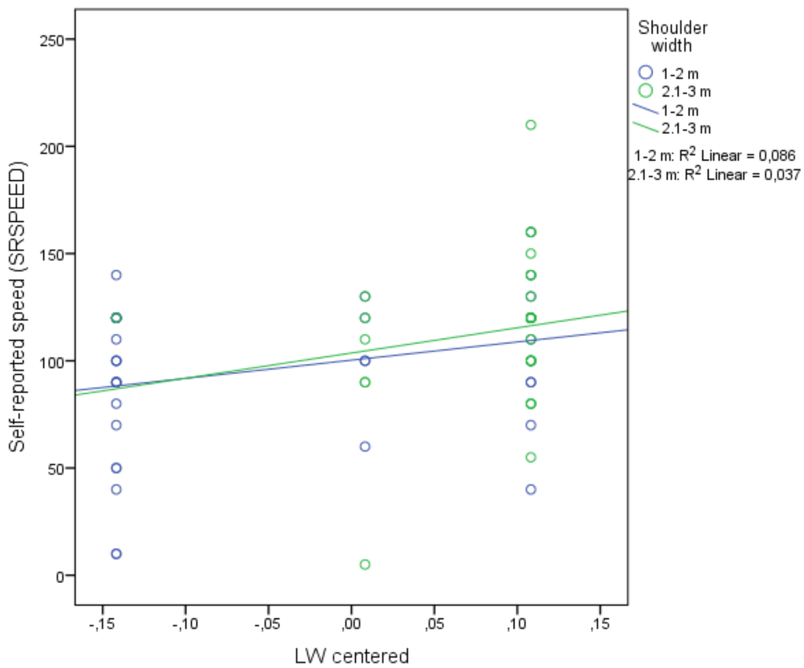


Figure 4.9. Scatter plot for lane width centered (Table 4.7) on the X-axis and SRSPEED on the Y-axis for rural environment; grouped according to shoulder width.

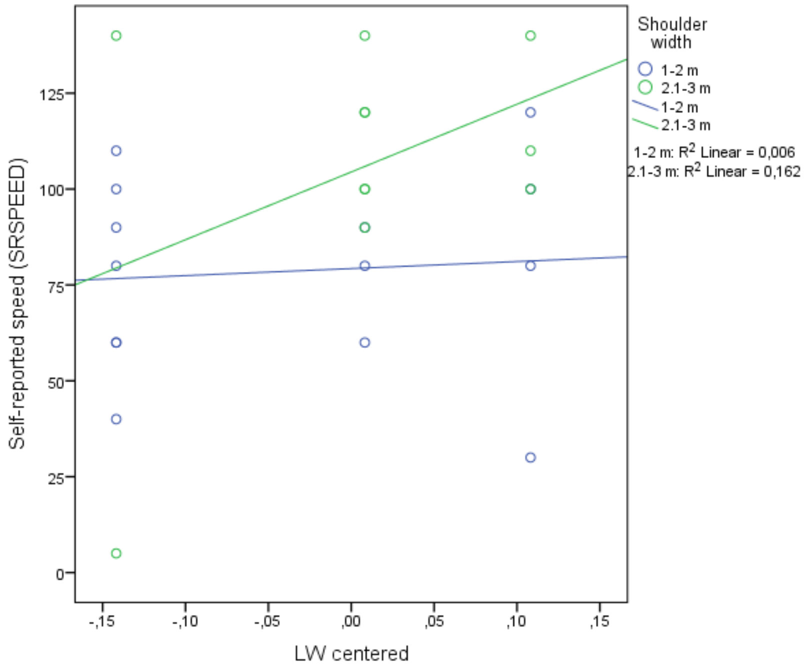


Figure 4.10. Scatter plot for lane width centered (Table 4.8) on the X-axis and SRSPEED on the Y-axis, for urban environments; grouped according to shoulder width.

2.3.2 Self-reported speed on T-intersections and curves

According to *Table 4.6*, none of the design elements that affect SRSPEED on straight sections affect SRPSEED at either T-intersections or curves. The only significant correlation can be observed between SRSPEED and TRAFD at T-intersections. SRSPEED increases under low traffic density conditions.

With regard to T-intersections specific design elements, namely left-turn lanes (present or not), sight triangle (present or not) and obstructed view (yes or no), the correlation between obstructed view and SRSPEED is marginally significant (r=0.27, p=0.06). A linear regression reveals that SRPSEED is predicted to be 29.76 km/h lower when the view is obstructed (β=0.027, p=0.06). With regard to curve specific design elements like openness and curve warning signs (present or not), no further correlations with SRSPEED could be found.

2.4 Specific objective four

277 out of 296 RTAs occurred either on straight sections (N 159), T-intersections (N 55), curves (N 48) or roundabouts (N 15) (*Figure 4.11*). The four main human factors account for half (49.8 %) of all

RTAs that occurred at one of these road location elements. As shown in *Table 4.9*, the main human factors are unequally distributed among the road location elements. 69.2 % and 54.4 % of the main human factors FATI and CON, respectively, occur on straight sections. Intuitively, it might be concluded that both factors have an adverse effect on maintaining the vehicle's lateral position which eventually leads to run-off the road or head-on RTAs (*Table 3.22*). Only one quarter (26.5 %) of the main human factor SPEED can be observed at straight sections. This finding is in line with the assumption that travelling at high speeds on a straight section is not necessarily accompanied with an increased RTA risk as long as there are no possible hazards on the road. A curve could be such a hazard. The driver would have to adjust his or her speed in a timely fashion in order to safely negotiate the curve. Accordingly, the table shows a relatively high prevalence of the risk factor SPEED at curves (52.8 %). In order to find out more about the interaction between a particular main human factor and a particular road location element it is necessary to look at each road location element individually.

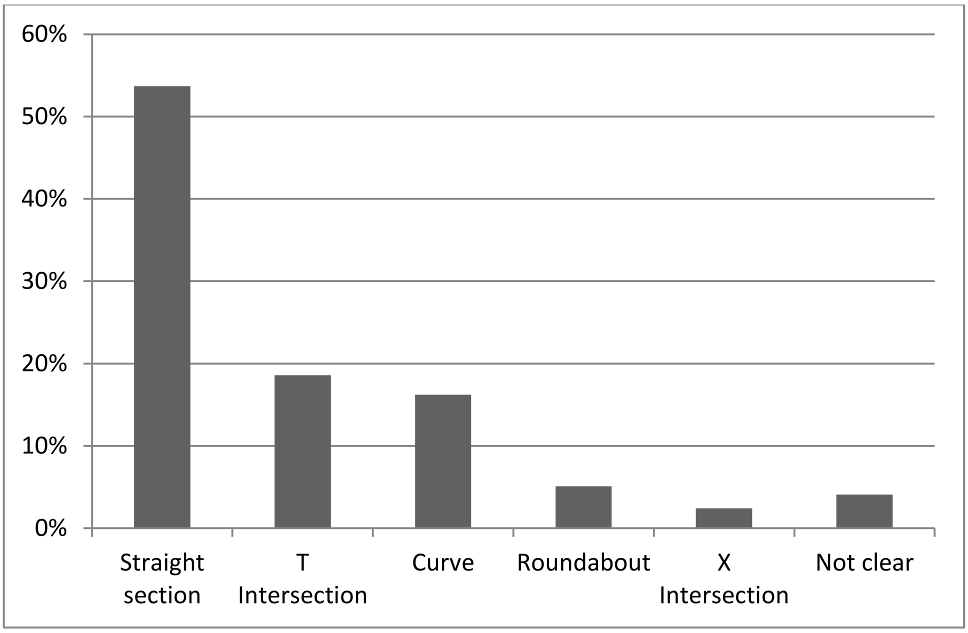


Figure 4.11. Frequency of road location elements at which RTAs occurred. Straight section 53.7 %, T-intersection 18.6 %, Curve 16.2 %, Roundabout 5.1 %, X-Intersection 2.4 %, not clear 5.1 %.

Table 4.9. Frequency of main human factors according to different road location elements.[1] Column percentage of risk factor type according to road location elements.

		FATI		SPEED		UIBLIND		CON	
		Yes	**No**	**Yes**	**No**	**Yes**	**No**	**Yes**	**No**
Straight sections	**Yes**	26 (69.2%)[1]	131	9 (26.5%)	149	5 (20.0 %)	153	25 (54.4%)	134
	No	18	118	25	109	20	113	21	114

T-Intersections	**Yes**	3 (6.8%)	52	2 (5.9%)	53	18 (72.0%)	36	7 (15.2%)	47
	No	36	190	31	196	5	222	36	192
Curves	**Yes**	8 (18.2%)	39	18 (52.8%)	30	0	48	8 (17.4%)	40
	No	36	210	16	228	25	218	38	208
Roundabouts	**Yes**	2 (4.6%)	13	4 (11.8%)	10	0	14	3 (6.5%)	12
	No	42	236	30	248	25	252	43	236

2.4.1 Straight sections

53.7 % of all RTAs occurred on straight sections. According to *Table 4.9* the prevalence of FATI, SPEED and CON on straight sections is greater than 25 %. Accordingly, these three main human factors will be further analyzed. The frequencies can be found in *Appendix B*.

2.4.1.1 Straight sections and fatigue

Driver fatigue is associated with mental demand (part II, 1.2.2). Some features of design elements (e.g. narrow lane width, urban environments) are likely to increase the mental demand of the driving task, whereas others are likely to decrease the mental demand (e.g. dual carriageways, rural environment). Consequently, it is expected that FATI occurs less frequently on roads that require the driver to fully concentrate. The high demand is believed to counteract fatigue (Desmond & Matthews, 1997).

Lane width (LW): The association between LW and FATI is not significant (Likelihood ratio test, p=0.421). The logistic regression shows a tendency for FATI to occur less frequent on narrow roads. Compared to the reference category (3.75 m), the odds for FATI to occur are lower for roads with a lane width of 3.5 m (OR=0.41, 95% CI [0.10.; 1.60]) and 3.65 m (OR=7.64, 95% CI [0.22.; 2.72]).

Shoulder width (SW): The association between SW and FATI is not significant (Chi² (DF=1, N=108), p=0.832). FATI occurs slightly more often on narrow shoulders (1-2 m) compared to wide shoulders (2.1-3 m) (OR=1.12, 95% CI [0.39.; 3.21]).

Shoulder type (ST): The association between ST and the occurrence of FATI is not significant (Chi² (DF=1, N=108), p=0.562). The risk for FATI to occur on roads with a hard shoulder is higher compared to soft shoulders (OR=1.12, 95% CI [0.47.; 4.84]).

Roadside development (RD): The association between roadside RD and the occurrence of FATI is not significant (Chi^2 (DF=1, N=134), *p*=0.958). The occurrence of FATI doesn't differ with regard to the road environment (RD) (OR=1.03, 95% CI [0.382.; 2.76]).

Road markings (RM): The association between RM and the occurrence of FATI is not significant (Chi^2 (DF=1, N=154), *p*=0.879). The occurrence of FATI doesn't differ with regard to the absence or presence of road markings (OR=1.09, 95% CI [0.371.; 3.18]).

Number of carriageways (NCW): The association between NCW and the occurrence of the main human factor FATI is significant (Chi^2 (DF=1, N=116), *p*=0.021). The odds for FATI to occur on roads with dual carriageways are 3.26 times greater when compared to roads with single carriageways (OR=3.26, 95% CI [1.16; 9.18]).

Traffic density (TRAFD): The association between TRAFD and FATI is not significant (Chi^2 (DF=1, N=156), *p*=0.723). There is a slightly decreased risk for FATI to occur under high traffic density conditions (OR=0.83, 95% CI [0.30; 2.28]).

Multiple regression analysis: With the exception of NCW, all straight section specific design elements are far from being significantly associated with the occurrence of FATI at a $p<0.15$ level. Therefore, it is not necessary to carry out multiple regression analysis. It appears that the only design element that affects the occurrence of FATI is the number of carriageways with dual carriageways being more prone to contribute to FATI.

2.4.1.2 Straight sections and speed

Recall that excessive speed doesn't necessarily contribute to the occurrence of RTAs on straight sections, but increases the RTA risk (if the driver would have to avoid a hazard, for example). On straight sections, these hazards are likely to be found under high traffic density conditions and in urban environments. Furthermore, this section will add to the understanding of whether or not exceeding design speed contributes to the occurrence of RTAs in which speed played a role.

Lane width (LW): The association between LW and SPEED is not significant (Likelihood ratio test, *p*=0.565). The logistic regression shows a tendency for SPEED to occur less frequent on narrow roads. Compared to the reference category (3.75 m), the odds for SPEED to occur are lower for roads with a lane width of 3.5 m (OR=0.36, 95% CI [0.04.; 3.29]) and 3.65 m (OR=0.48, 95% CI [0.05.; 4.53]).

Shoulder width (SW): The association between SW and SPEED is not significant (Likelihood ratio test, *p*=0.743). SPEED occurs more often on wide shoulders (2-2.1 m) compared to narrow shoulders (1-2 m) (OR=1.12, 95% CI [0.254.; 6.85]).

Shoulder type (ST): The association between ST and the occurrence of SPEED is not significant (Likelihood ratio test, *p*=0.204). The risk for SPEED to occur on roads with a hard shoulder is lower compared to soft shoulders (OR=0.34, 95% CI [0.06.; 1.92]).

Roadside development (RD): The association between RD and the occurrence of SPEED is not significant (Likelihood ratio test, *p*=0.763). The risk for SPEED to occur is greater on urban roads compared to rural roads (OR=1.26, 95% CI [0.287.; 5.53]).

Road markings (RM): The association between RM and the occurrence of SPEED is not significant (Likelihood ratio test, *p*=0.636). The risk for SPEED to occur is higher on roads without road markings when compared to roads with road markings (OR=1.56, 95% CI [0.30.; 8.12]).

Number of carriageways (NCW): The association between NCW and the occurrence of SPEED is not significant (Likelihood ratio test, *p*=0.527). The odds for SPEED to occur on roads with single carriageways are almost twice as great when compared to roads with dual carriageways (OR=1.94, 95% CI [0.22; 17.26]).

Traffic density (TRAFD): The association between TRAFD and SPEED is not significant (Likelihood ratio test, *p*=0.686). There is an increased risk for SPEED to occur under low traffic density conditions (OR=2.12, 95% CI [0.26; 17.90]).

Exceeding design speed (EXDSPEED): If self-reported speed was 11 km/h higher than the posted speed, the drivers exceeded the design speed. The association between EXDSPEED and the occurrence of SPEED is significant (Likelihood ratio test, *p*=0.021). The odds for SPEED to occur when exceeding the design speed are almost ten times higher when not exceeding the design speed (OR=9.93, 95% CI [1.05; 92.67]).

Multiple regression analysis: Similar to the investigation of the relation between straight section specific design elements and the occurrence of the main human factor FATI, multiple regression is not necessary. Only one design element (exceeding design speed) was significant at a *p*<0.15 level.

2.4.1.3 Straight sections and conversations

It was already argued that the main human factor conversation (CON) is likely to occur more frequently in situations that are perceived as safe (1.2.3). Accordingly, wide roads in general and roads with dual carriageway in particular should be associated with the prevalence of this risk factor.

Lane width (LW): The association between LW and CON is not significant (Likelihood ratio test, *p*=0.498). The logistic regression shows a tendency for CON to occur less frequent on narrow roads. Compared to the reference category (3.75 m), the odds for CON to occur are lower for roads with a lane width of 3.5 m (OR=0.62, 95% CI [0.12.; 1.67]) and 3.65 m (OR=0.48, 95% CI [0.12.; 1.93]).

Shoulder type (ST): The association between ST and the occurrence of CON is not significant (Likelihood ratio test, *p*=0.190). The risk for CON to occur on roads with a hard shoulder is twice as high compared to soft shoulders (OR=2.08, 95% CI [0.68.; 6.32]).

Roadside development (RD): The association between RD and the occurrence of CON is significant (Likelihood ratio test, *p*=0.019). The risk for CON to occur is greater on rural roads compared to urban roads (OR=3.85, 95% CI [1.08.; 13.75]).

Road markings (RM): The association between RM and the occurrence of CON is not significant (Likelihood ratio test, *p*=0.779). The risk for CON to occur is higher on roads with no road markings compared to roads with road markings (OR=1.18, 95% CI [0.37.; 3.75]).

Number of carriageways (NCW): The association between NCW and the occurrence of CON is not significant (Likelihood ratio test, *p*=0.118). The risk for CON to occur is higher for roads with single carriageway when compared to dual carriageways (OR=2.60, 95% CI [0.71; 9.51]).

Traffic density (TRAFD): The association between TRAFD and CON is marginally significant (Likelihood ratio test, *p*=0.080). The risk for CON to occur is lower under high traffic density conditions compared to low traffic density conditions (OR=0.31, 95% CI [0.07; 1.40]).

Multiple regression analysis: Three straight section specific design elements are associated with the occurrence of CON at a *p*<0.15 level, namely roadside development (RD), number of carriageways and (NCW) and traffic density (TRAFD). Including these design elements in a multiple logistic regression model reveals one significant effect and one marginally significant effect (*Table 4.10*). The risk for CON to occur increases on rural roads when compared to urban roads and decreases under high traffic density conditions when compared to low traffic density conditions.

Table 4.10: Multiple logistic regression analysis with the design elements traffic density (TRAFD), roadside development (RD) and number of carriageways (NCW).

	Sig.	**OR**	**95 % CI**	
			Lower	**Upper**
TRAFD	0.109	0.28	0.06	1.33
RD	0.031	5.42	1.17	25.12
NCW	0.227	2.28	0.60	8.73
Constant	0.000	0.038		
				Nagelkerkes R^2: 0.163; N = 115

2.4.2 T-intersections

18.6 % of all RTAs occurred at T-intersections. T-intersections are the second most RTA prone road location element. According to *Table 4.9* the prevalence of UIBLIND at T-intersections is greater than 50 %. The frequencies can be found in *Appendix B*.

2.4.2.1 T-intersection and unintended blindness

Although design guidelines generally require that the sight triangles are free of objects, it was argued that uncertainty of the presence of conflicting traffic might be less detrimental to safety than certainty (part II, 2.6.1). If so, unintended blindness (UIBLIND) should be less frequent at T-intersections in urban environments, without sight triangles and at inclines or declines (OBVIEW). Furthermore, it was argued that drivers are at higher RTA risk when turning at intersections with low traffic density.

Roadside development (RD): The association between RD and UIBLIND is not significant (Likelihood ratio test, p=0.279). The risk for UIBLIND to occur is lower at rural T-intersections compared to urban T-intersections (OR=0.49, 95% CI [0.13; 1.85]).

Left-turn lane (LTL): The association between LTL (present or not) and UIBLIND is not significant (Likelihood ratio test, p=0.431). The risk for UIBLIND to occur when no left-turn lane is present is lower compared to T-intersections where left-turn lanes are present (OR=0.50, 95% CI [0.09; 2.78]).

Sight triangle: (STR): The association between STR (sight triangle, yes or no) and UIBLIND is not significant (Chi^2 (DF=1, N=47), p=0.278). The risk for UIBLIND to occur when no sight triangle is present is lower when compared to T-intersections where sight triangles are present (OR=0.52, 95% CI [0.15; 1.72]).

Obstructed view: (OBVIEW): Unlike the design element sight triangle which was measured objectively using Google earth, OBVIEW is based on interview data and thus based on subjective accounts (part III, 2.4.2.2). The association between OBVIEW and UIBLIND is not significant (Likelihood ratio test, p=0.152). The risk for UIBLIND to occur at T-intersections where the view is obstructed is three times higher than at T-intersections where the view is not obstructed (OR=3.14, 95% CI [0.62; 15.92]).

Traffic density (TRAFD): The association between TRAFD and UIBLIND is marginally significant (Chi² (DF=1, N=47), p=0.053). The risk for UIBLIND to occur is higher under high traffic density conditions compared to low traffic density conditions (OR=3.31, 95% CI [0.96; 11.50]).

Multiple regression analysis: Strictly speaking, only TRAFD is associated with the occurrence of UIBLIND at a p<0.15 level. Yet, OBVIEW is very close to meeting this inclusion criteria (p=0.152). Hence, both design elements OBVIEW and TRAFD will be considered in a multiple logistic regression. As shown in *Table 4.11*, the risk for UIBLIND to occur at T-intersections with high traffic density is higher than for T-intersections with low traffic density while controlling for OBVIEW. Yet, the effect of TRAFD on the occurrence of UIBLIND is only marginally significant.

Table 4.11. Multiple logistic regression analysis with the design elements traffic density (TRAFD) and obstructed view (OBVIEW).

	Sig.	**OR**	**95 % CI**	
			Lower	**Upper**
TRAFD	0.056	3.47	0.97	12.39
OBVIEW	0.156	3.40	0.63	18.36
Constant	0.002	0.285		
Nagelkerkes R^2: 0.138; N = 54				

2.4.3 Curves

16.2 % of all RTAs occurred in curves, of which 20 (41.7 %) and 22 (45.8 %) occurred in right and left curves, respectively. In six cases (12.5 %), the direction of the curve could not be identified. According to Table 4.9 the prevalence of SPEED in curves is greater than 50 %. The frequencies can be found in *Appendix B*.

2.4.3.1 Curves and speed

Most RTAs in which SPEED played a role were run-off RTAs (*Table 3.22*). According to the reviewed literature, RTAs are likely to occur when the driver is entering the curve at high speeds. In most cases, the driver is not able to perceive the curvature while approaching. The risk of not perceiving the curvature increases when curve radius decreases. Furthermore, it was argued that the presence of road markings improves visual guidance.

Roadside development (RD): The association between RD and SPEED is not significant (Chi² (DF=1, N=41), *p*=0.678). The risk for SPEED to occur is higher at rural curves when compared to urban curves (OR=1.33, 95% CI [0.35; 5.00]).

Lane width (LW): The association between LW and SPEED is marginally significant (Likelihood ratio test, *p*=0.051). The logistic regression reveals that the risk for SPEED to occur in curves with a lane width of 3.5 m and 3.65 m are 6.6 and 1.7 times greater, respectively, when compared to the reference category (lane width 3.75 m).

Shoulder width (SW): The association between SW and SPEED is significant (Likelihood ratio test, *p*=0.019). The risk for SPEED to occur is nine times higher in curves with a shoulder with of 1-2 m than on curves with a shoulder of 2.1-3 m (OR=9.00, 95% CI [0.98.; 82.50]).

Shoulder type (ST): The association between ST and SPEED is significant (Chi² (DF=1, N=34), *p*=0.549). The risk for SPEED to occur is higher when the curves are equipped with soft shoulder instead of hard shoulders (OR=1.56, 95% CI [0.36.; 6.76]).

Openness (OPEN): The mean openness of curves is 115.44 m ± 96.86. The openness was dichotomized into curves with an openness < 115 m and >= 115 m. The association between SPEED and OPEN is not significant (Chi² (DF=1, N=41), *p*=0.812). The risk for SPEED to occur on curves with an openness of < 115 m is slightly higher when compared to curves with an openness of >= 115 m (OR=1.12, 95% CI [0.33.; 4.16]).

Presence of warning signs (POWS): Interviewees were asked if they perceived a road sign indicating the curve. The association between SPEED and POWS is significant (Likelihood ratio test, *p*=0.025). The risk for SPEED to occur in curves at which the driver did not perceive a warning sign is eight times higher than in curves where the driver did perceive a warning sign (OR=8.00, 95% CI [0.90.; 71.56]).

Road markings (RM): The association between RM and SPEED is not significant (Likelihood ratio test, *p*=0.417). The risk for SPEED to occur is lower on roads without road markings when compared to roads with road markings (OR=0.55, 95% CI [0.16.; 2.42]).

Number of carriageways (NCW): The association between NCW and SPEED is not significant (Likelihood ratio test, *p*=0.194). The risk for speed to occur on curves with dual carriageways is smaller when compared to curves with single carriageways (OR=0.33, 95% CI [0.06.; 1.92]).

Traffic density (TRAFD): The association between the TRAFD and SPEED is not significant (Likelihood ratio test, *p*=0.212). The risk for SPEED to occur in curves is higher when traffic density is low (OR=1.5, 95% CI [0.26; 8.72]).

Multiple regression analysis: Three curve specific design elements are significantly associated with the occurrence of SPEED in curves. As shown in *Table 4.12*, the risk for SPEED to occur is almost seven times higher in curves where the drivers didn't perceive a curve warning sign when compared to curves where the drivers did perceive a warning sign. The risk for SPEED to occur increases when SW (1-2 m compared to 2.1-3 m) or LW is narrow (3.5 m compared to 3.75 m). Yet, none of these effects is significant. Although Tukey (1991) argues that a *p*-level of <0.15 indicates a tendency towards statistical significance, the effects of POWS and LW (3.5 m) should be regarded carefully due to the small sample size.

Table 4.12: Multiple logistic regression analysis with the design elements SW, POWS and LW. The interaction term LW x SW was considered but removed from the model because it created extremely large standard errors, possibly caused by the small sample size and multiple cells with zero cases.

	Sig.	**OR**	**95 % CI**	
			Lower	**Upper**
SW	0.249	4.50	0.35	57.93
POWS	0.121	6.88	0.60	78.65
LW (3.75 m)	0.233			
LW (3.5 m)	0.113	5.20	0.68	39.90
LW (3.65 m)	0.983	1.03	0.70	16.27
Constant	0.015	0.02		
Nagelkerke's R^2: 0.426; N = 34				

2.4.4 Roundabouts

Only 5.1 % of all RTAs occurred at roundabouts; three times less when compared to RTAs that occurred at T-intersections. Intuitively, this leads to the conclusion that roundabouts are the safer option when dealing with intersecting roads. But it should not be forgotten that the proportion of intersections in Oman is larger than the proportion of roundabouts.

Due to the rather small percentage of RTAs that occurred at roundabouts it is not surprising that the prevalence of a particular main human factor is smaller than 50 %. The number of cases to investigate the association between particular design elements and the occurrence of a particular main human factor is therefore insufficient. However, merging the three main human factors that occur at roundabouts (FATI, SPEED and CON) reveals no significant association with roundabout specific design elements (see *Appendix B* for frequencies). Fisher's exact probabilities for both, TRAFD and diameter size are p=0.100. Taking into account that all roundabouts for which data is available differ in their design suggest that roundabouts are not self-explaining *(Figure 4.12*).

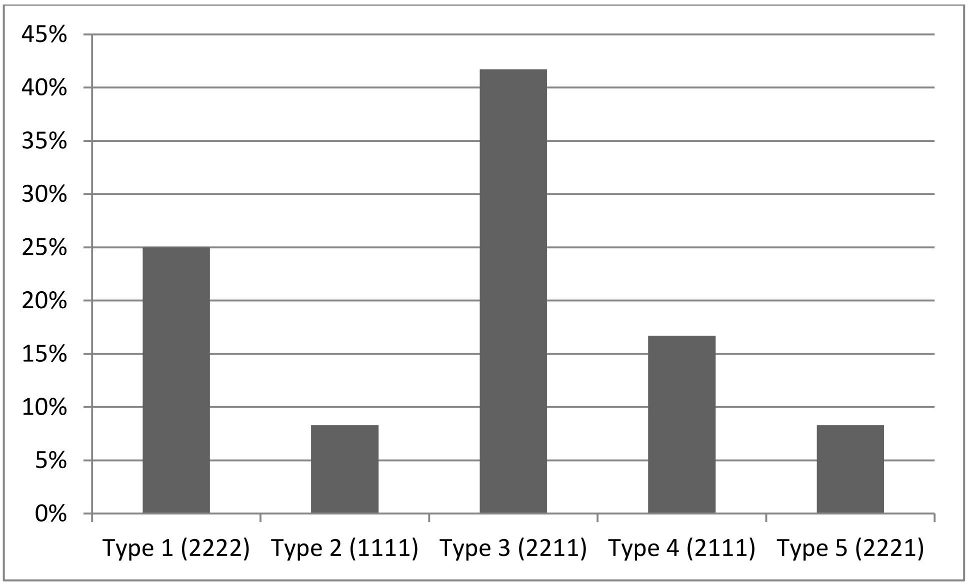


Figure 4.12. Frequency of roundabout types. The numbers in parentheses indicate the number of carriageways (one or two) per leg at a four leg roundabout. The exact frequencies are 25 %, N 3 (Type 1), 8.3 %, N 1 (Type 2), 41.7 %, N 5 (Type 3), 16.7 %, N 2 (Type 4) and 8.3 %, N 1 (Type 4).

Part V: Discussion and recommendations

1. General discussion

Human factors have been reported to account for the occurrence of 90 % of all RTAs. At the same time, road safety experts acknowledge that human factors are insufficiently considered in the design of roads. Adding to the understanding of how human factors could be incorporated in the design of roads would therefore help in reducing the third largest contributing factor to RTAs, namely HRI.

In order to provide recommendations on how to adjust the road design to human factors in Oman, two objectives were defined:

1. To identify the main human factor that contribute to the occurrence of RTAs in Oman.

In order to identify the main human factor contributing to RTAs in Oman, a culpability analysis was carried out as suggested by Gründl (2005). A multiple logistic regression analysis revealed five factors that significantly increase the risk of legally causing an RTA in Oman, namely inappropriate speed (OR 21.56), fatigue (OR 17.11), unintended blindness (OR 5.80), annual mileage between 20.000 and 40.000 km (OR 3.27) and having a conversation with the passenger (OR 2.77).

Inappropriate speed is among the most frequent RTA risk factors worldwide (WHO, 2004). But whereas inappropriate speed contributed to 11.8 % of all RTAs investigated for this thesis, ROP reports inappropriate speed to be the cause of almost half RTAs that occurred in 2012. This discrepancy can be explained by different categorization methods. ROP categorizes an RTA as caused by speed in case the drivers exceeded the speed limit, but if the interviewee exceeded the speed limit, the RTA was only related to inappropriate speed after a careful examination of the circumstances described in the RTA report. The necessity to carefully attribute the occurrence of an RTA to speed has also been emphasized in a recent paper by Al-Reesi et al. (2013). The authors didn't find a significant association between number of speeding violations and RTA history and conclude that exceeding design speed should not be considered as single cause for the occurrence of RTAs in Oman without a careful consideration of other factors. They further conclude that many RTAs might have been erroneously reported as caused by speed due to training deficiencies among ROP officers.

Fatigue is the second largest contributing factor to RTAs and contributed to 12.5 % of all investigated RTAs. Driver fatigue is also among the most frequent risk factors for RTAs in Western high income countries (Connor, Whitlock, Norton, & Jackson, 2001). According to ROP, fatigue only caused 27 out of 7719 RTAs in 2012 (ROP, 2012). But with 0.7 deaths per RTA, fatigue is the most severe cause. The circumstances under which ROP lists fatigue as cause are not quite clear, but in part based on witness accounts. One interview was conducted shortly after an RTA occurred. A driver entered the opposite lane and crashed frontal into an oncoming truck. The driver died on the spot. According to a witness, the driver fell asleep and accidently crossed the center lane. The police officer noted fatigue as the cause without any further investigation. With regard to cultural aspects it is noteworthy that the truck driver was astonishingly relaxed. Referring to God (Allah) he mentioned before the interviewee "*today him, tomorrow maybe me*." Assessing driver fatigue as a cause or contributing factor to RTAs is not uncomplicated because humans tend to underestimate the association between the subjectively perceived feeling of fatigue and the actual reduction of alertness (Banks & Dinges, 2007). In addition to the findings reported in this thesis, this suggests that the risk factor of fatigue is much more common in Oman than reported by ROP.

Unintended blindness is attributed to errors in perception and contributed to 8.7 % of all RTAs. Considering the various different categories that are defined as errors in perception in other studies (e.g. stimulus masking, wrong focus of attention, look but didn't see), any comparison with other studies should be regarded carefully. But since only a few studies on human factors as contributing factors for RTAs in low and middle income countries have been conducted so far, a vague comparison could at least indicate whether or not errors in perception approximately account for as many RTAs in the aforementioned countries as in Western high income countries. Two studies that provide errors in perception that seem to be most suitable for a comparison are Hendricks' (2001) study on RTAs in the United States and Vollrath et al. (2006) studies on RTAs in Germany who report a similar factor to account for 15.1 % and 9.2 %, respectively. At this point it is important to recall that the present study is similar to Gründl's study with regard to the structure of the questionnaire and the study design, but that contributing factors have occasionally been defined differently. Accordingly, the present results are not always comparable with Gründl's results. The cause reported by ROP that would correspond to the risk factor inattentional blindness is neglect. In 2012, ROP reported 7.4 % of all RTAs to be caused by neglect. Yet, ROP data provides no further information on this cause, while this thesis has demonstrated that five RTAs were caused by drivers failing to check the blind spot.

Drivers with a high annual mileage are more often involved in RTAs than drivers with low annual mileage. This finding is in line with other studies conducted in Western high income countries (Lourens, Vissers, & Jessurun, 1999; Massie, Green, & Campbell, 1997). Yet, the purpose was not to investigate the relationship between annual mileage and RTA involvement but to investigate the relationship between annual mileage and legal responsibility to cause an RTA. Accordingly, it was found that an annual mileage between 20.000 and 40.000 km increases the risk of legally causing an

RTA when compared to the reference category (<10.000 km). This finding is surprising because it would have been expected that those drivers who are more likely to be involved in RTAs should also be more likely to cause an RTA. But the drivers of the highest annual mileage category (>40.000 km) are almost equally distributed among the responsible and the non-responsible. A possible explanation could be the time of day. The more people travel, the more likely they are to travel by night where they are less likely to encounter other road users. This explanation is supported by the finding that driving by night doesn't increase the risk for causing an RTA (p=0.206). The results have already been compared to Gründl's findings in order to illustrate another important aspect between the occurrence of RTAs in a Western high income country such as Germany and a middle income that has recently been categorized as high income country such as Oman. This comparison revealed that there are more than twice as many Omanis who travel more than 40.000 km per year than Germans. Consequently, Omanis are more frequently exposed to RTA risk than Germans. Different exposure rates are an important aspect in the field of social determinants within countries and can now be considered an important aspect of social determinants across countries. This aspect of social determinants within countries is also reflected in the comparison between the results of this thesis and the results of the study conducted by Al-Reesi et al. (2013). The authors only focused on staff and students from Oman's most distinguished university and reported an annual mileage of 20.289 km which would correspond to a monthly mileage of less than 2000 km as opposed to an average monthly mileage of 4038 km as reported in this study. Staff and students from this university therefore have a comparatively low RTA risk. It is, however, worth mentioning that both samples had extremely large standard deviations.

Having a conversation with the passenger is the last main human factor that revealed a significant effect in the multiple regression analysis. Research has indicated that conversing with the passenger(s) decreases attention and increases the risk for perceptual errors (White & Caird, 2010). Interestingly, mobile phone usage (measured as distraction by technical device) revealed no significant effect in the bivariate analysis. It is generally argued that normal conversations are less risky than mobile phone conversations because the passenger shares situation awareness and the complexity of the conversation (e.g. emotional discussion) is determined by the traffic environment (Drews, Pasupathi, & Strayer, 2008). The significant association between having a conversation with the passenger(s) and causation of an RTA could be attributed to cultural and educational factors. It was already hypothesized that a conversation requires face-to-face contact which would expand the mental distraction with visual distraction. Moreover it could be possible that both the driver and the passenger(s) fail to adjust the complexity of the conversation to the traffic situation.

2. To investigate HRI as contributing factor to the occurrence of RTAs in Oman.

This objective was further structured into four specific objectives.

To assess the degree to which roads in Oman can be considered self-explaining.

The extent to which roads in Oman can be considered self-explaining was assessed by evaluating whether or not the roads in Oman are in accordance with the recommendations provided by Matena et al. (2006). This evaluation revealed that none of the three criteria proposed by Matena et al. are met. Among others, rural roads with single carriageway (2 m hard shoulder) with a lane width of 3.5 m were found to have a posted speed range between 60 km/h and 100 km/h. Acknowledging the complex requirements the road network in Oman is facing due to its topography, the huge discrepancies between road width and posted speeds suggest that road users in Oman are not able to select the appropriate speed based on design elements. Given that inappropriate speed has the largest effect on the occurrence of RTAs in Oman it seems plausible that this risk factor is at least in part facilitated by an incomprehensible road design.

To identify predictors for subjectively perceived safety of a road

A multiple logistic regression model was built with the dependent variable subjective perceived safety of road and various design elements as independent variables selected on basis of the reviewed literature and a bivariate analysis. A stepwise logistic regression revealed one significant effect. Controlling for other variables such as road width, shoulder type and roadside development, the only significant predictor for subjective perceived safety of a road is the number of carriageways with dual carriageway roads being almost seven times more likely to be perceived as safe when compared to single carriageway roads. This finding partially confirms Kapstein et al. (1998) results who report that the likelihood to encounter other road users affects road categorization. Dual carriageways drastically reduce the risk to encounter oncoming traffic and consequently decrease the likelihood of head-on RTAs which are the second most frequent RTA type in Oman.

To identify road design elements that affect driving speed.

As no objective speed measures were available, driving speed was measured in self-reported speed. The effect of design elements on self-reported driving speed was investigated for straight sections as well as for T-intersection and curves. Multiple linear regression models with self-reported driving speed as dependent variable and specific design elements were built. The regression revealed a significant effect for lane width on self-reported speed on straight sections in rural environments and a significant interaction effect between shoulder width and lane width on straight sections in urban environments. For T-intersections, self-reported speed significantly decreases under low traffic density condition. A marginal significant reduction in self-reported speed could be found under obstructed view condition. No effects could be found for curves.

Although roads with dual carriageway were the only significant predictor for subjectively perceived safety of a road, the number of carriageways is not correlated with self-reported speed. This finding is clearly contrary to other findings on driving speed and road design. Various studies indicate a relationship between dual carriageway roads and driving speed (Kapstein et al., 1998; Matena, 2006; Neuman, 2009). The results of this thesis suggest that the subjectively perceived safety of a road is not associated with higher speeds. Excluding dual carriageway roads from the analysis has shown that self-reported speed increases with lane width on rural roads. This result partially confirms the findings of previous studies. On the one hand, the positive correlation between lane width and self-reported speed has been demonstrated by Godley et al. (2004), on the other hand, the non-significant interaction between lane and shoulder width contradicts the joint effect of lane and road width on speed reported by Lewis-Evans and Charlton (2006). However, It should be noted that researchers often investigate the effects of the road geometry on speeding behavior usually either on rural or urban roads (Bella, 2008) and / or distinguish between hard and soft shoulders (Gross et al., 2009). Due to the small number of cases, such a distinction was only possible with regard to urban and rural roads. The shoulder type (hard or soft) could have modified the effect of shoulder width. A significant effect of the interaction lane width x shoulder width could be found for urban roads. Although this result confirms the importance of considering lane and road width jointly, this result shouldn't be overemphasized due to the aforementioned limitations and the small number of cases (N 24).

The finding that visual obstruction has a marginally significant effect on self-reported speed could lead to the conclusion that hazards associated with visual obstruction are well known among road users in Oman and that they adapt their driving behavior accordingly. Such a conclusion would be confirmed by the finding that self-reported speed is predicted to be 29.76 km/h lower when the view is obstructed. Visual obstruction could thus be considered as a factor that determines driving speed. However, the weak correlation (r=0.27) points to the necessity to further investigate this relationship under consideration of further factors.

To identify possible relationships between the occurrence of human factors and road design elements.

Four out of five main human factors were considered potentially related to the road design. These factors were inappropriate speed, fatigue, unintended blindness and having a conversation. If the prevalence of one of these factors was greater than 50 % (25 % for straight sections) at straight sections, T-intersections, curves or roundabouts, the relationship between the main human factor(s) and the respective road location element was further investigated by applying logistic regression modeling strategies. The prevalence of the main human factors and the design elements were considered as dependent and independent variables, respectively.

For straight sections it was found that the main human factor fatigue is significantly more frequent on roads with a dual carriageway. Recalling that dual carriageways predict safety, this result suggests that safety might induce a state of relaxation that decreases mental alertness. Interestingly, no effect of the road environment was found. Since the Omani road-network is characterized by roads of several 100 km lengths in a repetitive environment with a low rate of visual stimulation, it would have been likely to confirm the various findings (e.g. Thiffault & Bergeron, 2003; Wertheim, 1978) on the association between driving environment characterized by a low degree of visual stimulation and a decrease in mental alertness which could be interpreted as feelings of drowsiness and fatigue. It should, however, be taken into account that fatigue is related to more factors than covered in this thesis. The factor the most likely to modify the association between number of carriageways and occurrence of fatigue is the number of commuters. Roads with dual carriageways are almost always connected with the capital city Muscat and therefore often frequented by commuters who work in Muscat and live outside the capital area.

Inappropriate speed occurs more frequently on straight sections when the design speed is exceeded. This finding indicates that exceeding the design speed increases RTA risk. Contrary to the AASHTO it can be concluded that speeds greater than the design speed do compromise safety (Fitzpatrick et al., 2003). Exceeding the design speed could be, amongst others, associated with the lack of self-explaining roads identified according to specific objective one.

Having a conversation as contributing factor to RTAs can be more frequently observed on straight sections in rural areas than on straight sections in urban areas. Since no significant effect of the number of carriageways was found in the multiple analyses, it seems as if subjectively perceived safety doesn’t increase the likelihood of engaging into a conversation. The higher prevalence of the main human factor conversation on rural roads could also be associated with trip duration. On longer trips, drivers might be more likely to have conversations.

For T-intersections, a multiple regression analysis revealed one significant effect for traffic density on the occurrence of the risk factor unintended blindness. The risk for the main human factor unintended blindness to occur is higher under high traffic density condition than under low traffic density condition. This finding contradicts the results from the literature review reported in part II, 1.3.4. Visual obstruction as reported by the road user also increases the risk for unintended blindness to occur. Certainty about the presence of conflicting traffic therefore appears to be less detrimental to road safety than uncertainty. The assumption from the theory part can consequently be rejected. Although this effect is not significant, the *p*-value of 0.156 can be carefully considered a tendency to statistical significance (Tukey, 1991). To further interpret the different findings, more specific data would be required (e.g. TTC, stimulus masking, wrong focus of attention). Recalling that two visual obstruction variables were included in the analysis, namely visual obstruction reported by the road users and visual obstruction defined as sight triangle, the findings indicate that the road users' perspective can be more relevant for safety than a designer's bird view perspective.

The multiple regression analysis revealed no significant effects for curve specific design elements on the prevalence of the risk factor unintended blindness. Tendencies to statistical significance could be observed for the presence of warning signs and road width. If no curve warning signs were present and roads had a lane width of 3.5 m when compared to roads with a lane width of 3.75 m, then the risk for the main human factor inappropriate speed to occur increases. Although the positive effect of warning signs confirms that drivers need to be aware of the curve in order to adjust their driving behavior accordingly, Charlton (2007) demonstrated that curve warning signs alone are still not sufficient to ensure curve safety. The necessity to achieve a speed reduction and to capture the driver's attention as discussed in the theory (part II, 1.0) can be confirmed.

None of the main human factors had a prevalence of more than 50 % at roundabouts. Five different roundabout types were identified. Furthermore, each type varied in diameter size. The complexity of roundabouts and the large number of possible decisions a road user is offered at roundabouts when compared to intersections, suggest that RTAs at roundabouts occur due to errors associated with navigation and rule based behavior. Such error types have not specifically been captured by this thesis. The incomprehensibility of roundabouts is likely to be associated with the non-self-explaining roads in Oman.

2. Design recommendations

2.1 Applying basic design standards on road design

Roads differ in their functional categorization and road users should be able to categorize them accordingly. This is the very essence of self-explaining roads. Whether or not roads of different categorization are distinguishable is often decided in the design process which doesn't take into account the design elements of a road according to which a random road user categorizes a road. Not considering the road users "way of thinking" basically poses a violation of design principles:

“Good design begins with the needs of the user. No design, no matter how beautiful and ingenious, is any good if it doesn't fulfill a user need (UHK)”. In the context of road safety, the user need is not a road on which a driver can speed as he or she likes but being offered the possibility to understand the expected behavior.

Road users cannot refer to more than two design elements in order to differentiate between road categories (Kapstein et al., 1998). This finding suggests that another typical design principal should not be violated in the process of road design: Keep it simple. Yet the question of how roads should be “marked” remains unanswered. The reviewed literature provided no clear recommendations on how to answer this question. Even though there would have been suggestions, it was argued that there is considerable doubt that these suggestions would be applicable despite regional and cultural differences, as well as gaps in driver education. These doubts have been confirmed in the empiric part of this thesis by demonstrating that unlike in Western high income countries, roads which are perceived as safe are not correlated with high speeds. Taking into account the imprecise knowledge about which design elements affect road categorization and the assumed lacking knowledge about different kind or road categories, it is recommended to slowly introduce road users in Oman to the concept of self-explaining roads. A first step towards this direction could be made by redefining urban centers, especially in rural areas of Oman. The sole presences of roadside development only lead to a speed reduction of approximately 20 km/h. Road users should learn to distinguish between an urban center and rural areas based on one or two additional design elements such as road signs and markings that capture the drivers’ attention. In order to increase the likelihood of being detected, these elements could be combined with rumble strips or speed humps. Most importantly, however, is that the redefined categories are communicated by the media and controlled by ROP. Especially ROP would be required to strictly enforce these categories in order to achieve a conditioning effect. As argued in the introduction, improvements have to be made in all aspects of the triple E approach simultaneously.

2.2 Considering dual carriageways and overtaking lanes

The Omani authorities have already planned to transform various roads with single carriageway to roads with dual carriageway. Although no significant benefits for roads with dual carriageway were found with regard to the occurrence of the main human factors, dual carriageway roads do decrease the likelihood for overtaking RTAs to occur which are among the most frequent and severe RTAs in Oman. Yet, dual carriageways are associated with the occurrence of the main human factor fatigue. Accordingly, crash barriers should also be built on the right side of the road. Although no adverse effect of rumble strips were found, rumble strips should be considered carefully. Haptic stimuli caused by edge line rumble strips might surprise the sleepy driver which could result in a rapid uncontrolled movement of the steering wheel in the other direction. The consequence could be an RTA between various vehicles instead of one run-off the road RTA. Measures to counteract the occurrence of the main human factor fatigue could involve the positioning of billboards alongside the road. A constant winding design could also increase driver demand but would be associated with high costs. Nevertheless, it is a possible consideration for future designs if realizable in Oman's topography.

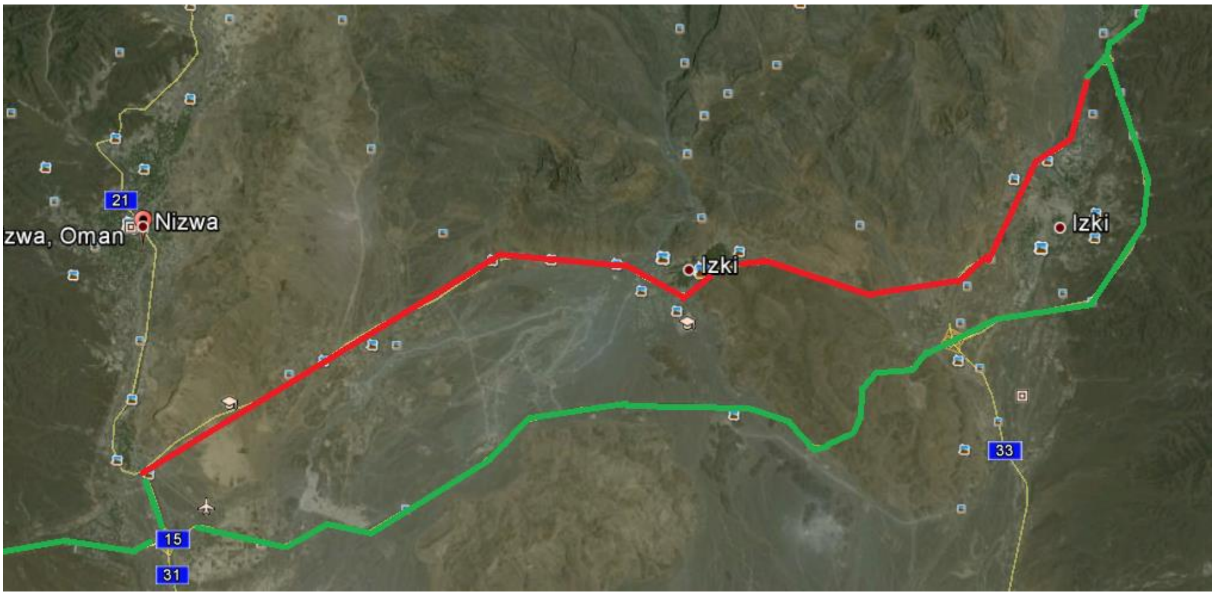


Figure 5.1. The green road is a dual carriageway road connecting Nizwa and Muscat built in 2002. The red road is a narrow road with single carriageway connecting Nizwa and Izki built in 1975.Using the red road in order to travel from Izki to Nizwa is much shorter than using the green road. Since there are three colleges / universities alongside the red road, it is used by many road users. One of these colleges / universities will be moved to the green road. This will ease the traffic on the red road.

Transforming roads with single carriageway to roads with dual carriageway or building new roads with dual carriageways will only partially add to the reduction of overtaking RTAs. Although the cities Nizwa and Izki (*Figure 5.1*) are connected with a fairly new road with dual carriageway, many road users still use the old road with single carriageway as shortcut. Hence, the new road only partially reduces the occurrence of overtaking RTAs on the old road. Future planning could consider the development of overtaking lanes along the old Nizwa-Izki road as well as on other similar roads. Roads signs could be erected to indicate the distance before approaching the overtaking zones (*Figure 5.2*).

Figure 5.2. Overtaking after 500 m. A possibility to inform road users about the distance to the next overtaking possibilities. Omani Cartoon with permission from Ibrahim Al-Abri 4 Design.

2.3 Capturing the road users' attention is insufficient for safe transitions

This study has revealed that the main human factor unintended blindness and inappropriate speed are more likely to occur at intersections with obstructed view and in curves, respectively. Both road location elements therefore require a transition or advance zone that prepares the road users for the approaching hazards (e.g. curve). One way to warn the road users could be road signs. In order for road signs to be perceived they need to be placed where a driver would expect them. But even though the driver perceives them, he or she only responds to them if the provided information is considered relevant.

It was previously proposed to combine visual and haptic stimuli. The visual stimuli (e.g. speed limit) alone might be regarded as unimportant for the driving task but adding haptic stimuli may increase the credibility of visually displayed information and therefore increases the likelihood for road users to respond to them by adjusting their driving speed. Another possibility to reduce approach speed could be the introduction of a stepwise speed limit. Instead of having a speed limit of say, 80 km/h on the straight section and say, 50 km/h before the curve, a third speed limit could be erected indicating a value between 80 and 50 in order to provide the driver with sufficient information to adjust his or her speed. Such a stepwise reduction would be in accordance with the positive guidance model and has been successfully applied in other countries such as Germany to achieve a speed reduction before working zones on highways. Since speed limit signs alone are often not considered relevant by drivers, warning signs (e.g. curve ahead) could be erected between the speed limit signs.

Speed limits in combination with warnings have a high likelihood to be responded to (Sommer, 2012). Lastly, the implementation of visual illusions has been reported to significantly decrease approach speed. The illusions discussed in this thesis resulted in an unconscious effect. Drivers reduced their speed but this speed could still be greater than the desired speed. In order to increase the likelihood for drivers to adjust their speed to the desired speed a combination of visual illusion and information filled with content is proposed (*Figure 5.3*).

Figure 5.3. The speed limit applied on the surface is much better to perceive than the speed limit sign on the right hand side behind the lamp. The effect caused by the illusion should result in a speed reduction, because the sign could be perceived as an object on the road.

2.4 Reducing speed and restricting affordances at T-intersections

The lower the driving speed, the higher the chance for a precise TTC estimation is and the less severe the consequences of an RTA would be. Hence, the speed at unsignalized intersections needs to be reduced. Although it was demonstrated that road users actually reduce their speed under obstructed view conditions, an obstructed view remains a risk factor. As the obstructed view is based on the driver's point of view and not the designer's bird eye point of view, it should be noted that the presence of a sight triangle is insufficient to provide safety. This is not to say that designers and engineers alike generally don't consider these aspects. In Denmark, you have to have very good reasons for right turn lanes on the major road. If you have a bus on this right turn lane, the driver attempting to enter this road from the minor road has no chance to see any vehicles behind the bus (J. Aalund, personal communication, June 20, 2012).

It is indispensable that the safety of a T-intersection is assessed by considering all possible situations, including those that might not be expected. Unexpected situations could be two or three drivers that try to turn simultaneously. Such a behavior, however, has to be afforded by the intersection design. Separate right turn lanes guiding the traffic from the minor on the major road connecting the two advance zones (*Figure 2.9, Figure 5.4*) with each other wouldn't afford such a behavior. Similar connections could be established for right turning vehicles coming from the major road. Having the right turn at the approach zone would still provide the traffic on the minor road with sufficient time to perceive traffic heading straight. Speed reductions could be achieved by various measures as proposed previously.

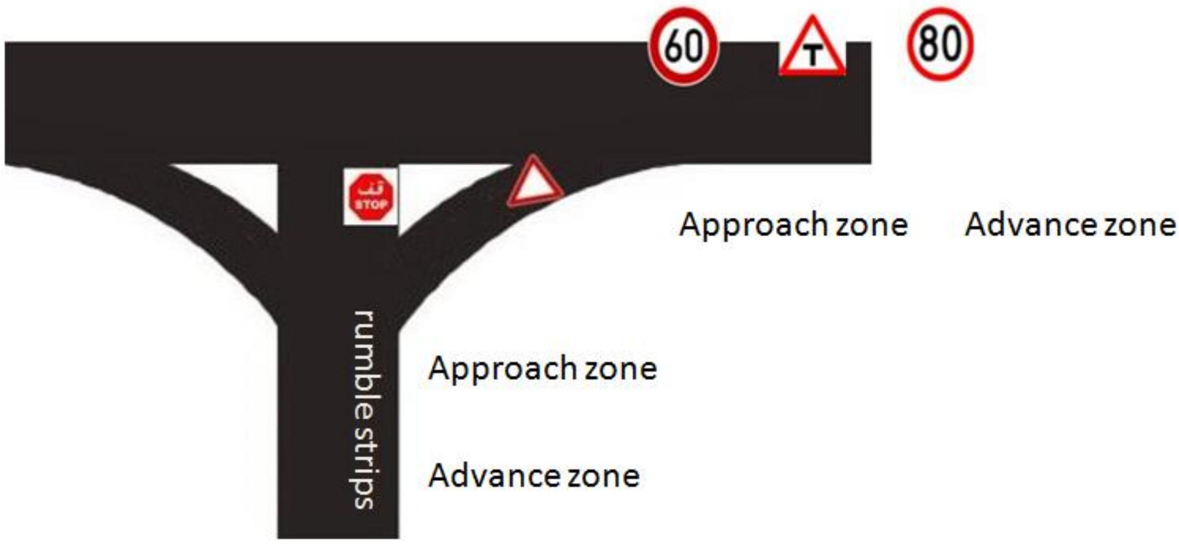


Figure 5.4. Overtaking / left-turn lanes could be considered as well. Road markings have to be added. The underlying idea is that traffic on both the major and the minor road reduces speed. It is, however, crucial that traffic on the major road travels at higher speeds than traffic on the minor road. Same speed could irritate road users in terms of right of way. Therefore, the rumple strips in addition to the stop sign (painted on the surface of the road) have been applied on the minor road as they are more likely to lead to a speed reduction. As mentioned in the text, the speed signs on the major road are erected together with a T-intersection sign in order to improve the speed limit signs' credibility.

2.5 Improving visual guidance in curves

With regard to curve safety, the findings of this thesis pointed to a typical problem associated with curves, namely difficulties in the perception of curve and curvature. It was demonstrated that curve warning signs do increase curve safety but argued that curve warning signs alone are insufficient to improve curve safety. Possibilities to improve the transition from straight sections to curves have been recommended in a previous paragraph. The curve itself should be equipped with chevrons and lane markings that assist the road users in negotiating the curve and also have a positive effect on speed perception (*Figure 5.5*). According to the findings with regard to lane width, curves should be designed forgiving. The expected approach speed of the curve should be below the curves design speed.

Figure 5.5. The repeater arrows have been pasted using a graphic program. The presence of these arrows clearly improves visual guidance allowing the road user to both anticipate curve and curvature. See Appendix A, Figure 12, for comparison.

2.6 Marking roundabouts according to different categories

A limited number of roundabout types is desired, yet difficult to realize due to the inconsistent road network. Alternatively, roundabouts could be compared and grouped according to the decisions a road user is able to make and marked accordingly, e.g. by applying road signs in different colors. Furthermore, the transition from straight sections to roundabouts is crucial and should be considered in the categorization. The transition from straight sections to roundabouts is also of importance because roundabouts are often used to provide transitions from one road category to another. But such a transition should not be built on the expenses of a comprehensible design. It could therefore be considered if signalized transitions might not be the better alternative to provide a connection between two different road categories.

3. Behavioral adaptations and safety audits

Risk homeostasis theory predicts that any modification of the road design would increase the accepted risk and consequently lead to negative behavioral adaptations (e.g. higher speeds). Due to this compensation process, any modification of the road design wouldn't result in an improvement of road safety. If the increased subjective safety would exceed objective safety, even the contrary could occur. Pfafferott and Huguenin (1991), however, have demonstrated that negative behavioral adaptations do not necessarily compromise safety. Although lane widening resulted in negative behavioral adaptations, the total effect on safety was assessed as positive. The results on self-reported speed on roads with dual and single carriageway, reported in this thesis, suggest that similar effects could be expected in Oman. The recommendations on the redesign of transitions and curves are likely to show similar adaptations as reported by Shinar et al. (1980). Positive changes of speeding behavior were observed after the implementation of advanced curve and transition warnings. While drivers who frequently used the road at which the warnings were applied returned to the same speed as before the modification, drivers not familiar with the location reduced their speeds. Taking into account that hazardous curves and transitions are especially dangerous for drivers unfamiliar with the respective location, both the behavioral adaptations and safety effect are positive. Some caution, however, is required for the design of T-intersections. As mentioned in the description of *Figure 5.4*, the desired speed reduction should be greater on the minor road than on the major road. If drivers on the major road travel at lower speeds than the drivers approaching the intersection from the minor road, both parties could be confused about who has to yield. Although the categorization principles defined by Undeutsch (part II, 2.2) predict that traffic that goes straight always has the right of way as opposed to turning traffic, the account of an engineer points to the assumption that speed is the stronger determinant that affects perceived right of way (J. Piel, personal communication, June 11, 2012). According to his account, an RTA prone T-intersection was modified by applying speed bumps on both the minor and the major road so that drivers from both roads basically had to enter the hazard zone (*Figure 2.9*) at almost identical speeds. The number of RTAs increased after the modification, possibly because of the aforementioned aspects related to speed and right of way.

To sum up, the total expected safety effect, after the recommended modifications, can be considered positive. Yet, further evaluations on possible behavioral adaptations would have to be made at the location to be modified. Such evaluations are generally carried out by road safety audits. For road safety experts, such audits, as well as specific guidelines, are the key for safer roads in Oman and thus should reduce the number of RTAs (J. Aalund, personal communication, June 20, 2012). Unlike traditional safety reviews, road safety audits consist of independent and inter-disciplinary teams and are involved in all stages of the road design (FHWA, 2013). Safety audits can also be involved in the evaluation of black spots to identify the hazards and possible countermeasures. With regard to this thesis it is worth mentioning that safety audits are required to have a strong focus on human factors by approaching a location with the question “What is it about this design that will cause road users to fail to cope with the road environment?” (NRA, 2004). Furthermore, the perspective of all age groups as well as vulnerable road users is considered. Despite these ambitions, these audits are only able to provide recommendations on human factors in as much as the audit members are able to think the way the road users think. This seems especially difficult if road users think differently. Such differences may be attributed to aspects such as driver education or cultural backgrounds (part II, 2.3). Safety evaluations should therefore use video surveillance and usability studies in order to assess a modified design. The former not only allows the investigation of near-RTAs but also provides information on a how road users afford (use) the design *(Figure 5.6*). The latter helps in understanding the underlying motivation and increases the chances to adjust the design to the road users. Usability studies would further have the advantage of including road users in the process to improve road safety.

Figure 5.6. The number of possible actions (affordances) of a road increases with the number of actions a person or vehicle is able to perform. With an SUV more actions are possible than with a normal passenger car. The high curb prevents passenger cars from parking on the sidewalk, but for SUVs, such an action is possible. These aspects should be considered in the design.

4. Limitations

Road safety research in low and middle income countries is still in its infancy. The lack of collaboration among governmental institutions in these countries can be considered one possible reason that impedes proper data collection. In addition, research is a relatively new concept for the population in these countries. Convincing an illiterate sixty year old Bedouin about the purpose of data collection is a bit of a challenge. This study therefore faces many limitations that will be summarized in the following paragraphs.

4.1 Interview data

Despite the efforts to understand the interviewee correctly, it should not be forgotten that the interviewer who conducted most of the interviews was not a native Arabic speaker. Misunderstandings associated with the language cannot be excluded. Furthermore, some of the interviewees might have sustained traumatic brain injuries. The resulting mental impairment might have biased their accounts and responses. Another issue is social desirability. Social desirability is a limitation that many, if not all, researchers face. Yet, the degree to which this limitation biases the results varies. Social desirability is associated with two other response styles, namely yea-saying (response acquiescence) and nay-saying (response deviation). Some methods to counteract these effects are described in Elmes et al. (2003). One of these methods is to provide detailed information about the research project in order to motivate the participants to report the truth. The fact that most participants were highly concerned with the magnitude of the road safety problem in Oman suggests that they were willing to help. Occasionally, a participant didn’t understand the purpose of some questions but didn’t refuse to answer them, whereas others shared photos from the RTA scene on their mobile phones that they might have received from witnesses and offered to call friends for more information. Yet, there were two challenges for which there was no solution. First of all, such research projects are relatively new in Oman and a small number of participants didn’t understand the purpose of this project at all. In one case, for example, a participant repeatedly said that the only thing that caused the RTA was rain. Although other patients in the room tried to explain to the participant the purpose of the interview, he refused to answer most of the questions. The data from this patient was not considered in the analysis. The fact that other patients were present at the time of the interview might also have biased responses. Especially with regard to violations such as speeding and intoxication, some interviewees might not have reported what actually happened. Some interviewees made sure nobody was listening before reporting that they were using their mobile shortly before the RTA occurred whereas others admitted to having used their mobile despite the presence of other patients. Social desirability is also associated with culture (Heine & Lehman, 1995). Considering this association would be beyond the scope of this thesis.

To sum up, the effect of social desirability on the results of this thesis is assessed as small. The assumption that some interviewees might have not understood the purpose of some questions and consequently were less motivated to retrieve the requested information from their memory, as well as possible limitations caused by mental impairment, is believed to be of more concern. Lastly, it is worth mentioning that only ten patients refused to be interviewed.

4.2 Road data

A recent study conducted by the Muscat Municipality (part I, 4.0) has revealed that the geometry from existing roads in the capital area deviate from the geometry specified in the design manuals. It cannot be excluded that these deviations also exist on roads in the areas for which the Directorate General of Road and Land Transport is responsible. Furthermore, some of the data could only be estimated. Although such estimates have been used in other research as well, proper tools would be required in order to deliver proper data. For other crucial data such as speed or traffic density, self-reports had to be considered. Objective data such as 85 percentile speed would have been much more precise. Lastly, it should be noted that road data was not available for all RTA locations which resulted in a comparatively small number of cases.

4.3 Culpability analysis

Culpability analysis is a valid method to determine RTA risk. Yet, it is associated with some limitations that have been summarized by Gründl (2005): Culpability analyses requires statistical independence, that is, only one of the road users involved in an RTA should be exposed to a respective risk factor. If both road users involved in an RTA are using their mobile phone, it is not possible to determine whether or not mobile phone use is associated with the risk of being responsible for causing an RTA. As a consequence, some risk factors such as darkness cannot be considered in culpability analysis as all involved drivers are exposed to this factor unless one of them is using night vision sight.

4.4 The effect of adjacent road location elements

The literature review has revealed that number of curves or roundabouts on a road affects driving behavior. Accordingly, it is likely that the driving behavior on the current road location element is affected by the preceding road location element. This thesis, however, focused on various road location elements one at a time. Possible effects of adjacent road location elements are therefore not taken into account.

5. Concluding remarks

This is the first scientific work, in a Gulf Country, that has investigated human factors and the interaction between human factors and the road environment as well as possibly the first scientific work that has conducted such a study in a low and middle-income country in which 90 % of all RTA related fatalities occur. Although it is acknowledged that Oman has recently been classified as a high income country, Oman still has a much higher fatality rate than Western high income countries such as Great Britain, the USA or Germany. Although specific recommendations on how to improve road safety in Oman and other countries with similar problems have been provided, this thesis is to be considered a source for future road safety research in Oman and other countries rather than a design guideline. A good design has the potential to improve road safety and to reduce the number of RTAs in Oman, but it was argued and demonstrated that a good road design requires much more than wide, clean and well-maintained roads. Good road design begins with taking into account the road users' limitations. Currently, this is not the case in Oman.

Appendix A

Figure 1. The orange car (red circle) in the top image might not be perceived by the waiting driver because it is perceived as partial movement within a texture (bushes).

Figure2. Drivers need to fixate the tangent point in order to safely negotiate the curve. But the roundabout warning sign as well as the traffic sign board distract the driver from the fixation.

Figure 3. Don't place intersections in curves. Drivers are not able to judge the speed of other vehicles appropriately, because the flow of visual information for drivers on a curve is at different speeds for the left and right eye.

Figure 4. A dual carriageway road; the direction in which the vehicles on each carriageway are travelling is indicated by the color of the rear and front lights. One vehicle on the right carriageway has white rear lights. Accordingly, it could be perceived as wrong-way-driver. The way how this information is processed by other road users and how they respond determines the safety of the present situation.

Figure 5. Wide roads provide more space and are thus more likely to trigger risky driving behavior.

Figure 6. This is the only speed limit sign for the next approx. 20 km. It is place shortly before an intersecting road. Drivers would rather pay attention to conflicting traffic and not expect a speed limit sign at an intersection. The same applies for the sign indicating a no-overtaking section. Note that the driver is preparing to overtake the truck which was travelling at approx. 80 km/h.

Figure 7. White script on red background with a white frame has probably the highest warning potential. It can either be used for important warnings (left image) or less important warnings (right image). However, specific colors should always be associated with specific warning levels. This is not the case in the two images.

Figure 8. A commercial placed opposite an intersecting road. Road users might attend to the commercial on the left hand side instead to intersecting traffic on the right hand site. The fact that the intersecting traffic is partially obstructed by the bus stop even increases the RTA risk at this intersection.

Figure 9. Old road markings have occasionally not been removed after roads have been modified and new markings have been applied. As a result the road markings provide anything but visual guidance.

Figure 10. If road users refrain from driving on rumble strips or raised pavement markers, these measures would be appropriate to prevent risky behaviors as shown in the image. Note that the Toyota truck has no license plate.

Figure 11. Speed hump placed at an incline. As shown on the top image, the speed hump (bottom image) cannot be seen. Although a sign indicates the speed hump, most drivers are likely to not perceive the sign due to high approaching speeds or due to a different focus of attention (e.g. conflicting traffic, children from the school on the right hand side). Drivers who are not familiar with this location might need to perform a sudden stop. For cars not equipped with ABS, the consequences could be devastating.

Figure 12. No curve warnings, it is almost impossible for a driver to perceive the curve and / or curvature in order to safely negotiate the curve.

Figure 13. Roads with dual carriageway and central barriers not only prevent overtaking RTAs. But in order to yield the desired effects, crash barriers need to be set in concrete properly. In order to reduce costs, few contractors occasionally refrain from doing so (J. Zimmermann, personal communication, April 17, 2011).

Appendix A

Figure14. Monotonous road environments, such environments can lead to a decrease in mental alertness. Even being fully alert it is difficult to identify the object in the red circles as oncoming vehicle (top) or to perceive the camel (bottom).

Appendix B

Tables Part IV

2.2 Specific objective two

Frequency of SUBSAFE according to NCW.

		NCW		Total
		One	TWO	
SUBSAFE	No	77 (36.2%)	8 (3.8%)	85 (39.9%)
	Yes	77 (36.2%)	51 (23.9%)	128 (60.1%)
Total		154 (72.3%)	59 (27.7%)	213 (100.0%)

Frequency of SUBSAFE according to RD.

		RD		Total
		Rural	Urban	
SUBSAFE	No	63 (25.2%)	37 (14.8%)	140 (40%)
	Yes	78 (31.2%)	72 (28.8%)	150 (60%)
Total		141 (56.4%)	109 (43.6%)	250 (100.0%)

Frequency of SUBSAFE according to ST.

		ST		Total
		Hard	Soft	
SUBSAFE	No	46 (23.4%)	36 (18.3%)	82 (41.6%)
	Yes	85 (43.1%)	30 (15.2%)	115 (58.4%)
Total		131 (66.5%)	66 (33.5%)	197 (100.0%)

Frequency of SUBSAFE according to LW.

		LW			Total
		3.50 m	3.65 m	3.75 m	
SUBSAFE	No	37 (17.9%)	9 (4.3%)	38 (18.4%)	48 (40.6%)
	Yes	34 (16.4%)	37 (17.9%)	52 (25.1%)	123 (59.4%)
Total		71 (34.3%)	46 (22.2%)	90 (43.5%)	207 (100.0%)

Frequency of SUBSAFE according to SW..

		SW		Total
		1-2 m	2.1-3 m	
SUBSAFE	No	55 (27.8%)	28 (14.1%)	83 (41.9%)
	Yes	68 (34.3%)	47 (23.7%)	115 (58.1%)

Total		123 (62.1%)	75 (37.9%)	198 (100.0%)

2.4 Specific objective four

2.4.1.1 Straight sections and fatigue

Frequency of FATI according to LW.

		LW			Total
		3.50 m	3.65 m	3.75 m	
FATI	No	31 (27.7%)	22 (19.6%)	43 (37.5%)	95 (84.8%)
	Yes	3 (2.7%)	4 (3.6%)	13 (6.3%)	21 (15.7%)
Total		34 (30.4%)	26 (23.3%)	52 (46.4%)	112 (100.0%)

Frequency of FATI according to SW.

		SW		Total
		1-2 m	2.1-3 m	
FATI	No	51 (47.2%)	40 (37%)	91 (84.3%)
	Yes	10 (9.3%)	7 (6.5%)	17 (15.7%)
Total		61 (56.5%)	47 (43.5%)	108 (100.0%)

Frequency of FATI according to ST.

		ST		Total
		Hard	Soft	
FATI	No	76 (56.7%)	37 (27.6%)	113 (84.3%)
	Yes	14 (10.4%)	7 (5.2%)	21 (15.7%)
Total		90 (67.2%)	44 (32.8%)	134 (100.0%)

Frequency of FATI according to RD.

		RD		Total
		Rural	Urban	
FATI	No	76 (56.7%)	37 (27.6%)	113 (84.3%)
	Yes	14 (10.4%)	7 (5.2%)	21 (15.7%)
Total		90 (67.2%)	44 (32.8%)	134 (100.0%)

Frequency of FATI according to RM.

		RM		Total
		Yes	No	
FATI	No	105 (68.2%)	23 (14.9%)	128 (83.1%)
	Yes	21 (13.6%)	5 (3.2%)	26 (16.9%)
Total		126 (81.8%)	28 (18.2%)	154 (100.0%)

Appendix B

Frequency of FATI according to NCW.

		NCW		Total
		One	Two	
FATI	No	75 (64.7%)	23 (19.8%)	98 (84.5%)
	Yes	9 (7.8%)	9 (7.8%)	18 (15.5%)
Total		84 (72.4%)	32 (27.6%)	126 (100.0%)

Frequency of FATI according to TRAFD.

		TRAFD		Total
		High	Low	
FATI	No	26 (16.7%)	104 (66.7%)	130 (83.3%)
	Yes	6 (3.8%)	20 (12.8%)	26 (16.7%)
Total		32 (20.5%)	124 (79.5%)	156 (100.0%)

2.4.1.2 Straight sections and speed

Frequency of SPEED according to LW.

		LW			Total
		3.50 m	3.65 m	3.75 m	
SPEED	No	34 (30.1%)	25 (22.1%)	48 (42.5%)	107 (94.7%)
	Yes	1 (0.9%)	1 (0.9%)	4 (3.5%)	6 (5.3%)
Total		35 (31%)	26 (23%)	52 (46%)	113 (100.0%)

Frequency of SPEED according to SW.

		SW		Total
		1-2 m	2.1-3 m	
SPEED	No	58 (53.7%)	44 (40.7%)	102 (94.4%)
	Yes	3 (2.8%)	3 (2.8%)	6 (5.6%)
Total		61 (56.5%)	47 (43.5%)	108 (100.0%)

Frequency of SPEED according to ST.

		ST		Total
		Hard	Soft	
SPEED	No	61 (56.5%)	41 (38%)	102 (94.4%)
	Yes	2 (1.9%)	4 (3.7%)	6 (5.6%)
Total		63 (58.3%)	45 (41.5%)	108 (100.0%)

Frequency of SPEED according to RD.

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		RD		Total
		Rural	Urban	
SPEED	No	86 (63.7%)	41 (30.4%)	127 (94.1%)
	Yes	5 (3.7%)	3 (2.2%)	8 (5.9%)
Total		91 (67.4%)	44 (32.6%)	135 (100.0%)

Frequency of SPEED according to RM.

		RM		Total
		Yes	No	
SPED	No	121 (78.1%)	26 (16.8%)	147 (94.8%)
	Yes	6 (3.9%)	2 (1.3%)	8 (5.2%)
Total		127 (81.9%)	28 (18.1%)	155 (100.0%)

Frequency of SPEED according to NCW.

		NCW		Total
		One	Two	
SPEED	No	80 (68.4%)	31 (26.5%)	111 (94.9%)
	Yes	5 (4.3%)	1 (0.9%)	6 (5.1%)
Total		85 (72.6%)	32 (27.4%)	117 (100.0%)

Frequency of SPEED according to TRAFD.

		TRAFD		Total
		High	Low	
SPEED	No	31 (20%)	115 (74.2%)	146 (94.2%)
	Yes	1 (0.6%)	8 (5.2%)	9 (5.8%)
Total		32 (20.6%)	123 (79.4%)	155 (100.0%)

Frequency of SPEED according to EXDESPEED.

		EXDSPEED		Total
		High	Low	
SPEED	No	29 (27.4%)	72 (67.9%)	101 (95.3%)
	Yes	4 (3.8%)	1 (0.9%)	5 (4.7%)
Total		33 (31.1%)	73 (68.9%)	106 (100.0%)

2.4.1.3 Straight sections and conversations.

Frequency of CON according to LW.

		LW			Total
		3.50 m	3.65 m	3.75 m	
CON	No	30 (26.5%)	23 (20.4%)	41 (36.3%)	94 (83.2%)

	Yes	5 (4.4%)	3 (2.7%)	11 (9.7%)	19 (16.8%)
Total		35 (31%)	26 (23%)	52 (46%)	113 (100.0%)

Shoulder width (SW): The association between SW and CON is not significant (Likelihood ratio test, *p*=0.545). CON occurs more often on roads with wide shoulders (2-2.1 m) compared to narrow shoulders (1-2 m) (OR=1.34, 95% CI [0.50.; 3.77]).

Frequency of CON according to SW.

		SW		Total
		1-2 m	2.1-3 m	
CON	No	52 (48.1%)	38 (35.2%)	90 (83.3%)
	Yes	9 (8.3%)	9 (8.3%)	18 (16.7%)
Total		61 (56.5%)	47 (43.5%)	108 (100.0%)

Frequency of CON according to ST.

		ST		Total
		Hard	Soft	
CON	No	50 (46.3%)	40 (37%)	90 (83.3%)
	Yes	13 (12%)	5 (4.6%)	18 (16.7%)
Total		63 (58.3%)	45 (41.7%)	108 (100.0%)

Frequency of CON according to RD.

		RD		Total
		Rural	Urban	
CON	No	71 (52.6%)	41 (30.4%)	112 (83%)
	Yes	20 (14.8%)	3 (2.2%)	23 (17%)
Total		91 (67.4%)	44 (32.6%)	135 (100.0%)

Frequency of CON according to RM.

		RM		Total
		Yes	No	
CON	No	107 (68.6%)	24 (15.4%)	131 (84%)
	Yes	21 (13.5%)	4 (2.6%)	25 (16%)
Total		128 (82.1%)	28 (17.9%)	156 (100.0%)

Frequency of CON according to NCW.

		NCW		Total
		One	Two	
CON	No	67 (57.3%)	29 (24.8%)	96 (82.1%)
	Yes	18 (15.4%)	3 (2.6%)	21 (17.9%)

Total		85 (72.6%)	32 (27.4%)	117 (100.0%)

Frequency of CON according to TRAFD.

		TRAFD		Total
		High	Low	
CON	No	30 (19.2%)	102 (65.4%)	132 (84.6%)
	Yes	2 (1.3%)	22 (14.1%)	24 (15.4%)
Total		32 (20.5%)	124 (79.5%)	156 (100.0%)

2.4.2.1 T-intersections and unintended blindness

Frequency of UIBLIND according to RD.

		RD		Total
		Rural	Urban	
UIBLIND	No	12 (25%)	19 (39.6%)	31 (84.6%)
	Yes	4 (8.3%)	13 (27.1%)	17 (15.4%)
Total		16 (33.3%)	32 (66.7%)	48 (100.0%)

Frequency of UIBLIND according to LTL.

		LTL		Total
		Yes	No	
UIBLIND	No	3 (5.9%)	30 (58.8%)	33 (64.7%)
	Yes	3 (5.9%)	15 (29.4%)	18 (35.3%)
Total		6 (11.8%)	45 (88.2%)	51 (100.0%)

Frequency of UIBLIND according to STR.

		STR		Total
		Yes	No	
UIBLIND	No	19 (40.4%)	11 (23.4%)	30 (63.8%)
	Yes	8 (17%)	9 (19.1%)	17 (36.2%)
Total		27 (57.4%)	20 (42.6%)	47 (100.0%)

Frequency of UIBLIND according to OBVIEW.

		OBVIEW		Total
		Yes	No	
UIBLIND	No	3 (5.6%)	33 (61.1%)	36 (66.7%)
	Yes	4 (7.4%)	14 (25.9%)	18 (33.3%)
Total		7 (13%)	47 (87%)	54 (100.0%)

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Frequency of UIBLIND according to TRAFD.

		TRAFD		Total
		High	Low	
UIBLIND	No	7 (13%)	29 (53.7%)	36 (66.7%)
	Yes	8 (14.8%)	10 (18.5%)	18 (33.3%)
Total		15 (27.8%)	39 (72.2%)	54 (100.0%)

2.4.3.1 Curves and speed

Frequency of SPEED according to RD.

		RD		Total
		Rural	Urban	
SPEED	No	17 (41.5%)	7 (17.1%)	24 (58.5%)
	Yes	11 (26.8%)	6 (14.6%)	17 (41.5%)
Total		28 (68.3%)	13 (31.7%)	41 (100.0%)

Frequency of SPEED according to LW..

		LW			Total
		3.50 m	3.65 m	3.75 m	
SPEED	No	5 (14.3%)	5 (14.3%)	11 (31.4%)	21 (60%)
	Yes	9 (25.7%)	2 (5.7%)	3 (8.6%)	14 (20%)
Total		14 (40%)	7 (20%)	14 (40%)	35 (100.0%)

Frequency of SPEED according to SW.

		SW		Total
		1-2 m	2.1-3 m	
SPEED	No	12 (35.3%)	9 (26.5%)	21 (61.8%)
	Yes	12 (35.3%)	1 (2.9%)	13 (38.2%)
Total		24 (70.6%)	10 (29.4%)	34 (100.0%)

Frequency of SPEED according to ST.

		ST		Total
		Hard	Soft	
SPEED	No	15 (44.1%)	6 (17.6%)	21 (61.8%)
	Yes	8 (23.5%)	5 (14.7%)	13 (38.2%)
Total		23 (67.6%)	11 (32.4%)	34 (100.0%)

Frequency of SPEED according to OPEN

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		OPEN		Total
		< 115 m	>= 115 m	
SPEED	No	15 (36.6%)	9 (22%)	24 (58.5%)
	Yes	10 (24.4%)	7 (17.1%)	17 (41.5%)
Total		25 (61%)	16 (39%)	41 (100.0%)

Frequency of SPEED according to POWS.

		POWS		Total
		Yes	no	
SPEED	No	8 (19.5%)	16 (39%)	24 (58.5%)
	Yes	1 (2.4%)	16 (17.1%)	17 (41.5%)
Total		9 (22%)	32 (78%)	41 (100.0%)

Frequency of SPEED according to RM.

		RM		Total
		Yes	No	
SEED	No	22 (45.8%)	8 (16.7%)	30 (62.5%)
	Yes	15 (31.2%)	3 (6.2%)	18 (37.5%)
Total		37 (77.1%)	11 (22.9%)	48 (100.0%)

Frequency of SPEED according to NCW.

		NCW		Total
		One	Two	
SPEED	No	14 (40%)	7 (20%)	21 (60%)
	Yes	12 (34.3%)	2 (5.7%)	14 (40%)
Total		26 (74.3%)	9 (25.7%)	35 (100.0%)

Frequency of SPEED according to TRAFD.

		TRAFD		Total
		High	Low	
SPEED	No	5 (10.6%)	25 (53.2%)	30 (63.8%)
	Yes	2 (4.3%)	15 (31.9%)	17 (36.3%)
Total		7 (14.9%)	40 (85.1%)	47 (100.0%)

2.4.4 Roundabouts

Frequency of MHF occurence according to TRAFD

		TRAFD		Total
		High	Low	

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MHF occured	No	2 (16.7%)	5 (41.7%)	7 (58.3%)
	Yes	1 (8.3%)	4 (33.3%)	5 (41.7%)
Total		3 (25%)	9 (75%)	12 (100.0%)

Frequency of MHF occurrence according to diameter size;[1] mean diameter size.

		Diameter < 52[1] m		Total
		Yes	No	
MHF occured	No	2 (25%)	2 (25%)	4 (50%)
	Yes	2 (25%)	2 (25%)	4 (50%)
Total		4 (50%)	5 (50%)	8 (100.0%)

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تاريخ الحادث:	

1 أين وقع الحادث ؟ من فضلك حاول أن تشرح ذلك بالتفصيل؟

2 كيف وقع الحادث؟

3 يرجى وصف الثواني الاخيرة قبل وقوع الحادث ، حاول أن تتذكر: في ماذا كنت تفكر، وعلى ماذا كنت تنظر، وماذا كنت تفعل؟

4 هل تعتقد أنه كان بإمكانك تجنب وقوع الحادث؟	
(1) نعم	(1) لا

5 كيف كان يمكن تجنب الحادث؟

6 هل لاحظت او رأيت أي معلومات أو لافتات تحذرك من وجود خطر على الطريق؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، أي نوع من المعلومات أو علامات؟	

7 على أي مسافة زمنية منك كانت توجد المركبة الأخرى أو الشخص الأخر الذى سبب لك الحادث؟	
دقائق	ثوان

8 كيف تصرفت حينما لاحظت الخطر؟

9 هل تعتقد أن العلامات المرورية كان يمكن تجنب وقوع الحادث ؟	
(1) نعم	(2) لا
10 هل تعتقد أنه لو كان الطريق أفضل كان يمكن تجنب وقوع الحادث ؟	
(1)نعم	(2) لا

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11 هل تعتقد أن الأشخاص الآخرين هم المسؤولون عن الحادث؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، من هم ولماذا؟	

12 هل تسبب أي شخص أو أي شئ في تشتيت انتباهك؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، ماذا وأين؟	

13 هل تعتقد أن الحادث وقع بسبب الطريق؟	
(1) نعم	(2) لا
إذا كان الجواب نعم، لماذا؟	

14 هل لاحظت أي علامات مرورية قبل وقوع الحادث؟	
(1) نعم	(2) لا
إذا كان الجواب نعم، أي نوع من العلامات؟	
(1)	(2) لا استطيع التذكر

15 ما هي أهمية علامات المرور بالنسبة لك؟			
(1) غير مهمة على الإطلاق	(2) غير مهمة إلى حدا ما	(3) مهمة إلى حدا ما	(4) مهمة جدا

16 هل كانت علامات الطريق الأرضية (العلامات والخطوط المرسومة على الطرق) واضحة؟	
(1) نعم	(2) لا

17 ما هي أهمية علامات الطريق بالنسبة لك؟			
(1) غير مهمة على الإطلاق	(2) غير مهمة إلى حدا ما	(3) مهمة إلى حدا ما	(4) مهمة جدا

18 هل تعلمت عند تعلمك القيادة أنك يجب أن تستخدام علامات الطريق (خطوط الطريق) لترشدك وتوجهك؟	
(1) نعم	(2) لا

19 عند قيادتك للسيارة بصفة عامة هل تقوم بالقيادة فوق العلامات الأرضية والخطوط؟ أو تتعدي عليها؟			
(1) نعم في كثير من الأحيان	(2) أحيانا	(3) في بعض الحالات	(4) أبدا لم يحدث

20 هل كان موقع وقوع الحادث مرئيا وواضحا؟	
(1) نعم	(2) لا
إذا كانت الإجابة لا، أذكر لماذا؟	

21 هل كان الطريق مغمورا بالمياه؟	
(1) نعم	(2) لا

22 هل كان الطريق مبللا بالمياه أو رطبا بسبب الأمطار أو الندى؟	
(1) نعم	(2) لا

23 هل كانت على الطريق رمال أو أحجار أو نفايات أو مياه بسبب كسر أنابيب؟

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(1) نعم	(2) لا
إذا كانت الإجابة نعم، أذكر تحديدا ما هذا، وأين وجد؟	

24 هل كانت على الطريق أي أجسام أو أشياء منعتك من رؤية الخطر؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم، ما هي تلك الأشياء أو الأجسام وأين كانت توجد؟	

25 هل تعتقد أن الطريق كان آمنا وسليما؟	
(1) نعم	(2) لا
إذا كانت الإجابة لا، أذكر لماذا؟	

26 هل تعتقد أن الطريق كان ضيقا؟	
(1) نعم	(2) لا

27 هل تعتقد أن العلامات المرورية كان يجب أن تحذرك من الخطر؟	
(1) نعم	(2) لا

28 بصفة عامة هل تعتقد أن مطبات الطريق الصناعية مفيدة؟	
(1) نعم	(2) لا

29 عند وجود مطب هل تقود السيارة ‘لى أقصى يمين أو يسار الطريق لكي تتجنب مرور السيارة عليه ؟	
(1) نعم	(2) لا

30 كم السرعة (كم /ساعة) التي سوف تقود بها سيارتك على الطريق في الصورة (أ) وعلى الطريق في الصورة (ب)

صورة (أ) كم/ساعة:	صورة (ب) كم/ساعة:

31 هل وقع الحادث بين الساعة 6 مساءا والساعة 6 صباحا؟			
(1)نعم		(2) لا — (من فضلك لا تجب على باقي الأجزاء الخاصة بالسؤال 31-35)	
32 هل كانت أضواء (نور - ليتات) السيارة مفتوحة (في وضع التشغيل)؟			
(1) نعم		(2) لا	
33 هل كل أضواء السيارة تعمل؟			
(1) نعم		(2) لا	
34 ما هو الضوء (النور) الذي كان مفتوحا (في وضع التشغيل)؟			
(1) ضوء الانتظار	(2) الضوء المنخفض (الواطي)	(3) الضوء المرتفع (العالي)	(4) ضوء الضباب
35 هل كانت هناك أي مصابيح مضاءة على جانبي الطريق؟			
(1) نعم		(2) لا	

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36 هل كنت تنظر إلى الطريق أمامك قبل وقوع الحادث؟	
(1) نعم	(2) لا
إذا كانت الإجابة لا، أين كنت تنظر؟	

37 هل كان هناك شئ أو جسم أو شخص خارج السيارة أضعف أو حجب رؤيتك؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم: ما هي تلك الأشياء أو الأجسام أو الأشخاص وأين كانت؟	

38 هل كان هناك شئ أو جسم أو شخص داخل السيارة أضعف أو حجب رؤيتك؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم: ما هي تلك الأشياء أو الأجسام أو الأشخاص وأين كانت؟	

39 هل كانت رؤيتك متأثرة أوصعبة بسبب الشمس؟	
(1) نعم	(2) لا

40 هل كانت رؤيتك متأثرة أو صعبة بسبب أضواء سيارة أخرى؟	
(1) نعم	(2) لا

41 هل كانت رؤيتك متأثرة أو صعبة بسبب أضواء أخرى أو مصابيح؟	
(1) نعم	(2) لا

42 هل لديك نظارات طبية؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم، هل كنت ترتدي هذه النظارة أثناء الحادث؟	
(1) نعم	(2) لا

43 هل ترتدي غالبا نظارة شمسية؟	
(1) نعم	(2) لا

44 هل كنت ترتدي نظارة شمسية أثناء وقوع الحادث؟	
(1) نعم	(2) لا

45 هل زجاج نوافذ (شبابيك) الأبواب الأمامية للسيارة التي وقع بها الحادث كان مُظللا؟	
(1) نعم	(2) لا
46 هل زجاج نوافذ (شبابيك) الأبواب الخلفية للسيارة التي وقع بها الحادث كان مُظللا؟	
(1) نعم	(2) لا

47 هل استخدمت أي شئ للحماية من ضوء الشمس؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم، ما هو هذا الشئ وأين استخدمته؟	

48 هل كان الزجاج الأمامي الجانبي للسيارة نظيف؟	
(1) نعم	(2) لا

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49 هل توجد خدوش في زجاج السيارة؟	
(1) نعم	(2) لا
إذا كانت الإجابة نعم، أين توجد تلك الخدوش؟	

50 كيف كانت الرؤية؟			
(1) سيئة	(2) سيئة إلى حد ما	(3) جيدة إلى حد ما	(4) جيدة

51 هل كانت تمطر؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، هل كانت المساحات تعمل بشكل صحيح؟	
(1) نعم	(2) لا

52 كم من الوقت كنت تسوق قبل وقوع الحادث؟	
كم ساعة:	كم دقيقة:

53 هل قمت بعمل استراحة قبل وقوع الحادث؟	
(1) نعم	(2) لا

54 كيف كنت مجهدا؟			
(1) مجهدا جدا	(2) مجهدا إلى حدا ما	(3) منتبها إلى حدا ما	(4) منتبها جدا

55 هل كنت تتثاءب أو تشعر بالنوم أثناء القيادة؟	
(1) نعم	(2) لا

56 كم عدد ساعات نومك في الليلة التي سبقت وقوع الحادث؟
عدد الساعات:

57 كيف كان تركيزك إثناء القيادة؟			
(1) لم يكن لدي تركيز مطلقا	(2) تركيز ضعيف	(3) تركيز معقول	(4) تركيز كامل

58 كيف كان شعورك قبل وقوع الحادث؟				
(1)حزين	(2) غضبان	(3) سعيد	(4) شعور بالملل	(5) شعور أخر

59 هل كنت تنظر إلى شئ أو شخص على جانبي السيارة قبل وقوع الحادث؟ مثل المحلات التجارية، علامات مرورية، أشخاص؟	
(1) نعم	(2) لا
في حالة الإجابة نعم: ما هذا؟	

60 كيف كانت الكثافة المرورية؟			
(1) كثيفة جدا	(2) كثيفة إلى حدا ما	(3) كثافة ضعيفة ألى حدا ما	(4) كثافة ضعيفة جدا

61 هل رأيت أي شخص أو شيء على الطريق مباشرة قبل وقوع الحادث؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، ماذا رأيت وأين رأيت ذلك؟	

62 بصفة عامة في قيادتك للسيارة، هل تنظر في المرايا قبل تغيير حارة السير؟	
(1) نعم	(2) لا

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63 قبل وقوع الحادث هل كنت تنظر إلى أي شيء داخل السيارة، على سبيل المثال عداد السرعة ، النقال ، المكيف؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، إلى ماذا كنت تنظر؟	

64 قبل وقوع الحادث هل كنت تشغل أو تقوم بتعديل شيء ، على سبيل المثال الراديو ، الهاتف ، المكيف ، المقعد؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، ماذا كنت تشغل أو تعدل بالتحديد؟	

65 هل سيارتك ذات ناقل حركة أوتوماتيكي؟	
(1) نعم	(2) لا

66 هل كنت تستخدم نظام تثبيت السرعة في السيارة التي وقع بها الحادث؟	
(1) نعم	(2) لا

67 هل كنت تستخدم هاتفك النقال عند وقوع الحادث؟			
(1) نعم كنت أتحدث إلى شخص م	(2) نعم كنت أكتب أو قراءة رسالة نصية	(3) لا	(4) أخرى

68 هل كنت تستمع إلى الموسيقى أو تستمع إلى أي شيء آخر؟			
(1) نعم		(2) لا	
إذا كان الجواب نعم ، كيف كانت درجة الصوت؟			
(1) مرتفع جدا	(2) مرتفع	(3) مرتفع إلى حدا ما	(4) منخفض

69 هل كانت تشغل أو تضبط الراديو أو مشغل الأقراص المضغوطة أو الكاسيت أو مشغل MP3 أثناء وقوع الحادث؟	
(1) نعم	(2) لا

70 هل كنت تشغل أو تضبط مكيف الهواء؟	
(1) نعم	(2) لا

71 هل كان مكيف الهواء في وضع التشغيل (مفتوحا)؟	
(1) نعم	(2) لا

72 كيف كان صوت مكيف هواء سيارتك؟			
(1) مرتفع جدا	(2) مرتفع	(3) مرتفع إلى حدا ما	(4) منخفض

73 هل كان أحد النوافذ مفتوحا؟	
(1) نعم	(2) لا

74 هل كانت درجة الحرارة داخل سيارتك مريحة؟		
(1) نعم	(2) لا، كانت مرتفعة	(3) لا، كانت منخفضة

75 هل كان معك أشخاص آخرين داخل السيارة؟	
(1)نعم	(2) لا – (من فضلك لا تجب على باقي الأجزاء الخاصة بالسؤال 75-81)
إذا كان الجواب نعم، كم عددهم؟	
76 هل كنت تتحدث إليهم أو إلى أحدا منهم؟	
(1) نعم	(2) لا
77 إذا كان الجواب نعم ، كيف كان الحديث؟	

Appendix C

(1) مناقشة عادية	(2) سوالف مسلية ومضحكة	(3) حوار ساخن	(4) أخرى

78 هل كنت تتحدث أم كنت تستمع؟	
(1) كنت أتحدث	(2) كنت أستمع
79 هل كنت منزعجا أو متضايقا من قِبل بعض الأشخاص داخل السيارة ، على سبيل المثال من بكاء طفل؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، من كان يزعجك ولماذا؟	
80 هل كان هناك أطفال في المقاعد الخلفية؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، هل كانت أحزمة مقاعدهم مربوطة؟	
(1) نعم	(2) لا
81 هل كان يوجد طفل في المقعد الأمامي؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، هل كان حزام مقعده مربوط؟	
(1) نعم	(2) لا

82 هل كنت تأكل أو تشرب أو تدخن سيجارة في لحظة وقوع الحادث؟	
(1) نعم	(2) لا

83 هل سمعت صافرة آلة تنبيه قبل وقوع الحادث؟	
(1) نعم	(2) لا

84 هل كنت تنقل أشياء داخل أو فوق سيارتك ، على سبيل المثال حيوانات أو مواد البناء؟	
(1) نعم	(2) لا
إذا كان الجواب نعم ، ماذا كنت تنقل؟هل كانت الأشياء داخل أو فوق السيارة؟	

85 هل تعديت أو قمت بقيادة السيارة فوق علامات الطريق الأرضية (الخطوط) في لحظة وقوع الحادث؟	
(1) نعم	(2) لا
إذا كانت ألإجابة نعم ، لماذا؟	

86 ماذا تعتقد هل كان تصرفك تحت السيطرة أم كنت في حالة من الذعر؟	
(1) تحت السيطرة	(2) في حالة من الذعر

87 أين كانت يديك قبل وقوع الحادث مباشرة؟

88 أين كانت يديك على عجلة القيادة في لحظة وقوع الحادث؟
مثال:

89	ماذا كان الغرض من رحلتك؟

90	هل كنت تعرف الطريق و المكان؟
(1) نعم	(2) لا

91	هل تعتقد، أن سيارتك التي وقع بها الحادث كانت سليمة وآمنة؟		
(1)آمنة جدا	(2)آمنة إلى حدا ما	(3) غير آمنة إلى حد1 ما	(4) غير آمنة تماما

92	هل تعتقد أن السائقين الآخرين يقودون بصورة خطرة؟
(1) نعم	(2) لا

93	كيف تقيم مهاراتك في القيادة؟		
(1)جيدة جدا	(2) جيدة إلى حدا ما	(3) سيئة إلى حدا ما	(4) سيئة

94	هل كانت هناك سيارة تسير أمامك، وكيف كانت المسافة الفاصلة بينك وبينها؟
(1) لم تكن هناك سيارة	(2) نعم، المسافة التقريبية متر

95	كم كانت سرعة سيارتك؟
كم/ ساعة	

96	هل تعتقد أنك كنت تسير بسرعة كبيرة؟
(1) نعم	(2) لا

97	هل تعتقد أن أسلوبك في القيادة يكون خطيرا للآخرين في بعض الأحيان؟
(1) نعم	(2) لا

98	بصفة عامة، متى تقوم بتشغيل أضواء سيارتك؟	
(1) حينما تظلم	(2) عند ضوء الشفق (عند غروب الشمس)	في ضوء النهار، قبل الشفق

99	لماذا تقوم بتشغيل ضوء سيارتك؟	
(1) لأرى	(2) ليستطيع الآخرين أن يروني	(3) كليهما

100	هل تحب القيادة؟
(1) نعم	(2) لا

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101 هل تشعر بالحرية أثناء القيادة؟	
(1) نعم	(2) لا

102 هل أنت صبور؟			
(1)لا على الإطلاق	(2) غير صبور إلى حدا ما	(3) صبور إلى حدا ما	(4) صبور جدا

103 هل تشعر بالضيق حينما يقود الآخرين ببطء؟	
(1) نعم	(2) لا

104 هل كنت تشعر بالضيق أو الانزعاج من سائق أخر قبل وقوع الحادث؟	
(1) نعم	(2) لا

105 بصفة عامة، إذا تلقيت رسالة نصية أثناء القيادة، هل تقوم بقرأتها فورا؟	
(1) نعم	(2) لا

106 هل مهم بالنسبة لك أن تصل للعمل في المواعيد المحددة؟	
(1) نعم	(2) لا

107 هل مهم بالنسبة لك أن تأتي لأسرتك في الموعد المحدد؟	
(1) نعم	(2) لا

108 منذ كم عاما وأنت معك رخصة قيادة؟
عام

109 كم كيلومتر في المتوسط تسوقها شهريا؟ مثال: أنا أسوق 3000 كلو متر في الشهر
كم في الشهر:

110 هل حدث لك في الماضي حادث سيارة (سواء كنت غلطان أو مغلوط عليك)؟	
(1) نعم	(2) لا

111 من هو المسؤول عن السلامة المرورية؟		
(1) الحكومة	(2) الناس	(3) كليهما

112 كم عمرك؟

113 النوع؟	
(1) ذكر	(2) أنثى

114 ما هي جنسيتك؟

115 ما هو نوع وطراز السيارة الذي كنت تقتنيها ووقع بها الحادث؟

Appendix D

List of variables considered for analysis

Label	Name	Values	Source
AGE	Age	18-24, 25-59, (>60)	Interview
ANMIL	Annual mileage	< 10.000, 10.000–20.000, 20.000-40.000, > 40.000	Interview
CARSAFE	Assessing one's own car as safe	Safe / unsafe	Interview
CON	Conversation	Yes / no	Interview
DANDRI	Assessment of own driving behavior as safe dangerous for other road users	Yes / no	Interview
DARKNESS	Driving by night	Yes / no	Interview
DNTD	Distraction by non-technical device	Yes / no	Interview
DRISKI	Self-assessment of driving skills	Very good, good, bad	Interview
DS	Diameter size	Numerical	Google earth
DTD	Distraction by technical device	Yes / no	Interview
EMOS	Emotions	Normal / other	Interview
EXDSPEED	Exceeding design speed	Yes / no	Interview / Muscat Municipality / Directorate General of Road and Land Transport
FATI	Fatigue	Yes / no	Interview
HEADLIGHT	Blinded by headlight	Yes / no	Interview
IMPAT	Impatient	Yes / no	Interview
INTOX	Intoxication	Yes / no	Interview
LTL	Left -turn lane	Yes / no	Google earth
LW	Lane width	Numerical	Muscat Municipality / Directorate General of Road and Land Transport
NCW	Number of carriageways	Single / dual	Muscat Municipality / Directorate General of Road and Land Transport
OBVIEW	Obstructed view	Yes / no	Interview
OPEN	Openness of a curve	Numerical	Google earth
POWS	Presence of curve warning signs	Yes / no	Interview
RAIN	Rain	Yes / no	Interview
RD	Roadside development	Rural / urban	Google earth

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RM	Road markings	Yes / no	Interview, visiting RTA location
ROUTFAM	Familiar with the route (on which the RTA occurred)	Yes / no	Interview
RTAH	History of RTA	Yes / no	Interview
SAFEDIS	Insufficient safety distance	Yes / no	Muscat Municipality / Directorate General of Road and Land Transport
SAND	Sandstorm	Yes / no	Interview
SUBSAFE	Subjective perceived safety of the road	Yes / no	Interview
SUN	Blinded by sunlight	Yes / no	Interview
SPEED	Inappropriate speed	Yes / no	Interview
SRSPEED	Self-reported speed	Numerical	Interview
ST	Shoulder type	Hard / soft	Muscat Municipality / Directorate General of Road and Land Transport
STR	Presence of sight-triangle	Yes / no	Goolge earth
SW	Shoulder width	Numerical	Muscat Municipality / Directorate General of Road and Land Transport
TRAFD	Traffic density	High / low	Interview
UNBLIND	Unintended blindness	Yes / no	Interview
YDL	Years of holding driver's license	<1-2, 3-4, 5-6, >6	Interview

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