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THE ROLE OF ROAD ENGINEERING IN COMBATTING DRIVER DISTRACTION AND FATIGUE ROAD SAFETY RISKS

Technical Committee 3.2
Design and operation of safer road infrastructure
World Road Association

WORLD ROAD ASSOCIATION
MONDIALE DE LA ROUTE
AIPCR PIARC

STATEMENTS

The World Road Association (PIARC) is a nonprofit organisation established in 1909 to improve international co-operation and to foster progress in the field of roads and road transport.

The study that is the subject of this report was defined in the PIARC Strategic Plan 2012 – 2015 and approved by the Council of the World Road Association, whose members are representatives of the member national governments. The members of the Technical Committee responsible for this report were nominated by the member national governments for their special competences.

Any opinions, findings, conclusions and recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of their parent organisations or agencies.

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THE ROLE OF ROAD ENGINEERING IN COMBATTING DRIVER DISTRACTION AND FATIGUE ROAD SAFETY RISKS

Driver distraction and fatigue are a problem because, as remarkable as our abilities are, we humans are fallible and our abilities have limitations. Driver distraction and fatigue incorporates elements of both limitations and fallibility. On top of our limitations and fallibilities, driving a vehicle is a surprisingly complex task that involves numerous elements.

A driver is required to move between these tasks to effectively deal with the ever changing road environment and traffic situation. As an example, where there is sufficient sight distance, a driver can gain enough understanding of the road ahead to enable them to check their speed, monitor vehicles around them, and perhaps even adjust the comfort settings within the vehicle. By contrast, with insufficient sight distance and a busy roadway, the driver may not have reasonable opportunity to check their speed and the vehicles around them, increasing their crash risk. If the driver adds to these tasks, such as by eating a hamburger while driving, they could compromise their ability to perform these tasks further.

Road engineers have been empirically considering driver limitations for many years. Through engineering judgement and the testing of different configurations and treatments, an extensive array of standards and guidelines have been developed which seek to lower the risk of a crash occurring to an acceptable level and to enable the relevant road to serve its intended transport purpose. They have been cautious of items with the potential to take a driver's attention away from the road (e.g. advertising), have developed sight distance requirements based upon research into the human driver's ability to react and developed road marking and signage standards and guidelines that are increasingly intuitive to understand, visible, readable and spaced so as to give driver's every chance of understanding the message and responding appropriately to it. As a result, the majority of today's "*well designed*" road environments are rather slow and static in that they give the driver much surplus time to perform the driving tasks.

The review of the extensive literature related to driver distraction and fatigue, found an overwhelming focus on driver education and enforcement strategies seeking to encourage drivers to avoid being distracted or fatigued while driving. This might explain why it was also found that many jurisdictions have sought to combat driver distraction and fatigue by raising awareness of the risk, establishing rules (such as to prohibit texting) and imposing significant penalties to discourage non-compliance. However, it was also found that driver distraction and fatigue are distinct and each comprise a number of separate elements that can be detrimental to road safety in different ways.

CONTENTS

1. INTRODUCTION

Driver distraction and fatigue are a problem because, as remarkable as our abilities are, we humans are fallible and our abilities have limitations. Driver distraction and fatigue incorporates elements of both limitations and fallibility. In terms of our limitations:

- While we can take in information from multiple senses at once and co-ordinate/call upon several tasks that we have become accomplished in "*automatically*":
  - Our eyes can only focus on one thing at a time (see *illustration 1*);
  - We can only consciously decide one thing at the time;
  - There are limits on how much information we can consciously process;
  - Conscious attention requires energy; and
  - With high amounts of information processing, we tire relatively quickly, and so become prone to fatigue.[1]

Illustration 1: A driver can only focus on one thing at a time. Scientific observation of a driver travelling a roadway and monitoring their focal point over time[2]

- The novice driver is very challenged because they are not yet trained in the tasks that comprise driving and their conscious computing energies are pushed to and beyond the limits;
- With learning and practice, the performance of tasks becomes more and more efficient or "*automated*", as if the conscious brain can choose to change gears and it almost magically happens as our body implements the trained process to change gears;
- The experienced driver in a familiar environment can perform most of the driving task without much conscious attention and many people can recall a moment in their lives, usually after a challenging day at work, when they reached their driveway and then could not remember which route they travelled to get home – they were on autopilot;
- Our brains like to be regularly stimulated or our thoughts can start to wander elsewhere and we

1 For example, when we first start learning to drive, we need to consciously "*do everything*", it is hard work trying to do all the tasks that comprise driving. First time drivers tend to feel exhausted after just a one hour lesson and rates of error are much higher in learner drivers.

2 Uroš Brumec has built this illustration using material from internet sources as follows. Main image from: *http://www.tobii.com/eye-tracking-research/global/library/white-papers/tobii-eye-tracking-white-paper/.* Inserted pictures from: *http://www.scielo.br/scielo.php?pid=S0104-65002009000300002&script=sci_arttext* (*illustration 20*) and *http://www.viewpointsystem.com/* (print screen from videos).

can become prone to monotony fatigue, further increasing our reaction time. The additional reaction time is associated with the conscious brain needing to "*reboot*", however, the time this takes depends upon how deactivated it has become (see *illustration 3*);
- Our bodies are designed to withstand a level of impact energy that seems to match running at top speed and colliding into a solid object (like a tree) (Tingvall 1999). This is a physical limitation. On the road, we are potentially exposed to higher energy release rates owing to the much higher speeds and energy rising proportional to the square of the speed. If we wear our seatbelts, we can benefit from the vehicle's ability to absorb energy, increasing the threshold. Other safety devices like airbags can further increase the magnitude of the impact we can survive;
- We have evolved to sense certain dangers, such as a flickering flame (which can be sufficiently simulated with flickering lights) and movement (such as the legs of a horse galloping) (Kahnerman). For example, we sense danger when standing at height (e.g. tall building), however, we don't sense a commensurate level of danger associated with travelling past roadside trees at high speed, even though the real risk can be similar depending upon vehicle speed versus the relevant height (see *illustration 2*);
- In the heat of a sports match, the athlete's reaction time can be very brief. For example, sports such as table tennis, badminton, baseball and cricket require athletes to respond in fractions of seconds. The best sports people are known to be well versed in relaxing between plays, because the high level of concentration is very taxing. As a comparator, the average driver needs approximately two seconds to react to a braking car ahead (see *illustration 3* – Driver's Response). In a deactivated state (owing to monotony fatigue), the average drivers' required reaction time could rise to four seconds or more (see *illustration 3*, driver's response plus anticipation plus preparation);
- The given context can affect the level of risk we are willing to take. For example, if you are running late for an important appointment, you may be susceptible to running an amber light in order to avoid a traffic signal delay;
- Our spatial perception takes short cuts in order to increase our decision making efficiency. The magician or illusionist exploits such shortcuts to deceive our brains and the best magicians can deceive an entire audience. Some situations on the road can also trick the brain – (see *Section 3.1.3*).

In terms of our fallibility:

- A conversation with a passenger or day dreaming about a tough day in the office can distract us from driving a vehicle;
- We are naturally susceptible to risk taking such as speeding and using a mobile phone while driving;
- Our mood can affect our decisions, such as, an aggressive mood is likely to make us more susceptible to taking risks, while a happy mood might reduce susceptibility to risk;
- Our medical condition can affect our ability to drive, such as a diabetic's reaction to low sugar and other illnesses can slow reaction times, and a torn muscle might limit ability to control the vehicle.

On top of our limitations and fallibilities, driving a vehicle is a surprisingly complex task that involves numerous elements (*illustration 4*), such as:

- Scanning the roadside and traffic environment for relevant information;
- Identifying the road layout ahead and choosing/maintaining the course/position of the vehicle on the road;
- Undertaking navigation;
- Monitoring other vehicles and road users;
- Checking the speed of the vehicle, instrument panel and navigation device;
- Operating the vehicle controls (e.g. gears, cruise control, brakes, accelerator and steering); and
- Maintaining comfort (such as air temperature and radio volume).

A driver is required to move between these tasks to effectively deal with the ever changing road environment and traffic situation. As an example, where there is sufficient sight distance, a driver can gain enough understanding of the road ahead to enable them to check their speed, monitor vehicles around them, and perhaps even adjust the comfort settings within the vehicle. By contrast, with insufficient sight distance and a busy roadway, the driver may not have reasonable opportunity to check their speed and the vehicles around them, increasing their crash risk. If the driver adds to these tasks, such as by eating a hamburger while driving, they could compromise their ability to perform these tasks further.

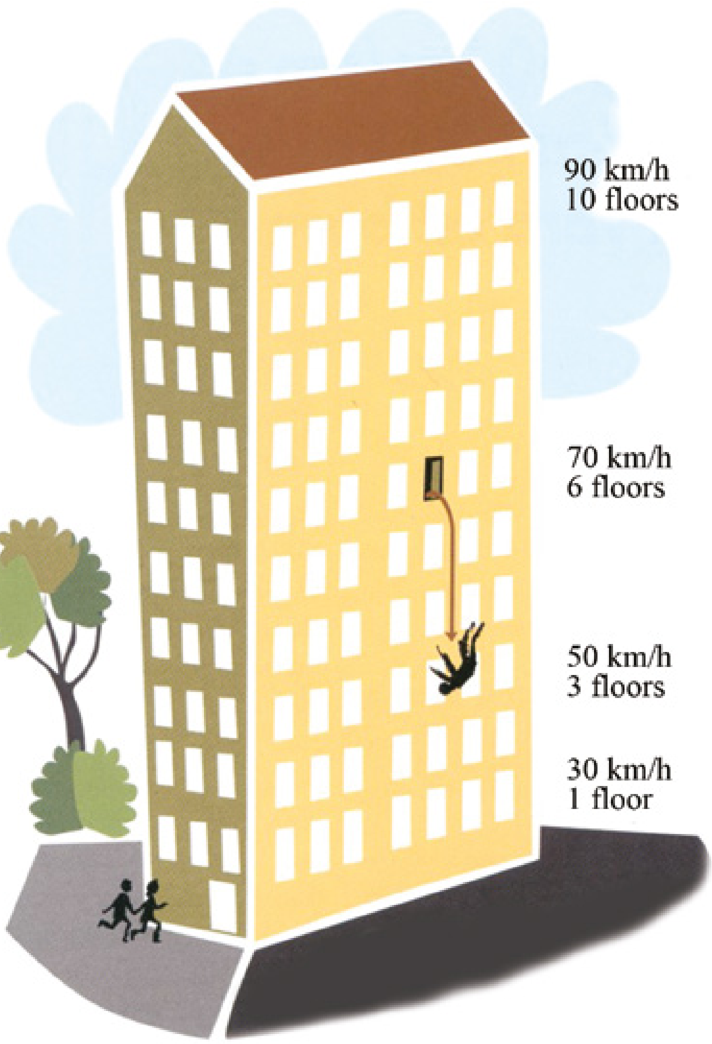


Illustration 2: Height of fall and impact speed (as a comparator to crashing into a tree), (Swedish Road Administration 2006).

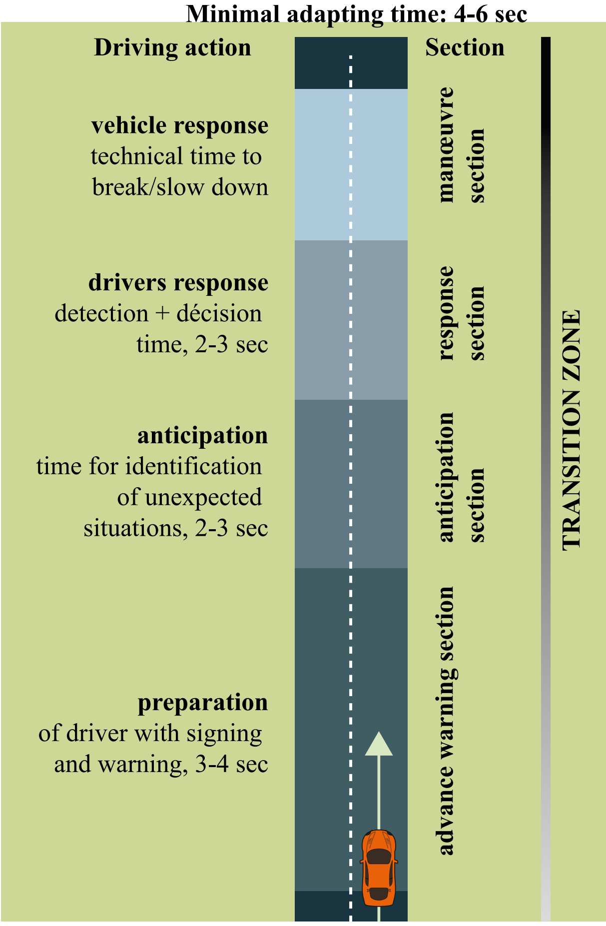


Illustration 3: Our natural human limitations lead to us requiring time to react (PIARC, 2008).

Road engineers have been empirically considering driver limitations for many years. Through engineering judgement and the testing of different configurations and treatments, an extensive array of standards and guidelines have been developed which seek to lower the risk of a crash occurring to an acceptable level and to enable the relevant road to serve its intended transport purpose. They have been cautious of items with the potential to take a driver's attention away from the road (e.g. advertising), have developed sight distance requirements based upon research into the human driver's ability to react and developed road marking and signage standards and guidelines that are increasingly intuitive to understand, visible, readable and spaced so as to give driver's every chance of understanding the message and responding appropriately to it. As a result, the majority of today's "*well designed*" road environments are rather slow and static in that they give the driver much surplus time to perform the driving tasks.

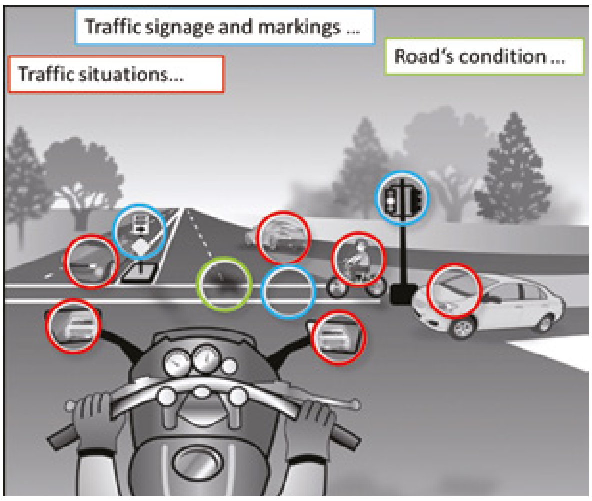


Illustration 4: Driver's tasks while driving (Ohio Department of Public Safety, 2015) (colour added by Uroš Brumec)

The generous sight distances can enable driver's to scan well ahead and move on through their cycle of driving tasks to be sufficiently informed for the next few seconds of travel and more. The "*good*" signs can be easily seen and read 200m or more in advance of them. Vehicle trajectories generally have sufficient predictability such that a quick check of the vehicles around you leaves the driver sufficiently informed for a reasonable, although short period of time. Even a quick check of our own speed can be sufficient to last for little while down the road before we need to check again.

Illustration 5 illustrates how a person could cycle through five tasks requiring conscious attention which cannot be performed simultaneously, are all needed for an activity like driving to be successfully performed, and for which each task's relevance decays from the moment it is completed. And so, a cycle of constant refreshment is required.

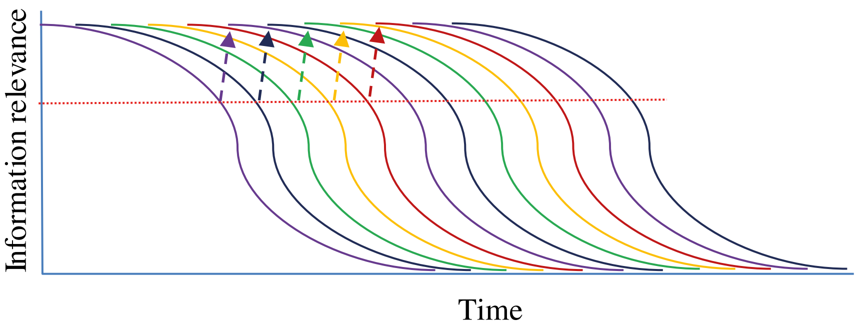


Illustration 5: Decay of information from five separately performed repetitive tasks.

If extra tasks are introduced, then more time elapses before the first task can be repeated. Just before the first task is refreshed, the overall activity is functioning based upon rather out of date information associated with task 1 – see *illustration 6*.

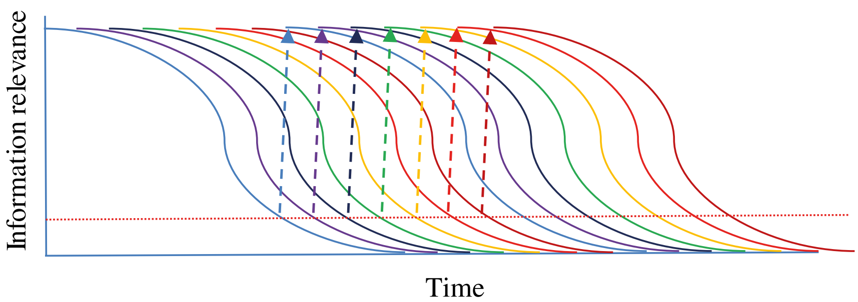


Illustration 6: Decay of information from seven separately performed repetitive tasks.

When a driver checks their speed to find that they are travelling too fast, then they will need to ease off the throttle, allow the speed to reduce and then find the new throttle threshold that enables the desired speed to be maintained. These extra tasks need to be slotted into the cycle. If an unfamiliar sign is difficult to understand, contains too much information, or causes us to start second guessing our route (as a congestion ahead message might cause), then extra tasks are occurring.

Non-driving related attention capturing matters may pose a hazard depending on how "*busy*" the driver is at the time, so it would seem to be conservative for the road engineering community to discourage non-driving related attention capturing matters.

Indeed, the review of the extensive literature related to driver distraction and fatigue, found an overwhelming focus on driver education and enforcement strategies seeking to encourage drivers to avoid being distracted or fatigued while driving. This might explain why it was also found that many jurisdictions have sought to combat driver distraction and fatigue by raising awareness of the risk, establishing rules (such as to prohibit texting) and imposing significant penalties to discourage non-compliance. However, it was also found that driver distraction and fatigue are distinct and each comprise a number of separate elements that can be detrimental to road safety in different ways.

2. DRIVER DISTRACTION AND FATIGUE

The problem with driver distraction or fatigue is that it has the potential to slow or even prevent the reaction of the driver to a hazard and, therefore, it creates crash risk.

By way of example, *illustration 7* describes a situation where a drivers' reaction time is normal versus prolonged owing to either driver distraction or fatigue. Typically a reaction time of a normal driver is about two seconds (see *Section 2*). In this example, a pedestrian is starting to cross the street in front of a car approaching the pedestrian crossing at 50 km/h. If the driver of the car is concentrating on the traffic situation, the reaction distance would be approximately 28 meters owing to a minimum 2 second reaction time (see *illustration 3*), plus a braking distance of 14 meters. However, if the driver was distracted or fatigued, their reaction time necessarily increases depending upon the level of distraction or fatigue, however, by at least another 2 seconds (minimum anticipation reaction time – see *illustration 3*) or an additional 28 meters. This additional distance requirement may result in a serious crash compromise the safe crossing of the pedestrian.

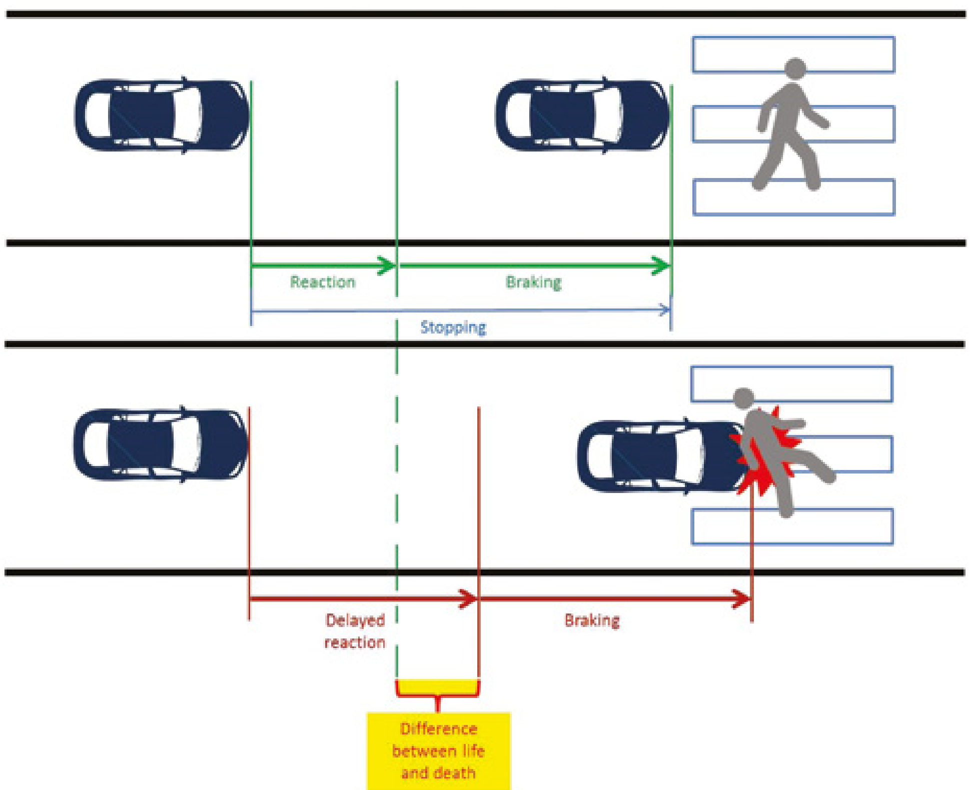


Illustration 7: Prolonged reaction time.

In order for road engineering to respond more effectively, driver distraction and fatigue need to be better defined and understood. Accordingly, their definitions and sub-elements are explored within this chapter.

2.1. DRIVER DISTRACTION:

Distracted driving can be defined as an insufficient attention to the driving task as a result of some competing activity occupying the conscious attention of the driver (adapted from Carsten, 2014). This definition excludes fatigue as fatigue lowers the total amount of conscious attention available to the driver, to zero in the case of sleep.

Important words in the above definition are "*insufficient attention*", which means that performing some secondary task while driving does not always qualify as distracted driving. This is because the driving task itself constitutes multiple tasks. For example you cannot check the road ahead at the same time as checking your mirrors, and you can't check your speed while you are checking your mirrors. Each of these happens individually, and what really counts is the time available to each.

When the duration of a task extends into seconds and more, the ongoing driving is being performed based upon increasingly out of date information (see *illustration 5* and *illustration 6*).

Texting while driving is particularly dangerous because it can take the conscious attention of the driver away from the driving task for seconds at a time and more. Changing the radio station on a car you are not familiar with can also be dangerous as you might fumble to find the right controls which takes time, however, may not be at all dangerous within a car you are familiar with where the task can be completed within an instant. Within the car you are familiar with, the radio changing process has perhaps become highly efficient and automated, leaving enough conscious attention for driving.

Like other tasks, driving becomes increasingly automated with training and experience. As a driver's experience grows, so does their efficiency and ability to suitably divide their attention between multiples tasks while still ensuring the sufficient allocation of attention to driving.

With experience, drivers also become more capable of safely adapting their driving to meet the demands of the moment. Also, if a driver recognises that they have insufficient attention to allocate to driving at a given pace, they can compensate by reducing their speed, so as to sufficiently lower the pace of the driving task such that it now matches their available attention levels.

Young and Regan (2007) propose that distraction is occurring when a driver's attention is, voluntarily or involuntarily, diverted away from the driving tasks by an event or object to the extent that the driver is no longer able to perform the driving tasks adequately or safely. This definition is consistent with the above discussion.

In 2009, Reagan, Young and Lee defined driver distraction as '*the diversion of attention away from activities critical for safe driving toward a competing activity*'. The consequence of such definitions is that almost anything unrelated to the driving task qualifies as a distraction because for the moment the competing activity is being focused upon, the driver's attention is away from activities critical for safe driving. However, the competing activity can only compromise safety if it takes away so much attention that the driver's "*model*" of the road environment has decayed to such an extent that driver decision making is compromised. Further, the driver requires a sufficient level of stimulation in order to avoid monotony fatigue (see *3.2.3. Monotony Fatigue*) and there are many road sections which offer little stimulation to the driver. In this context, briefly diverting the conscious attention of the driver away from the road, such as with public art, can be highly beneficial to road safety and so should not be categorised as a driver distraction. For example, an art piece located mid-way a long and straight road section may reactivate the driver boosting their conscious attention levels and ability to safely drive.

Therefore, PIARC has chosen to adopt the definition of Driver Distraction as:

A voluntary or involuntary competing activity that diverts the conscious attention of the normal driver away from the driving tasks to such an extent that the driver is no longer able to safely perform the driving tasks in a given context.

It is noted that the "*normal*" driver means a person not affected by other behavioural impediments to driving (such as fatigue, alcohol impairment, over speed, etc.) and is generally endeavouring to drive in a fit and proper state. Further, it is assumed that the amount of conscious attention required to simply perform the driving tasks is within the capability of the normal driver (otherwise the matter would be information overload).

Through a complex section of the road where a driver is required to consider many items, a conscious attention capturing matter unrelated to driving safely, such as a small eye catching advertisement, might be enough to compromise safety and become a driver distraction. By contrast, along a road-scape that does not place significant cognitive demands on the driver at any time, a large and bold public art piece might serve to briefly stimulate the driver (affected by monotony fatigue) and so would not constitute a driver distraction.

Research has typically categorized distraction into four distinct types:

- visual distraction occurs when the driver neglects to look at the road and traffic situation and instead focuses his/her visual attention on another target for an extended period of time;
- auditory distraction occurs when the driver focuses their attention on auditory signals rather than on the road environment;
- physical distraction occurs when drivers remove one or both hands from the steering wheel for extended periods of time; and
- cognitive distraction includes any thoughts that absorb the driver's attention to the point that they are no longer able to navigate through the road environment safely.

Further, the causes of distraction may come from inside or outside the vehicle.

Accordingly, to enable the dimensions and elements of driver distraction to be considered, the following groupings have been used:

- internal versus external to the vehicle;
- information overload due to excessive road and roadside information;
- optical illusions inherent in the road infrastructure or environment;
- day dreaming and other matters of the mind; and
- natural environments and the weather.

2.1.1. Internal versus External to the Vehicle

There is a diverse array of potential in-vehicle items which could draw upon the resources of the driver, such as:

- communication via conversation with passengers, the mobile phone, texting messages or reading email, social media or other messages;
- tending to adult, children and pet passengers;
- adjusting vehicle/dashboard/navigational unit settings (see *illustration 8*);
- enjoying or controlling on-board entertainment;
- consuming food or beverages;
- applying makeup or grooming; and
- avoiding or dealing with an insect that has somehow entered the vehicle.

Illustration 8: Numerous vehicle controls risking the overload of the driver (the Central Organisation for Traffic Safety in Finland, Finland, 2014).

They become an in-vehicle driver distraction when the driver is devoting insufficient resources to the driving tasks because they have devoted too many of their resources to one or more of these activities. These activities can adversely affect driver performance as follows:

- physical: they can affect the driver's range of motion and potentially interfere with the driver's ability to physically respond to a given situation (e.g. holding food or a mobile phone can limit the use of one or both of the driver's hands);
- perceptual: they can draw visual attention away from the road and the traffic, potentially increasing the opportunity for the driver to overlook important visual cues (for example, typing an SMS message or email can draw the driver's eyes away from the road for a prolonged period of time);
- cognitive: they can increase the cognitive workload of the driver and potentially leave insufficient capacity for the driving task, increasing the driver's decision-reaction time (for example, in understanding the person you are conversing with and forming a response, your brain is actively processing information taking away from the processing power available for driving the vehicle).

There are also a diverse range of potential driver distractions outside of the vehicle, such as:

- natural scenery, landmarks and public art visible from the road;
- people and animals visible from the road;
- other road users and vehicles;
- events, incidents and road work;
- weather events (see *Section 3.1.5*);
- signs (advertising or road related), road marking and lighting; and
- optical Illusions (see *Section 3.1.3*).

For example, *illustration 9* illustrates potential items to catch the driver's attention beyond the roadway such as natural scenery and advertisements which compete with the road for the driver's conscious attention.

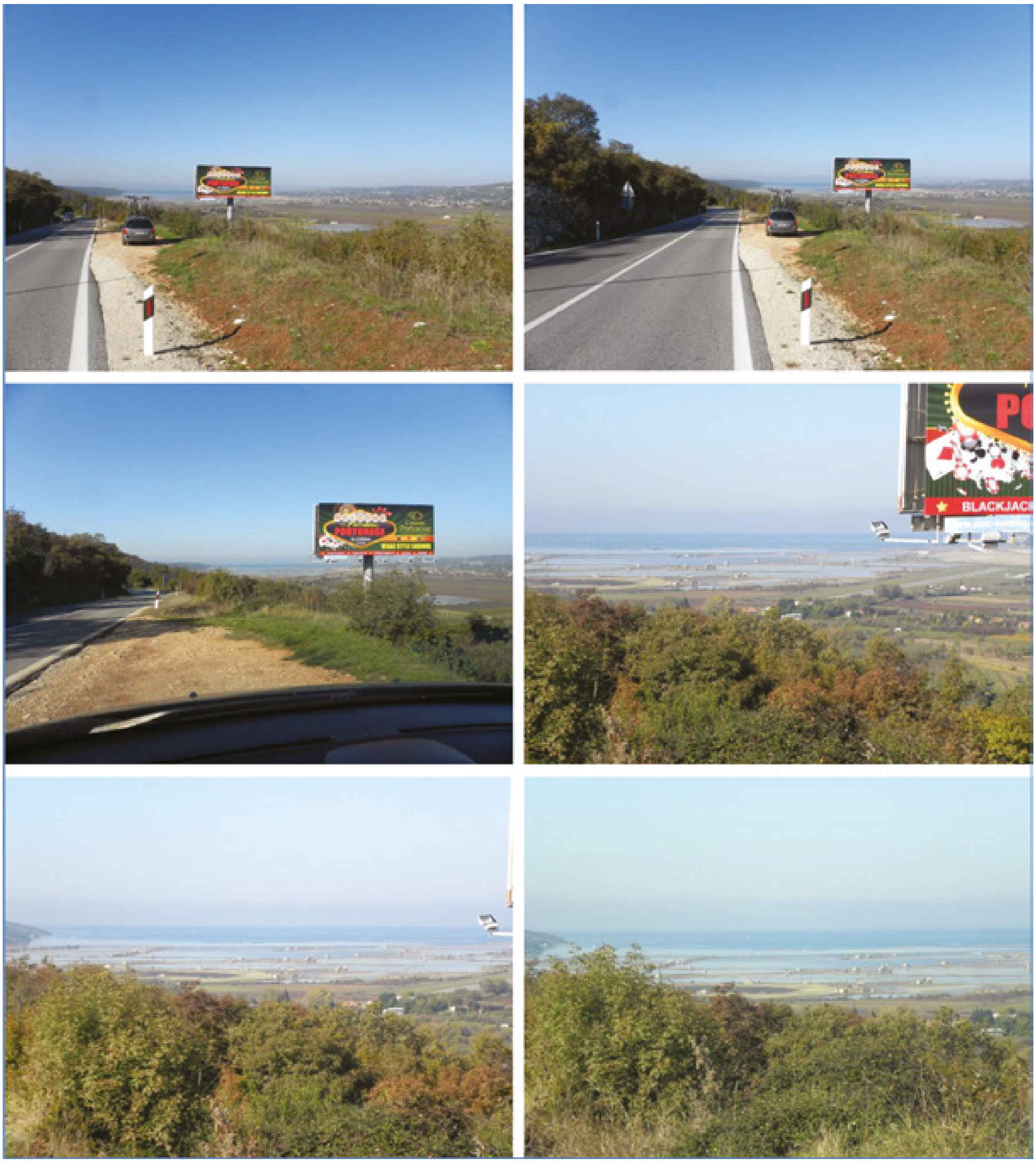


Illustration 9: Environmental (landscape) and manmade eye catching objects

Whether something external to the vehicle is likely to be a driver distraction can be assessed by considering whether it is within the driver's field of vision and field of peripheral vision (see *illustration 10, illustration 11* and *illustration 12*).

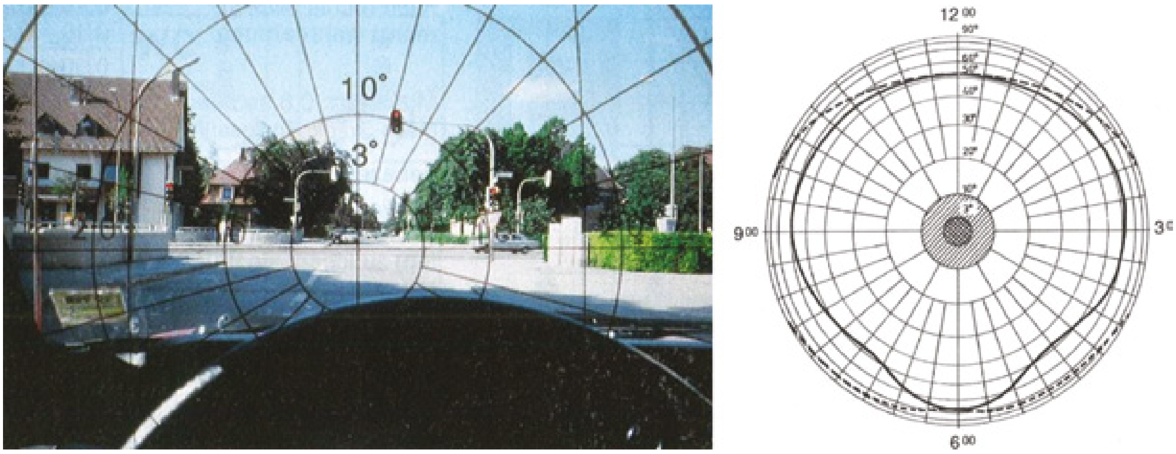


Illustration 10: Drivers' field of vision (Kirschbaum, 2002)

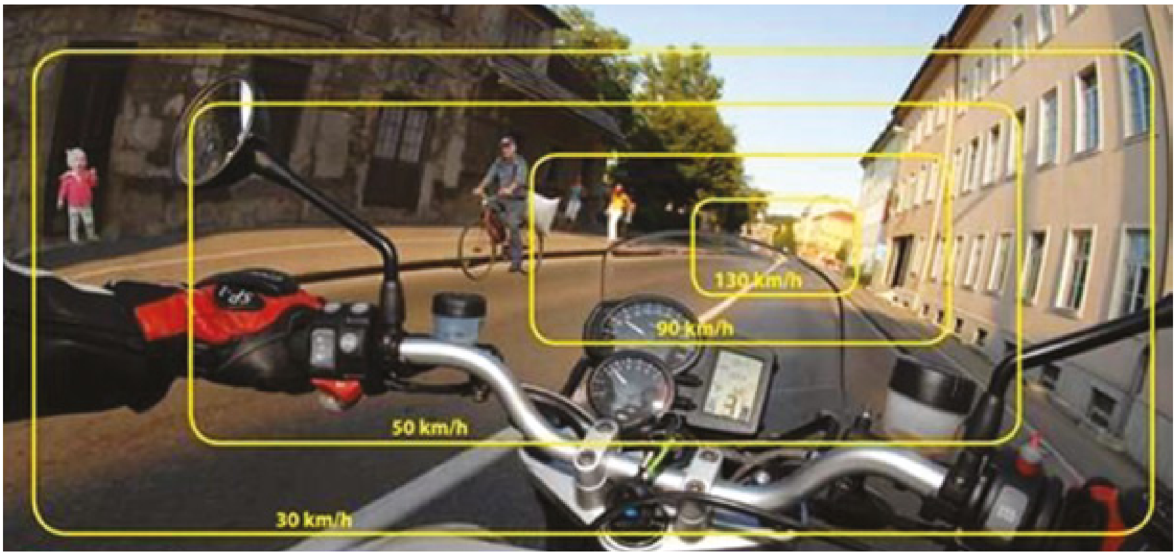


Illustration 11: Speed and field of vision (Ministry of Infrastructure, 2015)

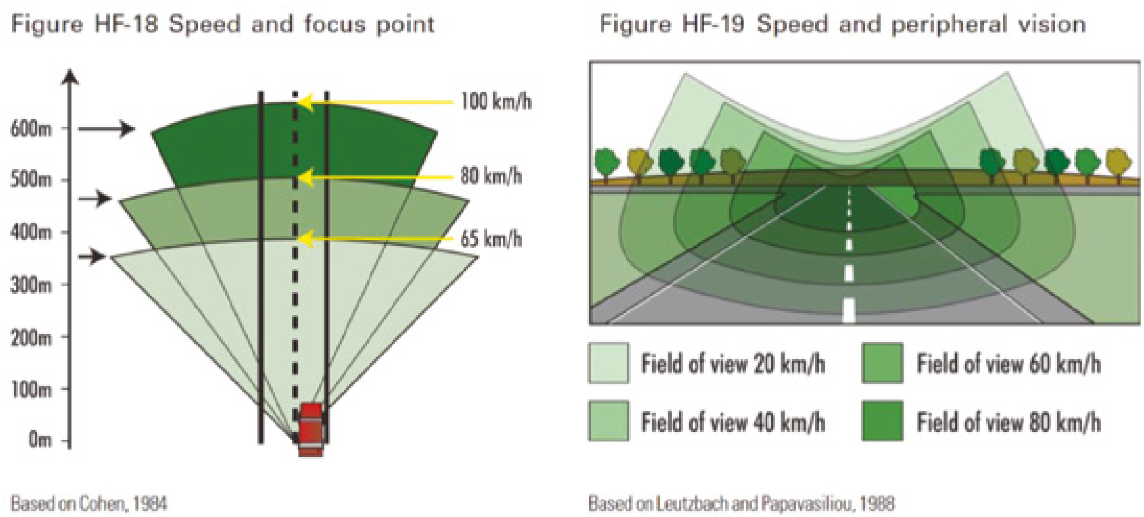


Illustration 12: Focus, peripheral vision (PIARC, 2003)

Another aspect relevant to distractions internal versus external to the vehicle is that the eyes focal length is usually short when focusing internal to the vehicle and longer when focusing external to the vehicle. For example,the middle photo in *illustration 13* illustrates that when we really focus our eyes closer to us, the background becomes blurry and the right photo illustrates vice versa. The result is that while we are focusing internal to the vehicle, it is difficult to detect hazards external to the vehicle using our peripheral vision. Also, while we are focusing external to the vehicle, we cannot rely upon our peripheral vision to monitor the controls internal to the vehicle, such as our speedometer.

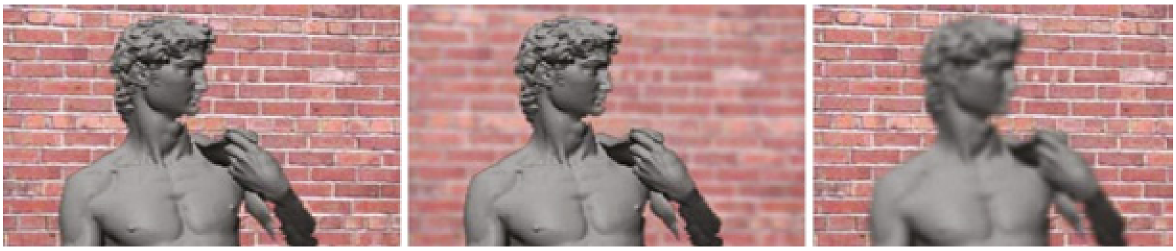


Illustration 13 Focus, depth perception / visual acuteness (Mandryk, 2003)

It takes time for the eye to move and refocus, such as shown in *illustration 1*. The eye movement time is approximately 0.15 – 0.33 seconds for shifting eye to new position and 0.20 – 0.35 seconds for focusing on the new object. Accordingly, as per *illustration 5* and *illustration 6*, distractions internal or external to the vehicle can add significant time to the cycle through which the driver is going to perform the driving tasks.

The internal and external distractions can, by adding time to the driver tasks, also contribute to the driver being overloaded with too much to do.

2.1.2. Information overload external to the vehicle

Information overloading such as through overwhelming roadside information, has the potential to distract the driver away from other key driving tasks such as watching the road, monitoring other traffic and maintaining proper vehicle control. Accordingly, the external information overload could compromise the driver's ability to safely perform the driving tasks owing to driver distraction. The cause of the distraction could be road signage itself and / or other information beyond the road (such as advertising) – see *illustration 14*.

Roadside advertising and information signs are intended to draw the attention of people in order to market the relevant product or convey the relevant information. Drivers may be affected, and if they are, they will then have less conscious attention available for the driving tasks. Whether or not this constitutes driver distraction depends upon whether enough conscious attention has been taken away from the driving tasks. Roadside advertising and information signs have the potential to cause driver's eyes to leave the road more often and for longer periods of time, potentially increasing reaction times and decreasing ability to control the vehicle. In fact, drivers more often stray from the lane in the vicinity of advertising and information signs. Moving displays, such as digital advertisements, flashing images or multi message Variable Message Signs can further comprise drivers' abilities. In addition, information overload of any variety can cause the driver to forget previously read traffic signs. (SWOV, 2012).

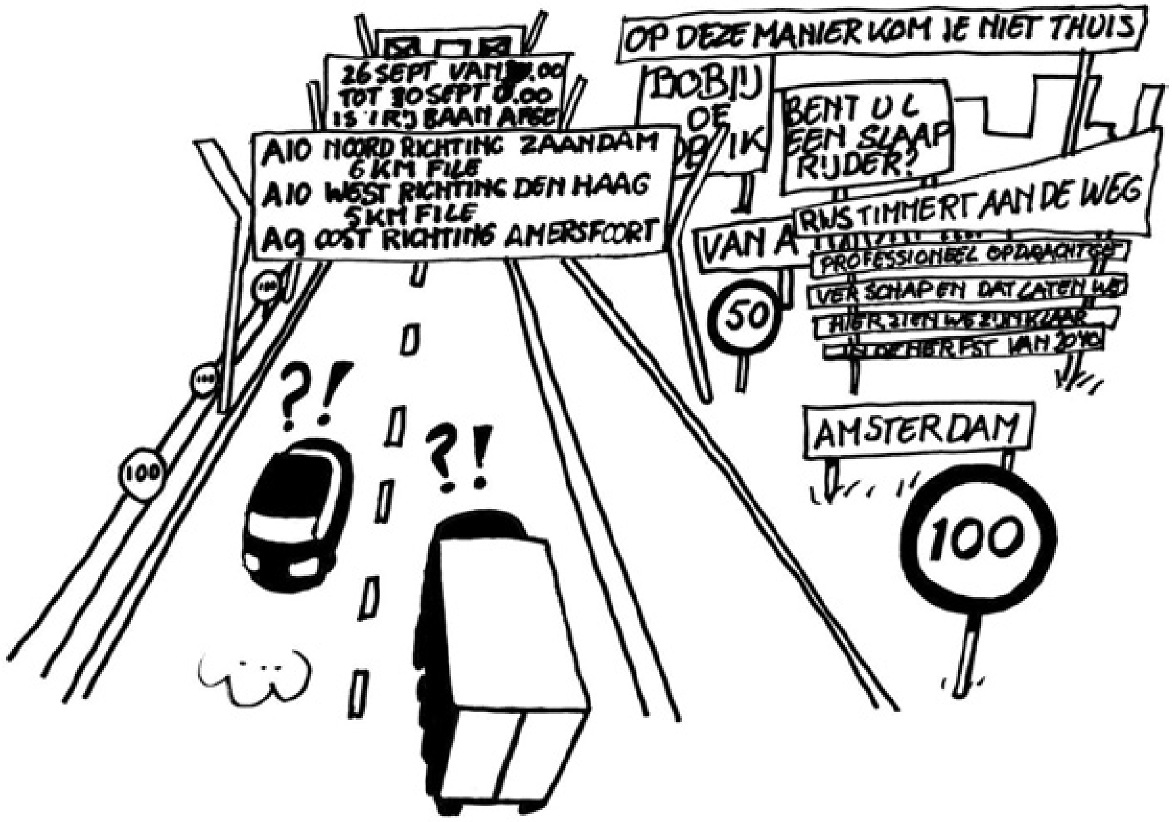


Illustration 14: Overwhelming information that distracts the driver from other key driving tasks (Ministry of Infrastructure and The Environment, 2008).

Illustration 15 demonstrates that the driver information overload risk can vary between night and day.

Illustration 16 provides an example where many things are happening on the roadway, there are numerous road signs and many competing advertising signs together, which creates the potential for information overload.

Information overload risks can also arise from within the vehicle, such as from the emerging in-vehicle technology systems, such as associated with navigation displays and in-vehicle driver warning systems (e.g. lane departure warning). While the intent of these technologies might be to aid the driver or enable corrective action, it is conceivable that there are times when such technologies could make matters worse.

Illustration 15: Illuminated distraction in night versus day (Uroš Brumec).

Illustration 16: Overwhelming information, examples from Slovenia (Uroš Brumec).

2.1.3. Optical Illusions

It is important to remember that driving constitutes multiple tasks and scanning the road ahead is just one of them. Should an optical illusion lead the driver to believe that the road goes in a different direction to what it really does (e.g. *illustration 17, illustration 18* and *illustration 19*), there is a chance that the driver will plan to go in the erroneous direction before moving on to the other driving tasks (such as checking speed, mirrors and roadside signage, etc.). By the time the driver re-engages in reviewing the roadway, it may be too late for them to adjust to the correct direction. The cause of the optical illusion is a distraction because it caught the attention of the driver and tricked them into planning to take the wrong course.

Illustration 17: The road looks like it is straight, however, veers to the right just after the crest.

Illustration 18: The cues from the part in the trees and the driveway indicate that the road goes straight ahead.

Illustration 19: The lane diverging to the right has signage indicating it bends to the right, and the road in distance reinforces this perception, however, the road veers to the left before sharply veering to the right.

Mori Y., Kurihara M., Hayama A. and Okhuma S. (1998) investigated the relationship between the perception of drivers and the combination of geometric alignments in an expressway. The work verified that some combinations of vertical and horizontal alignment could create a range of visual illusions similar to the examples above (Mori, 1998).

In Germany, the Road Directorate had long been cooperating with psychologists and experts in human factors to evaluate the contribution of road legibility in the mechanism of road crashes. Long term investigations concluded that a poor legibility of the road and its environment was implied in 35 to 40% of road crashes studied, including optical illusions such as a wrong perception of the alignment of the road or the absence of detection of a T junction with a secondary road.

In addition, there are other forms of optical illusions, such as a child appearing to the driver to be an adult positioned further along the road (see illustration 20).

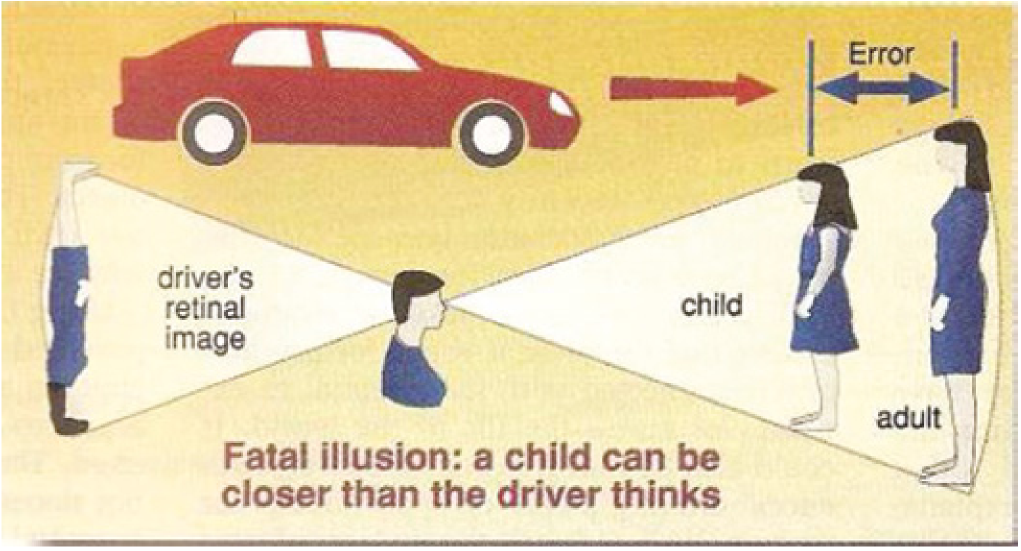


Illustration 20: Optical illusion of a child appearing to be an adult further along the road. (Aberdeen)

The PIARC Human Factors guide considers optical illusions and other related human – road interface issues and should be referred to for further information.

2.1.4. Day dreaming/ other matters on the mind

As most of our driving is to a large extent automated, often there is lot of the supplementary conscious capacity left for tasks other than driving. This surplus capacity is often used for other purposes, such as reflecting on a hard day at work or other forms of day dreaming.

Once daydreaming or thought about other matters has commenced, the driver requires additional reaction time to refocus their conscious attention back onto the driving tasks in order to adequately deal with matters out of the ordinary (4 to 6 seconds).

Giambra (1995) showed that day dreaming was more associated with the performance of uninteresting or uninvolving tasks. Therefore, if we are driving along an unstimulating road, we become at risk of being distracted by daydreaming or other matters of the mind.

NHTSA's National Centre for Statistics and Analysis conducted a survey to understand the role of inattention in crash occurrence. One of the categories considered was the cognitive distraction such as thinking about personal problems (a matter of the mind). It was found that inattentiveness due to unknown thought focus was the most prevalent factor among the non-driving cognitive activities. (Analysis, 2010)

The tendency to look straight ahead while in the middle of a daydream entails a failure to scan the environment such that a daydreaming driver becomes less aware of the other vehicles around them on the road. Jibo He found that a wandering (He, 2010) mind led to a horizontal narrowing of a drivers visual scanning (i.e. looking straighter ahead), shifts of lane position and a decrease in the variability of vehicle velocity (He, 2010). Accordingly, distraction by daydreaming or other matters of the mind contributes to an increased risk of crashing.

2.1.5. Natural environment issues

Natural environment issues might include:

- Natural Landscape: *Sections 3.1.1, 3.1.2* and *3.1.3* have discussed ways in which the natural landscape itself could lead to the distraction of the driver.
- Celestial matters: The setting or rising sun (e.g. *illustration 21*) can temporarily blind the driver or make visibility very difficult. A beautiful sunset may take the driver's eyes off the road.
- Weather: Difficult weather conditions require extra attention and may cause information overload. It also may distract drivers with the operation of extra driving tasks required to cope with the conditions (e.g. activation of the windscreen wipers or of the fog lights). In addition to the challenges of driving in heavy rain or wind, the sight of an approaching storm, approaching rainfall or a rainbow may lead to driver distraction. Examples of weather related possible distractions are provided in *Table 1* and see *illustration 23*.
- Wildfire/sandstorm/snowstorm: A nearby wildfire naturally catches the attention of the attention of the driver and may create other distractions such as smoke and the approaching dust of a dust or snow storm (see *illustration 22*).
- Animals: Animals within the roadway may distract the driver who is seeking to maintain speed yet avoid colliding with the animals, leading the driver to swerve into oncoming traffic (see *illustration 24*).

TABLE 1: EFFECT OF WEATHER CONDITIONS ON DRIVING CONDITIONS AND SAFETY

Weather condition	Effect on visibility	Effect on adherence	Effect on safety
Rain	Decrease in the perception of the road due to the presence of water on the wind shield and on the decrease of the air visibility. The effect depends on the intensity of the rain. For high intensity events, visibility can fall dramatically. The effect depends on the road environment (urban or interurban): speed limits, presence of traffic (spray on the road, glare), public lighting (Y/N). At night, the rain decreases the delineation of the driving lanes, due to the specular reflectivity which harms the visibility of standard road markings.	Rain and water drainage decrease the adherence of roads. Even with very thin water film (thickness of 0.05 mm), the adherence of the road surface falls by 30%.	Drivers usually slow down by rainy conditions, but generally less than needed relatively to the conditions. In rain conditions, more frequent but less severe crashes are generally observed by day. At night, the severity of crashes in rain conditions tend to be higher compared to the severity of the same crashes by day.
Wet Road after long dry periods	Limited effect after showers except water spray by traffic after significant rainfalls.	The adherence of the road surface can fall by 50%. The impact on vehicle controllability depends on local road pavement management. In case of poor maintenance of road pavement, conditions may become critical. Summer showers could create dangerous conditions in high traffic dirt roads which become very slippery.	Drivers don't slow down on wet surface (not considered as rainy conditions). In such conditions, more frequent but less severe crashes are generally observed by day. At night, the severity of crashes in wet conditions tends to be higher compared to the severity of the same crashes by day.
Fog	Fog has the maximum effect on the visibility for drivers. Due to fast changing local conditions, it can decrease very abruptly the visibility for drivers. Fog can decrease visibility to a very short preview time, which is not compatible with high speed.	Non relevant.	Fog is more dangerous in interurban roads, especially on sinuous roads leading to road departures, and on motorways leading to vehicles' pileups.

TABLE 1: EFFECT OF WEATHER CONDITIONS ON DRIVING CONDITIONS AND SAFETY			
Weather condition	**Effect on visibility**	**Effect on adherence**	**Effect on safety**
Snowfalls and snowy roads	Depending on its intensity, snow can differently affect the visibility for drivers. Dense snow can seriously decrease the visibility for drivers. In most cases, snow does not affect too much the visibility of the road, but could affect the visibility of the other vehicles. At night, snow can hide the road markings, the roadsides and/or even the course of the road in absence of maintenance.	Snow has a strong impact on the adherence of the road surface. With very low friction conditions, the risk of loss of control strongly increases in both lateral and longitudinal directions.	Depending on the road maintenance, and on the vehicle features and equipment (type of tires, additional equipment), snow can lead to losses of control and to severe crashes in undivided roads or on roads having non-forgiving roadsides.
Ice	Ice does not affect the road visibility itself, but it can affect the vehicle (windscreen), and request adapted cleaning and preparation before driving.	Ice has the maximum impact of every weather condition on the adherence of the road.	Depending on the road maintenance, and on the vehicle features and equipment, ice can lead to losses of control and to severe crashes.
Black Ice	Black ice does not affect the road visibility itself.	Black ice has the maximum impact of every weather condition on the adherence of the road. Black ice may occur locally in cold countries, creating slippery areas during winter. It addition to visible "*white/blue*" ice, it can be less predictable insofar it is located at specific spots which contrast with the adherence of the rest of the roadway.	Black ice is known to create severe crashes.
Wind	Wind does generally not affect visibility, except if combined with other events.	Wind can increase dynamic momentum of the vehicle and lead to loss of control	Wind can especially affect vehicles' control during overtaking manoeuvers between cars and trucks). Lateral wind can make heavy goods vehicles roll over.
Sand storm	A sand storm can decrease visibility to zero which make it impossible to drive safely.	Not reported.	Sand storm may lead to vehicles' pileups, especially on high trafficked, high speed roads.

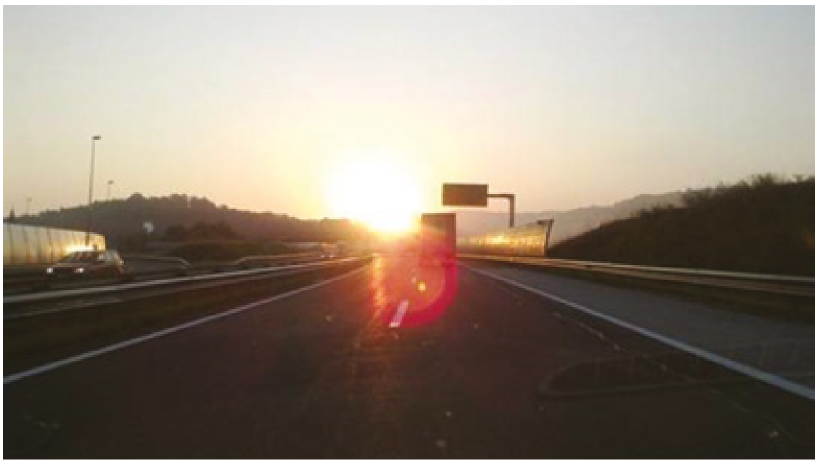



Illustration 21: The setting sun potentially leading to driver distraction.

Illustration 22: Dust storm in Phoenix, Arizona, July 2011.

Illustration 23: A snow storm in southern Finland (the Central Organisation for Traffic Safety in Finland, 2014).

Illustration 24: Animals on the road M32, Kyzylorder, Kazkhstan, 2013, photo by Hans Vollpracht.

Illustration 25: Street market at National Road No 1 in Egypt 2010, photo by Hans Vollpracht

Illustration 26: Street market and linear settlement at National Road 1 in Vietnam 2006, photo by Hans Vollpracht.

2.2. DRIVER FATIGUE

Thiffault and Bergeron define driver fatigue as a general psychophysiological state which diminishes the ability of the individual to perform the driving task by altering alertness and vigilance (Thiffault, Monotony of road environment and driver fatigue: a simulator study, 2003).

Symptoms of fatigue include restricted field of attention, slowed or impaired perception, decreased motivation, subjective feelings of fatigue and task aversion, and decrease in alertness, a lack of concentration and attention. Fatigue leads to an increased reaction time, a memory lapses and a reduced field of view.

Types of fatigue include general tiredness (*illustration 27*), driver exhaustion arising from over engagement, insufficient engagement of the driver (*illustration 28*) or infrastructure exhaustion factors. Driver fatigue can be a result of a driving situation involving four elements; diver, vehicle, behaviour of other road users and traffic conditions (Zuzewicz, 2006).

According to an evaluation of crashes completed in 2003 by the Virginia Commonwealth University for the Virginia Department of Motor Vehicles in the USA, driver fatigue accounted for 12% of the 2700 crashes involving distracted drivers. In Australia, a 1994 survey of coronial and police reports found that fatigue played a part in about 18% of the fatal crashes. It was determined that around 30% of the rural crashes in Western Australia could be directly attributed to fatigue. Fatigue was a major cause of crashes in Victoria resulting in 70 deaths and approximately 500 serious injuries each year.

Illustration 27: General tiredness (the Central Organisation for Traffic Safety in Finland, 2014).

Illustration 28: Route 99, California, USA, a monotonous road section owing to its straightness.

Fatigue is often a secondary or contributing factor in collisions (reduced capacity of avoidance/ reaction/judgment/concentration and/or reflexes). Also, the proportion of collisions attributed to fatigue increases with the degree of severity of the collision (CCMTA, 2005).

In 2005, the 100-Car Naturalistic Driving Study was completed by the Virginia Tech Transportation Institute (VTTI) and sponsored by the National Highway Traffic Safety Administration (NHTSA), Virginia Tech, Virginia Department of Transportation (VDOT), and Virginia Transportation Research Council (VTRC) (Neal, 2005). This study was undertaken with the goal of obtaining data on driver performance and behaviour in the moments leading up to a crash. The researchers installed instruments and sensors in 100 vehicles that were driven as ordinary vehicles by ordinary drivers for one year. Drivers were given no special instructions. The study collected data on 15 police-reported (VirginiaTech Transportation Institute, 2005) and 67 non-police reported crashes, 761 near-crashes and 8 295 incidents. The main discoveries were:

- Driver fatigue was a contributing factor in 20 % of all crashes and 16 % of all near-crashes; and
- Nearly 80 % of all crashes and 65 % of all near-crashes involved driver inattention (due to distraction, fatigue, or just looking away) just prior the conflict.
- Driving while fatigued results in a four to six times higher near-crash/crash risk relative to alert drivers[3].

The study did not distinguish between the different types of driver fatigue.

In Quebec, driver fatigue is the third cause of death on the road (SAAQ, 2015). According to the Canadian Council of Motor Transport Administrators (CCMTA), driver fatigue is a contributing

[3] Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., and Ramsey, D.J., DOT HS 810 594, The Impact of Driver Inattention on Near-Crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study Data, Virginia Tech Transportation Institute, 2006

factor in up to 19% of all fatal collisions resulting in about 400 deaths and 2,100 serious injuries every year. At 21 per cent, fatigue would rank as the third highest measurable cause of collisions behind alcohol impairment and speed-aggressive driving.

In New-Zealand, for the years 2011-2013, driver fatigue was a factor for 13 % of fatal crashes, 6 percent of serious injury crashes and 6 percent of minor injury crashes (MTNZ, 2014). Approximately 97% of the fatal crashes in which driver fatigue was identified as a contributing factor fall into two main categories: run off road and head-on crashes. When a vehicle starts drifting off the road one way, the driver may over-steer in the opposite direction, leading the vehicle to cross over into oncoming lanes of traffic or travel off the road into a hazard. Horne (Horne, 1995) and Reyner has also described typical sleep-related accidents as ones where the driver runs off the road or collides with another oncoming vehicle without any sigh of breaking before the impact.

In USA, the report on the impact of driver inattention on near-crash/crash risk following the 110-Car Naturalistic driving study indicated that driving while drowsy was a contributing factor for 22 to 24 percent of the crashes and near-crashes. According to an evaluation of crashes (University, 2003) driver fatigue accounts for 12% of the 2700 crashes involving distracted drivers. Since driver drowsiness may vary depending on time of day, the analysis shown that drowsiness was seen to slightly increase in the absence of high roadway or traffic demand (Klauer, 2006). In Australia, 16.6 % of fatal crashes and 19.6 per cent of fatalities were identified as fatigue-related by the operational definition (ATSB, 2002).

Illustration 29 presents some results from Finland using VALT (Finnish Motor Insurers' Centre) data on accidents.

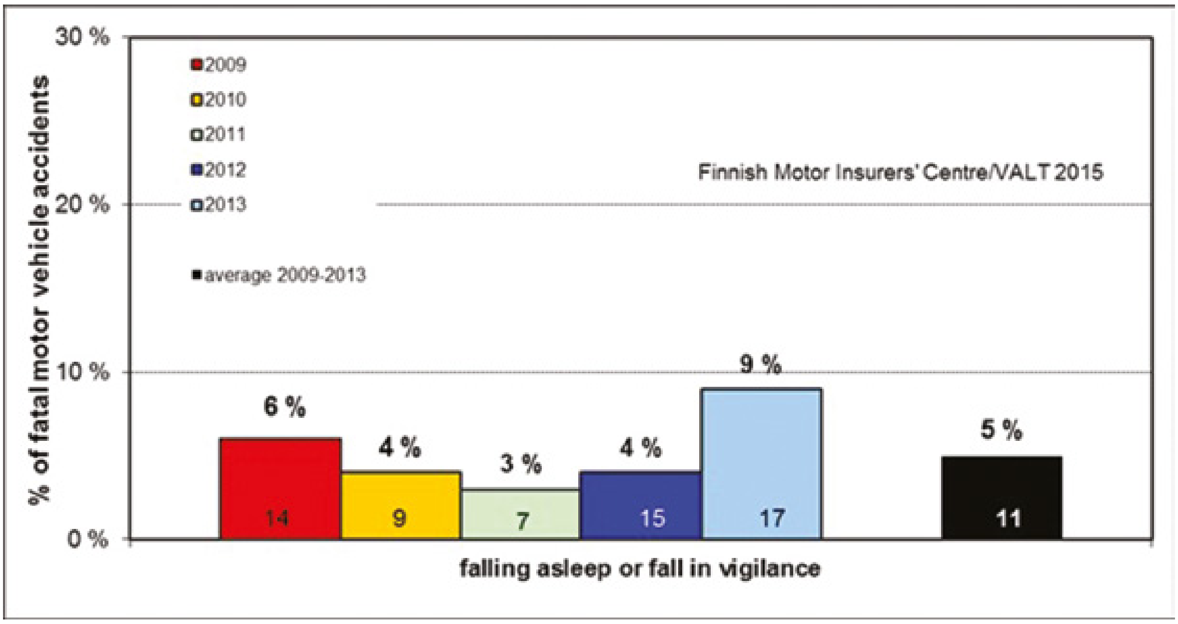


Illustration 29: Falling asleep or fall in vigilance as immediate risk factor in VALT-database 2009-2013 (Finland) of in-depth investigated fatal road accidents.

Fatigue can be a contributing factor behind almost all types of crashes, but falling asleep while driving is the most dangerous result of fatigue. It is generally thought that the number of fatigue related crashes are underestimated because a fatigue crash can be similar to other crash types, such as swerving to miss a deer. Also, where the outcome of the crash is very serious or fatal, it can be impossible to diagnose the cause of the crash as fatigue because those involved cannot be interviewed and, unlike alcohol-related crashes, there is no measurable test to quantify levels of fatigue at a crash site (Horne, 1995). Possible criteria to identify fatigue related crashes (Horne, 1995) included:

- blood alcohol levels below the legal driving limit;
- the vehicle either ran off the road or ran into the back of another vehicle;
- no signs of the brakes being applied beforehand (for example, no skid marks);
- no mechanical defect in the vehicle (or burst tyre);
- good weather conditions and clear visibility;
- elimination of "*speeding*" and "*driving too close to the vehicle in front*" as causes;
- the police officer(s) at the scene suspected fatigue as the prime cause;
- for several seconds immediately before the accident the driver could have seen clearly the point of run off or the vehicle hit.

Similarly in the United States, the Expert Panel on Driver Fatigue and Sleepiness (1997) characterised a fatigue-related crash by the following:

- occurred late at night, early morning or mid-afternoon;
- resulted in higher than expected severity;
- involved a single vehicle leaving the roadway;
- occurred on a high speed road;
- driver did not attempt to avoid the crash; and
- driver was the sole occupant in the vehicle.

In Australia, the ATSB operational definition of a fatigue-related crash employs some of the criteria used in United States, United Kingdom and some Australian States:

- includes single vehicle crashes that occurred during '*critical times*' (midnight–6am and 2pm–4pm);
- includes head-on collisions where neither vehicle was overtaking at the time;
- excludes crashes that occurred on roads with speed limits under 80 km/h, involved pedestrians, involved unlicensed drivers and drivers with high levels of alcohol (blood alcohol over 0.05g/100ml).

All of the criteria identified above are equally relevant to a driver distraction crash type (voluntary or involuntary), therefore, should never be used to definitively identify driver fatigue as the cause of a specific crash. However, for global statistics reporting, it might be possible to use such criteria or the findings of the Naturalistic Study to estimate ratios of driver fatigue versus other equally relevant crash causes.

2.2.1. General tiredness

Fatigue is a typical cause for inattentive driving. This internal state refers to reduced readiness for action at a physiological and psychological level. Fatigue and sleepiness can be simply a result of continuing driving for too long (Johansson, 2012).

Thiffault and Bergeron define fatigue as a psychological and physiological state which diminishes the ability to perform the driving task reducing alertness and vigilance (Thiffault, Monotony of road environment and driver fatigue: a simulator study, 2003). Symptoms of fatigue include restricted field of attention, slowed or impaired perception, decreased motivation, subjective feelings of fatigue and task aversion, and decreased performance in the form of irregularities in timing, speed, and accuracy (Fuller, 2002).

General tiredness is an internal state, involving the reduction of the ability to work. Drowsiness and lethargy refer to the need to fall asleep, which has a biological substrate. General tiredness is also associated with the reluctance to pursue previously undertaken actions, as a result of physical or mental effort. According to Austroads (Austroads, 2011), fatigue from general tiredness cannot be overcome simply by increased stimulation. While the general fatigued person might feel that the effects of fatigue are reduced through stimulation and drugs such as caffeine, the general fatigue remains.

The effect of general fatigue may go further than a psychological condition within the individual. Indeed, general fatigue is also related to physiological processes.

The cause of general fatigue is interference with the circadian rhythm (e.g. from sleep loss, stress, jet lag, night shift work, etc). Sleep loss over a number of nights can seriously affect performance. Most people are:

- least alert between midnight and 5am, and in the early afternoon ("*post lunch dip*");
- most alert best in the mid-morning and early evening.

The circadian rhythm is a little different for everyone, for example, not everyone will have the same low points, and the "*post lunch dip*" will be felt most strongly by people who are not getting enough sleep. *Illustration 30* demonstrates the Circadian Rhythm.

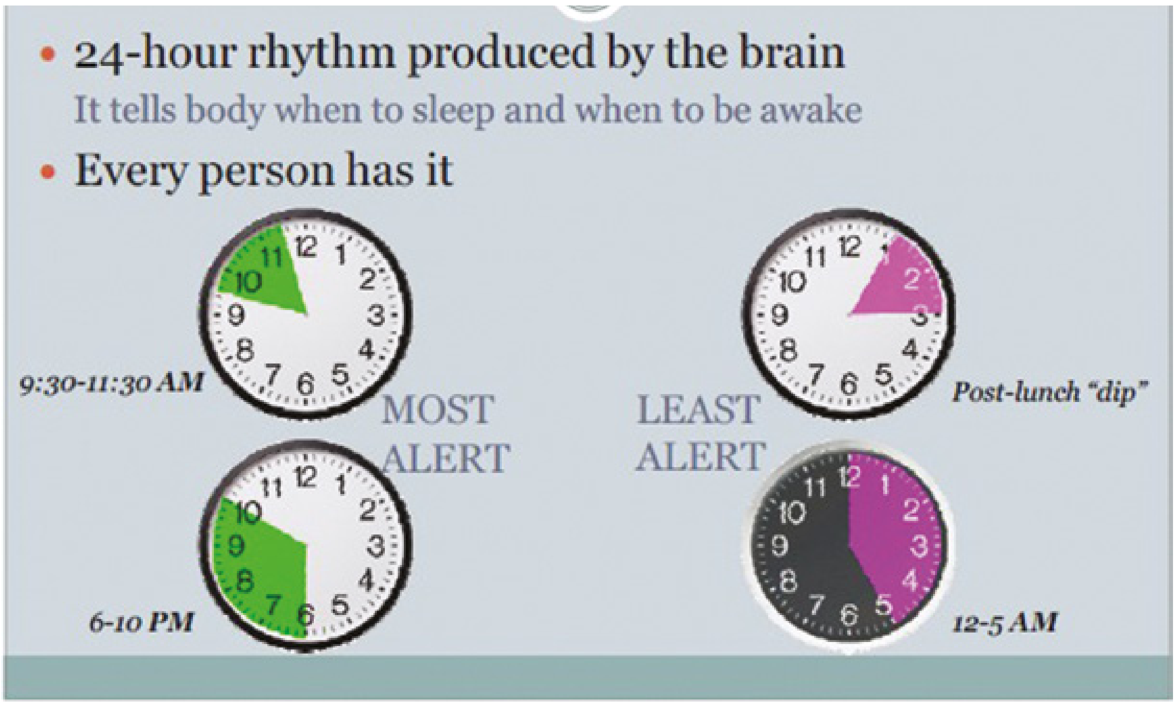


Illustration 30: The Circadian Rhythm.

Carskadon and Dement (Carskadon, 1987) observed the latency to sleep at two-hour intervals across the 24-hour day. The pattern of increasing and decreasing sleepiness reveal a greater need to sleep between 13:30 and 17:30 with a peak between 1:30 and 5:30 (see *illustration 31*).

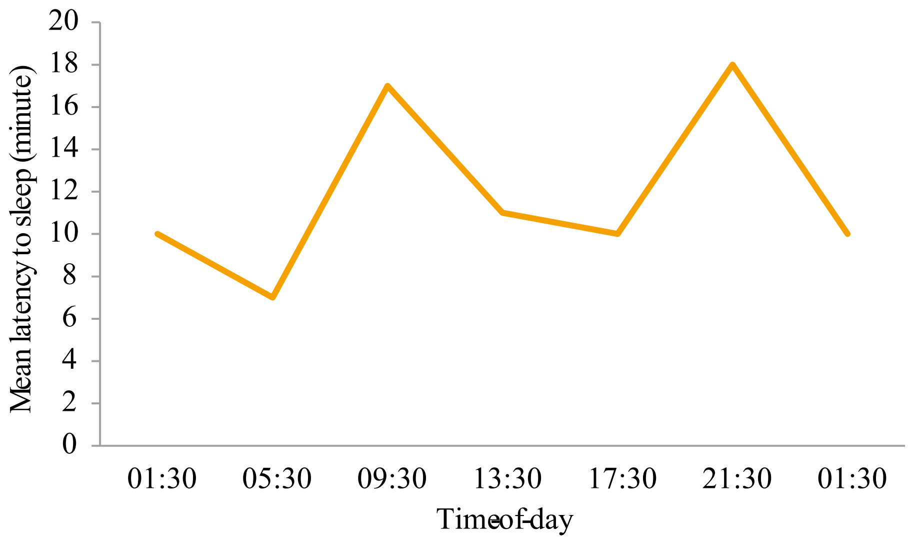


Illustration 31: Adaptation of Carskadon and Dement, 1987 –
Circadian effects on sleep latency during a schedule of 2-hour interval across the 24-hour day.

Knipling and Wang studied crashes and fatalities related to driver drowsiness/fatigue (Knipling, 1994). The report summarizes statistics, for the five year period 1989-93, on the incidence and characteristics of crashes involving general tiredness. From the accident report in which driver general tiredness it was cited that general tiredness crashes peaked sharply in the early morning and had a smaller peak in the afternoon (*illustration 32*). This temporal distribution of fatigue-related accidents was also reported by Mitler et al (Mitler, 1988). This distribution with night time and mid-afternoon peaks is consistent with human circadian sleepiness patterns.

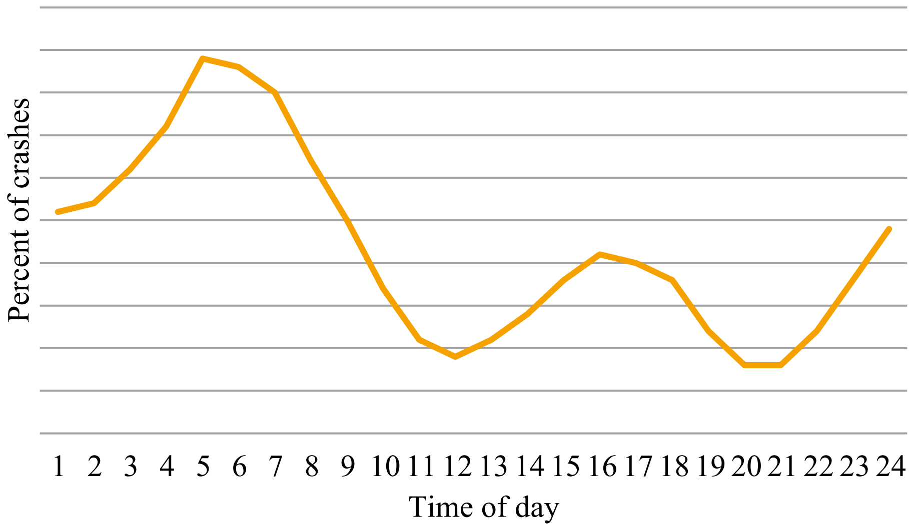


Illustration 32: Distribution of crashes

2.2.2. Driver Exhaustion (over engagement of the driver)

Road and driving conditions can greatly affect the rate and severity of fatigue through exhaustion of the driver. Driving at night, in inclement weather or through construction zones can increase stress and tire the driver out, lowering their attentiveness and ability to drive effectively. The physical and mental condition of the driver matters too. Driving under the influence of drugs or alcohol will most likely slow the driver's reaction time, as will driving with loss of sleep.

The unpredictable road environment caused by short and repetitive decision making and a complex roadway environment can both induce driver exhaustion resulting in higher risk of crashes and run off road events. This complex roadway can be experienced on urban roads as well as rural roads. A congested road during the peak period (e.g. *illustration 33*), resulting in stop and go traffic conditions and a continuous awareness of traffic changing lanes, can impair the driver's consciousness after just one hour of driving (Neal, 2005). In addition, a rural highway with every changing horizontal and vertical alignment can induce driver fatigue as the driver is continuously making decisions and so over time, becomes tired due to exhaustion and result in a higher risk of crashes.

Over engagement of the driver through a complex road environment that extends for a significant driving time can create driver exhaustion in the urban built up environment, transition zones and inter-city freeways. This effect could also be experienced on rural mountainous roads (*illustrations 34, 35*) with narrow cross sections and few stopping opportunities (*illustrations 36, 37*), can force ongoing decision making by the driver. Some typical crash types attributed to complex road environments include lane departures resulting in head-on, rear end or roll over crashes.

Basic crash statistics in the United States highlight the importance of human factors to road systems. In 2001, for example, there were more than 6 million police-reported (and many more non-reported) collisions in the United States which resulted in loss of life, property or productivity (NHTSA, 2002). Furthermore, driver error was usually a contributing factor in nearly half (approximately 44%) of the crashes leading to a fatality. Misperceptions, slow reactions and poor decisions result from a mismatch of the needs and capabilities of drivers with the tasks that face them (Campbell, 2012).

Illustration 33: Congestion on Route 99, California

Illustration 34: Demanding road environment owing to a narrow and unforgiving cross-section through mountainous terrain.

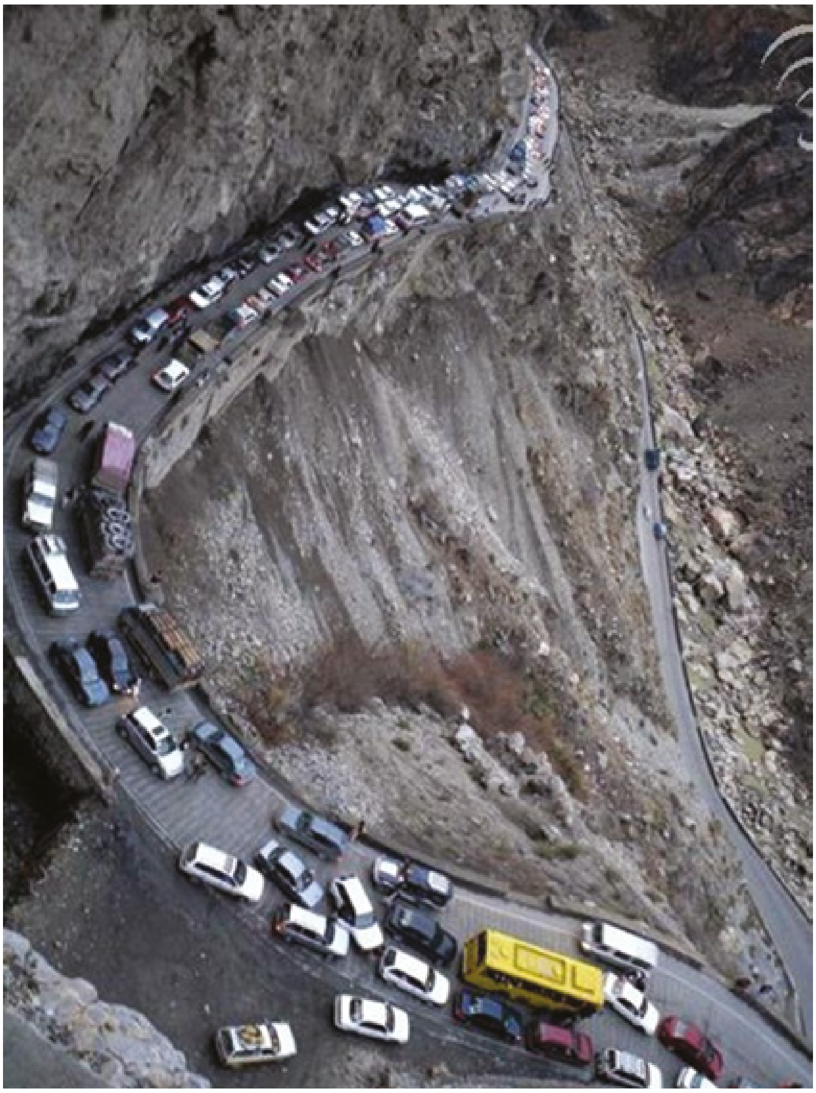


Illustration 35: Road between Jalalabad and Kabul at Kabul Gorge, Afghanistan (Networks, 2013).

Illustration 36: Demanding and congested road environment in Delhi, India, 2014.

Illustration 37: A road environment in Romania where road signage is camouflaged by advertising signage making the driving task demanding.

2.2.3. Monotony Fatigue

Freeway and open rural road environments (*illustrations 38,39*) have the potential to cause monotony fatigue due to a sustained length of time travelling involving little demands on the driver – also known as deactivation (see Human factors work of PIARC (PIARC, 2008) and *illustration 40*).

Driver simulator studies have concluded that the driver's attention and communication with the roadway is decreased after about for about two hours of continuous drive time (Thiffault, Fatigue and individual differences in monotonous simulated driving, 2003). Driver fatigue can be brought on in shorter time period as a direct result of a monotonous roadway. Another study from Belgium found that the onset of monotony fatigue could be detected (in the form of drivers missing more and more roadside signs) in as little as 10 minutes (Ceunynck, 2015). The effect of monotony fatigue can compound if the driver is affected by general tiredness and length of driving time. Studies have observed fatigue related behaviour was experienced after just 20 minutes of driving through a simulated monotonous road environment (Oron-Gilad, 2007).

Fatigue related crashes are common during monotonous driving conditions when the conscious and subconscious becomes blended together. The monotonous roadway can induce a driving hypnosis effect known as driving without full attention mode. This effect can result in a person driving in an automated manner, and them having no recollection of driving the previous stretch of road. In this state, the driver's conscious mind is focused more on the non-driving attention process and remains in a deactivated state of awareness.

Illustration 38: Route 99, California, USA

Illustration 39: Monotonous road examples from the Northern Territory and Western Australia, Australia.

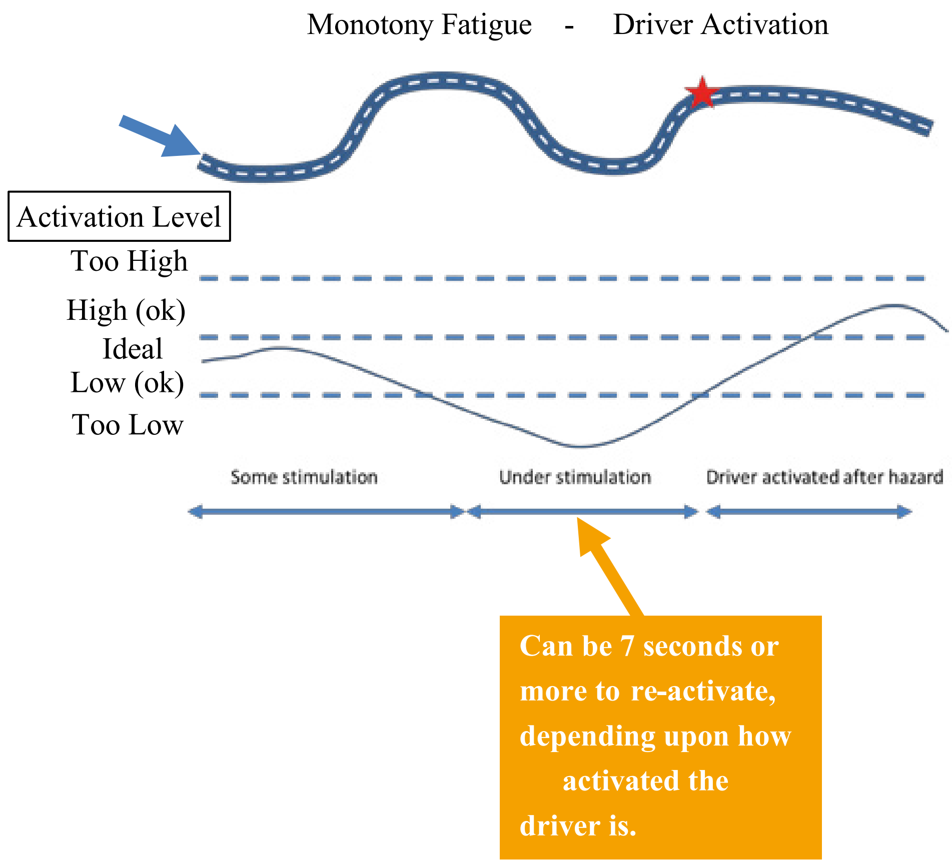


Illustration 40: Deactivation of the driver through an un-stimulating road environment leading to monotony fatigue and increased driver reaction time.

3. SAFE SYSTEMS, ROAD ENGINEERING AND DRIVER DISTRACTION AND FATIGUE

Limited amounts of literature has been identified which considers the role of road engineering in the context of driver distraction and fatigue and an even smaller sample considers the topic from the perspective of the Safe Systems approach (United Nations, 2011). Some features of the Safe Systems approach are that:

- it aspires to prevent fatal and serious injury crash outcomes (by managing energies to within the human tolerances);
- it is accepting that crashes are inevitable and humans are fallible; and
- it seeks to provide a shared responsibility across the pillars of road safety.

These features indicate that road engineering:

- cannot always rely upon good road user behaviour; and
- has a role in preventing serious crashes arising from driver distraction and fatigue.

Traditionally, the road engineering objective has been to reduce the risk of a crash occurring to an "*acceptable level*". Where this cannot be accomplished, then road engineering would consider countermeasures (such as road safety barrier) to reduce the severe crash rate to an acceptable level.

James Reason published an influential book on causation of accidents (Reason, 1990). In his philosophy, a human is susceptible to error in any environment, an environment may increase or decrease the probability of errors depending upon its features and for the error to occur, a chain of events must occur. For example, the driver might become susceptible making an error on a given road when they are distracted (e.g. by a piece of public art). Therefore, he argued that we should seek to reduce the risk of an error occurring by blocking at least one part of the error pathway, in this case, by removing the public art. His model is presented in *illustration 41*.

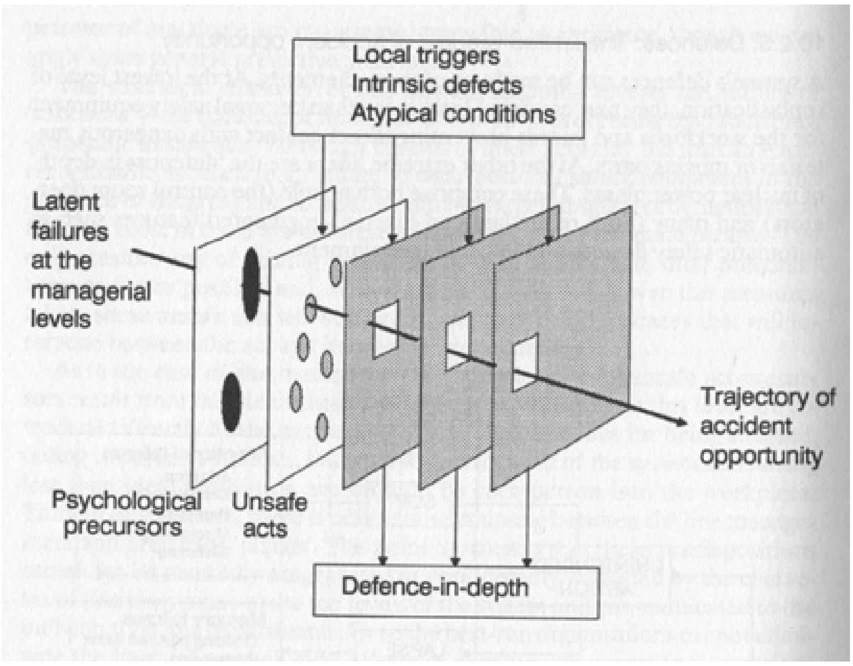


Illustration 41. The dynamics of accident causation (Reason 1990).

However, the Safe System approach, prioritises the prevention of serious crash outcomes rather than the reduction or elimination of errors. Whether an error will lead to a serious crash outcome or not is more dependent upon the safety features of the system. According to the United Nations (United Nations, 2011), the road system comprises the five pillars of Road Safety Management, Safer Roads and Mobility, Safer Vehicles, Safer Road Users and Post-crash Response. Accordingly, for road safety to be assured an intervention needs to be found within at least one of the pillars that blocks each serious crash outcome pathway (*illustration 42*).

Note that, as we have now accepted that drivers are fallible and have limitations (and so will always make errors), reliable mitigations to serious crash risks cannot be found within the Safer Road User pillar. Also, as the post crash response is called upon after the crash has occurred, this pillar also cannot reliably prevent serious crash outcomes. Therefore, to reliably prevent serious crash outcomes, solutions that block each serious crash outcome pathway must be found within the Road Safety Management, Safer Roads and Mobility and Safer Vehicles Pillars of road safety.

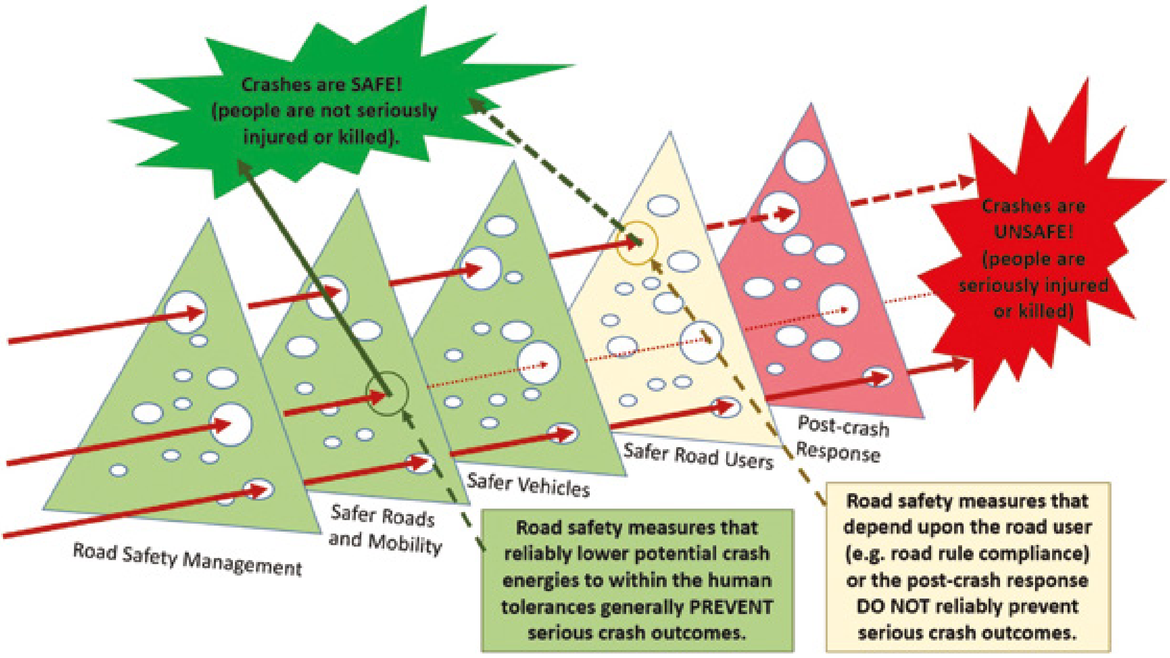


Illustration 42: Safe Road System Model for preventing serious crash outcomes (Marsh, 2015).

That we have a serious crash problem indicates that the design of the road system has weaknesses or latent errors within the Road Safety Management, Safer Roads and Mobility and/or Safer Vehicles parts of the system.

As the road safety priority under the Safe System approach is to prevent serious crash outcomes, the first priority of the system designer should be eliminate enough weaknesses within the Road Safety Management, Safer Roads and Mobility and Safer Vehicles pillars of road safety, so that serious crash outcomes are no longer possible.

However, the system designer has constraints such as budget limitations, technology limitation and competing objectives for which solutions to all of the serious crash risks have not been feasibly found. Also, as a second priority, the system designer should not be creating designs that cause crashes to occur, such as by placing demands on the normal driver beyond their human limitations.
Therefore, without increasing the number of serious crash risks (priority 1), the system should be designed and maintained to mitigate distraction and fatigue risks (priority 2).

It is the responsibility of the system designer to consider the relative effectiveness of different treatments before choosing the preferred combination. The following hierarchy of control has been identified consistent with the above priorities:

- lower energies through conflict points to within the human tolerances
  In the event of driver distraction or fatigue, infrastructure measures generally ensure vehicle speeds are within the human tolerances for serious injury through the relevant conflict points (see Section 2, for the human tolerances);
- design so the road "*talks*" to the road user
  Features are included in the road design to talk consciously and subconsciously to the driver to naturally cause safe road user behaviour, particularly when the user is approaching or in the vicinity of a serious crash risk. For example, the installation of audio tactile edge lines may wake or alert a driver to their distraction or fatigue as they start to drift off the road;

- design to provide opportunities for road users to recover from mistakes and non-compliance
  Opportunity is provided for crashes to be avoided in the case of driver distraction or fatigue. For example, locating road safety barrier further from the through traffic lanes provides opportunity for errant vehicles to recover before impacting the barrier (although, as the width increases, so does the possibility of a vehicle impacting a barrier in excess of the crash testing conditions);
- design to lower the risk of a crash occurring to an "*acceptable*" level
  Road design minimises the risk of driver distraction and fatigue occurring in the first place. For example, careful attention is paid to the human factors, such as to prevent the road from surprising the road user (e.g. with a concealed driveway or intersection).

Human tolerances were first published by Tingvall and Haworth (*illustration 43*) based upon the 10% likelihood of a fatality at the relevant speed based upon 1990's data.

Type of infrastructure and traffic	Possible travel speed (km/h)
Locations with possible conflicts between pedestrians and cars	30
Intersections with possible side impacts between cars	50
Roads with possible frontal impacts between cars	70
Roads with no possibility of a side impact or frontal impact (only impact with the infrastructure)	100+

Illustration 43: Human tolerances for serious crashes (Tingvall, 1999)

While these tolerances are only for car and pedestrian type conflicts, they tend to cause treatments that work for the overwhelming majority of road users across all jurisdictions. For example, a road safety barrier used to prevent serious head on collisions can prevent head on collisions for all classes of vehicle if the right test level is applied. For example, a speed reducing lateral shift tends to cause heavier vehicles to reduce their speed further than a car and a car further than a motorcycle, thereby lowering potential crash energies across the vehicle spectrum. Motorcyclists are more difficult to deal with, however, in general, they benefit from the lower energies at the key conflict points and iRAP suggests road safety barriers present equal or less risk to motorcyclists (iRAP, 2013, pp. 1-2).

Since Tingvall and Haworth released their paper, vehicle standards have generally improved and so it is reasonable to expect that over time, these thresholds will become safer and safer, consistent with the Safe System approach.

CRASH TYPE	POSSIBLE MAXIMUM CAR SPEED (HUMAN TOLERANCE FOR SERIOUS INJURY)
Car Lane Departure / Rollover / Rear End	< 70 km/h
Car – Car 90° Side Impact	< 50 km/h
Unprotected Road User	< 30 km/h
Prevent the above and > 100 km/h may be safe!	

Illustration 44: 2016 Human Tolerances for Serious Injury for designing a road's operational speed.

Note that the context of the human tolerance is critical. For example, it is known that a collision with a thin pole or tree can have a lower tolerance particularly in the case of a side impact because there is little protection at the side of the vehicle. However, the 70km/h in the table above remains appropriate for the design of the road's operational speed because in the case of a side impact with a pole, more commonly, speeds will have lowered in time due to a vehicle having needed to first lose control and speed will be lost in the motion. This explains why such serious crash types only really start to feature when operational speeds reach approximately 70km/h and above on the real road network.

The last statement of Tingvall and Haworth, that achieve the above and 100km/h and above may be safe is cautioned with the introduction of the rear end human tolerance. High speed roads should be equipped with variable speed limit systems that appropriately lower operational speeds in the case of traffic congestion ahead, broken down vehicles, maintenance of the road or another temporary serious crash hazard being on the road. Then high speed limits become possible.

These enable locations on the road network where serious crashes could foreseeably occur to be identified and treated with a road engineering solution that reliably lowers the operational speeds to within the human tolerances.

4. TREATMENT OF DRIVER DISTRACTION AND FATIGUE MATRIX

The following matrix has been developed to assist practitioners to identify and prioritise road engineering treatments of driver distraction and fatigue risks and is based upon the Safe System approach and the role of road engineering. Each hierarchy level of the matrix is presented in its own subsection in order to aid usability.

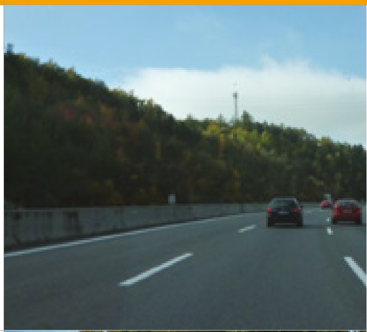
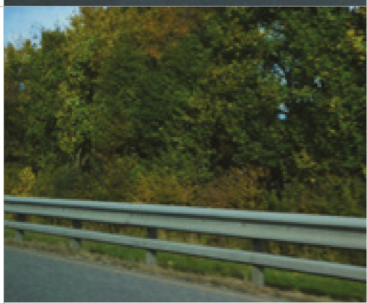
When using the matrix, the goal is to identify the most effective and feasible treatment. As the hierarchy level 1 treatments are most effective in preventing serious crash outcomes, the hierarchy level 1 part of the matrix is the first considered. If an effective and feasible treatment is identified, then it is selected, and, if multiple effective treatments are identified, the most feasible is selected. If an effective and feasible treatment is not identified within hierarchy level 1, then hierarchy level 2 treatments are considered, followed by level 3 then level 4.

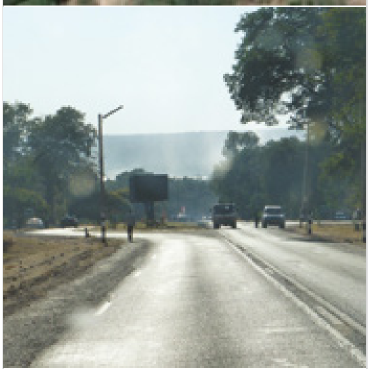
After the primary treatment is selected, consideration of further levels of the hierarchy can occur to add supporting treatments. This might be desirable to assist with mitigating the risk of crashes occurring (which is different to the primary road safety objective of preventing serious crash outcomes).

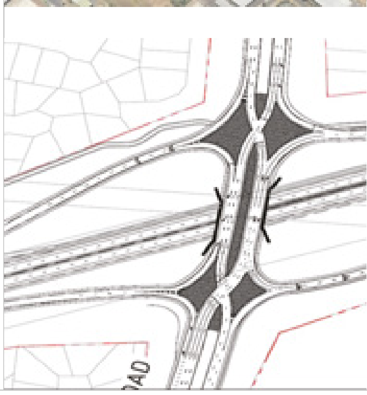
Treatments selected from lower in the hierarchy should never be allowed to affect the effectiveness of higher level treatments.

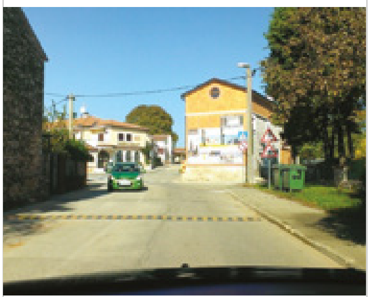
Please see *Appendix A* for examples of how the matrix can be applied to tackle driver distraction and fatigue issues.

4.1. HIERARCHY LEVEL 1 TREATMENTS

TREATMENT / ISSUE	PHOTO		COST AND OTHER EFFECTIVENESS COMMENTS
Concrete Road Safety Barrier / All driver distraction and fatigue issues		*Concrete road safety barrier located in the median on the autobahn between Vienna and Salzburg to prevent head on crashes. It is located very close to the closest traffic lane which helps to minimise the potential angle of impact, increasingly the likelihood of the barrier performing within its crash testing conditions.*	• Contains heavier vehicles • High initial cost, • Low maintenance cost • Better safety performance when placed close to the traffic • Prefer single slope barrier
Steel Road Safety Barrier / All driver distraction and fatigue issues		*Steel beam road safety barrier with motorcyclist protection (near Vienna, Austria)*	• Multiple systems available. • Moderate – high initial cost • Moderate to high maintenance cost • Better safety performance when placed close to the traffic
Wire Rope Road Safety Barrier / All driver distraction and fatigue issues		*Median wire rope near Stockholm, Sweden (complemented with verge road safety barrier) located on a '2+1' roadway.* Note: wire rope is not so good located close to traffic owing to more nuisance hits which can dislodge the wire and compromise performance (until repair).	• Multiple systems available. • Moderate initial cost • High maintenance cost • Lowest (out of barriers) internal forces on occupants based on crash testing results

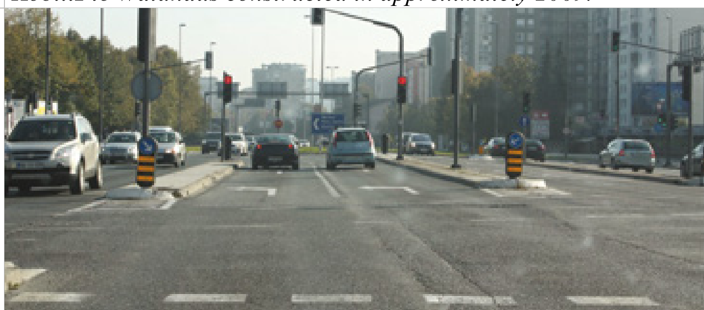
TREATMENT / ISSUE	PHOTO		COST AND OTHER EFFECTIVENESS COMMENTS
Lateral shift to reduce speed on approach to a serious crash risk / Effective for all driver distraction and fatigue issues provided it is installed sufficiently in advance of the risk.	  	*Approach into Victoria Falls townsite (Zimbabwe) contains a lateral shift and Variable Message Sign (VMS), slowing traffic speeds and increasing conspicuity of right turning vehicles.* *Lateral shift and other traffic calming features used to slow traffic in pedestrian precinct to beneath 30km/h (Stockholm, Sweden).*	• Low cost for new constructions, moderate cost for upgrading existing. The geometry provided should contain speed and provide runout areas or road safety barrier to safely arrest vehicles that misjudge the lateral shift. The design leading to the lateral shift should endeavour to prepare the driver for the lateral shift.

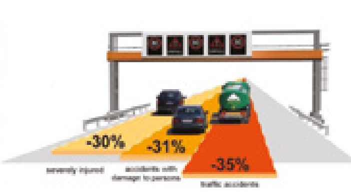
TREATMENT / ISSUE	PHOTO		COST AND OTHER EFFECTIVENESS COMMENTS
Roundabouts can be highly effective in reducing traffic energy at the side impact conflict point. / All driver distraction and fatigue issues	  	*Low cost roundabout replacement of traffic signals utilising traffic cones, Delhi, India.* *Urban street roundabout, Croatia.* *Spiral Roundabout, Mandurah, Western Australia.*	• The roundabout design should prevent high speed travel by laterally deflecting all vehicles sufficiently to lower speed. • Approach lateral shift geometry and/or speed humps can increase the effectiveness and reduce energies at pedestrian crossing points.
Grade Separated Interchanges / All driver distraction and fatigue issues	 	*Innovative single point diamond interchange under construction in Perth Western Australia, which significantly reduces the number of conflict points and tends to align remaining conflict points (e.g. Head On human tolerance 70km/h exceeds the side impact human tolerance of 50km/h).* *Another innovative interchange form showing promise is the "*Double Crossover Diamond*" (also known as "*Diverging Diamond Interchange*").*	• An interchange eliminates the major through intersection conflict points with grade separation. • The innovative interchange designs can eliminate further serious crash conflict points and sometimes enable thresholds to be raised.

TREATMENT / ISSUE	PHOTO		COST AND OTHER EFFECTIVENESS COMMENTS
Speed Humps		*A large and well worn speed hump in Gosnells, Western Australia, located in a pedestrian area. It would be better located on the approach to the pedestrian crossing because if a driver is distracted or fatigued, they may neither see the pedestrian or speed hump and still collide with the pedestrian at high energy because the speed hump has not yet arrested the vehicle.*	• Very low cost. For most reliable performance, select a speed hump that has the potential to disable a speeding vehicle. Locate speed humps before the serious crash risk to ensure vehicle energies are lowered independent of driver distraction and fatigue.
		*Right: This Slovenian speed hump is less severe, however, is located on the approach (and departure) to the pedestrian crossing.*	
Emerging in-vehicle technology that monitors driver and intervenes to prevent a serious crash			• Safety must no longer depend on the driver for the technology to qualify as hierarchy level 1.

4.2. HIERARCHY LEVEL 2 TREATMENTS

Audio-tactile lane marking	  *Milled audio tactile lane marking from the United States. Its suitability depends upon the pavement thickness (e.g. delamination risks). Can paint within the milling, for which the paint has lower ongoing costs. Water ponding concerns do not appear to have been realised where used.* *The milled version can be slightly higher cost but less maintenance. It is better where snow is an issue because winter maintenance can remove the painted variety.*	• Low install cost, requires maintenance. • Doesn't help all. • Generates noise pollution but talks to driver. • Best if used on all lane marking.
Audio tactile rumble strips	  *Approach to Romanian townsite to prepare drivers to slow down. In this case, they complement a hierachy level 1 chicane that physically contains vehicle speed through a lateral shift.*	• Very low cost. • Cause vehicle to vibrate and sound to be generated, arousing driver from their slumber.
Small Speed Humps	  *Market and transport (ride sharing) hub on the outskirts of Victoria Falls, Zimbabwe and one of the approaches to it.* *The road would otherwise be high speed rural and is the major transport corridor. Small speed humps have been installed on the approaches to slow vehicles through what has become a pedestrian zone.* *The road is said to* "talk to the driver" *due to the physical vibration and sound imparted to vehicle occupants. It is the speed humps that have made the difference, not the signs (which are complementary). The* "talk to the driver" *strategy has been actively pursued in Zimbabwe and found to be very low in cost and highly effective in reducing serious crashes.*	• Very Low Cost • Can be highly effective. • In this case the speed humps worked despite there being many road maintenance challenges. The road markings have worn, however, drivers are shocked into action by the vibration and noise, and much lower speeds prevail. • Speed humps have a broad range of uses.

Shoulders with larger stones protruding	 *A very low cost version was observed in Zimbabwe where larger boulders were embedded into the road should of a rural road. Left is an example from the United States where the cobble stones protruding are paved into the road, but only applied to the shoulder.*	• Labour costs • May require costly foundation treatment (e.g. set stones in concrete where snow plough operations relevant). Ongoing costs depend upon initial install design/ quality and traffic loading.
Recent example of a German Autobahn design (note temporary 60km/h speed limit).	 *The geometry of the road is constantly changing and the view opens then closes (between the trees), keeping the driver activated. Photograph from the Autobahn section Wernberg Koblitz to Waidhaus constructed in approximately 2009.*	• Can be lower cost as has potential to more easily follow the terrain. • Straights rarely exceed 1km, horizontal geometry of consistent radius designed to impart centrifugal forces on driver without surprise.
Traffic signals where the red light "*flickers*" using LED technology / All issues	 *Red traffic signals can be made to flicker* "like fire" *which naturally catches the attention of our brain. But in this case, we would not want to be distracted by the signals so much that we do not see the preceding stop line located just beneath the bottom of the photo.*	• Very Low Cost. • Most dangerous red light running occurs after lights have been red for a period of time. The flickering light resembles fire and triggers the subconscious to alert the conscious brain. • Used in high risk areas in US and has reduced crash rates.

Managed Motorways Intelligent Transport Systems	  *Source: Straßenforschung Straßenverkehrstechnik BMVBW in Germany.* *Full lane use management system with speed and warning signs to adjust traffic conditions to suit the conditions ahead. Can be invaluable for back of queue protection. However, the actual benefits achieved by any system depends very heavily on the operations regime used to operate the signs, for example, on how quickly issues are detected, how quickly the variable speed limit is adjusted to a safe speed and enforcement of the set speeds. The road safety benefits achieved reflects the quality of the operations regime implemented.*	• Side mounted – lower cost • Overhead gantry mounted – moderate cost. • Full Managed Motorways ITS can significantly lessen rear end crash risks if it is used to lower approach traffic speeds when traffic issues ahead arise.

4.3. HIERARCHY LEVEL 3 AND 4: PROVISION OF RECOVERY AREA AND GENERAL ROAD ENGINEERING THAT REDUCES THE RISK OF A CRASH OCCURRING.

As road engineers has long strived to reduce the risk of crashes occurring to an "*acceptable level*", the road design standards and guidelines developed over the past century should be applied in support of treatments from the above hierarchies.

However, as the road safety priority to prevent serious crash outcomes is very different in practice to the traditional road design approach and can often favour rather different treatments of any given risk.

Accordingly, the traditional standards and guidelines should not be applied in a way that compromises the effectiveness of higher level treatments, because this will almost certainly reduce the safety level of the road by increasing the risk of serious crashes.

Nonetheless, they should be carefully considered and generally followed to ensure that the economic costs of crashes generally are also minimised and to help ensure adequate performance of the road.

5. CONCLUSION

The driver distraction and fatigue aspect was found to encompass a wide variety of matters that can positively or negatively affect a driver's ability to negotiate a road.

However, most previous research have assumed the impacts are only negative and has focused upon the road user and methods for mitigating road user weaknesses and mistakes, and on punishing road users for violations of imposed road rules. However, human beings have inherent weaknesses and limitations that cannot be accounted for by road rules which must be managed by road design, e.g.:

- the ability to only focus consciously on one thing at a time;
- hard wired responses to certain stimuli (e.g. a flickering light similar to fire) that automatically captures attention;
- hard wired brain calculation assumptions that enable magicians / illusionists to ply their trade, which demonstrate the brain is easily deceived when certain situations occur; and
- a need for regular activation or stimulation.

There is significant potential for things to go wrong on the road network because road users are fundamentally fallible, explaining why crashes are considered to be inevitable under the Safe System approach and supporting this conclusion.

Accordingly, road engineering, in concentrating on road system design to prevent serious injury crashes, cannot rely upon road users obeying speed limits, obeying traffic signals or abiding by any other road rules. Rather it must lower potential crash energies at key conflict points to generally prevent serious crashes.

It is recognised that feasible or appropriate treatments are not available for all contexts and so there will always be remaining serious crash risks. Further, crashes themselves are undesirable. Therefore, road engineering must then design to reduce driver distraction and fatigue risks and for optimisation of the activation of the driver.

It is recommended that further research be undertaken to improve understanding of how the road engineering design can more reliably interact with road users to optimise the activation of drivers and better reduce the risks of driver distraction and fatigue.

It is concluded that the practice of road engineering design needs to be carefully reviewed and updated considerate of the Safe System approach and driver distraction and fatigue. For example, the currently common practice where a single design speed is chosen for a road does not represent best practice because:

- different conflict points along a road necessitate the imposition of differing design speeds for safety; and
- to maintain driver activation, variation of speed is desirable, although this must be done in a highly predictable way that does not surprise drivers (e.g. all bends of an equal radius which does impose significant centrifugal force on vehicle occupants).

Best practice road engineering to combat driver distraction and fatigue and achieve maximum road safety must aspire towards no longer depending upon speed limit signs and other road rules for preventing serious crashes. Under this best practice vision, speed limit signs and other road rules may still exist to smooth operations and help reduce the risk of crashes occurring, however, these ideally should not represent the front line defence against serious crashes.

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APPENDIX A: EXAMPLES OF DRIVER DISTRACTION AND FATIGUE ISSUES AND ENGINEERING SOLUTIONS.

This section of the report contains examples of driver distraction and fatigue issues and some engineering solutions.

A.1. DRIVER DISTRACTION:

A.1.1. Information overload due to overwhelming roadside or in vehicle information

In *illustration 45*, we can see different solutions regarding visibility of traffic signs due to roadside advertising. In the upper left picture a traffic sign for bicycle lane is set up on the left side instead on the right side. If the sign was be set up according to regulations, it would be less visible; so because of advertising, we must bend the rules, what should be unacceptable, but unfortunately in some countries it is not (political decision). As shown in the upper right picture, the best solution would be a removal of advertisement billboard. But as said before roads engineers are usually left to deal with the issues, so some possible solutions are shown in pictures beneath. The bottom left picture show emphasised traffic sign with fluorescent ring border, but due to colour contrast of traffic sign and advertising billboard it has little effect. In the last picture is shown Self Explaining cycle lane with well-regulated road environment.

Illustration 45: Traffic sign perception, with and without commercial advertising.

Illustration 46: Gradual process towards Sustainable safety solutions (Source: Uroš Brumec)

Similar problem can be seen on pedestrian crossing where advertising and private interest overcome public interest and road safety. Again left side picture shows current situation on road, middle picture shows what can be done with only road engineering solution, meanwhile right picture shows system approach, with less emphasised traffic signage and less degraded, more sustainable environment.

Illustration 47: Gradual process towards Sustainable safety and environment (Source: Uroš Brumec)

A.1.2. Visual treatment of legible roads preventing driving errors and improving drivers behaviour

Visual treatment of road should make them legible and self-explaining, preventing driving errors as well as improving drivers' behaviours and their main observable parameters (trajectory, including speed, longitudinal and lateral guidance, lateral position and accelerations).

A way to improve drivers' behaviour often used to manage speed is to create deliberate optical illusions for the drivers in order to reinforce the impression of velocity and to unconsciously incite them to speed down. This can be achieved either through cognitive process or through a behavioural process.

A cognitive process tries to influence the "*idea of speed*" for the driver by a semantic change in the environment. This semantic change deals with road typical visual attributes and should incite the driver to ask himself where he is driving and what speed limit he is supposed to respect given then road category he recognized.

A behavioural process tries to reinforce the visual message of the road at a lower level (optical flow, roadway and roadside conspicuity) than the semantic one, order to stimulate the perception of the driver and to make him detect and identify that he has to adapt his speed due to this change in the road condition.

Deliberate optical illusions have been used in different countries. In Australia (LTSA, 2002), urban-rural speed thresholds "*are located at interface between rural and urban areas and consist of physical and optical narrowing of the roadside to form pinch points*". Such thresholds lead to a reduction in vehicle speeds, as drivers perceive a change in the road environment ahead.

Legibility in the road geometric design includes the perception of the road course in the link section (and particularly the perception of the singular points) by a global study of the horizontal and vertical alignment, to ensure a good insertion of the road in the natural site, to respect the visibility rules and as much as possible a minimum visual comfort. In case of loss of visibility due to the vertical alignment, it is recommended to suppress them, and if too expensive, it is recommended to make the road course visible again at a minimum distance of 500m and to create a break in the vertical alignment clear enough to avoid further visual illusion.

Legibility in the road geometric design also includes the management of another type of visual illusion with the prevention of false perspective or of direct view on a lateral way (annex traffic lane or old road).

Similar considerations apply for non-graded road junctions, which have to be clearly perceived. For normal junctions, simplicity and compactness also are important factors for legibility. For roundabouts, the landscape design could improve its legibility and perception for users.

For highway branches and highway interchanges, a special attention has to be paid to the road traffic devices (road markings, delineators, road signs) which could effectively contribute to the drivers' perception of the exchange points, of the branches and of the gore areas, and of the driving directions (to prevent wrong way intrusions). *Illustration 48* to *illustration 51* provide illustration of this discussion.

Illustration 48: Emphasized dangerous intersection point on motorway and lack of guidance results of unsafe situation
(Source: Yoshihashu Murashige).

Illustration 49: Emphasized dangerous intersection point on motorway with emphasized guidance of traffic (on one lane)
(Source: Yoshihashu Murashige, modified Uroš Brumec)

Illustration 50: Emphasized dangerous intersection point on motorway with emphasized guidance of traffic (both lanes)
(Source: Yoshihashu Murashige, modified Uroš Brumec)

Illustration 51: Emphasized dangerous intersection point on motorway with emphasized guidance of traffic (both lanes) and excessive vertical guidance
(Source: Yoshihashu Murashige, modified Uroš Brumec)

FURTHER INFORMATION FROM SWOV:

The SWOV identified a number of infrastructural measures that can be implemented to improve drivers' behaviour and support enforcement of road traffic law. The objective of these is to prevent most violations from occurring, influencing unintentional behaviour or at least preventing errors and unintentional violations. Infrastructure can support drivers by providing cues that are meant to affect both conscious and unconscious behaviour. By providing continuous feedback about location-specific rules, drivers are provided with instantaneous and explicit knowledge of what rules are in place, for instance when they have missed the posted speed limit.

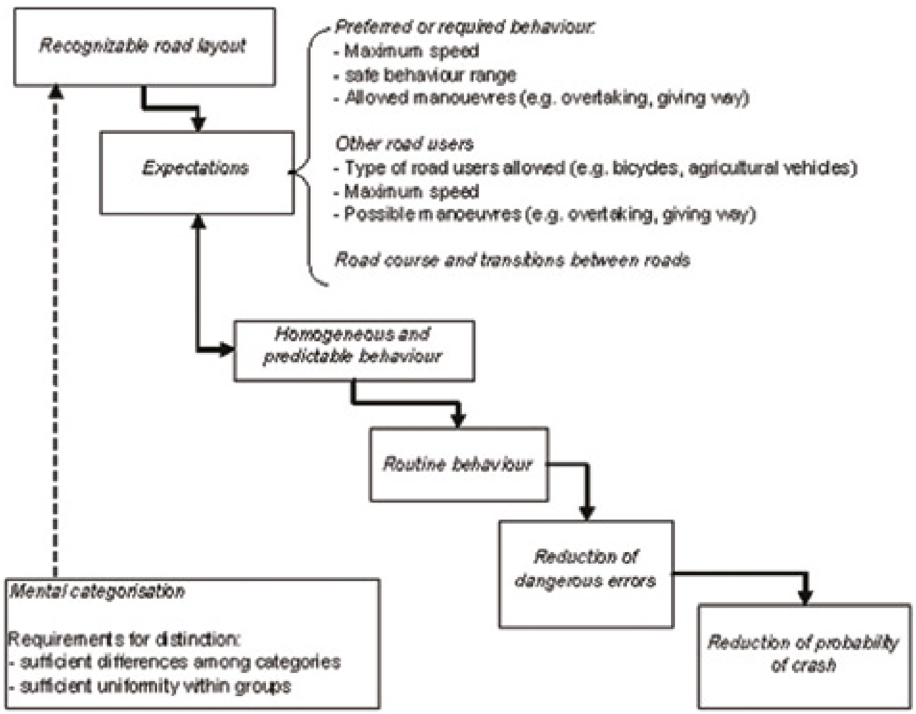


Illustration 52: Chain of elements within the predictability principle.
Letty Aarts, senior researcher, SWOV.

A logical fit of road layout and location-specific rules provides support for better and more natural or intuitive compliance. This fit can also support the predictability of rules and the behaviour of other road users on a road ('Recognisable Roads'), and so the implicit expectations of drivers. Research has shown that supporting expectations of drivers decreases the probability that they miss important information and make errors that can result in a crash. This idea of implicit and explicit information by road design and layout is linked to the concept of Self-Explaining Roads (SER). In the Netherlands, the '*predictability of roads*' concept is preferred. *Illustration 52* shows the chain of elements involved.

Supporting driver expectations

The Netherlands is one of several countries that have looked to make roads more informative for drivers. This started within a framework inspired by the national Sustainable Safety vision. The core of this vision is to prevent severe crashes from happening and to decrease the probability of severe injury in the case of a crash by an integral human-centred approach of engineering, education and enforcement measures.

The elaboration in the Netherlands of informative, predictable and recognisable roads is unique as it is based on a limited number of road categories. The general principle is that, ideally, roads have only one (a flow or an exchange) function. Road layout facilitates homogeneous use in speed, mass and direction that fits safely to the function. This also holds for the forgivingness of roadsides and results in three different road categories.

High-speed (100 or 120km/h) through roads feature physical separation of the driving directions. Slow, vulnerable road users are prohibited and there are access restrictions for mopeds, cyclists and agricultural vehicles. Intermediate-speed (50 or 70km/h urban and 80km/h rural) distributor roads feature intermediate speeds on road sections and low speeds at intersections. Physical separation of slow and vulnerable road users and fast traffic is preferred and there are some access restrictions.

On access roads, the mixture of all traffic types requires low speeds (30km/h urban, 60km/h rural), which are also enforced by the road layout. The unique design characteristics of each have to be recognisable.

Illustration 53: Traditional road layout and road layout according to the guideline 'essential recognisability characteristics' for the three sustainable safe road categories. As implementation of ERCs has particularly taken place on rural roads, only rural road variants are shown

Implementation started with road authorities categorising their networks. Subsequently, Essential Recognisability Characteristics (ERCs) were defined in a design guideline which was the start for large-scale adaptation of the traditional (less informative) road layout into something more informative and recognisable. *Illustration 53* shows rural road design.

Expectational influences

The ERCs comprise combinations of roadside markings and separation of driving directions. These are evidence-based road layout elements and can be quite easily implemented in practice. Before the ERCs were defined the road design elements that would help to make roads distinguishable and eventually self-explaining were studied.

Studies were mainly performed with manipulated photographs of roads and found that, in general, distinction between road categories is enhanced when the differences among categories are sufficiently large and when the variation within each category is not too large. Roadside chevrons were found to make roads better distinguishable from traditionally designed roads. It has also been suggested that speed colour coding may enhance the distinctiveness of road types, and red cycle lanes were found to be self-explaining. Motorways turned out to be very recognisable as high-speed roads with access restrictions for slow traffic, when the road is equipped with emergency lanes, safety barriers and gantries. Low-speed zones, in their turn, are easily recognised as such when they are characterised by a credible low-speed design (a narrow and curved road, with uneven surface, and a built-up area near to the road).

Characteristics that could add to the recognisability of roads had to be continuously visible, practically implementable and feasible (which ruled out the use of lighting as this is added to only a very few roads), not detrimental to road safety and visible in all conditions (so not causing a road surface to become slippery, and being visible during darkness and adverse weather). This led to edge markings and separation of driving directions being adopted.

After ERC implementation, it turned out that access roads could be distinguished quite well. Through roads and distributor roads, however, were often mixed up by drivers. Probable reasons for this are the variations in road layout that are still allowed within each road category (*illustration 54*) and the use of side markings as distinguishable characteristics between these road categories, although it is not this characteristic but the separation of driving direction which is more meaningful to drivers. Explicit information about the meaning of the road layout improved performance (this is particularly so for the green centreline used on regional through roads; it is a salient, unique road layout element which is however not self-explaining for road type and its comprising characteristics). Sufficient distinction between road categories, using salient road layout elements, also turns out to be important for making transitions between road categories and the change in expectations and behaviour noticeable for road users.

In short, implementation of the ERCs in the Netherlands has been a step towards improving the recognisability of road types. As the ERC guidelines still allow for a lot of layout variation within road categories, consistency is an issue that has to be improved.

Illustration 54: Example of variations in road layout of regional through roads

Behavioural influences

A huge body of work has shown the behavioural effects of road layout elements. Most studies are related to speeding behaviour and the concept of 'credible speed limits'. As a starting point, speeds should be safe and supported by a credible limit. The latter is defined as one which matches the image that is evoked by the road and the traffic situation. Credible speed limits have been found to be influenced by: primary credibility factors, which physically force drivers more or less to adapt their speed (straightness of a road and physical measures such as speed humps); and secondary ones (the density of elements near to the road, road width, and type and quality of the road surface). Secondary factors are related to the speed feedback they give. The more signals the environment provides, for example because of a large number of trees along the road or uneven surface, the higher the perceived task demand and the higher the probability that driver will adapt their speeds.

A study in the Netherlands of credibility of speed limits on provincial single-lane rural roads with a speed limit of 80km/h roads showed that free chosen self-reported driving speeds differed largely (speeds of 75 to 95km/h were reported). Layout characteristics related to speed choice included: sight length; road and lane width; density of the vegetation and buildings along the road, particularly on the driving side of the road; and separation of driving direction, being easily over-ride able (markings) or not (barriers).

These findings have given rise to discussion among road authorities about how uniform layout within a road category has to be. Related to this is which essential characteristics can be defined that cost a minimum of effort without having adverse effects on road safety.

As the implemented ERCs are also meant to lead to more homogeneous behaviour, the behavioural effects were studied too, mainly using driving simulators to control other influential road characteristics. A study that tested the effects of traditional road layout, ERC layout and a more physical layout that meets the standards of a safe system design (*illustration 55*), found that the more recognisable and safe layout led to lower speeds and to a lateral position towards the edge of the road. It is however important to notice that these findings are the combined result of recognisability and the behavioural effect road elements evoke directly by their presence. In the studied layouts, lane width, for instance, was smaller by markings (ERC) or barriers (Safe System design) than in the traditional layout, and this is known to reduce speed even if not consistently adopted per road category.

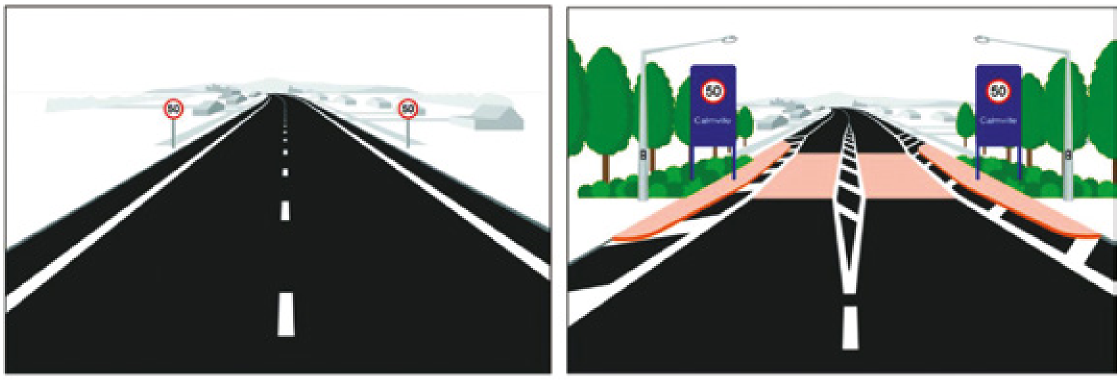
Illustration 55: Example of a distributor road in different road layouts: traditional, ERC and according to a real safe system approach

Recognisability and concepts like credible speed limits are meant to act on both the explicit knowledge of rules and intuitive behaviour. In this way, it should evoke compliant behaviour in the majority of road users, and give the police a better starting point for the enforcement of rules against those drivers who still don't want to comply.

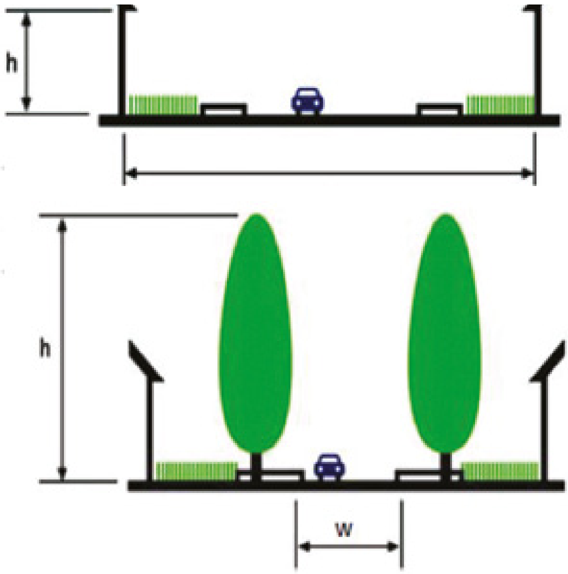
The principle of recognisability of roads and predictability of road layout and behaviour has been elaborated in the Netherlands, based on scientific evidence and practical considerations. Implementation started in 2004 and will continue. Although the consistency of road elements within road categories as well as behavioural and direct safety effects of the chosen characteristics are issues that show room for improvement, implementation of the ERCs has improved the situation for drivers: they now have a better opportunity to know which road type they are driving on and what speed to adopt.

END OF THE SWOV ARTICLE

THE EFFICIENCY OF SUCH THRESHOLDS DEPENDS ON SEVERAL FACTORS.		
Parameters influencing threshold efficiency	**Conditions for use**	
Location	Approach speed section	Max speed reduction with very high approach speed; lower effect when located at or near physical features in the road that limit speed, such as a blind bend or summit
	Consistency between speed limit and observed speed	Better compliance of users with speed limit if consistent with the level of roadside development along the road and the road function; Lower effect with inadequate, underestimated speed limits
	Progressively reduced speed limit areas	Location at the higher speed limit area or at the beginning of the most crucial area after investigation (speeds, crashes, types of users)
	Property accesses and intersections	The road frontage development, sight lines from nearby properties or interference with access to properties have to be considered, the same applies for intersections
	Visibility to approaching drivers	Approaching drivers can see them in time to adjust their speed to appropriate levels. Thresholds must be visible over at least the stopping sight distance for the 85th percentile of the approach speed, including in curves.
Roadway Narrowing Roadway Narrowing	By the appropriate use of horizontal and vertical elements, the roadway should be narrowed over a length of 10-20 meters. The road width will vary depending on circumstances but must allow all entitled vehicles to pass through it.	
	Horizontal elements	Horizontal design elements are used to reinforce the road narrowing effect: sealed width should be narrowed by installing solid “*build-outs*”, or if not possible pavement markings; median islands for interrupting the forward view, and reducing the optical width of the carriageway; solid median islands must be clearly delineated so they are visible both night and day to approaching motorists. Pavement markings such as diagonal shoulder markings can be used to narrow traffic lanes and also give an optical illusion of a narrow carriageway. Likewise, flush island or median markings can be used in the pinch point areas where lane narrowing is required but a solid median island is not suitable.
	Vertical elements	Vertical elements must always be used as they improve the visibility of the threshold to approaching drivers. Examples of vertical elements include trees and shrubs, combined speed restriction and place name signs, and the structure or poles that support these signs. Street lighting can also be incorporated as a vertical element. Research indicates drivers travel at a reduced speed where the height of vertical features is greater than the width of the street.



Typical untreated approach to a township *Completed threshold*



Optical width > optical height (encouraging speed)

Optical width < optical height (discouraging speed)

The use of optical speed bars

Optical speed bars have been widely used in the UK, in Australian and in the United States (Arnold, 2007). Katz's study indicated that perceptual techniques can provide results beneficial to safety and can also reduce speeding (Katz, 2004). However, the perceptual pavement markings have not always demonstrated the ability to reduce speeds over the long term. Furthermore, questions have been raised if the decrease in travel speeds was due to the speed illusion or simply because the drivers recognized the presence of pavement markings as a warning of a hazardous location (NCHRP 500 vol 6).

A.1.3. Day dreaming/ other matters on the mind

Day dreaming can be associated to concentration loss which can be seen as a type of driver distraction where the source of distraction is internal. While the conscious mind wanders off, the subconscious takes over the driving. An emergency can snap the driver back to full awareness but reaction time will be longer and increase the risk of accident.

Studies show that road traffic crash caused by day dreaming accounted over half of road traffic crash in France (Galera, 2014) and, according to National Highway Traffic Safety Administration data analysed by Erie Insurance, for a much higher 62 percent of crash in America related the distraction drivers experienced before they were involved in a fatal car accident.

Eliminating completely day dreaming related cars collisions is difficult or may not be possible, due to few reasons: firstly, many drivers may not even be aware that they are daydreaming; secondly, there is no way to legislate day dreaming; thirdly, day dreaming can occur in any situation. Indeed, although driver practices good habits to avoid distraction, he cannot get away from his mind. There is an inextricable link between emotion and cognition (Smallwood, 2009) (Antonio, 2005).

However, there are some ways to minimize the amount of internal distraction or day dreaming while driving. The first, driver can change his driving route. Seeing the same thing over and over allows him to get used to them. In low arousal situations, he is more likely to become distracted. Changing up his route ensure he doesn't go into «auto-pilot», mood in which drivers, in a state of low arousal, start to dream while awake. Second, chewing something while driving, like gum or something more solid or crunchy can help to reduce mental distractions and improve ability to focus (Morgan, 2013). Next, driver can drive defensively, envisioning emergency scenarios. Indeed, keeping his mind active, alert, busy, can help to keep it from wandering in allowing driver to concentrate on his surroundings. Finally, driver can keep his eyes moving. This helps to change the focus and to break the staring habit.

Measures discussed above can be taken by the driver to reduce day dreaming.

But from an engineering point of view, mitigation measures can be identified to reduce daydreaming and they are similar to those considered to alleviate fatigue and monotony, as addressed in other parts of the document. Countermeasures should aim to "*wake up*" drivers. Geometrical design, horizontal geometry with regular small radius, rumbles strips on highway, addition of movement/flickering features to critical information such traffic signs and stop sign, etc., must be used in the way to keep driving task and mental workload - activation at an optimal level. Type of scenery and roadside visual stimulation can also contribute to appease day dreaming.

A.1.4. Natural environment issues, such as heavy rain, snow or landscape which may lead to the driver focusing on something else

When dealing with natural environment issues, we are usually left to deal with distraction more or less from road engineering point of view. If we look again the problem of environmental distraction (very alluring view on sea salt pans and bay of Piran) and advertising distraction (billboard), what are possible solutions? As seen in modified pictures below, the optimal solution would be a removal of advertising distraction (billboard).

Illustration 56: Illustration of removal of billboard (Source: Uroš Brumec)

Furthermore we could go one step ahead and arrange a safe stopping area, where drivers could stop and take a look of sea salt pans and a bay and also rest to reduce fatigue factor. That’s how we can combine Driver’s Distraction and Fatigue factors in suitable solution.

Illustration 57: Illustration stop / rest and sights seeing area
(Source: Google Maps, modified Uroš Brumec)

Of course removal of manmade distraction (billboard) would be an optimal solution, as shown in illustration below.

Illustration 58: Illustration stop / rest and sights seeing area without advertising billboard
(Source: Google Maps, modified Uroš Brumec)

A.2. FATIGUE

A.2.1. General tiredness

Fatigue can be the result of prolonged mental or physical effort or elicited by monotony. Infrastructures changes to the road and road environment can influence driver and his behavior. Main countermeasures should provide rest opportunities or reduce monotony for drivers.

Active fatigue associated with the need to sleep can be addressed by providing rest opportunities. Providing attractive rest areas at appropriate intervals should be considered as an effective countermeasure. Although adequate rest areas are important, signs encouraging drivers to rest may be also a valuable fatigue-related crash countermeasure.

Illustration 59: Aesthetic aspect of the building is important to encourage the use of rest area. Exterior lighting, and particularly for parking lot and pathway, contributes to the safety of the rest area users

To provide possible rest areas at regular interval, minor rest areas should be located at maximum intervals of 50 km and major rest areas, with services, should be located at maximum intervals of 100 km. It is also recommended to place advance signs offering information relating to upcoming and distance to next rest areas.

When possible, the analysis of fatigue-related crashes can help to determine high risk lengths of road. McArthur[4] founded that the proximity of a road segment to the nearest rest area significantly influences crash frequencies on both freeways and two-lane highway. The study results demonstrate that roadside rest areas give a safety benefit. The crash prediction models developed in this research provide a practical tool for agencies. But the safety impacts of rest areas may vary by region on the basis of differences in geography, roadway design, and driver population.

Many rural roads cross small or medium sized towns which can often serve the purpose of rest areas and should be signed accordingly. The *Village étape* in France or the *Village-relais* in Québec consist in a small town designated to provide a complete set of services and safe place to stop for national or provincial highway travellers. In addition to services, the *villages-relais* offer cultural and natural attractions, quality amenities and an environment that suits them, making visitors want to extend their stay.

In France, *Village étape* is standing or just off a motorway or national dual-carriageway that has been accepted by the « *Village étape* » Association as meeting numerous criteria. In Québec, a *Village-relais* is a municipality recognized by the ministère des Transports du Québec that offers, in cooperation with the local businesses, a variety of services and a pleasant stay.

Village-relais or *Village étape* are implemented with the objective to increase the safety of road users (automobiles, trucks, buses, recreational vehicles) by offering facilities where they can stop at all times.

Village-relais
un refuge au cœur du voyage

FÉDÉRATION FRANÇAISE DES VILLAGES ÉTAPES
VILLAGES ÉTAPES
FAITES UNE PAUSE D'INTÉRÊT GÉNÉRAL !

A number of highway safety features exist relevant to alerting fatigued drivers of an impending danger by causing the vehicle to vibrate and generate an audible rumbling noise. Some devices can alarm or awaken drowsy drivers. These include rumble strips and patterned road markings. Rumble strips on both edgeline and centerline installed on high-speed, controlled-access, rural roads can help to reduce run-off-road collisions.

Illustration 60: Research in the USA showed that continuous hard shoulder rumble strips, also used along motorways in the UK and Canada, can reduce single-vehicle run-off road accidents by approximately 20% (Griffith, 1999).

4 McArthur A. &al. Effects of Public Rest Areas on Fatigue-Related Crashes, Transportation Research Record, No 2386, D.C.,2013 pp.16-25

Literature provides no clear evidence of the effectiveness of rumble strips on the approach to a change in speed limit, roundabout or toll.

Research suggests that drivers proactively rely on these features with 63% of surveyed drivers believing that rumble strips would wake them if they fall asleep (NORDBAKKE, 2007). This is despite a simulator study that found that the alerting effects of a rumble strip only lasted for up to 3-4 minutes before the driver is back to pre-hit drowsiness (Anund, 2011).

Rumble strips:

- shoulder rumble strips help prevent single-vehicle run-off-road crashes. The noise and vibrations generated by driving over them work together to warn impaired drivers (drowsy, distracted or drunk) they are too close to the shoulder;
- transverse rumble strips may be used to call the road user's attention to roadway environment where there is a need to exercise extraordinary caution;
- according NCHRP, shoulder rumble strips reduce single vehicle run-off-crashes by 20 % (TRB, 2005);
- transverse rumble strips reduce all types of crashes by 28 % and rear end crashes by 90 % (Federal Highway Administration, 2014).

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