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Reliability prediction for the vehicles equipped with advanced driver assistance systems (ADAS) and passive safety systems (PSS)

Khashayar Hojjati-Emami[a], **Balbir S. Dhillon**[a] and **Kouroush Jenab**[b]

[a]*Department of Mechanical Engineering, University of Ottawa, Canada*
[b]*Society of Reliability Engineers-Ottawa, Canada*

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ABSTRACT

The human error has been reported as a major root cause in road accidents in today's world. The human as a driver in road vehicles composed of human, mechanical and electrical components is constantly exposed to changing surroundings (e.g., road conditions, environment)which deteriorate the driver's capacities leading to a potential accident. The auto industries and transportation authorities have realized that similar to other complex and safety sensitive transportation systems, the road vehicles need to rely on both advanced technologies (i.e., Advanced Driver Assistance Systems (ADAS)) and Passive Safety Systems (PSS) (e.g.,, seatbelts, airbags) in order to mitigate the risk of accidents and casualties. In this study, the advantages and disadvantages of ADAS as active safety systems as well as passive safety systems in road vehicles have been discussed. Also, this study proposes models that analyze the interactions between human as a driver and ADAS Warning and Crash Avoidance Systems and PSS in the design of vehicles. Thereafter, the mathematical models have been developed to make reliability prediction at any given time on the road transportation for vehicles equipped with ADAS and PSS. Finally, the implications of this study in the improvement of vehicle designs and prevention of casualties are discussed.

1. Introduction

The daily road accidents result a huge cost to our modern life (Fletcher, 2009). OECD (2006) reported that the road accidents could be considered as the primary cause of death for young European males. Each year more than one million people die worldwide in traffic crashes and further fifty million people are seriously injured as the result of driving (WHO, 2001).

Because the condition of road systems is constantly changing, drivers constantly have to make dynamic adjustments and adaptations to their driving behavior in response to the dynamic changes (Young& Salmon, 2012). Any drivers' distractions reduce drivers' situation awareness that may lead to road crashes (Salmon et al., 2011). In 2012, Young & Salmon investigated various non-driving-related activities that caused drivers' distractions.There is no doubt that driver's error is a major factor in road

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* Corresponding author. Tel: +1(416)454-9767, Fax: +1(888)206-2004
E-mail: Jenab@ieee.org (K. Jenab)

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fatalities (Treat et al., 1979). Neale et al. (2005) found through experiments that 78% of accidents and 67% of near accidents involved momentary inattention (within 3 seconds) before the incident. It has been reported that driver's error is a causal factor in 75% (Hankey et al., 1999) and even up to 95% (Rumar, 1990) of road crashes. Literature pertaining to the human error studies have been conducted in a wide range of industries such as aviation, nuclear power, and healthcare (Jou et al., 2011; Kontogiannis & Malakis, 2009; Shappell et al., 2007; Taib et al., 2011), whereas relatively little research has systematically been conducted to examine the nature and factors contributing to driver error in road transportations (Stanton & Salmon, 2009). The driving performance is impaired when insufficient attention is devoted to the driving tasks(Young & Salmon, 2012)or the driver is distracted by engagement in another task(Sandin, 2009; Staubach, 2009).Literature pertaining to the driver's distraction investigated reduced longitudinal (Rakauskas et al., 2004; Strayer & Drews, 2004), lateral control (Engstrom et al., 2005; Reed & Green, 1999); reduced situation awareness (Kass et al., 2007); and degraded response times to road hazards (Burns et al., 2002; Lee et al., 2001). The technology (e.g., reaching CD player, using GPS map, using cell phones) and non technology based (e.g., sightseeing, talking with passengers) distractions (Young & Salmon, 2012) cause an increased risk of crash involvement, with estimates indicating that secondary task distraction is a contributing factor in up to 23% of crashes and near-crashes (Klauer et al., 2006).More recently, both human and non-human related factors causing the driver error and their interfaces were analyzed and modeled (Hojjati-Emami et al., 2012). Factors such as fatigue, distraction, and inattention are still becoming more prominent in road safety (Fletcher, 2009; Treat et al., 1979;Stutts et al., 2001; Neale et al., 2005; Zador et al., 2000) and the data related to fatigue-induced accidents from the Australian Road Crash Database (ATSB 2006) acknowledges this fact.

Considering the driver's error resulting in severe consequences in road transportations, the development of countermeasures to mitigate the human errors through training and technology (e.g., Intelligent Transport Systems) and a better road system becomes critical (Young& Salmon,2012).The law enforcement resulted in significant reduction of accident rates since the 1970s as the result of improvement in vehicle and road design along with promotion of public awareness(ATSB, 2004; OECD, 2006).However, an idealistic approach in elimination or reduction of road fatalities is to substitute as much as possible the failing component (i.e., the human driver) with more reliable means (Fletcher, 2009).About 14,000 lane change and road departure crashes could have been prevented with warning systems in vehicles in the European Union (Abele et al., 2005). Further, Kuehn et al.(2009) mentioned almost 24,000 rear-end, 2000 lane change, and 3000 road departure crashes could be prevented in Germany if the vehicles had crash avoidance technologies. The occupant survivability subsequent to crashes has been increased with improvements in vehicle design (Farmer &Lund, 2006), and the recent approach in automobile designs is to avoid crashes altogether (Jermakian, 2011).The ADAS and PSS technologies are two approaches used in modern vehicles to mitigate the risk of accidents or casualties resulting from human error.

This study highlights and analyzes the safety features of ADAS and PSS in the design of road vehicles considering the demanding and tedious nature of operating a road vehicle which may pose drivers at the risk of committing error. This study proposes novel logical and mathematical modeling approaches to make assessment and prediction, at any instance of time, on the reliability of a modern vehicle composed of human as a driver, ADAS Warning System, ADAS Crash Avoidance System, and PSS. The findings of this work are expected to be used in design and improvement of vehicles and utilized in the safety assessment of road transportations and the development of new safety promotion policies, standards and methodologies by the transportation safety authorities and researchers.

2. Active and passive safety system and ADAS technology

The reduction or elimination of road transportation casualties can be achieved by integrating both "Active" and "Passive" safety approach in design of vehicles (Morris et al., 2010). The passive safety system refers to the safety technology embedded in a vehicle, which is specifically designed to reduce injuries in the event of a crash (e.g., airbags and advanced seat belt) (Morris et al., 2010). On the other hand, the active safety refers to technologies that are designed to prevent crash incidence (e.g., Intelligent Speed Adaptation (ISA), Lane Departure Warnings (LDWs), Speed Warning) (Morris et al., 2010). The modern vehicles are typically equipped with both passive and active safety devices such that if the active safety measures fail to act effectively then a level of protection of the occupants is provided in accidents through passive safety systems(Morris et al., 2010).

ADA Saims at supporting drivers by either providing the warning to reduce risk exposure (e.g., driving over the speed limit, raising driver alertness (Spyropoulou et al., 2008)) or triggering control tasks which takes over the vehicle control to eliminate many of the driver errors leading to accidents(Piao &McDonald, 2008),to prevent DUI (Driving under Influence) (ICADTS, 2001; Mathijssen, 2005),and to assist in a better control of the vehicle (e.g., improving visibility of the road environment (Spyropoulou et al., 2008)).Now, technologies such as forward collision warning and avoidance systems, lane departure warning, side view assist, adaptive headlights, adaptive cruise control, and many more have become available in the market and many more are under development (Piao& McDonald, 2008;Jermakian, 2011).ADAS functions can be achieved through either an autonomous approach that includes on board intelligent vehicle systems, and wayside systems or cooperative approach which rely on interfaces between the vehicle and other vehicles on road and the road system components (Piao & McDonald, 2008).

2.1. Positive and Negative Impacts of ADAS and PSS

The use of ADAS system may have several positive impacts such as mitigation of exposure to risky conditions, and improvement of driver behavior (e.g., reduced driving speed and speed variability, smaller lane deviations, faster reaction times, less harsh braking and enhanced alertness) (Spyropoulou et al., 2008) and eradication of driver errors (Stanton and Salmon, 2009). However, the potential negative effects include 1) drivers' shifted attention to road environment information that causes insufficient attention to the primary driving tasks, 2) inappropriate driver reactions (e.g. harsh braking) that results in unexpected warnings (Spyropoulou et al., 2008), 3)driver frustration with warning systems due to unnecessary frequent system warnings,4) driver frustration when certain elements of the driving tasks are taken over by the system in contrast to driver's desire (Spyropoulou et al., 2008).

The positive impact of PSS is to protect the lives of people in case of accident as the last resort by designers in the event of human and ADAS failures. However, the inappropriate designed and equipped PSS may result in injuries and even death for passengers and driver involved in accident.

2.2. A Concise Review on Available ADAS Technologies

In this section, the concepts of some of the available ADAS technologies are described.

Cooperative Based Systems connect individual vehicle by communication to the other vehicles or road infrastructures (Burton, 2004). With inter-vehicle communication, for example, forward collision warning and avoidance, systems can send an emergency braking message to its following vehicles (Tsugawa, 2005) or a vehicle can send Global Positioning System (GPS) data to the other vehicles in order to warn them of approaching vehicles beyond their range of view (Misener&Sengupta,2005). Also, road operators can provide drivers with dynamic information such as conditions of road surface, traffic, and weather (Piao & McDonald, 2008).Road train systems, which could connect the leading vehicle to the following vehicles let the driver experience hands and feet free of driving tasks while the computer system takes control (EURONEWS, 2012).

Forward Collision Warning and Collision Avoidance Systems are developed to reduce rear-end collisions, which represent about 28% of all collisions between vehicles (Vahidi & Eskandarian, 2003). The system is made up of cameras and radar sensors to monitor the area in front of a vehicle (Jermakian, 2011). Forward collision warning systems provide warnings (visual, audible, haptic) to a driver when the occurrence of imminent crash with the leading vehicle is likely (Krishnan et al., 2001) and the collision avoidance systems take action only if the driver fails to respond to the warning indicated, for example by applying a limited or full brake (Piao & Mcdonald, 2008).

Side and Rear View Assistant Systems use cameras or radar sensors to monitor surrounding areas of a vehicle and warn the driver of vehicles in the side or rear blind zones (Jermakian, 2011; Stanton & Salmon,, 2009).

Lane Departure Warning Systems use cameras to monitor vehicle position within the lane, warning the driver if the vehicle is in risk of straying across lane markings (Jermakian, 2011; Dickmanns & Graefe, 1988b; Pomerleau & Jochem, 1996; Bertozzi, et al., 2000).

Vision Enhancement Systems capture and presents the road scene with a greater contrast in situations with degraded visibility using an infrared camera with either head-up or head-down display (HUD/HDD) (Stanton & Pinto, 2000; Stanton & Salmon, 2009).

Adaptive Cruise Control Systems is used for a longitudinal vehicle control with the use of a microwave radar, sensor, and distance control device by maintaining a safe gap such that the set speed of the vehicle is maintained until the leading vehicle gets slower speed than the following vehicle. This results in reduction ofthe speed in the following vehicle (Stanton et al., 1997; Stanton & Salmon, 2009).

Vigilance Monitoring System monitors time that driver’s views are off the road and it warns the driver if his/her eyes are off the road for an extended time (Takemura et al. 2003) as head position and eye closure are strong indicators of fatigue (Haworth et al. 1988).Thiffault and Bergeron (2003) found that the visual monotony is a key input to driver fatigue.

Navigation System assists a driver in planning routes and navigates in real time so that the driver may be advised of when to join or leave roads safely in a timely manner (Stanton & Salmon, 2009).

3. The reliability modeling of interface between driver, ADAS warning, ADAS crash avoidance and passive safety systems

Although the functional failure of the autonomous technologies in vehicles is remote (reliability over 98%), they might be tricked by complex and unexpected situations, whereas human may be capable to resolve the problems when they are not susceptible to fatigue, distraction, and inattention (Fletcher, 2009).

In a typical vehicle, a driver applies the control systems in order to move the vehicle through the road environment, whereas in more advanced vehicles, two drivers (i.e., the human driver and the autonomous driver) could collaboratively control the vehicle (Fletcher, 2009; Regan, 2005). All drivers experienced warnings from a passenger on a potential dangerous situation in roads; these warnings can save numerous lives every day (Fletcher, 2009). Regan (2005) mentioned that unlike other complex and potentially dangerous vehicles such as planes and ships, road vehicles is operated by a single person, whereas that the person is prone to error and slow to recognize potential hazards. A vehicle equipped with ADAS technologies as automated co-driver can double check life critical actions, relieve the driver of tedious activities, and warn about missed road events to improve the driver's reaction time and if necessary act autonomously to avoid crashes(Fletcher, 2009).

In an ear future, all vehicles will be equipped with suitable ADAS technologies to save countless lives. Though, both active and passive safety systems remain vital in vehicles to protect lives in the event of driver's error. Thus, the nature and sequence of interactions between the driver as vehicle operator, ADAS warning, ADA Scrash avoidance system and vehicle passive systems can be demonstrated by a stand-by Reliability Block Diagram (RBD) as shown in Fig.1 (Model 1).This model represents a design in a way that once the driver fails to operate the vehicle safely, the ADAS warning system gives necessary alarms to driver, the failure in ADAS warning leads to activation of ADAS Crash avoidance system and finally the failure in ADAS crash avoidance system results in activation of vehicle passive system (PSS). This model is macro level of the models 2-4 which are developed and presented subsequently. The risk of accidents is expected to be lowest with this principle of design (i.e., modules in parallel) which remains same across four models presented here.

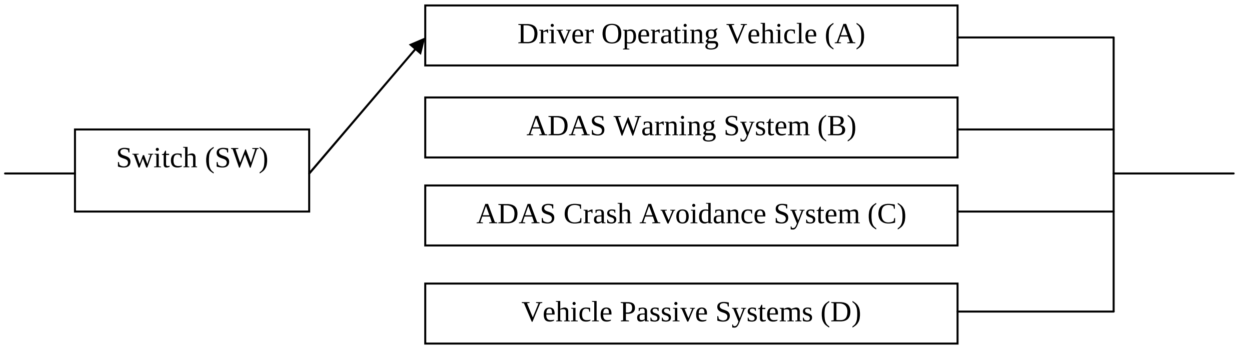

Fig. 1. RBD of Stand-by System Composed of Uni-Component of Driver, Vehicle Equipped with ADAS Systems and Passive Systems(Model 1)

The reliability of such system composed of Driver, Active (ADAS Warning and ADAS Crash Avoidance Systems) and Passive safety systems as illustrated in Fig. 1can be determined at any given time from Eq. 1.

$$\boldsymbol{R_{system\ of\ Model\ 1}} = R_{switch-A\ to\ B}.R_A(t) + \int_0^t f_A(x_A).R_{switch-A\ to\ B}.R_B(t - x_A).d_{x_A} + \int_0^t f_A(x_A).\int_{x_A}^t f_B(x_B).R_{switch-B\ to\ C}.R_C(t - x_A - x_B).dx_B.dx_A + \int_0^t f_A(x_A).f_B(x_B).\int_{x_b}^t f_c(x_C).R_{switch-C\ to\ D}.R_D(t - x_A - x_B - x_C).dx_A.dx_B.dx_C \tag{1}$$

Notations Used:

R_{system}= System Reliability

$R_{switch-A\ to\ B}$ = Reliability of Switching Mechanism from System A to System B

$R_{switch-B\ to\ C}$ = Reliability of Switching Mechanism from System B to System C

$R_{switch-C\ to\ D}$ = Reliability of Switching Mechanism from System C to System D

$R_A(t)$= Reliability of Driver Operating the Vehicle at time t (A)

$R_B(t)$ = Reliability of ADAS Warning System at time t (B)

$R_C(t)$ = Reliability of ADAS Crash Avoidance System at time t (C)

$R_D(t)$ = Reliability of Vehicle Passive System at time t (D)

$f_A(x_A)$ = Probability Density Function of Driver Failure (A)

$f_B(x_B)$ = Probability Density Function of ADAS Warning System Failure (B)
$f_C(x_C)$ = Probability Density Function of ADAS Crash Avoidance System (C)

$x_{A\ or\ B\ or\ C\ or\ D}$ = Time of failure of component A or B or C or D

It is to be noted that the methodology for developing ‘Model 1’ is going to remain the same for each potential stream of failures leading to an accident. It means that each type of human failure may trigger a certain type of ADAS warning, subsequently failure in that triggered ADAS warning is going to activate a certain ADAS crash avoidance system, and finally the failure in that activated ADAS crash avoidance system will lead to the activation of a particular passive safety system.

Furthermore, the human component in Model 1can be divided into mental and physical components in series in which the failure in each can result in failure of the driver. Further, the ADAS warning and ADAS crash avoidance components in ‘Model 1’can be decomposed to sub-systems in a series structure. With respect to Vehicle Passive Safety System in ‘Model 1’, this type of system in vehicles may contain several components in series that are all triggered by an incident in order to protect passengers (i.e., activation of air bag and advanced seatbelts). Thus, ‘Model 1’ illustrated in Fig. 1 can be transformed into a more micro level in form of a stand-by parallel series model as depicted in Fig.2 (Model 2).

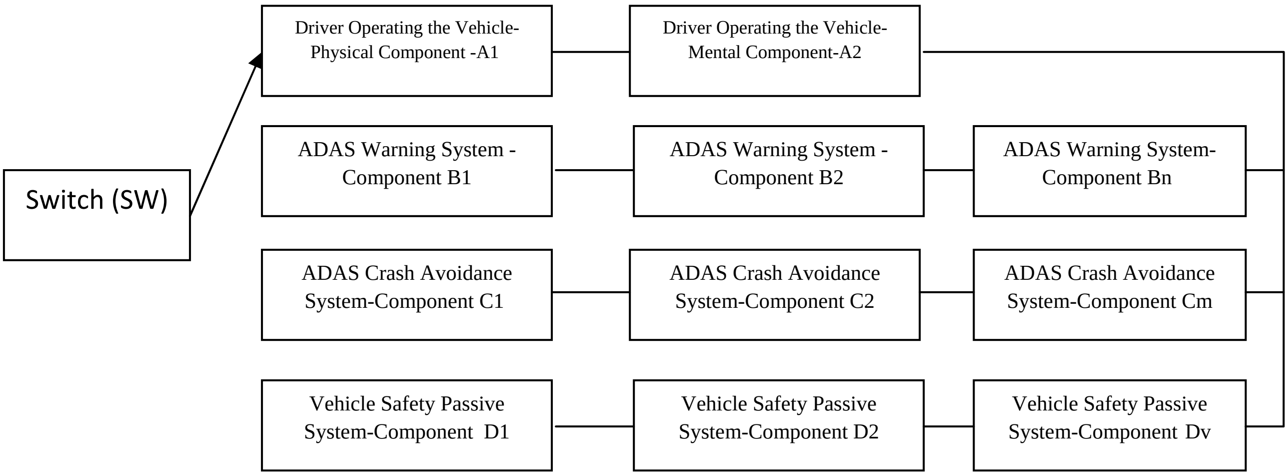

Fig. 2. RBD of Stand-by System Composed of Multi-Components of Driver (Series), ADAS Warning Systems (Series), ADAS Crash Avoidance Systems (Series) & Passive Systems (Series) (Model 2)

Accordingly, the reliability estimation of ‘Model 2’ can be obtained from Eq. (2)

$$\begin{aligned}\boldsymbol{R_{system\ of\ Model\ 2}} =\ & R_{switch-A\ to\ B}.R_{A1}(t).R_{A2}(t) + \\ & \textstyle\sum_{i=1}^{2}(\int_0^t f_{Ai}\,(x_{Ai}).R_{switch-A\ to\ B}.(\prod_{j=1}^{n} R_{Bj}(t - \\ & x_{Ai}))\,d_{x_{Ai}}) + \sum_{i=1}^{2}(\sum_{j=1}^{n}\int_0^t f_{Ai}\,(x_{Ai}).\int_{x_{Ai}}^{t} f_{Bj}(x_{Bj}).R_{switch-B\ to\ C}.(\prod_{k=1}^{m} R_{Ck}\,(t - x_{Ai} - x_{Bj}))).dx_{Bj}.dx_{Ai} + \\ & \textstyle\sum_{i=1}^{2}(\sum_{j=1}^{n}(\sum_{k=1}^{m}\int_0^t f_{Ai}(x_{Ai}).\int_{x_{Ai}}^{t} f_{Bj}(x_{Bj}).\int_{x_{Bj}}^{t} f_{Ck}(x_{Ck}).R_{switch-C\ to\ D}.\prod_{l=1}^{v} R_{Dl}\,(t - x_{Ai} - x_{Bj} - \\ & x_{ck}))))dx_{Ai}.dx_{Bj}.dx_{Ck}\end{aligned} \qquad (2)$$

As Fig. 3 illustrates the other potential design of a vehicle consisting of a driver, ADAS systems, and PSS can be consistent with the reliability block diagram of ‘Model 3’.In this model, the physical and mental components of a human as a driver remain in a series but the other systems including ADAS Warning, ADAS Crash Avoidance and Passive Systems would be broken down to components in a parallel structure. The reliability value of such system as illustrated in Fig. 3 (‘Model 3’) can be determined by Eq. 3.

$$\boldsymbol{R_{system\ of\ Model\ 3}} = R_{switch-A\ to\ B}.R_{A1}(t).R_{A2}(t) + \sum_{i=1}^{2}((\int_0^t f_{Ai}\,(x_{Ai}).R_{switch-A\ to\ B}.(1 - \prod_{j=1}^{n}(1 - R_{Bj}(t - x_{Ai}))\,d_{x_{Ai}}))) + \sum_{i=1}^{2}(\int_0^t f_{Ai}\,(x_{Ai}).\int_{x_{Ai}}^{t}(\prod_{j=1}^{n} f_{Bj}(x_{Bj})).R_{switch-B\ to\ C}.(1 - \prod_{k=1}^{m}(1 - R_{Ck}\left(t - x_{Ai} - x_{Bj}\right))).dx_{Bj}.dx_{Ai} + \sum_{i=1}^{2}(\int_0^t f_{Ai}(x_{Ai}).\int_{x_{Ai}}^{t}(\prod_{j=1}^{n} f_{Bj}(x_{Bj})).\int_{x_{Bj}}^{t}(\prod_{k=1}^{m} f_{Ck}(x_{Ck})).R_{switch-C\ to\ D}.(1 - \prod_{l=1}^{v}(1 - R_{Dl}\,(t - x_{Ai} - x_{Bj} - x_{ck})))dx_{Ai}.dx_{Bj}.dx_{Ck} \tag{3}$$

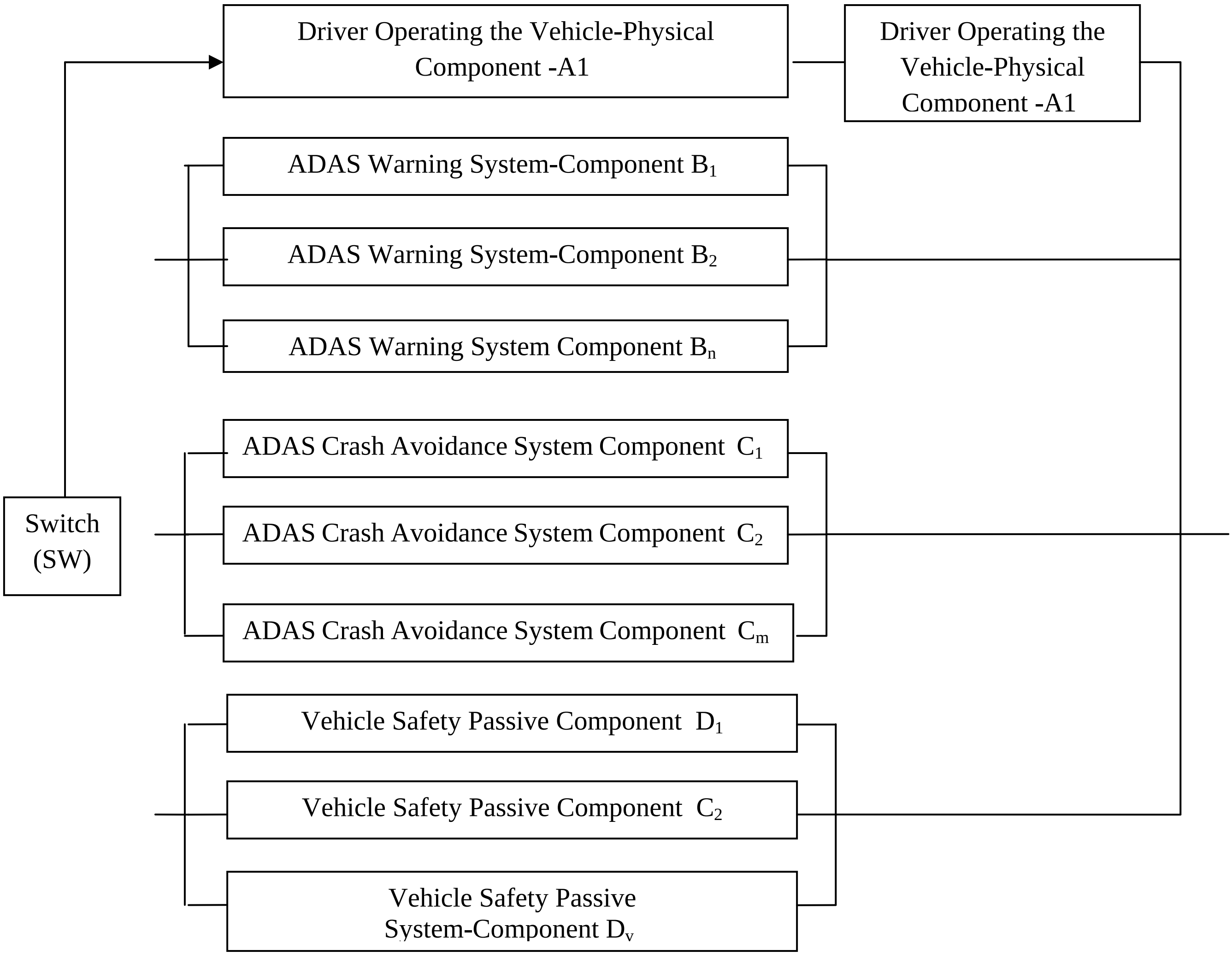

Fig. 3. RBD of Stand-by System Composed of Multi-Components of Driver (Series), ADAS Warning Systems (Parallel), ADAS Crash Avoidance Systems (Parallel) & Passive Systems (Parallel) (Model 3)

Further expansion of Models 1-3 may lead to a most possible complex model as shown in Fig. 4.In this model the human elements remains in series, whereas the constituting components of each of ADAS Warning, ADAS Crash Avoidance and PSS modules are designed in parallel-series structure as presented in Model 4. The modules themselves are designed in parallel in relation to each other in order to achieve greatest possible reliability in system. The reliability of ‘Model 4’as illustrated in Fig. 4 can be predicted from Eq. 4.

$$\begin{aligned}\boldsymbol{R_{system\ of\ Model\ 4}} = {} & R_{switch-A\ to\ B}.R_{A1}(t).R_{A2}(t) + \textstyle\sum_{i=1}^{2}((\int_0^t f_{Ai}\,(x_{Ai}).R_{switch-A\ to\ B}.(1 - \\ & \textstyle\prod_{j=1}^{n}(1-\ (\prod_{p=1}^{r,\forall j=1;p,\forall j=2;\dots;q,\forall j=n} R_{Bjp}(t-\ \ x_{Ai})))\,d_{x_{Ai}}))) + \\ & \textstyle\sum_{i=1}^{2}(\int_0^t f_{Ai}\,(x_{Ai})\,.\int_{x_{Ai}}^{t}(\prod_{j=1}^{n}(\sum_{p=1}^{r,\forall j=1;p,\forall j=2;\dots;q,\forall j=m} f_{Bjp}\left(x_{Bjp}\right)))\,.R_{switch-B\ to\ C}.\Big(1-\ \prod_{k=1}^{m}(1- \\ & \textstyle(\prod_{d=1}^{u,,\forall j=2;\dots;x,\forall j=n} R_{Ckd}(t-x_{Ai}-x_{Bj}\Big))).dx_{Bj}.dx_{Ai} + \\ & \textstyle\sum_{i=1}^{2}(\int_0^t f_{Ai}(x_{Ai})\,.\int_{x_{Ai}}^{t}\big(\prod_{j=1}^{n}(\sum_{p=1}^{r,\forall j=1;p,\forall j=2;\dots;q,\forall j=m} f_{Bjp}\left(x_{Bjp}\right)\big). \\ & \int_{x_{Bj}}^{t}\left(\prod_{k=1}^{m}(\sum_{d=1}^{u,=1;v,\forall j=2;\dots;x,\forall j=n} f_{Ckd}(x_{Ckd}))\right).R_{switch-C\ to\ D}.(1-\prod_{l=1}^{y}(1-\prod_{p=1}^{e,\forall j=1;f,\forall j=2;\dots;g,\forall j=m} R_{Dlp}\,(t \\ & \qquad -x_{Ai}-x_{Bj}-x_{Ck)}))dx_{Ai}.dx_{Bj}.dx_{Ck}\end{aligned} \tag{4}$$

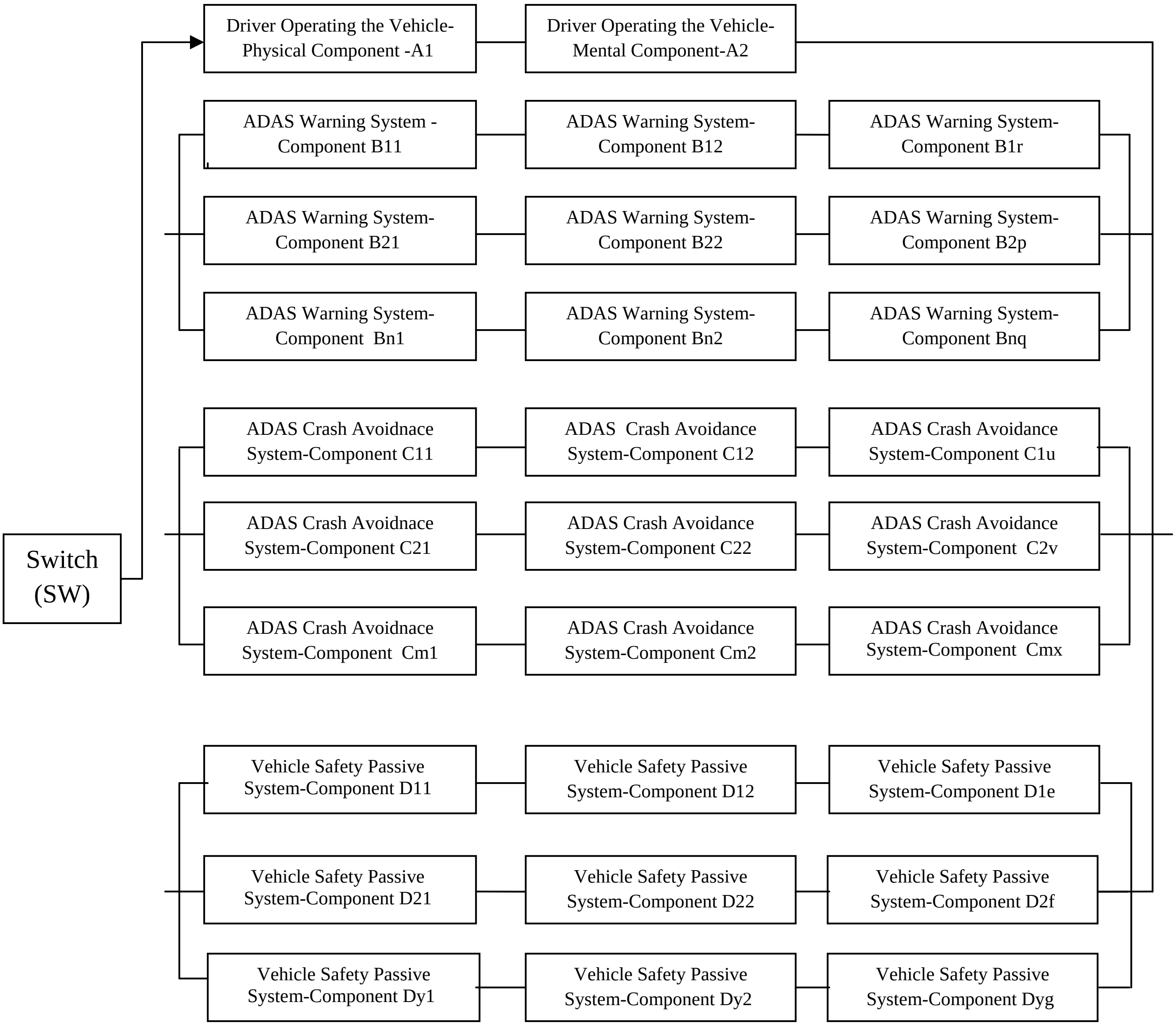

Fig. 4. RBD of Stand-by System Composed of Multi-Components of Driver (Series), ADAS Warning Systems (Parallel-Series), ADAS Crash Avoidance Systems (Parallel-Series) & Passive Systems (Parallel-Series) (Model 4)

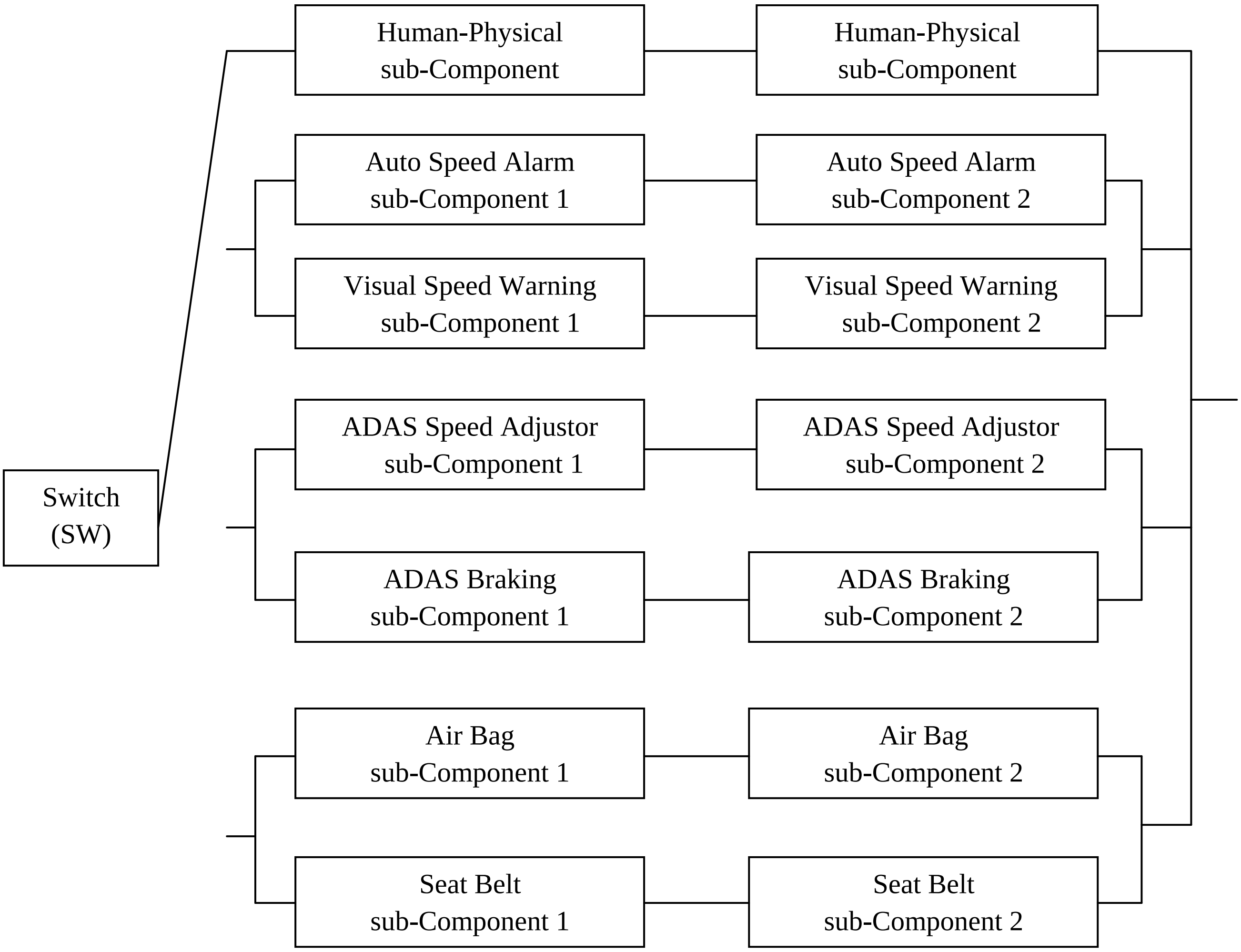

Fig. 5. A Real Example of Model 4 as the Most Complex Models Developed in the Research

A simple example of the application of 'Model 4' as the most complex form of models developed in this research, though the foundation of all four models are alike, is presented in Fig. 5. In this example, the human fails to control the speed within safe limit due to mental or physical failure, as the result the visual and audio warnings are presented to the driver. The failure in effectively controlling the speed with these warnings cause the activation of ADAS speed adjustor and braking systems. Finally, failures in the ADAS activation systems will result in activation of seatbelt and airbag systems as the last resort to protect the human casualties.

It is noteworthy that as the reliability of systems in a series structure is expected to be lower than that of a parallel structure when the number of components remains the same, thus the designers are expected to put the modules (i.e., Model 1-4) in parallel in relation to each other in order to enhance the safety of a system as much as possible. As the result, the total reliability of a vehicle composed of a number of modules each similar to either of Models 1-4 can be estimated by Eq. (5):

$$R_{Total} = 1 - \prod_{i=1}^{n} (1 - R_{System\ of\ Model\ i}) \tag{5}$$

4. Discussion and Conclusion

The human as driver is a person in the control of a vehicle until the moment of crash but it has to be understood that the human is under continued impact by various factors including road conditions and environment, vehicle and human's state, abilities and conduct (Hojjati-Emami et al., 2012).The current designs of vehicles and roads have been intended to provide drivers with extra comfort with less physical and mental efforts, whereas the fatigue imposed on driver is just being transformed from overload fatigue to under-load fatigue and boredom (Hojjati-Emamiet al., 2012). Hojjati-Emami et al. (2012) showed how human as a driver of transportation systems is prone at any given time with a varying risk to inevitable errors leading to accidents and casualties. It is note worthy to mention that databases detailing the different types of errors and their causal factors in road transportations are indeed scarce in the world (Salmon et al., 2010). Appropriate error databases can be used for the identification of different errors and causes in road transportation accidents and the development of error counter measures (Salmon et al., 2010).The potential error countering measures can be focused at such categories as driver error reduction (e.g., improved ergonomically designed vehicles, improved road environment design, training), the use of ADAS technologies to prevent or minimize risk of accidents in the event of driver's error and finally the passive systems (e.g., seatbelts, airbags) in the event of failure in ADAS and driver's error/failure.

This research for the first time explored how these three groups of error counter measures interact in a vehicle system in terms of reliability of their individual and overall functions and how the failures in any combination of the constituting components of these three groups of counter measure systems affect the reliability of total system in light of occurrence of accidents. The reliability prediction of vehicles equipped with ADAS and passive systems are mathematically determined at any given time by the models varying in the degree of complexity. The findings of this research are expected to be useful for examining the reliability of system preferably in conceptual stage of vehicle design by auto industries, road transportation authorities and the researchers. With systematic collection and in depth analysis of data regarding accidents involving vehicles equipped with ADAS and Passive Systems and feeding them to such assessment models and methodology as developed in this research and into the design and R & D processes of vehicles development, the casualties resulting from road accidents shall be expected to decline constantly in the future.

The prediction and optimization modeling of the total reliability of the road transportation containing interacting multi vehicles (different in degree, type, and complexity of use of ADAS and PSS technologies), pedestrians, road infrastructures, drivers with varying skills, etc. for the purpose of understanding the best strategic decisions, regulations and directions on the road safety in macro level are yet to be investigated by researchers.

References

Abele, J., Kerlen, C., Krueger, S., Baum, H., Geissler, T., Grawenhoff, S., Schneider, J., & Schulz, W. (2005). Exploratory Study on the Potential Socio-economic Impact of the Introduction of Intelligent Safety Systems in Road Vehicles (SeiSS Final Report).*VDI/VDE Innovation + Technik GmbH,* Teltow, Germany.

Australian Transport Safety Bureau (ATSB) (2004). *Serious injury due to road crashes: road safety statistics report.* Technical Report, Australian Government.

Australian Transport Safety Bureau (ATSB) (2006).*Fatal Road Crash Database.* http:www.atsb.gov.auroadfatal_road_crash_database.aspx.

Bertozzi, M., Broggi, A., & Fascioli, A. (2000). Vision-based intelligent vehicles: State of the art and perspectives. *Robotics and Autonomous Systems,* 32, 1–16.

Burns, P.C., Parkes, A., Burton, S., Smith, R.K., &Burch, D.(2002). How dangerous is driving with a mobile phone? Benchmarking the impairment to alcohol, 56. TRL Limited.

Burton, P. (2004) *D2: Scenarios, Policy and Legal Framework.* CVHS project deliverable. Available at: http://www.fabermaunsell.com/media/4751.pdf.

Dickmanns, E. D. & Graefe, V. (1988). Applications of dynamic monocular machine vision. *Machine Vision and Applications,* 1(4), 241–261.

Engstrom, J., Johansson, E., & Ostlund, J. (2005).Effects of visual and cognitive load in real and simulated motor way driving. *Transportation Research Part F: Traffic Psychology and Behaviour, 8(2),* 97–120.

EURONEWS (2012). Available at:http://www.euronews.com/2012/03/01/the-future-is-hands- free-driving/

Farmer, C.M., & Lund, A.K. (2006). Trends over time in the risk of driver death: what if vehicle designs had not improved?.*Traffic Injury Prevention,* 7 (4), 335–342.

Fletcher, L. (2009). Driver Inattention Detection based on Eye Gaze–Road Event Correlation, *The International Journal of Robotics Research,* 28(6), 774–801.

Hankey, J.M., Wierwille, W.W., Cannell, W.J., Kieliszewski, C.A., Medina, A., Dingus, T.A., & Cooper, L.M. (1999). *Identification and Evaluation of Driver Errors: Task C Report, Driver Error Taxonomy Development (Draft Technical Report).* Project No. DTFH-61-97-C-00051.Center for Transportation Research, Blacksburg, VA, Virginia Tech.

Haworth, N. L., Triggs, T. J., & Grey, E.M. (1988).*Driver fatigue: Concepts, measurement and crash countermeasures. Technical Report, Federal Office of Road Safety Contract Report 72,* Human Factors Group, Monash University, Department of Psychology.

Hojjati-Emami, K., Dhillon, B, & Jenab, K. (2012).The integrative time-dependent modeling of the reliability and failure of the causes of drivers' error leading to road accidents**.** *International Journal of Strategic Decision Sciences,* 3(4), *(In Press).*

ICADTS (2001). Alcohol Ignition Inter-lock Devices I: Position Paper. *ICADTS (ISBN 90–802908–4–x).*

Jermakian, J.S. (2011).Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis and Prevention,* 43, 732–740.

Jou, Y. T., Yenn, T. C., Lin, C. J., Tsai, W. S, & Hsieh, T.L. (2011). The research on extracting The information of human errors in the main control room of nuclear power plants by using Performance Evaluation Matrix. *Safety Science,* 49(2), 236–242.

Kass, S.J., Cole, K.S., & Stanny, C.J. (2007).Effects of distraction and experience on situation awareness and simulated driving. *Transportation Research Part F: Traffic Psychology and Behaviour,* 10, 321–329.

Klauer, S.G., Dingus, T.A., Neale, V.L., Sudweeks, J.D., & Ramsey, D.J. (2006). *The Impact of Driver Inattention on Near-crash/Crash Risk: An Analysis Using the 100-Car Naturalistic Driving Study data. Blacksburg.* Transportation Institute, Virginia, Virginia Tech.

Kontogiannis, T., & Malakis, S. (2009). A proactive approach to human error detection and identification in aviation and air traffic control. *Safety Science,* 47(5), 693–706.

Krishnan, H., Gibb, S., Steinfeld, A., & Shladover, S. (2001). Rear-end collision-warning system: design and evaluation via simulation. *Transportation Research Record,* 1759, 52–60.

Kuehn, M., Hummel, T., & Bende, J. (2009). Benefit estimation of advanced driver assistance systems for cars derived from real-life accidents. Paper no. 09-0317. In: *Proceedings of the 21st International Technical Conference on the Enhanced Safety of Vehicles. National Highway Traffic Safety Administration,* Washington, DC.

Lee, J.D., Caven, B., Haake, S., & Brown, T.L. (2001). Speech-based interaction with in vehicle computers: the effect of speech-based e-mail on drivers' attention to the roadway. *Human Factors,* 43, 631–640.

Mathijssen, M. P. M. (2005). Drink driving policy and road safety in the Netherlands: a retrospective analysis. *Transportation Research,* 41(5), 395–408.

Misener, J. A., & Sengupta, R. (2005). Cooperative collision warning: enabling crash avoidance with wireless technology, in: *Proceedings of the 12th World Congress on Intelligent Transport Systems,* San Francisco, CA, 6–10 November.

Morris, A., Brace, C., Reed, S., Fagerlind, H., Bjorkman, K., Jaensch, M., Otte, D., Vallet, G., Cant, L., Giustiniani, G., Parkkari, K., Verschragen, E., & Hoogvelt, B.(2010).The development of a European fatal accident database. *International Journal of Crashworthiness,* 15(2), 201–209.

Neale, V. L. et al. (2005). Overview of the 100-Car Naturalistic study and findings.*Proceedings of the International Conference on Enhanced Safety of Vehicles*.

OECD (2006). Organisation for Economic Co-operation and Development, Factbook 2006 – Economic. *Environment and Social Statistics: Quality of life,* http://www.sourcecd.org, December.

Piao, J., & McDonald, M. (2008).Advanced Driver Assistance Systems from Autonomous to Cooperative Approach. *Transport Reviews,* 28(5), 659–684.

Pomerleau, D., & Jochem, T. (1996).Rapidly adapting machine vision for automated vehicle steering.*IEEE Expert: Special Issue on Intelligent Systems and their Applications,* 11(2), 19–27.

Rakauskas, M.E., Gugerty, L.J., & Ward, N.J. (2004).Effects of naturalistic cell phone conversations on driving performance. *Journal of Safety Research,* 35(4), 453–464.

Reed, M.P., &Green, P.A. (1999).Comparison of driving performance on-road and in a low-cost simulator using a concurrent telephone dialling task. *Ergonomics,* 42(8), 1015–1037.

Regan, M. A. (2005). Keynote address. Proceedings of the Australasian College of Road Safety (acrs), NSW Joint parliamentary standing committee (Staysafe). *International Conference on Driver Distraction,* 29–73.

Rumar, K. (1990). The basic driver error: late detection. *Ergonomics,* 33 (10–11), 1281–1290.

Salmon, P.M., Lenné, M.G., Stanton, N.A., Jenkins, D.P., & Walker, G.H. (2010). Managing error on the open road: The contribution of human error models and methods, *Safety Science,* 48, 1225–1235.

Salmon, P.M., Stanton, N.A., &Young, K.L. (2011). Situation awareness on the road: review, theoretical and methodological issues, and future directions. *Theoretical Issues in Ergonomics Science. doi:10.1080/1463922x.2010.539289.*

Sandin, J. (2009). An analysis of common patterns in aggregated causation charts from intersection crashes. *Accident Analysis & Prevention, 41(3),* 624–632.

Shappell, S., Detwiler, C., Holcomb, K., Hackworth, C., Boquet, A., & Wiegmann, D.A. (2007). Human error and commercial aviation accidents: an analysis using the human factors analysis and classification system. *Human Factors, 49,* 227–242.

Stanton, N.A., &Salmon, P.M. (2009). Human error taxonomies applied to driving: a generic driver error taxonomy and its implications for intelligent transport systems. *Safety Science, 47(2),* 227–237.

Stanton, N. A.,& Pinto, M. (2000). Behavioural compensation by drivers of a simulator when using a vision enhancement system. *Ergonomics, 43(9),* 1359–1370.

Stanton, N.A., Young, M.S., & McCaulder, B.(1997). Drive-by-wire: the case of driver workload and reclaiming control with adaptive cruise control. *Safety Science, 27(2/3),* 149–159.

Spyropoulou, I., Pentinen, M., Karlaftis, M., Vaa, T., & Golias, J.(2008).ITS Solutions and Accident Risks: Prospective and Limitations. *Transport Reviews,* 28(5), 549–572.

Staubach, M. (2009). Factors correlated with traffic accidents as a basis for evaluating Advanced Driver Assistance Systems. *Accident Analysis & Prevention,*41(5), 1025–1033.

Strayer, D.L., & Drews, F.A. (2004). Profiles in driver distraction: effects of cell phone conversations on younger and older drivers. *Human Factors,* 46(4), 640.

Stutts, J. et al. (2001). *The role of driver distraction in traffic crashes*. Technical Report, Foundation for Traffic Safety, USA.

Taib, I.A., McIntosh, A.S., Caponecchia, C., & Baysari, M.T. (2011). A review of medical error taxonomies: a human factors perspective. *Safety Science,* 49(5), 607–615.

Takemura, K. et al. (2003). Driver monitoring system based on non-contact measurement system of driver's focus of visual attention. *Proceedings of the IEEE Symposium on Intelligent Vehicles,* 581–586.

Thiffault, P., & Bergeron, J. (2003). Monotony of road environment and driver fatigue: a simulator study. *Accident Analysis and Prevention,* 35, 381–391.

Treat, J.R., Tumbus, N.S., McDonald, S.T., Shinar, D., Hume, R.D., Mayer, R.E., Stansifer, R.L., & Catellian, N.J. (1979). Tri-level Study of the Causes of Traffic Accidents: Final Report, vol. 1: Causal Factor Tabulations and Assessments. Institute for Research in Public Safety, Indiana University. Cited by: Dingus, T.A., Jahns, S.K., Horowitz, A.D., Knipling, R., 1998.Human factors design issues for crash avoidance systems. In: Barfield, W., Dingus, T.A. (Eds.), *Human Factors in Intelligent Transportation Systems*. Lawrence Erlbaum Associates, Mahwah, NJ.

Tsugawa, S. (2005). Issues and recent trends in vehicle safety communication systems. *IATSS Research,* 29(1), 7–15.

Vahidi, A., & Eskandarian, A. (2003). Research advances in intelligent collision avoidance and adaptive cruise control. *IEEE Transactions on Intelligent Transportation Systems,* 4(3), 143–153.

WHO (2001). *World health report. Technical Report,* World Health Organisation, http://www.who.int/whr2001/2001/main/en/index.htm.

Young, K.L., & Salmon, P.M. (2012). Examining the relationship between driver distraction and driving errors: A discussion of theory, studies and methods. *Safety Science,* 50, 165–174.

Zador, P. L., Krawchuk, S. A., & Vocas R. B. (2000). *Final Report—Automotive Collision Avoidance (ACAS) Programme.* Technical Report No. DOT-HS-809-080 (Washington, DC: NHTSA, U.S. DOT).