

An Overview of Design Considerations for 3-wheel Vehicle Safety Improvement, considering Supplementary Restraint Systems industrial revolution

Rosine, Mouchou Tchamdjeu

Mechanical & Industrial Engineering Department
University of Johannesburg, DFC campus
Johannesburg, South Africa

rosinemt@uj.ac.za , rosinemouchou@yahoo.com

Prof. Tien-Chien Jen

Mechanical Engineering Science
University of Johannesburg
Johannesburg, South Africa

DPhil: Mechanical Engineering, University of California

tjen@uj.ac.za

Dr. Opeyeolu Timothy Laseinde

Mechanical and Industrial Engineering Department
University of Johannesburg, DFC campus
Johannesburg, South Africa

otlaseinde@uj.ac.za

Abstract

Supplemental Restraint Systems (SRS) are safety devices built into contemporary vehicles, to reduce the direct impact vehicle interior parts have on drivers and passengers in the event of sudden collision. The need for safety features in 3-wheel vehicles is imperative due to increasing use of unconventional vehicles for both passenger transport and e-commerce last mile logistics. The paper reviews technological advancements in SRS with focus on their features in terms of innovation and applicability. This informed the design considerations for a suitable SRS system for unconventional vehicles. The paper shares historical background and significant changes that have occurred from the initial models installed in motor vehicles, to emerging technologies which are currently being installed in 2 and 4-wheel vehicles. It further researched innovative devices that complement airbags for improved vehicle safety. The study involved a logical review of literature to gain insight into the historical background of airbags and considerations from design perspective. The findings set pace to track evolution in airbags using an exploratory study approach. The study findings have created a benchmark for airbag installation in 3-wheeled vehicles.

Keywords

Supplemental Restraint Systems, SRS, vehicle safety, airbag, emergency tension device

1. Introduction

Airbags, also called Supplemental Inflatable Restraint (SIR) or Supplemental Restraint System (SRS), have mandatorily come to stay in light passenger vehicles based on international vehicle standards. Airbags are restraint systems built into the steering wheel

and other strategic locations of a vehicle to improve safety in the event of sudden collision ([Nayak et al., 2013](#)). SRS are frequently referred to as airbags and they work simultaneously with Emergency Tension Devices (ETD) and other complementary safety instruments. Airbags protect vehicle occupants by applying a smaller restraining force than the force the body would naturally experience if it has direct impact with the vehicle dashboard, side frame, steering wheel or other interior parts.

The working principle of Supplementary Restraint Systems (SRSs) dates back to Sir Isaac Newton's first law of motion which emerged from a systematic study of motion initiated by Galileo in the 17th Century ([Scheck, 2005](#)). Newton's First law of motion states that an object moving at a constant velocity continues at that same velocity in a given direction unless an external force acts upon it. This law, known as the law of inertia, is demonstrated during a motor vehicle collision.

The intrinsic property of material body which resists change, in its state of rest or of uniform motion along a straight line is called inertia and can be interpreted mathematically as:

$$\Sigma F = 0 \quad (1)$$

where $a = 0$ and

$$\Sigma F \neq 0 \quad (2)$$

where $a \neq 0$ when (F = Force and a =acceleration)

When a motor vehicle suddenly comes to a halt, when traveling at relatively high velocity of above 60km/h, as the case is during high impact accidents, the body inside the car will continue moving forward at the same velocity as the car was moving prior to the collision because its inertial tendency will continue moving at constant velocity. However, the body does not continue moving at the same velocity for long; it rather comes to a stop when it collides with some object in the car, such as the steering wheel, dashboard, side doors, windows or car post. The opposing reactive force exerted on the body changes its velocity and when such forces are in excess, it results in injuries ([Bandak et al., 2002](#)).

The research aims at exploring evolving developments in airbag technology, from its invention to the current state. It extends the study to evaluate SRS in commercial transportation vehicles as a means of improving commercial vehicle safety.

Conventional air bag system consists of three basic parts namely: (1) An air bag module (2) crash sensors and (3) a diagnostic unit. Some systems may also have an on/off switch, which allows the air bag to be manually deactivated ([NHTSA, 2011](#)). However, several changes are rapidly occurring in the nature of accessories built around air bag mechanisms today. The air bag module comprises of both a lightweight fabric material air bag and an inflator unit which blows up the airbag. When fully inflated, the steering air bags at the driver's side are commonly slightly smaller in diameter than the steering wheel though some models differ; while those installed in the passenger dashboard area are much larger in size ([Drean et al., 2007](#), [Drean et al., 2008](#)). The passenger air bag can be two to three times larger, since the distance between the right-front passenger and the instrument panel is much greater than the distance between the driver and the steering wheel.

Vehicles can have one or more crash sensors which are commonly located around the frontal part of the vehicle, rear end or/and within the passenger side. The sensors are typically activated by forces generated in significant frontal or rear side crashes ([Mukherjee et al., 2005](#)). Vehicle crash sensors typically measure deceleration, which is the rate at which the vehicle slows down. According to the theory of linear motion, acceleration (a) is equivalent to the rate of change in velocity, expressed mathematically as:

$$a = (v_f^2 - v_i^2)/2d \quad (3)$$

where v_f = Final velocity, v_i = Initial velocity, d =distance.

When the change in velocity is negative (decreases), it is expressed as the deceleration. The diagnostic unit monitors the readiness of the air bag system. The unit is activated when the vehicle's ignition is turned on and this is usually displayed on the electronic dash board of vehicles. If the unit identifies a problem, a warning light alerts the driver to take the vehicle to an authorized service centre for inspection of the air bag system. Most diagnostic units have a device, which stores sufficient electrical energy to deploy air bag if the vehicle's battery gets disconnected upon sudden impact in a crash sequence. Crash sensors have greatly improved in newer versions of high end vehicles as newer models come with added features. Vehicle side mirror collision sensors now come as default in some models of passenger vehicles. Similarly, the reverse sensors that notify drivers when a vehicle is in extreme proximity to an external object are now interconnected to the SRS diagnosis unit.

To clearly understand the current changes and envisage innovations in airbag technology, a careful evaluation of the history of SRS is imperative. The article presents literature on advances made in SRS, with an objective study of the historical progression from the early models to currently obtainable designs. It shares the historical background and obvious transformation in the use of airbags which has been applied to vehicles running on 2 wheels, such as motorcycles/motorbikes, as against the traditional application in only 4 wheel vehicles. It further looks into the application of airbags in vehicles running on 4 wheels. Vehicle safety through the use of innovative devices that complement airbags was explored due to the need for improved vehicle safety.

The findings from the study set pace to track evolution in airbags using an exploratory study approach. The findings from the study equally serves as a benchmark for exploring airbags in commercial mass transportation systems. Improvements in conventional airbags and current research focus were elaborated.

2. Literature

This is an important part of this paper because it attempts to take its readers through the origin of SRS, and significant innovation witnessed within the vehicle airbag industry. From a broad perspective, the literature covers various distinguishing determinants based on the authors method of categorization.

2.1 History of Airbags and Associated Safety Systems

Airbags have been commonly available in automobiles since the early 1980's; however, research on airbags dates far back as the 1940s when they were first invented ([Khan and Moatamedi, 2008](#)), and patented in 1953 ([Nayak et al., 2013](#)). It was an invention conceived by Walter Linderer, who had it patented with German patent DE 896 312, filed 6 October 1951; issued 12 November, 1953 and American John W. Hetrick who received U.S. Patent no. (2 649 311) in 1953 ([Sawyer, 2012](#)). The airbag developed by Walter Linderer's was based on compressed air system, which gets inflated by bumper contact, or manually actuated by the driver. However, the latter approach was a last resort because accidents are barely predictable. On the other hand, John W. Hedrik's patent was based on what he referred to as a 'safety cushion assembly for automotive vehicles' ([McCormick, 2004](#)). Allen Breed was holding the US patent no. (5 071 161) to the only crash sensing technology available at the emergence of the airbag industry. Breed invented a 'sensor and safety system' in 1968, the world's first electromechanical automotive airbag system. However, rudimental patents for airbags sensors back to the 1950's.

After the two major patents, effort was made to improve the airbag designs. Ford Motors and General Motors (GM) which were major automobile manufacturers, encountered two major challenges with the airbags. One was associated with impact sensing of the magnitude of collision required to activate airbags while the other issue was secondary injuries to passengers caused by discharged airbags ([Lemov, 2015](#)).

In the late 1950's, the automobile industry started to research airbags and soon discovered that there were many difficulties in the development of a successful airbag. Crash tests showed that for an airbag to be useful as a protective device, the bag must deploy and inflate within 40 milliseconds. Later research proved that compressed air could not blow the bags out fast enough ([Nayak et al., 2013](#)). The system must also be able to detect the difference between a severe crash and a minor impact. These technological difficulties account for the long years of incubation between the first airbag patent and the current evolved models available today ([McCormick, 2004](#)).

Equally, within the 1950's, padded dashboards were introduced but safety was not the ultimate selling point in automobiles. Horse Power (HP), Speed, glittering plated parts and unique designs were features that excited automobile buyers. Nevertheless, constant safety improvements were made ([Nayak et al., 2013](#)). Chrome plated hooter, which pierced several drivers during vehicle crashes, was replaced. Door and window handles which were metal were gradually replaced with softer materials ([Lemov, 2015](#)). A collapsible spacer was introduced in the steering column to protect the chest of drivers in the event of an accident.

Rear-view mirrors were developed with breakaway features as safety approach, and vehicle wind shields were made of glass that disintegrate upon impact to avoid sharp pieces from piercing through drivers ([Lemov, 2015](#)). More recently, Antilock Brake Systems (ABS) were introduced to replace conventional hydraulic and air brakes; vehicle bumpers and fenders which used to be fabricated with steel were replaced with plastic films and currently, emerging vehicle models are moulded using fibre materials which are designed to crush upon impact, thereby absorbing most of the impact forces before they spread to the inner supporting structure of vehicles and their occupants ([Sawyer, 2012](#)).

Currently, vehicles are designed to bend and distort upon impact through what is called crumple zones, which aid the dissipation of impact forces thereby protecting vehicle passengers. The Cervical Thorax, head, chest and even foot are presently being protected by airbags. Airbags have saved more than 8 800 lives, according to the United States [NHTSA \(2011\)](#) and in a survey conducted in the year 2003, about 8 000 lives were saved by airbags while another 109 000 were saved by seatbelts from 1991 through 2001 ([Glassbrenne, 2003](#)). Airbags are called 'supplemental' because they

are supposed to be used with or as a supplement to seat belts. Although they may save an unbelted person from death, maximum effectiveness is achieved only by combining a seat belt and an airbag.

Table 1. Lives saved by federal motor vehicle safety standards and other vehicle safety technologies, 1960–2002 (Neill, 2009).

Standard	Technologies	LIVES SAVED	
		All years	2002
208	Safety belts	68 524	14 570
203/204	Energy absorbing steering assemblies	53 017	2 657
208	Frontal airbags	12 074	2 473
206	Improved door locks	28 902	1 398
214	Side door beams	14 703	994
201	Instrument panel improvements	21 043	930
105	Dual master cylinder & disc brakes	13 053	538
221	Adhesive windshield bonding	6 710	347
Total	All technologies	328 551	24 561
Total saved in year 2002			2 473
Total saved between survey period(1960–2002)			12 074
%Equivalent from 2002 statistics			20.50%

Several studies have shown the lifesaving potential of airbags. Of significance is a study from Monash University Accident Research Centre conducted between years 1995 and 2010 which showed that 2 700 lives had been saved and a further 36 000 drivers and passengers had escaped serious injury on Australian roads by the deployment of airbags ([Innovategroup, 2010](#)). A more recent study published by the National Highway Transportation Safety Administration (NHTSA) showed that there was significant increase in the number (see Table 2).

Table 2. Lives Saved by Restraint Use. Excerpt from 2008–2011/2012 Fatality Analysis Reporting System (FARS) Final Files published by the National Highway Traffic Safety Administration ([NHTSA, 2013](#)).

Year	Lives saved Age 4 & younger	Lives saved Age 5 & older	Lives saved Age 13 & older
	Child restraints	Sate belts	Front air bags
2008	286	13 312	2 557
2009	307	12 763	2 387
2010	303	12 582	2 315
2011	262	11 983	2 210
2012	284	12 174	2 213
TOTAL	1 442	62 814	11 682

Ford began research into airbags for automobiles in the early 1970s but did not install them in any of its vehicles. General Motors however developed airbags on a test fleet of the 1973 model of Chevrolet Impalas ([Lemov, 2015](#)).

Automatic seat belts, a more economical feature, eventually were not implemented by auto manufacturers. Mercedes-Benz was the first car company to offer airbags in all of its 1986 models exported to the United States and currently one of the few manufacturers using the Emergency Tension Device on some of its models.

Initially, airbags were installed only on the driver's side and steering wheels; but in 1993, passenger side airbags were offered ([Nayak et al., 2013](#)). Starting from 1998 vehicle models, both driver and passenger-side airbags have been required internationally in passenger vehicles as a standard. Today, most light passenger vehicles are mandatorily equipped with 2 frontal airbags. The steering wheel airbag protects the driver while the passenger airbags in the dash board, protects the passenger. Their inflation volume varies between models of cars. On average, driver airbags are designed with air volume intake of 60 litres and approximately 150 litres for the passenger airbag ([Nayak et al., 2013](#)). They were initially overpowered but as progress was made in research towards safer airbags, they were gradually depowered. They deploy with much less force, which is intended to minimize the risk of injury during low-speed collisions. The dual stage inflators was an innovation which made this possible.

The US National Highway Traffic Safety Administration (NHTSA) carried out a systematic audit of its safety technologies introduced into vehicles since 1960 through its Federal Motor Vehicle Safety Standards (FMVSS) which evaluated the standards between 1975 and 2004 and the findings showed that these safety technologies was estimated to have saved 328 551 individuals between 1960 to 2002. From the report, airbags were rated as the third most effective live saving technology installed in vehicles ([Charles and J, 2004](#)).

3. Airbag Design innovation

3.1 Innovations in Airbag Technology

In evaluating advanced air bag systems, laboratory tests utilizing a family of crash test dummies were initially required. In addition to tests using dummies representing young adults, current vehicle airbag systems are being tested with dummies representing a wider demography of occupants such as: average adult, children of varying ages, infants and physically challenged persons. These new requirements are being adopted with some vehicles already in production. However, this paper presents the evidential advances in automotive airbags in terms of: (1) components and type (2) vehicle type (3) methods and types of crash tests in use (4) location of airbags (5) airbag, fabric and folding.

3.2 Innovations in Terms of Components and Types of Airbags

3.2.1 Smart airbags

These devices are currently installed in some vehicles while it is being improved upon, but it is generally perceived as a promising technology. Different car occupants would be sensed, and a diagnosis will determine performance of the airbag. Potential developments include adjustment of the triggering force, gas volume and inflation rate. Advanced sensing and control systems will be necessary for these to get fully operational. Airbags of the future will deploy at different rates or with different intensities based on the person sitting in the vehicle's seat. Ideally, the airbag will deploy differently, depending on whether a seat occupant is a child or adult and if they are strapped up on a seat belt or not. The design involves a lot of Artificial Intelligence (AI) and Fuzzy Logic modelling.

Ford began installing such airbags in its Taurus Year Model (YM) 2000 ([Nayak et al., 2013](#)). The company states that the advanced restraint system is a collection of components that permits the car to analyse the crash, understand its severity, examine the driver's position in the seat to ascertain proper use of the seatbelt; and based on the analysed information, decide how to deploy the airbag. With this system, dual stage airbags inflate at two different rates depending on the processed information from the analysed parameters ([Alcalá et al., 2009](#)). Smart airbags which fall under third-generation airbags are mostly installed as default in 3, 5 & 7 Series BMW vehicles, on Honda Accord, Mercedes-Benz S-Class, and most of the luxury cars among others. Many smart systems employ a switch in the seat belt buckle sending a message to the controller that the occupant is buckled up.

The technology that makes them smart varies among vehicle manufacturers. For example, General Motors installed a bend sensor in the seats of the 2000 YM Cadillac Seville. Developed by Flexpoint Inc., the sensor is reportedly so sophisticated that it can distinguish between a child located in a car seat, an adult in the seat or just an item placed on the seat. It measures not only the weight but also the object pattern and shape.

Some of the other sensing devices include a type of scale that would calculate the size of the person (or object) sitting on the seat. A major drawback at the onset, indicates that the sensors do not detect if the seat belt is being used nor if used properly ([Sawyer, 2012](#)). The sensors installed inside the seat belt latchet are still required to effectively detect the use of the belt. In addition, ultrasonic wave generators could provide 2-dimensional rendering of the seat's occupant and infrared beams would equally operate similarly.

From the Jaguar Year Model (YM) 2000, the Adaptive Restraint Technology System (ARTS) became standard on all 2001 XK series sports cars ([Gunnell, 2007](#)). Using ultrasonic sensors in the front pillars and new roof console, the system determines the presence and position of front seat passengers in relation to the door equipped with the airbag. Likewise, if the Front-Right occupant gets too close to the dashboard, sensors in the roof console will trigger a warning light to notify the passenger that the airbag has been turned off. According to [Bloch \(2001\)](#), when the passenger moves back, another sensor will reactivate the airbag. This equally holds for the driver's sitting position as a sensor in the seat, measures the driver's distance from the steering wheel. Additional sensors in both seat belt buckles inform the system of occupants not putting on seat belts ([Endo et al., 2012](#)).

Other restraint technology that automakers are utilizing includes Reflective Capacitive Sensors, which determine the mass of an object in a seat and differentiates between a human and object placed on the seat. Currently in use are electric field proximity sensor technologies, which use micro antennas to receive reflected signals.

3.2.2 Electronic Control Unit

A computer, also known as an Electronic Control Unit (ECU), permanently measures vehicle change in speed (acceleration and deceleration). An impact is read as a very violent acceleration is experienced. To do this, the ECU which is generally installed in the middle of the vehicle at the frontal vehicle compartment, analyses information delivered by the accelerometers ([Endo et al., 2012](#)). Sensors provide the ECU microprocessor with data key deterministic parameters of the vehicle's position and velocity changes. When an impact is detected due to an exceeded value of vehicle acceleration parameters, the ECU determines its direction and intensity. As soon as these are above a threshold considered critical, the ECU triggers inflation of the airbags. It does this by sending a pulse to a pyrotechnic air pump. This firing causes a strong, almost instantaneous release of gas, obtained by a chemical reaction based on solid reactants, which inflates the airbag within microseconds. Vents calibrated slits made in the fabric of the bag allow it to deflate rapidly within 10-40 microseconds following the impact. Furthermore, as the ECU computes the direction of the impact, it can selectively trigger either the frontal airbags or the side airbags, or both simultaneously. To ensure correct deployment of the airbags even in the event of destruction of the vehicle battery at the time of the impact, the system is equipped with an energy storage bank which provides sufficient alternative backup electrical power, even when the power from the battery cuts off. The backup supply lasts between one second and ten minutes depending on the vehicle model. Some Ford models hold charge for only one minute while most General Motors (GM) vehicles hold 10 minute backup charge (Skyline, 2001).

Many advanced air bag technologies are being developed to tailor air bag deployment to the severity of the crash vehicle occupants' posture and size, belt usage and the closeness of the vehicle occupant to the air bag module. Many of the developed systems utilize multi-stage inflators which have the capacity of deploying less forcefully in stages, in moderate crashes than in very severe crashes. Based on this information and crash severity information, the air bag is deployed at either a high force level, a less forceful level or not at all ([Nayak et al., 2013](#)).

Two airbag designs that reduce the risk of head injuries and help keep the head and upper body inside the vehicle are (1) inflatable tubular structures and (2) inflatable curtains. Some vehicles are now equipped with a different type of inflatable curtain designed to help reduce injury and ejection from the vehicle in rollover crashes ([McClafferty and German, 2008](#)). At the National Highway Traffic Safety Administration, a comprehensive 'uniform test procedure' for side airbags has been developed. The test procedures will assist air bag designers to evaluate the risk associated with different sizes of passengers with the aim of designing the airbag systems to minimize risk. Hence, all vehicle manufacturers have agreed to utilize these tests when designing future side air bag systems ([Summers et al., 2001](#)).

3.2.3 Event Data Recorder (EDR)

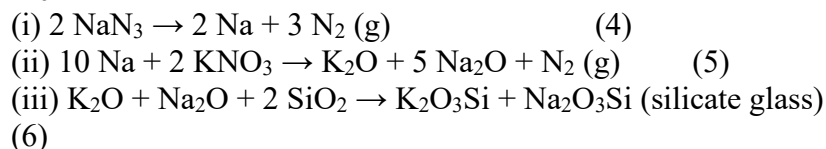
The EDR is an Airbag Sensor Assembly that monitors and controls certain aspects of the vehicle. These computers assist in driving and maintaining optimal vehicle performance. This is called an Event Data Recorder (EDR). The Airbag Sensor Assembly contains the EDR which works similar to a black box within the front cabin of aircrafts

according to the NHTSA vehicle crash test database ([Gabler, 2007](#)). In a crash or a near car crash event, EDR's capture detail of driver's seat position, SRS airbag deployment data, detail showing if driver and front passenger wore the seat belts or not, and SRS airbag system diagnostic data. The information is intended to be used for the purpose of improving vehicle safety performance and a means of guiding vehicle Insurance firms, in evaluating crash compensation after an incident. Unlike general data recorders, the EDR is not equipped for sound data recording such as conversation between passengers unlike the black-box in aircrafts. At the moment, human right laws generally frown at vehicle voice recording due to human rights infringement and as such oppose voice recorder as a preinstalled component in vehicles, however these may change in the future.

3.2.4 Airbag gas generators

One of the simplest designs employed for the crash sensor is a steel ball that slides inside a smooth bore. The ball is held in place by a permanent magnet or by a stiff spring, which inhibits the ball's motion when the car drives over bumps or potholes. However, when the car decelerates very quickly, as in a head-on crash, the ball suddenly moves forward and turns on an electrical circuit, initiating the process of inflating the airbag. Once the sensor has turned on the electrical circuit, a pellet of Sodium Azide (NaN_3) is ignited. A rapid reaction occurs, generating Nitrogen gas (N_2). The gas fills the bag made of nylon or polyamide material such that the front face of the bag propels at a velocity of between 150 to 250 miles per hour ([Gabler, 2007](#), [Schmitt et al., 1997](#)).

Generally, airbags have a gas generator and a mixture of NaN_3 , KNO_3 , and SiO_2 . Upon vehicle collision, the ECU triggers the 3 chemicals inside the generator. Sodium Azide (NaN_3) decomposes at 300°C to produce Sodium metal (Na) and Nitrogen gas (N_2) ([Nayak et al., 2013](#)). The deceleration sensor ignites the gas generator mixture by an electrical impulse, creating the temperature necessary for NaN_3 to decompose. The Nitrogen gas that is generated quickly fills the airbag. The purpose of the KNO_3 and SiO_2 is to remove the sodium metal which is highly reactive and potentially explosive by converting it to a harmless material. The chemical reaction process is detailed in equations 4–6 below:



More recently, alternative non-azide based propellants are being explored. Pyrotechnic propellants such as nitrocellulose-based substances ([Sandstroem J, 1994](#), [Canterberry et al., 2003](#)), are in use due to its lower cost and lower toxicity ([Dunne, 2002](#)). Cyclotrimethylenetrinitramine (RDX) based propellants are equally alternative options ([Walsh, 2003](#)). Both products generate a gaseous mixture of N_2 , CO_2 and water with some minor undesirable gases such as Carbon monoxide (CO) and Nitrogen oxides (NO). Some of the non-azide propellants can generate 100% gas-phase products eliminating the costly requirements of slag filtration. "A non-azide propellant composed of a mixture of azodicarbonimide, potassium perchlorate (KClO_4) and cupric oxide (CuO) was selected to replace the traditional azide based propellants" ([Schmitt et al., 1997](#)), which are reported to be relatively safe, environmentally friendly and achieve satisfactory performance during deployment.

A key component in airbags is the gas generator. The Fraunhofer Institute for Chemical Technology have developed a new variant for the intelligent airbag system ([Fraunhofer-Institute, 2001](#)). It consists of a casing, an ignition element and a solid propellant in tablet form which produce as much as 100 litres of gas within 40 milliseconds. To prevent a driver, who is sitting too close to the steering wheel from receiving the full impact and possibly sustaining vital injuries, sensors identify the driver's exact position and induce a time delay in the flow of gas. However, in comparison to airbags standard today, the gas is generated at relatively low combustion temperatures. Equally, the gas generator is entirely safe and impervious to external influences. Scientist at Fraunhofer have developed tailor made a gas-generator casing as part of the new package. The new gas generator responds at a lower pressure which allows for simpler casing design with lower requirements for achieving mechanical durability ([Fraunhofer-Institute, 2001](#)).

More recently, Advantech plastics published an online article on new developments on the moulding process for airbag covers based on the achievements of the plastic research laboratory at the Fraunhofer Institute for Chemical Technology (ICT), Germany ([Advantech, 2013](#)). Previously, manufacturing these airbag casings resulted in a lot of waste and striations (long blemishes) but the new process promises 30% reduction in the amount of material used, fewer striations (ridges, furrows or linear marks) in finished parts, and easier designing for engineers. The new process

pioneered by the Fraunhofer Institute for Chemical Technology (ICT) produces airbags structural parts without the striations that form during standard foam injection.

3.3 Innovation in Terms of Vehicle Types

3.3.1 Motorcycle Airbag System

In September, 2005 Honda Motor Co., Ltd. announced its success in developing the world's first motorcycle airbag system ([Khan and Moatamedi, 2008](#)). The motorcycle airbag system is comprised of the airbag module which includes the airbag and its inflator, crash sensors which monitor acceleration changes and an ECU which performs calculations to instantly determine when a collision is occurring ([Mukherjee et al., 2005](#)). When a severe frontal collision occurs, the four crash sensors mounted on the front fork measure the change in acceleration caused by the impact and convey this data to the airbag ECU, which determines that a collision is occurring and whether or not it is necessary to inflate the airbag. If the calculations performed by the ECU indicate that airbag deployment is necessary, the ECU sends an electronic signal to the airbag inflator, which instantaneously responds by inflating the airbag. Inflating rapidly after the impact, the airbag can absorb some of the forward energy of the rider, reducing the velocity at which the rider may be thrown from the motorcycle and help reduce the severity of injuries caused by the rider colliding with another vehicle or with the road ([Mukherjee et al., 2005](#)). By conducting extensive crash tests at its indoor Omni-directional real world crash test facility, applying advanced computer simulation technology and leading the way with the introduction of motorcycle rider test dummies, Honda has gathered and analysed a wide array of data on the behaviour of motorcycles during collisions ([Honda-Motor, 2007](#)). It has also taken full advantage of the experience of its automobile operations in the development of airbags, applying its expertise in the development of the motorcycle airbag system ([Honda-Motor, 2013](#)).



Figure 1: Motorcycle Airbag system ([Honda-Motor, 2007](#))

3.3.2 Fixed wing aircraft

Airbags are being used to provide soft-landing capability for heavy military airdrops such as dropdown of relief materials and ejection of crew in escape crew capsules ([Taylor et al., 2001](#)). In 2001, inflatable restraints began appearing in the bulkhead-row seats of Jetstream regional airliners. Today they are in virtually all Boeing and Airbus aircrafts. Smaller crafts are equally equipped with airbags today ([Wright, 2005](#)).



Figure 2: Aircraft airbag

3.4 Innovation in Terms of Methods and Type of Crash Tests Being Performed

3.4.1 Barrier tests

Vehicles have to be subjected to system performance evaluation to ensure optimal safety under various operations and crash conditions. Barrier impact tests are widely used to evaluate the vehicle structural crashworthiness, crash sensing system, and restraint systems ([Hinch et al., 2001](#)). Previously, airbags were tested by running a vehicle into a barrier at 30 mph with a test dummy sitting rigidly in the driver's seat. But in real world crashes, the driver usually is out of a static position which led to variation in this model. Currently, in a rigid barrier test, the car hits the wall at a 90 degree angle, both straight head on and at a 30 degree angle. Speed variation was equally implemented with different circumstances such as crashing with and without seatbelts ([Nayak et al., 2013](#)).

For 2-wheelers, Honda has been exceptionally committed to motorcycle safety by its early introduction of ISO 13232-certified crash-test dummies designed for motorcycle testing ([Miller and Gu, 1997](#)). Unlike the early automobile crash test dummies utilized at the commencement of automobile crash tests, motorcycle crash test dummies contain embedded sensors that record crash test data. Sensors embedded in the head, neck, chest, stomach, and limbs make it possible to measure the extent of injuries over virtually the entire body.

3.4.2 Dynamic sled test

Dynamic crash sleds are often used in laboratories as a non-destructive and reusable simulation tool for the development of the vehicle interiors. In an effort to make crash tests more realistic, a sled test was developed. Instead of crashing into a wall, the vehicle is mounted to a sled that decelerates quickly ([Miller and Gu, 1997](#)). Rather than crashing into solid walls, the vehicle is mounted to a sled that decelerates quickly. According to [Stein \(1997\)](#), it is a rather cost effective method of executing tests of this magnitude. Because it is less severe than the barrier test, the sled allows for less powerful airbags and dummies not set with seat belts. The dynamic sled test is performed to obtain information about the dynamic performance of supplemental restraint systems, vehicle seating systems, and body closure systems. Dynamic sled tests are capable of simulating the vehicle barrier specifications and properties. Speed variation has equally been implemented with different circumstances such as crashing with and without seatbelts ([Smyth and James, 2007](#)).

3.4.3 Computer simulation technology

The rapid advancement of computer technology provides a powerful and practical tool to explore alternative options for testing vehicle performance before the physical vehicle parts are produced and assembled. A wide range of automobile collision tests have been introduced using computer simulated models. So many of such applications have been developed for the automobile industry to help evaluate and predict areas that may need amendment in airbag designs and deployment. The cost of air bag modelling and testing using Virtual Reality (VR), through Computer Aided simulated test beds have greatly led to the reduction in the initial cost of new vehicles performance check. Simulation can also lead to a reduction in the number of tests required, faster product development time and the potential to optimize the realisation of the occupant safety ([Mahangare et al., 2006](#)).

Computer simulation utilizes the principles of multi-body dynamics, continuum mechanics, and Finite Element (FE) methods along with numerical techniques to imitate the physical systems using mathematical models ([Miller and Gu, 1997](#), [Smyth and James, 2007](#)). ISO 13232 includes standards for assessing the effectiveness of rider protection devices using computer simulations. The computer simulations developed by Honda allow for a highly precise analysis of the impact on the airbag-equipped motorcycle, the automobile involved in the accident, and the dummy from the time of initial impact to the time when the rider falls from the bike. Some well-known simulation programming Software's commonly used in the industry include: MADYMO, LS-DYNA, PAM-CRASH and Articulated Total Body (ATB) ([Mahangare et al., 2006](#), [James et al., 1997](#), [W, 1995](#), [Lim et al., 2010](#))

According to [Chawla and Mukher \(2007\)](#), using Finite Element analysis, it may be concluded that inflating airbags in motorcycles do not pose a significant injury threat. Therefore, the inflation stage of the airbag is of significant concern. The ALE (Arbitrary Lagrange–Euler) approach was seen to correctly predict experimentally observed airbag deployment sequences. Though computationally more expensive than the traditional Control Volume (CV) approach, an Arbitrary Lagrange–Euler (ALE) airbag model) can effectively simulate the initial stages of deployment better when experimentally measured airbag shape during deployment as explained by [Cirak and Radovitzky \(2003\)](#).

Computationally, the dummy is usually subjected to different conditions while analysing different possible collision scenarios. This is achieved by testing different positions and identifying body movement in the event of sudden stops when brakes are applied at varying speeds and angle of steering direction.

3.5 Innovations in Terms of Location of Airbags

There are two types of airbags commonly installed by default in modern vehicles today: frontal and the various types of side impact airbags. Advanced frontal air bag systems automatically determine if and with what level of power the driver frontal air bag and the passenger frontal air bag will inflate. The appropriate level of power is based upon sensor inputs that can typically detect: (1) occupant size (2) seat position (3) seat belt use of the occupant and (4) crash severity. Side impact air bags (SABs) are inflatable devices that are designed to help protect the head and chest in the event of a serious crash involving the vehicle side. Currently, research is being carried out on various auto safety sites across the globe. Based on impact assessment and other discoveries from accidents, airbags are proposed to be placed in various parts of automobiles. Pedestrian protection airbags are also being explored as presented in Figure 7 ([Greenwell, 2013](#)). These includes inflated back passenger seat belt airbags, knee airbags, carpet/floor airbags, head and thorax (chest) airbags, pedestrian protection airbags and multiple external collision absorption/impact repulsion airbags.

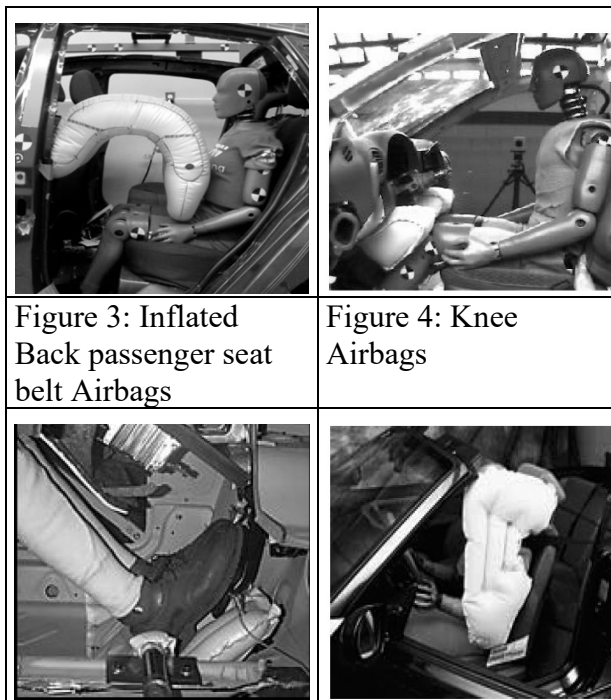




Figure 5: Floor Airbags	Figure 6: Head & thorax (chest) airbags
	
Figure 7: Pedestrian protection airbags	Figure 8: Rear passenger head supporting airbags

3.6 Innovation in Terms of Airbags features

3.6.1 Materials

Airbags have been mostly made from flexible fabric such as nylon or polyester that inflates in a head-on collision. At present, these are being replaced by the use of composite materials. One of such installed in some of the 2012–2013 Year Model cars, is made from a combination of nonwoven materials and films. Lighter fabrics are also being adopted compared to the former ones which had poor pack ability features. Airbags are designed to have two (2) or more holes situated at the bottom of an inflated airbag which facilitates the immediate collapse and withdrawal of the built up air in the airbag after its deployment.

3.6.2 Airbag folding

For smooth ejection of airbags with highly uniform deployment without any one side protruding before others, airbags need to be carefully folded into the compartment and casing. Within the airbag module, the airbag is folded such that it unfolds as quickly and smoothly as possible in a specific direction ([Mabuchi et al., 2008](#)). Different airbags are folded with different numbers and types of fold using different methods. Some of the major folds include: (1) Simple fold, (2) Open fold, (3) Rolling fold, (4) Tuck fold (5) Accordion fold (Z fold), (6) Reversed accordion fold (7) Pleated accordion fold, (8) Leporello fold (L-fold) (9) Raff fold, (10) stochastic fold (S fold) (11) Ring fold (R fold) and (12) Overlapped fold.

Conversely, the most commercially available folds are: Ring folding, stochastic folding, accordion folding and L-folding ([Ruff et al., 2007](#)). The R-folding airbag fabric is arranged circularly around the gas generator. Stochastic folding is arbitrarily arranged without any specific order or pattern but the basic similarity between manufacturers is that they are placed flat and they deploy according to how they are folded. The Z-folded airbag fabric is similar to the wind instrument called an accordion. The fabric is arranged in a radial circular manner around the propellant. The L-folding was used in early airbag designs. They are simple, compact and their fabric is usually folded in a linear direction along the seams.

3.6.3 Coatings

Neoprene was the original coating used because of availability, low cost, applicability and most manufacturers are quite familiar with its behaviour under various atmospheric conditions. Currently, Silicone is quickly replacing Neoprene. The major reason for considering Silicon is based on Silicon's low or non-flammability characteristics, abrasion resistance property, flexibility characteristics, low gas permeability of < 0.51 cubic meter of air per hour (m^3/h) and its thermal aging stability. These features make it most suitable for effectiveness of roll over activated and drop down side curtain airbags in reducing fatalities in accidents resulting from vehicle rollovers ([Padmanaban and Fitzgerald, 2012](#)). There are two types of airbag fabrics available commercially. They are the coated types and

uncoated models. Airbags installed in motor vehicle drivers' side are usually coated, while passenger side airbags are generally uncoated ([Partridge and Mukhopadhyay, 2002](#), [Ziegahn et al., 2004](#), [Hirth et al., 2007](#)).

3.6.4 Innovations complementing SRS in light vehicles

Adaptive Driver assistance Systems have been confirmed to effectively prevent numerous avoidable accidents. [Yoshida et al. \(2004\)](#) explains how adaptive driver's assistance systems reduces drivers fatigue, by interactively displaying warning signs in foreseen dangers, and taking over the vehicle control to avoid collision which is called Autonomous driving. The framework for autonomous driving substantiated composes of: Adaptive Cruise Control (ACC), pre-crash braking, stop-and-go systems, crash avoidance assistance, lane keep support system and lane-departure warning system. The Adaptive Cruise Control system adapts to the driving speed of the preceding vehicle by controlling the distance between a vehicle and that ahead to avoid a rear collision. The Lane keep Support system (LKS) likewise tracks the white coated road lines by adapting to the road through image processing data capture vision sensors, mounted on the sides of the vehicle to keep it on track, thereby avoiding sudden deviation during driving.

4.0 Design of SRS for 3 wheelers

A typical 3 wheeled passenger transport vehicle and a variant used for delivery of light weight goods is shown in figure 9 and 10 respectively. Figure 10 is a Mahindra Alpha model which is designed with a more powerful engine than commonly available tricycles which have gained popularity in Asia and Africa due to ease of use, fuel economy, and sufficient volume of space for last mile delivery of goods for supporting e-commerce.

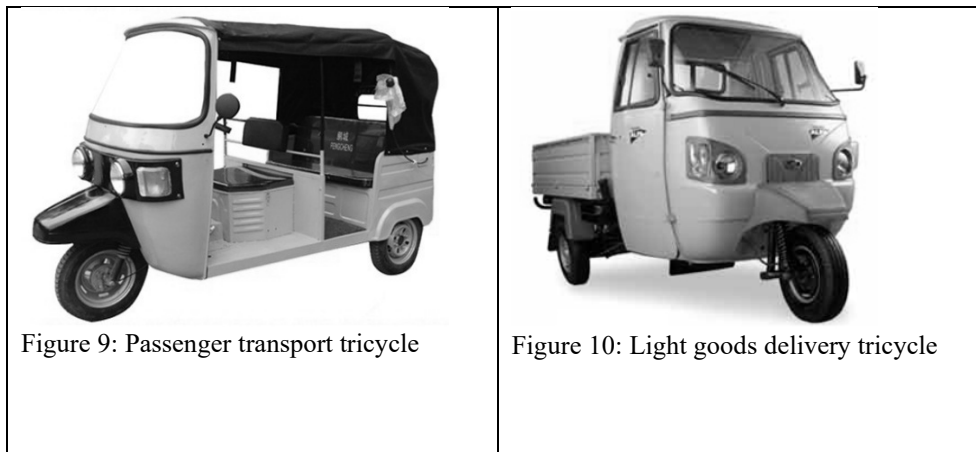


Figure 9: Passenger transport tricycle

Figure 10: Light goods delivery tricycle

Based on the structural design of wide variety of 3-wheel vehicles, comprehensive design considerations are required before selecting off the shelf SRS that may be applied. This is because the cabin space of tricycles varies significantly according to the purpose of use (passenger transport system, goods delivery system) thereby preventing the possibility of a one-size fits all system. Most 3-wheel passenger vehicles are partially open and have no provision for standard windows and frames. They are light weight and generally convey only 2 passengers per time except if designed with larger sitting dimensions. They are usually limited in height (about 1.3 to 1.7m) and many models are considerably cramped. They mostly have single- or double-cylinder engines and are widely used across Africa due to their high fuel efficiency, low purchase cost, and fewer transportation regulatory restrictions. Most of the last-mile logistics delivery vehicles have closed cabin compartment with defined side windows.

To design a suitable Supplementary Restraint System for tricycles, the design of a typical tricycle must be thoroughly analysed, and its mode of operation must be understood. Airbags must not be deployed without satisfying the conditions of an accident based on various parameters which include ride/drive speed during collision, sensor collision recognition algorithms, and the angle of tilt of the 3-wheel vehicle when the sensors pick up possible accident signals. For tricycles, it is difficult to design seat belt restraint systems typical of a motorcycle due to space constraints. As such, the pretensioner (seat belts) which is a supplementary restraint device aiding the airbags will have to be replaced with a different variant.

In terms of operations, the impact rough and uneven roads have on shocks and springs based on the maximum threshold of, camber angle while turning must be considered. This is because excessive camber deflection is not large enough to send crash signals.

5. Conclusion

Significant advances in automotive SRS industry from inception to date have been explored. The findings reveal major changes experienced in the airbag industry, from inception till date. The automotive industry attributes most of its safety innovations and vehicle improvement to the invention of the airbag. As a supplemental protection device, the airbag has been extensively researched and ongoing studies across the globe are mainly towards improving its overall performance and exploring its life saving potential. From the Federal motor vehicle safety standards data in Table 1, the 2 473 saved from the year 2012 alone out of a total of 12 074 lives saved within the survey period amounts to 20.5% of lives saved. Many of the improvements in airbags were witnessed after the late 90s and this partly suggest the reason for this achievement. Table 2 equally shows the complementary benefit, airbags contributed to the overall statistics of lives saved based on the fatality analysis report. The index shows that between the year 2008–2012, 11 682 lives were saved which was achieved within a 5 year period compared to the 12 074 lives saved from 1960–2002 (42 year period). We can deduce from the figures that airbags have progressively and consistently supplemented the seat belt and other vehicle safety devices.

Research is ongoing on the use of external airbags as presented in Figure 7 which promises to be the next breakthrough in reducing impact between colliding vehicles and vehicle-pedestrian collision (VPC). The sensitivity of the SRS control sensors has also witnessed tremendous improvements within the last 20 years. From the research, it was discovered that some commercial public passenger vehicles have not been given much priority in terms of airbag installation. A major source of intercity transportation system within Africa, Asia and part of the middle east is the tricycle; indeed the safety of this daily commuting transportation system should be explored because very little research work has been presented in this area. Scientists in Africa need to increase their involvement in vehicle safety research, based on the fact that most of the commercial tricycles and commercial buses with limited safety features are domiciled within the continent and all the airbag patents identified thus far, originate from Europe, Asia, Australia and America .

The fatalities and injuries experienced by poorly detonated airbags have been on the decline and this will further reduce as more innovations are evolving in the airbag industry. ‘In the upcoming years, innovations in smart airbag systems will be focused on special intelligent features, such as, automatic radioing for assistance and information about the location, severity and number of occupants involved in the crash, pre-tensioning the seat belts, switching off the fuel pump and other appropriate systems, among others. Future growth in the market will also be driven by continued investments in technology development and R&D as manufacturers seek newer air bag applications areas to offset the stabilizing opportunities in the mature front impact airbags sector’ ([Global-Industry-Analysts, 2012](#)).

Acknowledgements

The authors wish to express their appreciation to the Faculty of Engineering and Build Environment (FEBE) at the University of Johannesburg, South Africa for the research support. It also recognizes the support provided by the Royal Academy of Engineering, UK through an IAPP grant. The National Research Foundation (NRF) South Africa is equally recognized through the Thuthuka funding instrument TTK170513230840.

References

- Advantech (2013). *New process for molding airbag covers not just a lot of hot air*.
- Alcalá, E., Martínez, L., Rodríguez, C. J., López, A. and Neira, F. (2009). Analytical Matlab/Simulink model of pyrotechnical gas generators for airbags. *International Journal of Crashworthiness* **14**, 6, 641-657.
- Bandak, F. A., Chan, P. C., Ho, K. H. and Lu, Z. (2002). An experimental air bag test system for the study of air bag deployment loads. *International Journal of Crashworthiness* **7**, 2, 129-166.
- Bloch, B. (2001). The coming revolution in airbag technology. *Auto safety design* 98-S5-W-30, US, 1163-1174.
- Canterberry, J., Patel, K. J. and Lange, L. (2003). *Auto ignition for gas generators*. US.
- Charles, J. and J, K. C. (2004). Lives saved by the Federal Motor Vehicle Safety Standards and other vehicle safety technologies, 1960–2002 – passenger cars and light trucks – with a review of 19 FMVSS and their effectiveness in reducing fatalities, injuries and crashes. NHTSA Report Number DOT HS 809 833.

- Chawla, A. and Mukher, S. (2007). Motorcycle safety device investigation: A case study on airbags. *Sādhanā* **32**, 4, 427-443.
- Cirak, F. and Radovitzky, R. (2003). A new Lagrangian-Eulerian shell-fluid coupling algorithm based on level sets. *Collection of technical papers - AIAA/ASME/ASCE/AHS/ASC Structures, Structural Dynamics and Materials Conference* **2003**, 4, 2624-2628.
- Drean, E., Schacher, L., Adolphe, D. and Bauer, F. (2007). *Smart textiles for automotive: application to airbag development*. Springer.
- Drean, E., Schacher, L., Adolphe, D. and Bauer, F. (2008). Smart textiles for automotive: application to airbag development. *Experimental Techniques* **32**, 4, 44-48.
- Dunne, S. R. (2002). *OUP LLC-Process and apparatus for inflating airbags and remediating toxic waste gases*. US.
- Endo, J., Haji, Y., Azuma, T. and Maeno, Y. (2012). Development of low-cost airbag-ECU for emerging markets. *FUJITSU Ten technical Journal* **2012**, 37, 12-17.
- Fraunhofer-Institute (2001). Airbags with IQ. **2001**, 1, 1-2.
- Gabler, C. H. (2007). Characterization of advanced air bag field performance using event data recorders (EDR). *U.S. National Highway Traffic Safety Administration (NHTSA). Paper 07-0349*. US. 2007, 1-12.
- Glassbrenne, D. (2003). *Estimating the lives saved by safety belts and air bags*.
- Global-Industry-Analysts (2012). *Global automotive airbags market to reach 474 million units by 2017*. San Jose, California.
- Greenwell, N. K. (2013). *Pedestrian versus non-frontal fatalities: Evaluation of the certified-advanced air bags*. NHTSA. US.
- Gunnell, J. (2007). Standard catalogue of Jagua 1946-2005. *Krause publication*.
- Hinch, J., Hollowell, W. T., Kaniathra, J., Evans, W. D., Klein, T., Longthorne, A. and Ratchford, S. (2001). Airbag technology in light passenger vehicles. *Office of Research and Development National Highway Traffic Safety Administration (NHTSA)*
- Hirth, A., Haufe, A. and Olovsson, L. (2007). *Airbag simulation with LS-DYNA: past-present-future*. Anwenderforum. Frankenthal, Germany.
- Honda-Motor (2007). *CSR Report: Striving to be a company society wants to exist*. Honda Publishers. Japan.
- Honda-Motor (2013). *Striving to be a company society wants to exist*. Honda Publishers. Japan.
- Innovategroup (2010). *Fleet essence*. Sept. edn.
- James, M. B., Nordhagen, R. P., Warner, C. Y., Allsop, D. L. and Perl, T. R. (1997). Limitations of ATB/CVS as an accident reconstruction tool *Anthropomorphic dummies and crash instrumentation sensors* SAE Technical Paper 971045, 45-54.
- Khan, M. U. and Moatamedi, M. (2008). A review of airbag test and analysis. *International Journal of Crashworthiness* **13**, 1, 67-76.
- Lemov, M. R. (2015). *Car Safety Wars: One Hundred Years of Technology, Politics, and Death*. Rowman & Littlefield.
- Lim, J. M., Choi, J. W. and Park, G. J. (2010). Automobile side impact modelling using ATB software. *International Journal of Crashworthiness* **2**, 3, 286-298.
- Mabuchi, S., Kashio, A., Kanto, T., Sato, E. and Naruse, M. (2008). *Airbag apparatus and airbag folding method*, US Patent 7,396,042. US.
- Mahangare, M., Trepess, D., Blundell, M., Freisinger, M., Hoffmann, J. and Smith, S. J. (2006). A methodology for the simulation of out-of-position driver airbag deployment. *International Journal of Crashworthiness* **11**, 6, 511-517.
- Mcclafferty, K. and German, A. (2008). *High-Tech motor vehicle safety systems road safety research*. Whistler, British Columbia.
- Mccormick, L. W. (2004). *A Short History of the Airbag*.
- Miller, M. P. and Gu, H. (1997). *Sled Testing Procedure for side impact airbag development*, SAE technical Paper 970570. Detroit, Michigan.
- Mukherjee, S., Chawla, A. and Jangra, J. (2005). *Studies for motorcycle airbags*. Prague, Czech Republic.
- Nayak, R., Padhye, R., Sinnappoo, K., Arnold, L. and Behera, B. (2013). Airbags. *Textile Progress* **45**, 4, 209-301.
- Neill, B. O. (2009). Preventing Passenger Vehicle Occupant Injuries by Vehicle Design—A Historical Perspective from IIHS. *Traffic Injury Prevention* **10**, 2, 113-126.
- Nhtsa (2011). *Air Bags and On-Off Switches Information for an Informed Decision*. US.
- Nhtsa (2013). *Lives saved in 2012 by restraint use and minimum drinking age laws*.
- Padmanaban, J. and Fitzgerald, M. (2012). *Effectiveness of rollover-activated side curtain airbags in reducing fatalities in rollovers*. International Research Council on the Biomechanics of Injury. Dublin, Ireland.

- Partridge, J. and Mukhopadhyay, S. (2002). Automotive Textiles. *Journal of Textile Institute* **91**, 3, 397-409.
- Ruff, C., Jost, T. and Eichberger, A. (2007). Simulation of an airbag deployment in out-of-position situations. *Vehicle systems dynamics* **45**, 10, 953–967.
- Sandstroem J, H. A., Sjoeborg P. (1994). *Propellant for airbags*. Karlskoga, Sweden.
- Sawyer, C. (2012). *Developing Airbags*. Gardner Business Media.
- Scheck, L. F. (2005). *Mechanics: From Newton's Laws to Deterministic Chaos*. 4th edn. Springer.
- Schmitt, R. G., Butler, B. P. and Freesmeier, J. J. (1997). Performance and CO production of a non Azide airbag propellant in a pre-pressurized gas generator. *Combustion Sci and Tech* **122**, 1-6, 305-330.
- Smyth, B. J. and James, S. W. (2007). *Developing a sled test from crash test data*. Detroit, Michigan.
- Stein, D. J. (1997). *Apparatus and Method for Side Impact Testing*, SAE Technical Paper 970572. Society of Automotive Engineers, Inc. Detroit, Michigan.
- Summers, L., Hallowell, W. T. and C, R. G. (2001). NHTSA'S Advanced air bag technology research program *National Highway Traffic Safety Administration (NHTSA) United States, Paper no. 9865-W-29. US. 2001*, 1163-1174.
- Taylor, A. P., Benney, R. and Bagdonovich, B. (2001). *Investigation of the application of airbag technology to provide a soft landing capability for military heavy airdrop*. Boston, MA.
- Grimes, W.D. (1995). *Using ATB in collision reconstruction*, SAE Technical Paper 950131. SAE International. Detroit, Michigan.
- Walsh, C. M. (2003). *The USA rep. by Secretary to navy airbag propellant*. US.
- Wright, T. (2005). Air Bags Come To Aviation: Bringing automotive technology to the Cockpit. *Aircraft owners and pilots association publication*.
- Yoshida, T., Kuroda, H. and Nishigaito, T. (2004). *Adaptive Driver-Assistance Systems (DAS)*.
- Ziegahn, K., Haufe, A. and Franz, U. (2004). *On the simulation of out-of-position load cases with the ALE-method*. Karlsruhe, Germany.

Biographies

Mouchou TR. is a Mechanical Engineering PhD researcher and an academic member at the Mechanical & Industrial Engineering Technology Department at the University of Johannesburg South Africa. She has an engineering background with a Masters and Bachelor degree in Industrial Engineering. She has work experience in Industrial Engineer R&D in an industry and she is a member of the Engineering Council of South Africa (ECSA). She is passionate and focuses female researcher that has demonstrated her love for science and contribution to the 4IR.

Jen TC. is a Full Professor of Mechanical Engineering Science Department at the University of Johannesburg, South Africa. He is also the Director of Manufacturing Research Center at the University of Johannesburg, and very recently he has successfully established a joint UJ-Nanjing Tech Joint Research Center on Sustainable Materials Processing and Manufacturing. He was an interim Dean of College of Engineering and Applied Science from 2010 to 2012, and a Full Professor at Mechanical Engineering Department of University of Wisconsin, Milwaukee, USA. He received the prestigious NSF-GOALI award in 1999, which is the first of its kind that has been awarded to UWM. Due to his outstanding contributions to the field of thermal sciences, he was elected to the fellow status from the American Society of Mechanical Engineers (ASME Fellow) in 2011.

Laseinde OT. is an academic staff in Mechanical & Industrial Engineering Technology Department, at the University of Johannesburg South Africa. He has an engineering background with qualifications in Mechanical/Production engineering, and workplace experience in industrial engineering. He has vast experience in projects involving competitiveness improvement, quality management systems, performance evaluation, data analysis, engineering life cycle management, mechanical engineering machine design, and the application of Computer-Aided Design (CAD) for content development associated with virtual reality, robotics and automatic control. He has worked as an engineering consultant in Sustainability Development Goal's (SDG) projects for global organizations and is currently working as an academic within the teaching and research sector, where he is exploring avenues for pioneer innovations in the fourth industrial revolution.