Hindawi
Journal of Robotics
Volume 2019, Article ID 3927935, 12 pages
https://doi.org/10.1155/2019/3927935

Research Article

A Study of Damage Patterns on Passenger Cars Involved in Road Traffic Accidents

Joseph Kurebwa and Tawanda Mushiri

Department of Mechanical Engineering, University of Zimbabwe, Faculty of Engineering, PO Box MP167, Mt Pleasant, Harare, Zimbabwe

Correspondence should be addressed to Tawanda Mushiri; tawanda.mushiri@gmail.com

Received 31 May 2018; Accepted 18 December 2018; Published 2 January 2019

Academic Editor: L. Fortuna

Health emergencies occur in passenger cars where victims do not have immediate access to either layperson or professional, proper medical services, resulting in deterioration of their health or death. Installation of robotic first aid system for passenger-car occupants has been proposed. This study is part of a larger work of designing the system and seeks to identify the safest location inside the vehicle for it to survive any form of impact in a crash and retain the ability to assist the victims. The study population comprised 70 passenger cars (14 automakers across 7 segments) involved in road traffic accidents, which had been recovered by a roadside vehicle assistance company based in Harare, Zimbabwe, and were on the company's premises on September 23rd, 2017. Vehicle damage was rated considering direction of force in comparison to a clock-point diagram, area damaged, and the damage severity on a scale of 1 to 7, following an official vehicle damage guide for traffic crash investigators. Data were analysed in Microsoft Office Excel 2016. In cases where vehicles were damaged in more than one area, all areas were recorded, hence 95 points of impact were analysed. Damage direct to the front denoted by 12 on the clock-point was the most common at 26%. This was compatible with the rate of frontal damage on vehicles, which was the highest at 51%, followed by the right and left sides that had 22% and 19%, respectively, the rear at 6%, and lastly the top (due to 2 recorded rollovers) at 2%. 56% of the damaged areas had a severity rating of either 5, 6, or 7. By eliminating all areas which had received damage in the study population, the robotic first aid system's best chances of car crash survival are at the middle, towards the floor of the vehicle. It is advisable that the system does not depend on components in the proximity of the vehicle's body as they are prone to damage in crashes. There is need for further research into the magnitude of impact that could reach the middle of different vehicles to define the strength of the robotic first aid system.

1. Introduction

1.1. Background. Worldwide, road traffic accidents (RTAs) kill 3,000 people every day and injure over 3 million every year [1]. However, the odds are getting better with the advent of autonomous driving. The consensus in the automotive industry is that autonomous vehicles (AVs) are the way to go for safer transportation, among other reasons [2]. In comparison to the myriad of faults human drivers exhibit while being behind the wheel, a computer is the ideal motorist [3, 4]. Likewise, robots show strong potential to transcend the limitations of human healthcare in surgical procedures [5, 6]. Similar to AV technology, robotic surgery is marred with scientific, legislative, and socioeconomic challenges [7–19], but it is evident that the idea of robotics and artificial intelligence (AI) envisaged in the concepts seems to be in the right direction for public health.

Vehicle safety is considered one of the key selling points by most automotive brands and car buyers alike [20, 21]. As such, a lot of effort is being put into the research and development of vehicle safety features by automakers, governments, and other players concerned within road transport safety. However, fatalities and injuries due to road traffic accidents continue to soar in some regions of the world, especially low- and middle-income countries, and road traffic injuries are a leading cause of preventable death [1, 22–24]. In addition to road traffic injuries, passengers may also suffer nontraumatic medical emergencies including cardiovascular and respiratory complications [25–27]. Human intervention in the form of first aid given to victims of RTAs is known to preserve life, prevent further harm, and promote recovery in most cases [28–31]. Of course, it works only when given properly, and the sad truth is that there are high chances of victims not getting proper help for reasons including absence of bystanders, responders fearful of legal action should they make mistakes, and entrapment of victims in the wreckage, thus being inaccessible [29, 32–38]. Getting help and getting it fast is the key to surviving a major-medical emergency, such as a trauma with serious injury, a stroke, or a heart attack. It is against this background that the researchers are convinced that an on-board robotic first aid (RFA) system in all passenger cars is an avenue worth exploring.

Robotic first aid is still in its infancy in terms of development and implementation, and so far there is no such research exclusive to passenger-car on-board systems. However, the few researches carried out so far envision faster and better quality first aid through human-robot integration [41–44]. Axiomatically, the RFA will ipso facto only work given that it survives the RTA without any damage. It is necessary, therefore, to study damage patterns on vehicles involved in RTAs to identify the safest location of the RFA system in the vehicle. To explore the design of a robotic first aid system for passenger-car occupants, a survey instrument was developed to gain deeper insight into key questions including the following:

(1) Which parts of the vehicle are most prone to damage in RTAs?

(2) What auxiliary units (that could possibly assist the RFA system in operation) are prone to damage in RTAs?

(3) Where should the RFA system be placed for minimal disturbance in RTAs?

(4) Are there any disparities in damage patterns in relation to the vehicle's physical characteristics?

Answer to these questions and more will provide a foundation of specifications for the RFA system.

1.2. Definitions

(i) Damage patterns refer to the distribution of physical harm that impairs the value, usefulness, or normal function of a motor vehicle.

(ii) A passenger car is a road motor vehicle, other than a motor cycle, intended for the carriage of passengers and designed to seat no more than nine persons (including the driver) (Eurostat, ECMT and UNECE, 2002; Collins English Dictionary, 2017).

(iii) A road traffic accident (RTA), also called a motor vehicle collision (MVC) among other terms, is the occurrence where a vehicle collides with another vehicle, pedestrian, animal, road debris, or other stationary obstruction, such as a tree, pole, or building.

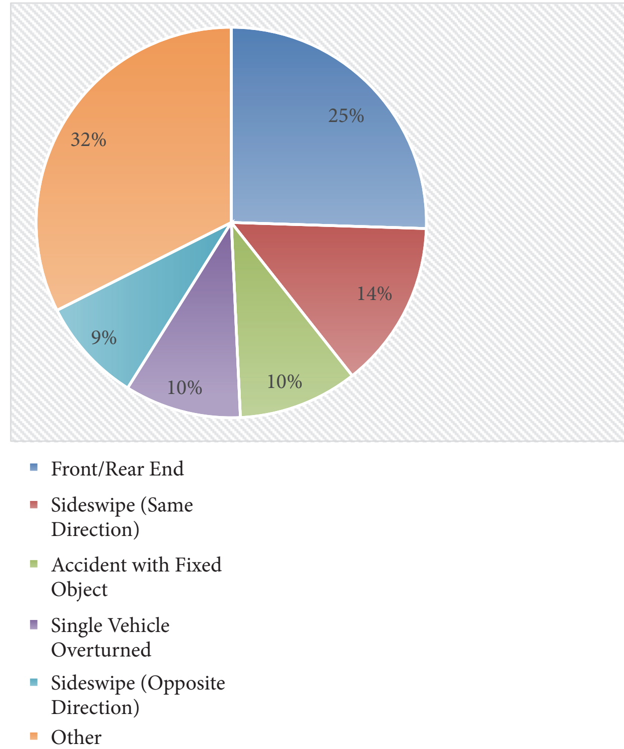


Figure 1: The frequency distribution of road traffic accident typed recorded [39].

1.3. Literature Review

1.3.1. Types of Crashes. A study was carried out on the R44 road in Western Cape, South Africa, to investigate the causes of road accidents [39]. The results were obtained from 404 accident reports which had occurred along a 25 km stretch of the road from 1999 to 2003. 14 accident types, shown in Figure 1, were observed. The most frequent RTAs were primarily front- and rear-end impacts, followed by sideswipes.

These findings resonate with those in another study, which presented descriptive statistics about RTAs, including the types of vehicles involved in crashes and the damage to the vehicles [45]. More than 94 percent of the 11 million vehicles involved in motor vehicle crashes in 2005 were passenger cars or light trucks. Regardless of crash severity, most vehicles in single- and two-vehicle crashes were going straight prior to the crash. The next most common vehicle manoeuvre differed by crash severity: negotiating a curve for fatal crashes, turning left for injury crashes, and stopped in traffic lane for property-damage-only crashes. Frontal collisions were the most common, followed by side and rear impacts. The findings of the data analysis regarding damage severity and points of impact are summarised in Figure 2.

1.3.2. Vehicle Characteristics as a Factor of Damage. A study was conducted to determine the patterns of use, collision types, and injury outcomes, comparing large and small cars in real world crashes [40]. It categorised impact direction

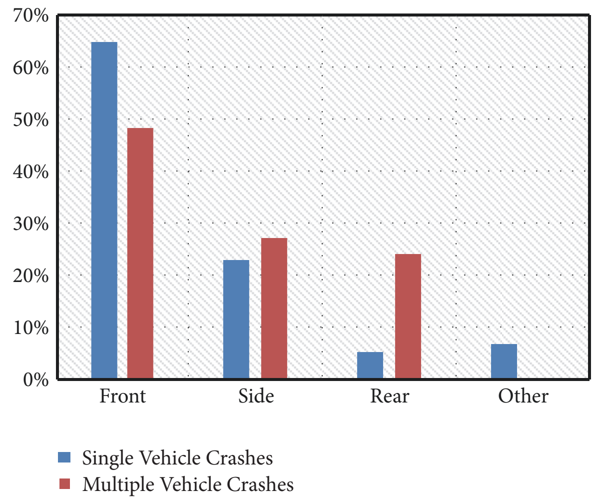


Figure 2: Frequency distribution of passenger cars involved in crashes by initial point of impact and crash type.

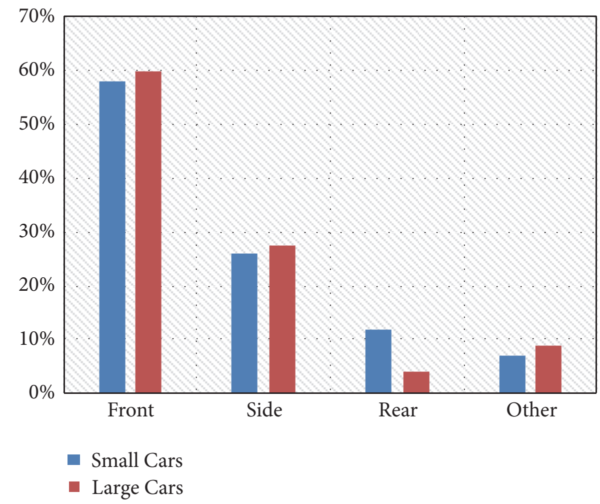


Figure 3: Primary impact direction in relation to vehicle type as studied by [40].

in RTAs as front, side, rear, and rollover judging from the principal direction of force and the surface contacted. The distribution of direction is shown in Figure 3 for small and large cars. It was observed that small cars were involved in similar rates of frontal and side impacts. However, 12% of small cars were involved in rear impacts compared to 4% of large cars. One factor that may have influenced this outcome is that small European cars are frequently of the hatchback type (A or B segment), meaning that there is a reduced crush space available before the car becomes immobilised.

The patterns in the study are reiterated by a survey of vehicles involved in RTAs which was conducted to examine the types and extent of vehicle damage sustained in front and rear collisions [46]. Since the data were obtained from motor vehicle insurance companies, vehicle damage was reported in terms of insurance claims. The mean damage claims were higher for small cars ($949) than for sport utility vehicles (SUVs) ($925) or minivans ($877). From this, it can be concluded that small cars sustain more severe damage in RTAs than SUVs and minivans, which are larger in size.

1.3.3. Power Problems to Autonomous Vehicles. While all these efforts are being carried out, it is also necessary to note the power usage by the car. The model obtained [47] is being exploited as a component of complex control systems able to manage the energy flows between fuel cell stack, battery pack, auxiliary systems, and electric engine in a zero-emission vehicle prototype. One cell cannot power an engine and it is important that a well-organised manner is devised to connect the cells so that powering is done. This is generally called a hybrid battery system and the battery works to its maximum power; hence, this will be useful if done in this research paper. In particular, for nonlinear modeling purposes as what is noticed also in this vehicle study and damage patterns, a multilayer perceptron has been adopted [47]. The model obtained does not rely on a single cell modeling, instead providing a macro-model of the whole stack. The resulting dynamic model relies on inputs which are easily measurable quantities, like reactant pressures and stack temperature. Data is trained in Artificial Neural Networks (ANN) and this will help for data storage and ease of use for the vehicle. Power is of huge concern in this research and this method is very useful.

1.3.4. Driving Assistance Using Smart Devices. For drivers' safety, it is very important to use smart devices for assistance in case they lose concentration or a general problem occurs to the car or the driver [48]. Two algorithms which can be easily implemented in a smart device and make use of standard on-board sensors, such as the camera and the accelerometer, were described. The first exploits the high performance in image processing of Cellular Nonlinear Networks to detect the occurrence of blinking eyes during driving, which can be associated with a state of fatigue of the driver. The second algorithm addresses the problem of brusque braking in order to enhance the capabilities of existing braking assistance devices [48]. The obtained experimental results assess the capabilities of the proposed algorithms and their effectiveness in increasing driver safety at a low cost. This will be a useful way to reduce accidents in this time of industry 4.0 and its applications.

2. Materials and Methods

2.1. Study Setting. The study took place at the premises of a roadside vehicle assistance company based in Harare, capital of Zimbabwe. The site was chosen for the variety of vehicle brands, damaged areas, and severity of the damage, which give a wide spectrum of effects a random RTA could have on the RFA system.

2.2. Study Population. The study population comprised 70 passenger cars involved in RTAs, which had been recovered

Table 1: Vehicle damage rating components.

Vehicle Damage Rating		
XX	ABC	Y

(i) **XX** described the direction from which the vehicle damage was received resembling numbers on a clock (1–12). It was shown with a 1– or 2–digit numeric character,
(ii) **ABC** described the area of the vehicle that received damage, reported with a 2 or 3 alpha character code.
(iii) **Y** described the severity of the damage received and was reported with a single–digit numeric character between 0 and 7.

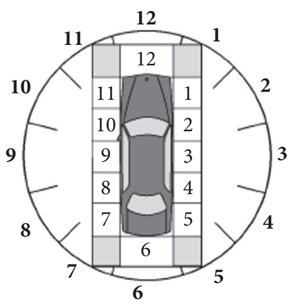


Figure 4: The passenger-car clock-point scale used to determine the direction of force in the crash.

by roadside vehicle assistance company, and were on the company's premises on September 23rd, 2017.

2.3. Data Collection. All the required data was collected by the researchers on the same day from 1050 hrs to 1315 hrs CAT, by filling out forms that required entries for the vehicle make, model, year of manufacture, and segment. More importantly, there were columns for the damage rating as illustrated in Table 1. The rating scales for all the components describing the damage were guided by the system developed by the Texas Department of Transportation in accordance with the American National Standards Institution (ANSI) D16.1 standard. The guide was selected because it was readily available online and it was observed to be adequate in assisting the researchers to correctly and accurately assess the damage sustained by passenger cars in RTAs. Raw data collected are shown in Appendix A.

2.3.1. Determining the Direction of Force. To determine the direction of force, the researchers imagined a superimposed circle around the vehicle, with numbers 1 to 12 as on a clock. Each number represented a direction or angle in which the vehicle may have received damage. Figure 4 shows the number value indicating direction of force for passenger cars.

The clock-point diagram shown in Figure 4 shows direction of force for a passenger car. For instance, the direction of force for a vehicle involved in a head-on collision where force was received by the front of the vehicle would be a 12. Direction of force for a vehicle receiving damage directly from behind would be a 6. A perpendicular hit to the right side of the vehicle was shown as a 3 and a perpendicular hit to the left side was a 9.

Figure 5 shows the population of cars affected by the RTA's. Toyota is at the top that shows the highest population not because it is highly involved in accidents but generally the cars are many followed by Nissan in that order.

2.3.2. Determining the Point of Impact. The guide had a Vehicle Damage Index with diagrams of cars and arrows showing the directions of the principal impact force. These were accompanied by a detailed description of the type of damage associated with the impact. Corresponding damage description codes were also listed in the guide as shown in Table 2. In cases where vehicles were damaged in more than one area, the researchers entered the descriptions of all damaged areas, beginning with the area showing the most severe damage.

2.3.3. Determining Severity of Damage. A Vehicle Damage Scale in the guide was used by the researchers to determine the severity of damage to passenger cars involved in RTAs. The Vehicle Damage Index mentioned before determined the scale to which the researchers referred for damage resulting from specific types of crashes. The next step was to compare the damage on the vehicle with a photograph on the selected page of the Vehicle Damage Scale. If, for example, the front-end damage on the first vehicle appeared to match that on the bottom photograph on the page labelled "BC" (rear-end damage, concentrated impact), the damage description and severity rating would be "BC-6". However, if the damage was more severe than the damage in the photo adjacent to "BC-6", the damage description and severity rating of "BC-7" was used, and if less severe, but greater than "BC-4", the rating was "BC-5".

2.4. Data Analysis. Entries for each vehicle were added chronologically to a Microsoft Office Excel 2016 worksheet. For vehicles with damage to multiple areas, the make, model, year, and segment were entered on the first row only and the rest were left blank. Otherwise, each row of the spreadsheet represented a subject. This insured that the number of vehicles investigated was not inflated when the "COUNTIF" function was called.

In creating data tables, independent variables, such as vehicle make and direction of impact, were entered manually. Dependent variables (Frequency) were computed using the "COUNTIF" function, which counted the number of cells that met a certain criterion. For example, to count the number of vehicles in the J segment, the formula was entered as

=COUNTIF($D$3:$D$93,L23)

in cell M23. The formula in this instance counted the number of cells with "J" (the value in L23) in cells D2 through D93. The frequency distribution was obtained by the formula:

=M23/SUM ($M$19:$M$25),

again referring to the J segment instance. The "SUM" function added cell values in the range from M19 to M25, which amounted to all study subjects (70).

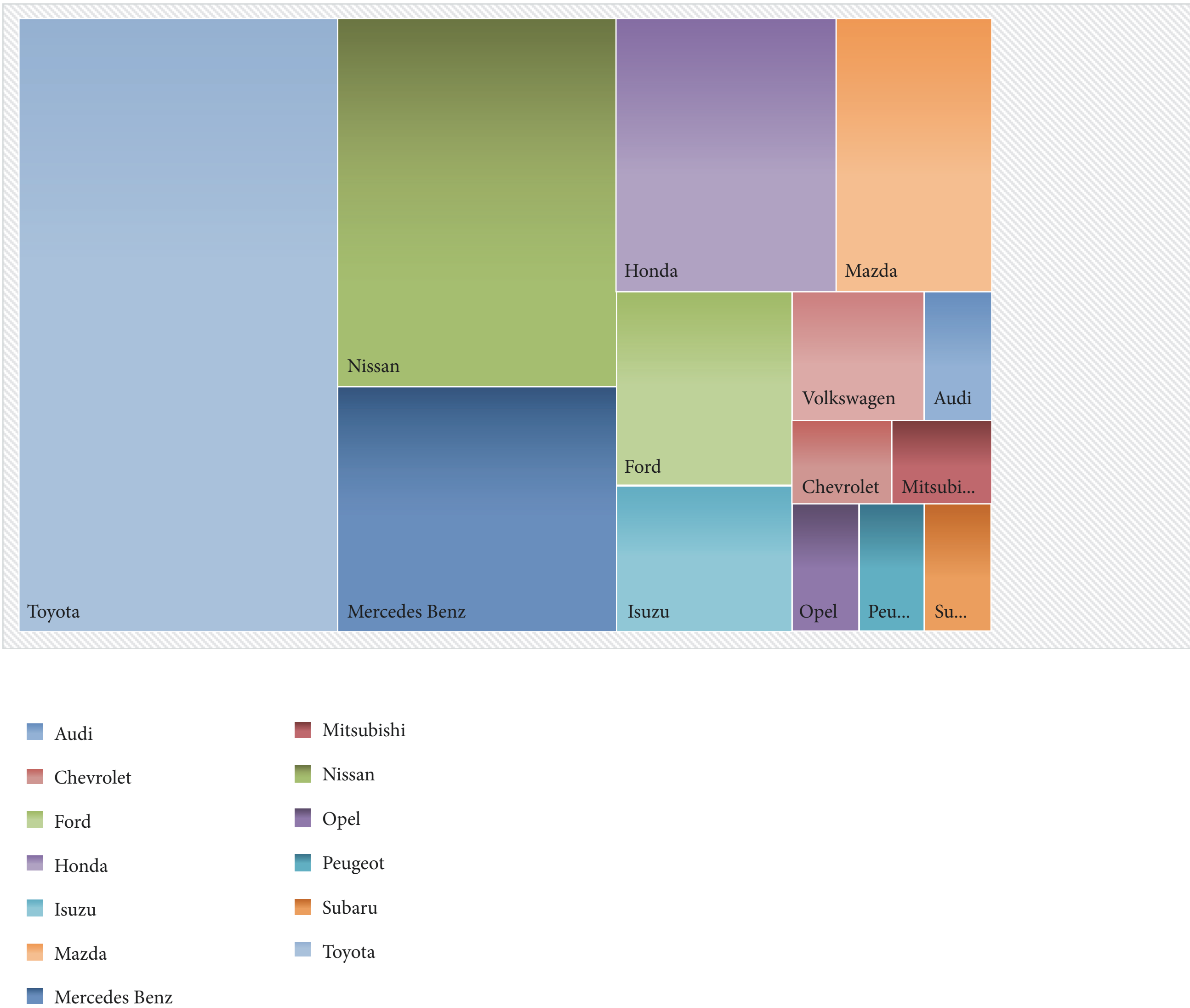


FIGURE 5: Population distribution by type of car.

TABLE 2: A representation of the diagrams, nomenclature, and corresponding descriptions used to determine the points of impact.

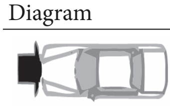
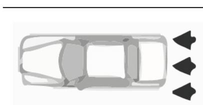
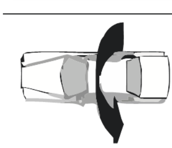
Diagram	Type of Impact	Description
	Front end damage due to concentrated impact resulting from collision of subject vehicle with tree, utility pole, or other narrow objects.	FC
	Rear end damage due to distributed impact resulting from full contact of rear end of subject vehicle with another vehicle or object. Applicable to rear-end collisions.	BD
	Left side and top damage due to rollover. Right side and top damage due to rollover.	LT RT

Table 3: Vehicle make frequency distribution.

Vehicle Make	Frequency	Frequency Distribution
Audi	1	1%
Chevrolet	1	1%
Ford	4	6%
Honda	7	10%
Isuzu	3	4%
Mazda	5	7%
Mercedes Benz	8	11%
Mitsubishi	1	1%
Nissan	12	17%
Opel	1	1%
Peugeot	1	1%
Subaru	1	1%
Toyota	23	33%
Volkswagen	2	3%
Total	70	100%

Table 4: Vehicle segment frequency distribution.

Passenger Car Segment	Frequency	Frequency Distribution
B	6	9%
C	16	23%
D	9	13%
E	5	7%
J	9	13%
MPV	9	13%
Pick-Up	16	23%
Total	70	100%

Appropriate charts were inserted for all tabulated data combinations.

In creating the modified clock-point in Figure 10, the opacity of the representative blocks' transparency was directly proportional to the probability of the event occurring. This probability was obtained by treating direction of force and point of impact as two independent events. Since each direction on the clock-point scale can only result in impact on one side (for 12, 3, 6, 9) or two sides for diagonal directions, the probability of impact was calculated theoretically using the length and width of the vehicle.

For instance, a vehicle in motion in the "2" direction relative to an obstacle could have been damaged on either the front or the right side. If a and b were the projections of width and length in the direction of 2, the projected width would be $a * \sin(30^{\circ})$ and projected length $b * \cos(30^{\circ})$. The probability of impact frontal impact would then be $a/(a+b)$. It is assumed that if the study population was large, the experimental results would match the theoretical ones.

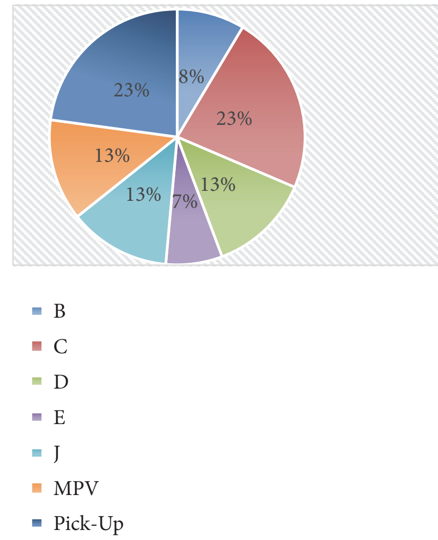


Figure 6: Distribution of the study population according to vehicle segment.

3. Results

A total of 70 passenger cars were inspected and their damage following RTAs was recorded. The population consisted of 14 automotive brands distributed as shown in Table 3. Toyota was the most frequent brand constituting 33%, followed by Nissan and Mercedes Benz at 17% and 11%, respectively.

3.1. Distribution by Vehicle Segment. Vehicle classification was guided by Euro Car Segment standards. Pick-ups and medium cars (Pick-up and C segments, respectively) were the most common at 23% each. These were followed by large cars (D), SUVs, and multipurpose vehicles (MPVs), which constituted 13% of the population each. Small cars (B segment), e.g., Volkswagen Polo, made up 9% of the study population. Executive cars (E segment) were the least frequent segment present, constituting 7%. These data are presented in Table 4 and Figure 6.

3.2. Distribution by Direction of Impact. The direction of impact was dominated by 12 on the clock-point scale for passenger cars. 26% of the impacts observed were direct to the front of the vehicle (12). 1 and 11 directions had equal numbers of impacts recorded at 18% each. The rest of the distribution is shown in Table 5 and Figure 7.

3.3. Distribution by Point of Impact. Corresponding to the distribution of direction of impact, frontal damage (denoted by F) was the most common, constituting 51% of all impacts. Damage to the right side of the vehicle (R) was ranked as second at 22%, while the left (L) was third with 19%. 6% of the recorded impacts were to the rear or back of the vehicle (B). Two vehicles had rolled-over, meaning that 2% of the damage recorded was to the top (T). It may be noted that the total number of impacts recorded under direction of force is two less than that for points of impact, a difference which is

Table 5: Direction of force frequency distribution.

Direction of Impact	Frequency	Frequency Distribution
1	17	18%
2	5	5%
3	6	6%
4	3	3%
5	2	2%
6	4	4%
7	6	6%
8	0	0%
9	3	3%
10	6	6%
11	17	18%
12	24	26%
Total	93	100%

Table 6: Point of impact frequency distribution.

Point of Impact	Frequency	Frequency Distribution
F	48	51%
B	6	6%
L	18	19%
R	21	22%
T	2	2%
Total	95	100%

Table 7: Severity of damage frequency distribution.

Severity of Damage	Frequency	Frequency Distribution
1	4	4%
2	8	8%
3	12	13%
4	18	19%
5	16	17%
6	11	12%
7	26	27%
Total	95	100%

accounted for by the two incidences of damage to the top of the vehicle in rollovers that could not be represented by the clock-point scale. This is shown in Table 6.

3.4. Distribution by Severity of Damage. The most severe damage on the vehicle damage scale was the most frequent, constituting 27%. Ratings 5 and 6 had made up 17% and 12%, respectively. 19% of the damaged areas investigated were given a rating of 4, while ratings of 1, 2, and 3 constituted 4%, 8%, and 13%, respectively. This is shown in Table 7 and Figure 8. Figure 9 shows the frequency distribution by the severity of damaging and 7 is has the highest frequency.

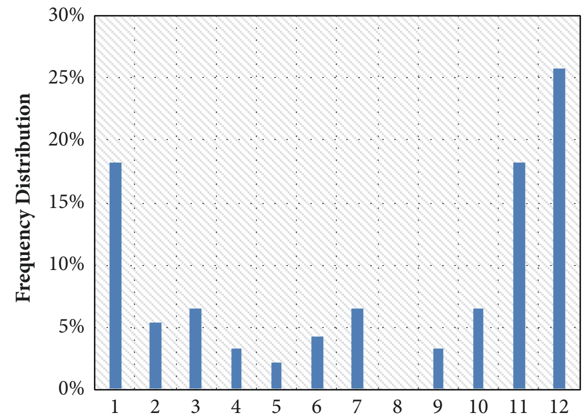


Figure 7: Frequency distribution by direction of force.

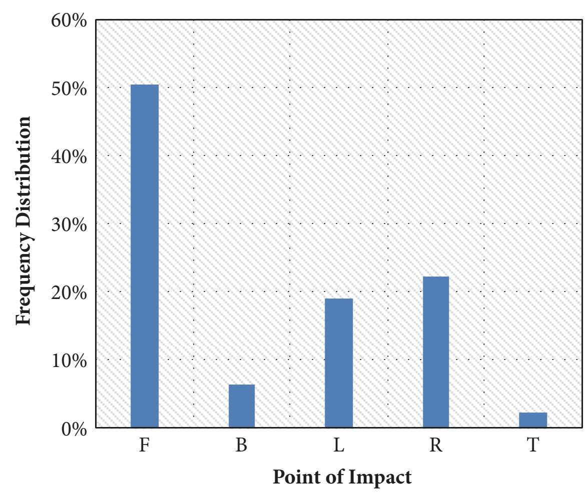


Figure 8: Frequency distribution by point of impact.

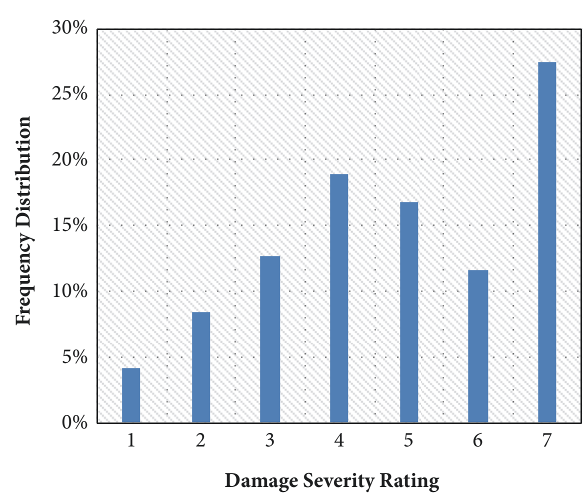


Figure 9: Frequency distribution by severity of the damage.

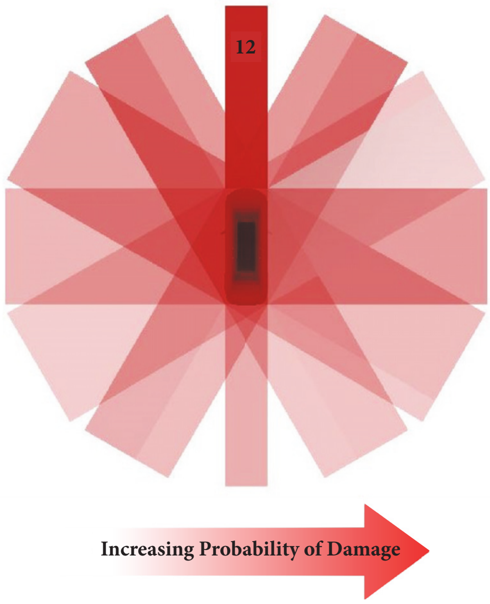


Figure 10: A modified clock-point scale showing the probability of damage for various directions and severity.

Figure 10 shows the frequency distribution by severity of damaging.

3.5. Probability of Damage Distribution. The summary of the frequency distribution of direction of force, point of impact and severity is presented in.

4. Discussion

Health emergencies occur in passenger cars where victims do not have immediate access to either layperson or professional, proper medical services, resulting in deterioration of their health or death. Studies have shown that human intervention in the form of first aid given to victims of RTAs can preserve life, prevent further harm, and promote recovery in most cases. Of course, it works only when given properly, and the sad truth is that there are high chances of victims not getting proper help for reasons including absence of bystanders, responders fearful of legal action should they make mistakes, and entrapment of victims in the wreckage, thus being inaccessible. A robotic first aid system has therefore been proposed by the authors for installation in passenger cars. The usefulness of the robotic first aid system depends on its survival of RTAs, yet damage patterns on passenger cars involved in RTAs remain unclear. Identification of areas on the vehicle that are most prone to damage in RTAs will facilitate definition of specifications and parameters for the robotic first aid system, including location and size.

In this study, the researchers investigated the damage on passenger cars involved in RTAs. Information obtained included the direction of force or impact, the point of impact, and severity of the impact on all damaged areas. Damage rating was guided by the Vehicle Damage Guide for Traffic Crash Investigators published by the Texas Department of Transportation, USA. The various vehicle segments and accident types studied represent a variety of common impacts that the robotic first aid system should not be exposed to or at least should survive with minimal damage. The most common and severe damage was to the front of the vehicle, followed by the rear and sides. This finding confirms the results from studies in the literature. Moreover, the whole body of the car, including the roof, was found vulnerable to the most severe damage on the damage rating scale. It is therefore advisable to place the robotic first aid system away from the periphery of the vehicle. Axiomatically, all components near the vehicle's body are also prone to damage and incapacitation.

From the 70 vehicles studied, two rollovers were recorded, one on an SUV and the other on a pick-up truck. Studies in the past have also shown that such vehicles have a higher propensity to rollover than smaller, lighter cars. However, this does not dismiss the possibility of such crashes in smaller vehicles, and the roof should also be avoided in placement of the RFA system.

Having discredited all four sides of the vehicle as well as its roof, the safest place for the RFA system is in the middle of the car, closest to the floor as possible. Furthermore, components which are essential to the operation of the RFA system should be placed in the same manner. For instance, the RFA system will require a power source for it to carry out its tasks. It is not advisable to design one which draws power from the vehicle's main battery, which is in an area with the highest probability of damage, the front, lest it is damaged or disconnected upon impact and renders the RFA system useless.

4.1. Limitations. The study was limited by the data collection method of visual inspection. Research shows that the information generated by human inspection is mostly qualitative and thereby subjective [49]. Moreover, vehicle damage ratings were heavily dependent upon the skill and judgement of the researchers, who had no experience or training in the process. A more experienced car crash damage assessor could have obtained different results. Therefore, there may be little consistency between different inspectors. However, the consistency of the researchers in using the vehicle damage indices on various vehicles is high and subjectivity can be neglected.

In addition to this, the researchers did not utilise exceptions outlined in the Vehicle Damage Guide. These were to be referred in cases where vehicles had acquired damage from occurrences besides the types of impacts described in the damage description table. For instance, some vehicles had sustained top damage only but were classified under side-parallel or angular impact. Hence damage was not correctly assessed and accurately recorded in these instances. Although the data collected may not accurately describe the damage on a vehicle, they do highlight the areas damaged, which is what is required in the parent-work to this study, the design of a RFA system.

5. Recommendations and Conclusion

This research aimed at studying vehicle damage patterns on passenger cars involved in road traffic accidents and is part

Table 8

Vehicle No.	Make	Model	Year	Segment	XX |ABC| Y	Impact No.
1	Nissan	Navara	2007	Pick-Up	12FD3	1
2	Mercedes Benz	C240	1999	D	12FC4	2
3	Ford	Ranger	2008	Pick-Up	1RD1	3
4	Nissan	NP300	2005	Pick-Up	1FC5	4
5	Mercedes Benz	E200	2003	E	1FC4	5
6	Toyota	Corolla	2002	C	2FD6	6
					6BD3	7
7	Toyota	Spacio	2000	MPV	12FD4	8
8	Toyota	IST	2001	B	11LF5	9
					9LP2	10
9	Nissan	Hardbody	2005	Pick-Up	2RD4	11
10	Toyota	Corolla	1997	C	1FC7	12
11	Honda	Fit	2001	B	11FC4	13
12	Honda	Legend	2006	E	7BC5	14
					12FD4	15
13	Toyota	Allex	2000	C	1FC6	16
14	Mercedes Benz	C200	1999	D	12FC4	17
15	Toyota	LC J70	2009	J	10LD4	18
					3RD2	19
					1RD1	20
16	Mazda	Familia	2000	C	11FC3	21
17	Opel	Astra	2001	C	11FC4	22
18	Mercedes Benz	E320	2002	E	11FC7	23
19	Mercedes Benz	C200	1999	D	12FD2	24
10	Nissan	Sunny	1995	C	12FD4	25
21	Audi	A4	2001	D	11FC5	26
22	Peugeot	406	1998	D	6BC4	27
					1RD1	28
23	Honda	Odyssey	2003	MPV	6BC7	29
					11FC6	30
24	Isuzu	KB300	2014	Pick-Up	12FD7	31
25	Honda	Fit	2001	B	12FD2	32
26	Toyota	Nadia	1998	MPV	12FC7	33
27	Ford	Ranger	2009	Pick-Up	1LD3	34
28	Toyota	Vitz	2005	B	12FD7	35
29	Nissan	Navara	2003	Pick-Up	3RT7	36
					10LT5	37
					12FC2	38
30	Mazda	BT50	2015	Pick-Up	2RD5	39
					9LBQ1	40
31	Honda	Elysion	2004	MPV	7BC6	41
					12FD6	42
					9LP3	43
					3RBQ2	44
32	Nissan	Bluebird	2001	D	12FC6	45
33	Nissan	Hardbody	1995	Pick-Up	3RP7	46
34	Volkswagen	Polo	1998	B	11FC3	47
35	Mitsubishi	Pajero	1996	J	10LT7	48
36	Toyota	Ipsum	2000	MPV	11FC4	49
37	Mercedes Benz	E320	2003	E	12FD4	50

Table 8: Continued.

Vehicle No.	Make	Model	Year	Segment	XX |ABC| Y	Impact No.
38	Toyota	Corolla	1999	C	4RD7	51
					2RD7	52
39	Nissan	Sunny	1991	C	12RC7	53
40	Ford	Ranger	2015	Pick-Up	1FD7	54
					7LBQ3	55
41	Toyota	Chaser	2000	E	1FC4	56
42	Honda	CR-V	1995	J	11FC7	57
43	Mazda	Eagle	2006	Pick-Up	2RFQ7	58
44	Toyota	Ipsum	1996	MPV	1FD7	59
45	Mazda	Tribute	1995	J	3RBQ5	60
					11LD3	61
46	Toyota	Corolla	2001	MPV	12FC6	62
					10LP3	63
47	Toyota	Raum	2003	MPV	3LP7	64
48	Isuzu	KB72	2005	Pick-Up	11FC6	65
49	Nissan	Rasheen	2000	J	12FC5	66
50	Nissan	X-Trail	2001	J	12FD7	67
51	Mazda	B2200	1991	Pick-Up	1FD7	68
52	Isuzu	KB280	2001	Pick-Up	1RD7	69
					11FD5	70
					10LP4	71
53	Toyota	Corolla	2003	C	11LFQ2	72
54	Mercedes Benz	C200	1002	D	5RP5	73
55	Chevrolet	Aveo	2008	B	7LBQ5	74
56	Honda	Civic	2002	C	6BC6	75
					10LFQ5	76
57	Nissan	Elgrand	2001	MPV	12FC5	77
58	Toyota	Corolla	2002	C	11FD4	78
59	Toyota	Allion	2004	C	12FD3	79
60	Toyota	Belta	2008	C	1FC3	80
61	Ford	Ranger	2012	Pick-Up	1RFQ5	81
62	Mercedes Benz	C200	1998	D	12FC5	82
63	Toyota	Hilux Surf	1997	J	7LRQ2	83
64	Toyota	Runx	2003	C	12FC4	84
65	Volkswagen	Golf	2004	C	11LD3	85
66	Nissan	Sunny	1995	C	1FD7	86
					7BD7	87
67	Toyota	Hilux	2007	Pick-Up	1FC7	88
					4RBQ6	89
68	Toyota	Progress	1998	D	12FC5	90
69	Toyota	LC Prado	2003	J	11FC7	91
70	Subaru	Forester	2005	J	5RD6	92
					4RFQ4	93

of larger work of designing a robotic first aid system for passenger-car occupants. The robotic first aid system should survive road traffic accidents; thus, it should be in the safest place available in the vehicle. The front of the vehicle is the most vulnerable in car crashes, with the highest probability of severe damage in crashes. The sides and rear are also prone to damage in car crashes although to a lesser extent. The front, rear, sides, and roof, therefore, should be avoided to minimise chances of damage. Furthermore, it is advised that the system does not depend on components in the proximity of the vehicles body for its operation. Damage of such components could render the system useless when it is needed the most.

This leaves the middle of the vehicle, away from the roof and towards the floor. However, although damage reaching the middle of the car was recorded on a few instances, there is need for further research into the magnitude of impact that could reach the middle of different vehicles to define the strength of the robotic first aid system. As the study has demonstrated, the robotic first aid system should be modular, self-sufficient, and structurally sound. For future studies, it is important and necessary to consider bigger cities and confusion that can lead to accidents. Indeed in high confusion big city a traffic model could be approached and to it to relate possible accidents [50]. It is topical indeed where most cars are being designed in mass production, population is increasing, and everyone is hurrying up to arrive in time that congestion becomes a major issue [50]. In particular, they suggested a cellular automata model on a complex network to simulate the motion of vehicles along streets, coupled with a congestion aware routing at street crossings. Such routing makes use of the knowledge of agents about traffic in nearby roads and allows the vehicles to dynamically update the routes towards their destinations. By implementing the model in real urban street patterns of various cities, they showed that it is possible to achieve a global traffic optimization based on local agent decisions. This will be important to reduce accidents and is of concern and can be considered in the future.

Appendix

A. Raw Data

See Table 8.

Nomenclature

AI: Artificial Intelligence
AV: Autonomous Vehicle
RFA: Robotic First Aid
RTA: Road Traffic Accident
SUV: Sport Utility Vehicle.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this article.

Acknowledgments

This work was supported by a roadside vehicle assistance company. The views and conclusions expressed in this paper are those of the authors and have not been sponsored, approved, or endorsed by the organisation.

References

[1] World Health Organisation, *Global Status Report On Road Safety*, Geneva, Switzerland, 2015.

[2] G. Silberg and R. Wallace, *Self-driving cars: The next revolution*, KPMG, USA, 2012.

[3] National Highway Traffic Safety Administration, *An Analysis of recent improvements to vehicle safety*, US Department of Transportation, USA, 2012.

[4] L. M. Clements and K. M. Kockelman, "Economic Effects of Automated Vehicles," in *Proceedings of the 96 th Annual Meeting of the Transportation Research Board*, pp. 1–19, 2017.

[5] J. Suthakorn, *Robotics in Medical Applications*, ISBME, Bangkok, Thailand, 2004.

[6] Y. Zheng, G. Bekey, and A. Sanderson, "Robotics for Biological and Medical Applications," in *Robotics: State of the Art and Future Challenges*, pp. 63–72, Imperial College Press, London, UK, 2008.

[7] V. V. Dixit, S. Chand, and D. J. Nair, "Autonomous vehicles: disengagements, accidents and reaction times," *PLoS ONE*, vol. 11, no. 12, Article ID 0168054, 2016.

[8] B. Schoettle and M. Sivak, *A Preliminary Analysis of Real-World Crashes Involving Self-Driving Vehicles*, Michigan, 2015.

[9] N. Kalra, *Challenges and Approaches to Realizing Autonomous Vehicle Safety*, RAND Corporation, Santa Monica, Calif, USA, 2017.

[10] D. J. Fagnant and K. Kockelman, "Preparing a nation for autonomous vehicles: Opportunities, barriers and policy recommendations," *Transportation Research Part A: Policy and Practice*, vol. 77, pp. 167–181, 2015.

[11] T. Litman, "Autonomous Vehicle Implementation Predictions Implications for Transport Planning," *Traffic Technology International*, pp. 36–42, 2014.

[12] D. Mohan, "Autonomous vehicles and their future in low and medium-income countries," in *Proceedings of the Conference on Driverless Technology and its Urban Impact*, pp. 1–22, 2015.

[13] C. Johnson, *Readiness of the road network for connected and autonomous vehicles*, RAC Foundation, London, UK, 2017.

[14] D. B. Camarillo, T. M. Krummel, and J. K. Salisbury Jr., "Robotic technology in surgery: Past, present, and future," *The American Journal of Surgery*, vol. 188, no. 4, pp. 2–15, 2004.

[15] R. A. Beasley, "Medical Robots: Current Systems and Research Directions," *Journal of Robotics*, vol. 2012, Article ID 401613, 14 pages, 2012.

[16] C. BenMessaoud, H. Kharrazi, and K. F. MacDorman, "Facilitators and barriers to adopting robotic-assisted surgery: Contextualizing the unified theory of acceptance and use of technology," *PLoS ONE*, vol. 6, no. 1, 2011.

[17] T. P. Cundy, H. J. Marcus, A. Hughes-Hallett, A. S. Najmaldin, G.-Z. Yang, and A. Darzi, "International attitudes of early adopters to current and future robotic technologies in pediatric surgery," *Journal of Pediatric Surgery*, vol. 49, no. 10, pp. 1522–1526, 2014.

[18] S. R. Markar, I. Kolic, A. P. Karthikesalingam, O. Wagner, and M. E. Hagen, "International survey study of attitudes towards robotic surgery," *Journal of Robotic Surgery*, vol. 6, no. 3, pp. 231–235, 2012.

[19] M. Zineddine and N. Arafa, "Attitude towards Robot Assisted Surgery: UAE context," in *Proceedings of the 2013 9th International Conference on Innovations in Information Technology, IIT 2013*, pp. 175–179, UAE, March 2013.

[20] S. Koppel, B. Clark, E. Hoareau, J. L. Charlton, and S. V. Newstead, "How Important Is Vehicle Safety for Older Consumers in the Vehicle Purchase Process?" *Traffic Injury Prevention*, vol. 14, no. 6, pp. 592–601, 2013.

[21] N. J. Hung and R. Yazdanifard, "The Study of Vehicle Safety Aspects Influencing Malaysian Urban Consumer Car Purchasing Behaviour," *International Journal of Management and Economics*, vol. 2, no. 28, pp. 913–924, 2015.

[22] Z. Bodalal, R. Bendardaf, and M. Ambarek, "A study of a decade of road traffic accidents in Benghazi-Libya: 2001 to 2010," *PLoS ONE*, vol. 7, no. 7, Article ID e40454, 2012.

[23] J. Hasanzadeh, M. Moradinazar, F. Najafi, and T. Ahmadijouybary, "Trends of mortality of road traffic accidents in Fars Province, Southern Iran, 2004 – 2010," *Iranian Journal of Public Health*, vol. 43, no. 9, pp. 1259–1265, 2014.

[24] A. A. Al-Thaifani, N. A. Al-Rabeei, and A. M. Dallak, "Study of the Injured Persons and the Injury Pattern in Road Traffic Accident in Sana'a City, Yemen," *Advances in Public Health*, vol. 2016, Article ID 4138163, 5 pages, 2016.

[25] E. Zakariassen, R. Burman, and S. Hunskaar, "The epidemiology of medical emergency contacts outside hospitals in Norway - a prospective population based study," *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, vol. 18, no. 9, pp. 1–9, 2010.

[26] D. C. Peterson, C. Martin-Gill, F. X. Guyette et al., "Outcomes of medical emergencies on commercial airline flights," *The New England Journal of Medicine*, vol. 368, no. 22, pp. 2075–2083, 2013.

[27] S. M. Jensen, H. Q. Do, S. W. Rasmussen, L. S. Rasmussen, and T. A. Schmidt, "Emergency team calls for critically ill non-trauma patients in the emergency department: An observational study," *Scandinavian Journal of Trauma, Resuscitation and Emergency Medicine*, vol. 23, no. 7, 2015.

[28] M. A. Vakili, A. Mohjervatan, S. T. Heydari et al., "The efficacy of a first aid training course for drivers: An experience from northern Iran," *Chinese Journal of Traumatology (English Edition)*, vol. 17, no. 5, pp. 289–292, 2014.

[29] E. M. Larsson, N. L. Mártensson, and K. A. E. Alexanderson, "First-aid training and bystander actions at traffic crashes-A population study," *Prehospital and Disaster Medicine*, vol. 17, no. 3, pp. 134–141, 2002.

[30] A. I. Olugbenga-Bello, O. K. Sunday, B. A. Nicks, O. A. Olawale, and A. O. Adefisoye, "First aid knowledge and application among commercial inter-city drivers in Nigeria," *African Journal of Emergency Medicine*, vol. 2, no. 3, pp. 108–113, 2012.

[31] D. Khorasani-Zavareh, H. Khankeh, R. Mohammadi, L. Laflamme, A. Bikmoradi, and B. J. A. Haglund, "Post-crash management of road traffic injury victims in Iran. Stakeholders' views on current barriers and potential facilitators," *BMC Emergency Medicine*, vol. 9, no. 1, p. 8, 2009.

[32] U. Pallavisarji, G. Gururaj, and R. Nagaraja Girish, "Practice and Perception of First Aid Among Lay First Responders in a Southern District of India," *Archives of Trauma Research*, vol. 1, no. 4, pp. 155-60, 2013.

[33] H. F. Oxer, *Simple first aid can save lives in traffic crashes*, WA Inc., Perth, Australia, 1999.

[34] P. Arbon and J. Hayes, *First Aid and Harm Minimisation for Victims of Road Trauma: A Population*, Flinders University, Adelaide, Australia, 2007.

[35] A. R. N. Dias, S. D. C. V. Abib, L. F. Poli-de-Figueiredo, and J. A. J. Perfeito, "Entrapped victims in motor vehicle collisions: Characteristics and prehospital care in the city of São Paulo, Brazil," *Clinics*, vol. 66, no. 1, pp. 21–25, 2011.

[36] S. Fattah, A. S. Johnsen, J. E. Andersen, T. Vigerust, T. Olsen, and M. Rehn, "Rapid extrication of entrapped victims in motor vehicle wreckage using a Norwegian chain method - cross-sectional and feasibility study," *BMC Emergency Medicine*, vol. 14, no. 1, 2014.

[37] J. Wall, J. Woolley, G. Ponte, and T. Bailey, "Post crash response arrangements in Australia compared to other high performing road safety nations," in *Proceedings of the 2014 Australasian Road Safety Research, Policing & Education Conference*, p. 2009, 2014.

[38] B. P. Choulagai, H. Ling, P. Sharma, S. R. Mishra, M. Ahmed, and P. B. Chand, "Epidemiology of Road Traffic Accidents in Nepal: Data Review and Qualitative Analysis," *SM Online Scientific Resources*, vol. 1, no. 3, pp. 1–4, 2015.

[39] L. Vogel and C. J. Bester, "A relationship between accident types and causes," in *Proceedings of the 24th Annual Southern African Transport Conference, SATC 2005: Transport Challenges for 2010*, pp. 233–241, South Africa, July 2005.

[40] P. Thomas and R. Frampton, "Large and small cars in real-world crashes - patterns of use, collision types and injury outcomes," in *Proceedings of the Annual proceedings/Association for the Advancement of Automotive Medicine*, vol. 43, pp. 101–118, 1999.

[41] M. Saw, *Conceptual design of a gripper for a first-aid robot*, Cardiff University, 2011.

[42] A. Momont, "Ambulance Drone," in *Delft Outlook*, vol. 31, no. 4, p. 5, Delft University of Technology, Delft, Netherlands, 2014.

[43] H. Samani and R. Zhu, "Robotic Automated External Defibrillator Ambulance for Emergency Medical Service in Smart Cities," *IEEE Access*, vol. 4, pp. 268–283, 2016.

[44] R. Hemavathi, V. Karthigayini, N. Kushma, P. Megala, and A. P. Nithyapriya, "Robotic Ambulance for Emergency Medical Service in Smart Cities," *International Journal of Innovative Research in Science*, vol. 6, no. 3, pp. 149–155, 2017.

[45] S. Nunn, "Indiana Traffic Safety Quick Facts," *Indiana*, vol. 12, 2012.

[46] A. T. McCartt and L. A. Hellinga, *Types and Extent of Damage to Passenger Vehicles in Low-Speed Front and Rear Crashes*, Arlington, 2003.

[47] R. Caponetto, L. Fortuna, and A. Rizzo, "Neural Network Modelling of Fuel Cell Systems for Vehicles," in *Proceedings of the IEEE International Conference on Emerging Technologies and Factory Automation, ETFA vol. 1, 2 vols, 2005, article number 1612519, PP. 187-192, 10th IEEE International Conference on Emerging Technologies and Factory Automation, ETFA 2005; Catania; Italy; September 2005*.

[48] A. Buscarino, L. Fortuna, and M. Frasca, "Driving assistance using smartdevices," in *Proceedings of the 2014 IEEE International Symposium on Intelligent Control, ISIC 2014*, pp. 838–842, France, November 2014.

[49] D. J. Edwards, G. D. Holt, and F. Harris, *Maintenance management of heavy duty construction plant and equipment*, Chandos Pub., 1998.

[50] S. Scellato, L. Fortuna, M. Frasca, J. Gómez-Gardeñes, and V. Latora, "Traffic optimization in transport networks based on local routing," *The European Physical Journal B*, vol. 73, no. 2, pp. 303–308, 2010.