# DIGITAL TRIANGULAR ROAD SIGNS FOR IMPROVING ROAD SAFETY

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## Abstract

*Road accidents result in the loss of life and property, and statistics reveal that they are now the leading cause of death worldwide, surpassing diseases like HIV/AIDS, tuberculosis and diarrhea. Among the causes of road accidents are broken down vehicles parked on roads. Usually, drivers of broken vehicles use emergency triangular road signs (reflective triangles) to alert oncoming drivers. However, the effectiveness of reflective triangles is hindered by the inability of oncoming drivers to notice those reflective triangles at a reasonable distance due to bad weather and the topography of roads. To solve this problem, the present paper develops a Digital Triangular Road Sign (DiTRoS) algorithm. The algorithm complements the reflective triangles installed on the rear and front sides of a vehicle to warn oncoming drivers. The development of DiTRoS algorithm builds on the navigation system enabled by global positioning system that works on portable devices – specifically smartphones. The DiTRoS algorithm is tested in the natural environment. Results demonstrate that the DiTRoS algorithm is effective in notifying oncoming drivers in advance about the presence of a broken vehicle. The study ends by recommending a minimum distance at which an oncoming driver may start receiving alerts.*

**Keywords:** Digital triangular road sign; triangular road sign; vehicle breakdowns; road safety; notifiable zone

## 1. INTRODUCTION

The number of road traffic-related deaths continues to rise, reaching 1.35 million in 2016; and more people currently die as a result of road traffic injuries than from diseases like HIV/AIDS, tuberculosis and diarrhoea (World Health Organization, 2018). Between January and June 2019, Tanzania lost four people per day, while another eight were injured in road accidents (Yusufu, 2019). However, in 2019, deaths and injuries dropped by 25% and 27% respectively as compared to the 2018 statistics. Globally, 93% of fatalities on roads occur in low- and middle-income countries; and in the case of car-to-car collision, the fatality risk for car occupants is 85% (WHO, 2020). Road accident causes in Tanzania include negligent driving, motorbike riders, speeding and pedestrian negligence (Yusufu, 2019). Besides such causes, vehicle breakdowns are another area contributing to road accidents, especially on two-lane highways.

No driver would wish to be in a scenario where their car breaks down thereby resulting in inconveniences and possibility of car-to-car collision. To avoid this, a driver of a broken vehicle places emergency reflective triangular road signs in front and rear sides of the broken-down vehicle to alert oncoming drivers. Occurrence of breakdowns may have large-scale effects on other traffic as well as other road users. The difficulty of oncoming drivers to recognize the existence of a broken-down car within a safe distance is one of the key challenges connected with breakdowns. Drivers may be unable to see broken-down vehicles from a safe distance due to poor eyesight caused by curved roads, hills, valleys, bad weather and nighttime driving. In case oncoming drivers unexpectedly notice a broken-down vehicle within a short distance, they may barely be able to avoid the ensuing catastrophe. Drivers might also be unable to maneuver their vehicles in an effort to slow down or safely overtake. Most often, such failures may result in a car-to-car collision, signifying that emergency triangular road signs that are fixed in front and rear sides of a vehicle may be ineffective. Throughout the present paper, emergency triangular road signs are referred to as reflective triangles.

The use of reflective triangles has existed for decades as a major way to notify oncoming drivers about the presence of vehicle breakdowns ahead of them. The reflective triangles, usually installed not less than 45 metres[1] away from a broken vehicle, have appeared the compelling solution in use today. Although the use of reflective triangles appears common, situations like curved roads, bad weather and high speed may affect their effectiveness. Even when reflective triangles have been put in place, there are still some car-to-car collisions involving oncoming and broken-down vehicles.

Some solutions to this problem have been advanced in the literature (Ahire, 2014; FE Online, 2017; Ling & Huong, 2019; Rajkumar & Mahendran, 2014; Yu et al., 2009). However, the techniques suggested in literature are scarcely adaptable to adequately address the drawbacks of reflecting triangles that are physically installed. While some techniques are affected by weather, others enable drivers to see obstacles within a short distance, and other techniques which extend to several road segments are too expensive to afford. Thus, a novel approach

[1] https://www.arrivealive.mobi/the-emergency-triangle-and-safety-on-the-road

that is simple for users (drivers) to adopt is required. Typically, the novel approach must be easy to learn and use; simple to test and deploy, and should as well as be characterized by a lessened requirement for supplies and equipment (Yocco, 2015).

While it is necessary to warn oncoming drivers that there is a broken vehicle ahead of them, some challenges emerge. First, it is unclear about the distance at which drivers of approaching cars should begin to receive alerts. Second, it is still uncertain about the interval at which oncoming vehicles should be alerted. Third, there is no established method for coordinating and cutting off communication after an oncoming car has passed a broken vehicle. The current study suggests a solution that satisfies the requirements for an adoptable solution while using the existing equipment (smartphones) to save the expenditures of purchasing new equipment. The use of smartphones is typically in line with drivers' lifestyles; and it is simple to use, understand, and experiment. To this end, the central objective of the present paper is to develop a Digital Triangular Road Sign (DiTRoS) algorithm that notifies oncoming drivers in advance about the presence of breakdowns ahead. In line with this research objective, one Research Questions (RQ) is addressed: *what is the reasonable distance at which a driver may start to receive notifications?* The algorithm developed in current paper seeks to complement the use of physically erected reflective triangles to improve road safety.

The rest of the paper is structured in six sections. Section 2 discusses the automation of vehicle driving systems; and is succeeded by presentation of the research methodology in section 3. Section 4 presents the development of a Digitalized Triangular Road Sign (DiTRoS) algorithm, which is later experimented in section 5. Results and discussion of the findings are presented in section 6. The paper ends in section 7 by providing concluding remarks, limitations and future works.

## 2. Automation of Vehicle Driving Systems

This section presents the design of automated driving systems (subsection 2.1), sensory enabling technologies in vehicle driving (subsection 2.2), vehicle collision avoidance systems (subsection 2.3), and driving support systems (subsection 2.4).

### 2.1. Design of automated driving systems

Driving begins with manual systems, whereby human drivers are responsible for full control of all functions. Usually, a human driver has a set of static physical traits (eyes, hands), and dynamic mental traits, expressed through behaviour, that may be categorized into perceptual, cognitive and action skills (Calvert et al., 2020). During driving, these behavioural components are continuously revisited and revised based on new perceptions, decisions and actions. Revisiting and revising are driven by road dynamics attributed to the existing environment, such as other traffics, pedestrians, terrain and changing weather. These features require human-drivers to bear constant vigilance to avoid accidents. Parallel to this, a model for situation awareness in dynamic decision-making emphasizes perceiving and comprehending elements in the current situation, projecting future status, and making decisions afterward (Endsley, 1995).

To reduce workload on human driver, a continued growth of digital technology is promising because several digital improvements (solutions) are being developed. Such digital solutions account for partial or full automation tasks carried out by human drivers. Automation is now becoming common in many industries such as manufacturing, health, logistics and transportation in particular. Automation is understood as an execution (partially or fully) by a machine agent (normally a computer) of a function that was previously carried out by a human (Parasuraman & Riley, 1997; Wickens et al., 1998). Automation of various functions in transport logistics falls into four types, which are information acquisition, information analysis, decision selection and action implementation (

**Fig. 1**).

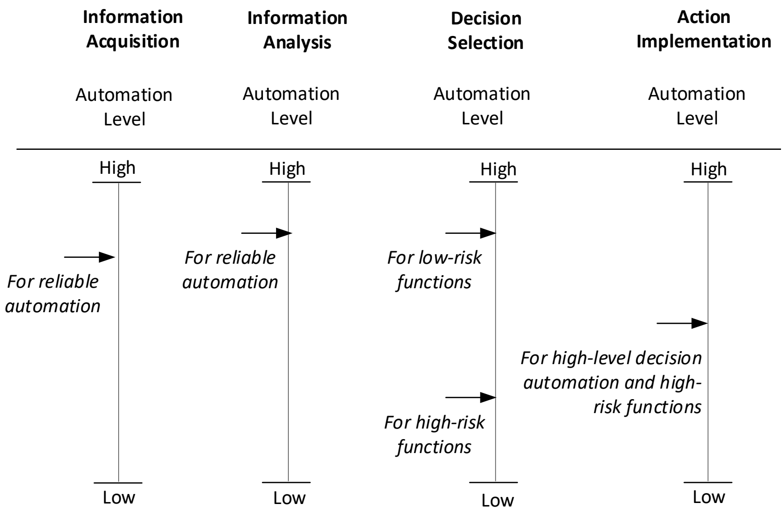


**Fig. 1. Recommended Types and Levels for Future Air Traffic Control Systems**
(**Source:** Parasuraman, Sheridan and Wickens, (2000)

With reference to Figure 1, information acquisition stresses that information must be acquired by a range of sensory percepts (devices) such as cameras, Global Positioning System (GPS), and RFID tags. These devices are equivalent to human eyes and ears used by human drivers to sense their environment while they are en-route. Specific to this study, information is acquired through GPS embedded in the smartphones possessed and used by drivers. In the next stage, the acquired information is analyzed depending on the typical data collected. Since the acquired information is in a form of coordinates comprising latitudes and longitudes, information analysis has to involve calculating the distance between two points. Furthermore, for reliable avoidance of collision, the design must take into consideration high automation of information acquisition and analysis. This study comprehends the high-level automation under information acquisition by specifying frequent collection of information to feed the information analysis module.

The next levels of automation are decision selection and action implementation. As the present study does not automate action implementation, design specification focuses on decision selection. To avoid overloading the human driver, the analysed information has to be presented to a driver in a form of an audio. The automation ought to read aloud the distance remaining between the oncoming and the broken vehicle. Once the distance remaining is shorter, the human-driver is alerted to take actions including braking to reduce speed, and the wheel steering to diverge from the obstacle.

There are many scales of levels of automation of decision and control actions. As depicted in Table 1, level number 10 indicates a high level of automation where the computer is autonomous; and decides everything without assistance from a human being. Level number 1 indicates the low level or no automation because a human must take all decisions.

**Table 1: Scale of Levels of Automation of Decision and Control Action**

| Level | Description of the automation |
|---|---|
| 10 | The computer decides everything and acts autonomously, ignoring the human |
| 9 | informs the human only if it, the computer, decides to |
| 8 | informs the human only if asked, or |
| 7 | executes automatically, then necessarily informs the human, and |
| 6 | allows the human a restricted time to veto before automatic execution, or |
| 5 | executes that suggestion if the human approves, or |
| 4 | suggests one alternative, and |
| 3 | narrows the selection down to a few, or |
| 2 | The computer offers a complete set of decision/action alternatives, or |
| 1 | The computer offers no assistance: the human must take all decisions |

**Source:** Wickens et al., (1998)

Concerning decision making, the design of automation in the present study takes levels 4, 3, and 2. The automation has to provide an estimated distance remaining between the oncoming driver and the broken vehicle as one suggested alternative. Since the distance between the oncoming vehicle and the broken vehicle keeps decreasing, the distance provided to the human drivers after a certain period of time constitutes a complete set of (selections) decisions within a given time. The design accentuates further that beyond a set threshold distance, a human-driver may choose the distance at which s/he may start to apply the brake. Automation level 2 occurs when the human-driver has reached the shortest remaining (threshold) distance before colliding with the broken vehicle.

## 2.2. Sensor enabling technologies in vehicle driving

Working principles in the automation of vehicle driving support systems depend primarily on the ability to sense an internal state of the system itself and its environment. That sensing is usually realized using sensors of various sorts. Based on their operational principles, sensors may be classified as internal state sensors, tasked to measure internal values of a dynamic system and; external state sensors, tasked to acquire information (data) from system's surroundings (Yeong et al., 2021).

There are different types of sensors used in vehicles, including GPS, video cameras, fuel sensor, ultrasonic sensor, inertia sensor, pressure sensor, infrared sensor and RADAR sensor (Guerrero-Ibáñez et al., 2018). Particular examples of internal state sensors include Inertia Measurement Units (IMU), encoders, inertial sensors (gyroscopes and magnetometers), and positioning sensors (Global Navigation Satellite System (GNSS) receivers) (Yeong et al., 2021). Typical examples of external state sensors, as underlined by authors, are cameras, Radio Detection and Ranging (Radar), Light Detection and Ranging (LiDAR) and ultrasonic sensors.

Some technologies have been employed to improve road safety with a view to avoiding vehicle-to-vehicle (V2V) collisions. V2V collision depends on the ability of one vehicle to communicate with another. The V2V communications are envisioned to be dedicated to short-range communication, although it can also be derived using non-vehicle-based technologies such as GPS to identify the location and speed of a vehicle (Narla, 2013). With respect to sensors used to avoid V2V collision, forward collision systems use cameras, radar, or LiDAR sensors to monitor an area in front of a vehicle and alert the driver of a potential collision with another vehicle or object (Jermakian, 2011). LIDAR works by firing off continuous beams of laser light (Guerrero-Ibáñez et al., 2018) whereas radar uses radio waves to detect objects. Both radar and LiDAR can detect many objects based on how long it takes for reflected radio waves/light to hit back. Despite the advantages of the sensor technologies discussed in this section, their use to improve reflective triangles has drawbacks. For example, the topography and weather, among other elements, may have an impact on the signals produced by these sensors. Adopting such sensor technologies may also require purchasing new equipment, which would incur additional costs that owners and drivers of the corresponding cars might find unpleasant.

## 2.3. Vehicle collision avoidance systems

Collision of vehicles on roads occurs due to various causes, such as human and environmental factors. Human factors may emanate from human drivers who ignore road signs. For example, careless driving on curved roads and road segments that have terrains may cause collision of vehicles. Collisions may also occur when drivers engage in an inattentive change of lane.

Literature proposes a range of algorithms for avoiding collision of vehicles. To eliminate collisions during lane change, the study builds on the vehicle-to-vehicle communication strategy to develop a dynamic automated lane change maneuver (Luo et al., 2016). Accordingly, trajectory planning and trajectory tracking are used as key technologies, whereby the former calculates a reference trajectory that satisfies demands of safety and updates it to avoid potential collisions until the lane change is complete. Nishi and Takagi (2001) propose a collision avoidance algorithm that derives the best movement to avoid collision and allow vehicles to exchange the speed, coordinate position and direction. The algorithm is characterized by preconditions, variables, calculation of safety distance and movable area, and retrieval of the route. Moreover, there have been efforts to use Radio Frequency Identification (RFID) to avoid collision and accidents on roads. RFID is usually a wireless system that comprises tags (labels), readers and antenna. Kubota, Okamoto and Oda (2006) use the RFID system to sense the presence and position of pedestrians, cyclists and wheelchairs (with RFID tags), then send the data to an onboard device. According to the authors, the setup of the system requires that streets have Low Frequency (LF) generators along the road, such that when the tag enters the area of the magnetic field generated by the LF-signal generator, it gets excited. Upon excitement, it transmits the tag ID together with positional data to indicate the precise position of the object to be displayed on the car navigation display for alerting the driver (Kubota et al., 2006).

The collision avoidance algorithms described in this section may hardly be applied to address the challenge outlined in the present paper as they work better when vehicles (or subjects/objects) involved are closer. The case is, however, different when vehicles are far apart whereby the oncoming driver needs to be notified within a reasonable distance, for example, at the distance of 5 kilometers. Data transmission between vehicles is difficult to do over such vast distances with current technology. Furthermore, environmental elements like the topography and curving roadways may have an impact on such signals.

## 2.4. Driving support systems

Driving support systems may be classified into manual and digital forms. The latter has been accelerated by the continued growth and use of Information and Communication Technologies (ICT). Already the use of ICTs in transport logistics has become apparent, from vehicle tracking to monitoring of the speed of vehicles. Although ICT has many applications in transport logistics, the discussion in this section is inclined to works related to driving support systems in the viewpoints of manual and digital systems. Along this course, the present discussion focuses on reflective triangles; the intelligent vision for automobiles at night; the night vision camera; vehicle detection and tracking system for improved night vision; intelligent imaging system; augmented reality head-up display, and roads that honk. Table 2 is illustrative.

# Table 2: Existing Driving Support Systems and their Limitations

| System | Description | Limitations |
|---|---|---|
| Reflective triangles | Installed 45 metres away from the broken vehicle to alert oncoming drivers | • Affected by weather and terrain<br>• Noticed within the shortest distance |
| Intelligent Vision for Automobiles at Night (Yu et al., 2009) | Detecting, illuminating and recognizing road signs at night using infrared to tackle the problem of low visibility | • Distract drivers by engaging them, for example, to zoom for road signs<br>• Cannot detect objects out of camera focus |
| Night Vision Camera (Ahire, 2014) | Provides the driver with the black and white image of the driving environment ahead of the vehicle | Visibility is affected by bad weather such as fog or rainfall |
| Vehicle Detection and Tracking System (Rajkumar & Mahendran, 2014) | Identify and classify the moving vehicles in the presence of unwanted light sources | • Detect vehicle within the shortest distance<br>• Affected by weather and terrain |
| Intelligent imaging system (Ling & Huong, 2019) | • Intelligent imaging system for optimal nighttime driving<br>• Allow drivers to see and foresee road hazards sooner, give time to react | • Affected by signal to noise ratio<br>• Unsuitable for nighttime driving because of the low quality of images<br>• Economically unviable due to cost |
| Augmented Reality Head-up Display (Abdi et al., 2015) | • Impose less cognitive load onto the driver<br>• Facilitate a new form of a dialogue between a vehicle and a driver | Meant to aid dialogue between vehicle and driver, but not detection of vehicles |
| "Roads that Honk" System (FE Online, 2017) | Comprises smart poles that honk to alert drivers on blind turns to avoid a head-on collision | Difficult to scale along many geographical locations due to cost |

**Source:** Literature Review

The first system, the reflective triangle, is a form of physical signal installed by the driver of the broken vehicle to alert other oncoming drivers. The reflective triangles are installed some metres away before and after the broken vehicle. In other areas, some drivers use tree branches to complement reflective triangles. Although this method may appear effective, in some circumstances, oncoming drivers may fail to notice the installed reflective triangles at a plausible distance. Additionally, as outlined in section1, the effectiveness of reflective triangles decreases because of low visibility resulting from bad weather, darkness, curved roads, hills and valleys.

The second, third and fourth systems are the intelligent vision for automobiles at night (Yu et al., 2009), night vision camera (Ahire, 2014) and vehicle detection and tracking system (Rajkumar & Mahendran, 2014) respectively. These systems, as proposed in the literature, help drivers manage safe driving (Table 2), but in different capacities. The intelligent vision for automobiles system tackles the problem of low visibility at night. It uses infrared light to improve visibility thereby detecting, illuminating, and recognizing road signs at night using infrared light. However, the intelligent vision for automobiles system distracts drivers; and imposes hardship in detecting objects outside the focus of a camera such as on curved roads. The third system, the night vision camera, provides an image of the driving environment ahead of the vehicle. Nonetheless, the system suffers from low visibility that results from bad weather such as fog and rainfall. The function of the fourth system, the vehicle detection and tracking system, is to identify and classify the moving vehicles under environment that feature unwanted light from other sources. Such system provides promising applications. Although it is useful, its efficiency is affected by the signal-to-noise ratio, and it is less suitable for nighttime driving because of the low quality of images. In this case, all these three systems are difficult to apply or adapt in addressing the limitations of reflective triangles.

In conjunction with the previous paragraph, literature contributes to driving support systems from another related perspective. Along with this perspective, the fifth, sixth, and seventh systems are the intelligent imaging system (Ling & Huong, 2019), augmented reality head-up display system (Abdi et al., 2015), and “roads that honk” system (FE Online, 2017) respectively. The fifth system enables optimal nighttime driving, and allows drivers to see and foresee road hazards sooner and give them more time to react. Despite its strength, the intelligent imaging system is disturbed by the signal-to-noise ratio. It is also economically less viable due to the cost of purchasing digital equipment. The function of the augmented reality head-up display is to reduce cognitive load onto the driver by providing driving-safety information that superimposes augmented virtual objects onto a real scene. This system is meant to aid dialogue between vehicle and driver, but not detection of vehicles. The seventh system "roads that honk" comprises smart poles erected on roads that honk to alert drivers on blind turns to avoid head-on collisions. Its fragility lies on costs of deploying smart poles on every curved segments of the roads, on the one hand. On the other hand, since those poles are stationary, they can only sense objects in their locality.

Overall, the remedies already proposed in the literature provide encouraging comforts in the situations for which they were intended. Some of these systems such as intelligent imaging systems, night vision cameras, and intelligent vision for automobiles would be adapted with little effort to address the limitations of reflective triangles. However, those systems require equipping vehicles with digital tools such as cameras, which add investment costs in managing road safety. Alternatively, this paper proposes a DiTRoS road safety system.

The DiTRoS makes use of already-existing devices, tools and infrastructure such as smartphones, Global Positioning System (GPS) embedded in a smartphone, and cell towers that provide wireless internet. It is easy to deploy and requires minimal investment costs, such as a smartphone with internet connectivity.

## 3. Methodology

The present paper follows a Design Science Research Methodology (DSRM), which includes many processes, such as problem identification and motivation, definition of solution objectives, design and development, and assessment. The full description of the problem definition, motivation as well as the objective of the desired solution have already been presented in section 1 of the present paper. Section 1 also includes the research questions (RQ) that is related to problems that arise during the accomplishment of the primary objective.

The design and development to produce an artifact is further staged into the development of the DiTRoS concept and transformation of the DiTRoS concept into a computational algorithm. In the first stage, the DiTRoS concept in section 4 is developed by remodeling physical installation of reflective triangles on the front and rear sides of the broken vehicle. Such mode of realization assumes to reinstate physical reflective triangles into virtual forms; meanwhile, enabling the ability to point the exact location of both broken and oncoming motor vehicles. Such re-establishment takes into consideration that the location of the broken vehicle is fixed while that of the oncoming vehicle is dynamic. Fulfillment of this requirement demands tracking the navigation of vehicles. Driven by this requirement, therefore, this study employs GPS to locate the whereabouts of the vehicle breakdowns and oncoming drivers. Thanks to internet connection powered by cell towers available along the most parts of the road that transmit data to and from smartphones of en-route drivers. Generally, this stage of developing the DiTRoS concept is realized by using the modeling method, which is commonly adopted in computing sciences.

The second stage involves transforming the conceived algorithm into the computational ambiance. That transformation comprises specifying functional requirements, designing the process and data models to capture both generated and processed data. The stage uses the Unified Modeling Language (UML) as a tool to communicate process and data model designs symbolically. Other parts for designing and developing the artifact are presented in sections 4.2 and 5. The last step, evaluation, is covered in section 6.

## 4. The DiTRoS Algorithm

The current section details development of the DiTRoS algorithm (subsection 4.1) and its transformation into the computational instance (subsection 4.2).

### 4.1. Conception of the DiTRoS algorithm

The present subsection focuses on development of an algorithm that is innovative from the viewpoints of comparative advantage, compatibility and simplicity. The algorithm being developed is backed up on the advantage of technology like GPS-equipped smartphones, computer servers, and supporting infrastructure like cell towers. Cell towers provide wireless connections that allow communication between the driver's mobile phone and the central database. Its development proceeds as detailed in next paragraphs.

A motor vehicle may break down due to one or many reasons such as flat tire, empty fuel tank or engine failure. As a result, the driver comes to a complete halt on the road. In accordance with practice, the driver must manually install reflective triangles in the front and rear side of the broken-down vehicle to alert oncoming traffic to its existence.

With regard to Figure 2, the driver of motor vehicle "P" has experienced a break down. As a backup plan, the driver chooses to stop the vehicle and leave it idling on the road. The driver picks up a smartphone and immediately starts the mobile application to inform a cloud server of the fault (Figure 3). The driver reports crucial data in the communication, including the precise location of the breakdown in terms of latitude and longitude. The driver keeps working on the automobile after reporting.

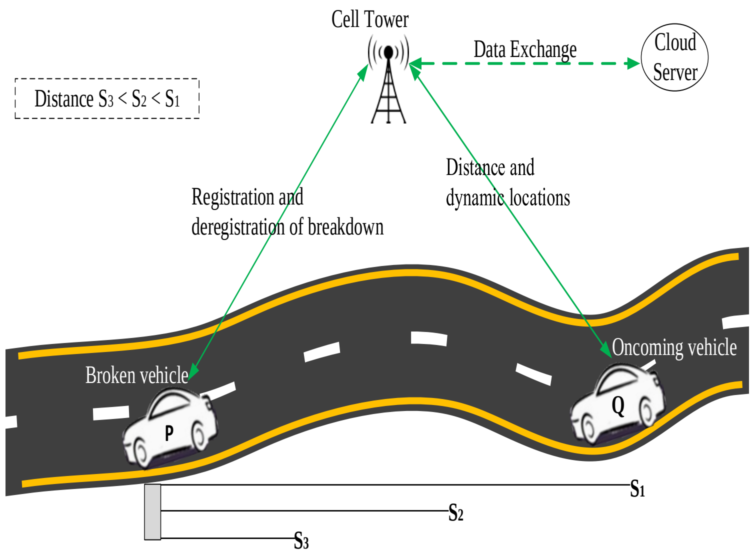


**Fig. 2. An Approach to the DiTRoS Concept**
**Source:** Author

While the on-site driver works to fix the broken-down automobile oncoming drivers in both directions, like motor vehicle "Q," in Figure 2 above, would already have

activated their mobile application. The activation enables drivers to receive alerts regarding the possibility of breakdowns ahead of them (see Fig. **3**). With the activation, the coordinates of the oncoming driver are captured and instantly transmitted to the cloud server via wireless cell towers. After capturing location data, the algorithm checks for presence of any breakdown in that particular route. If a breakdown exists, the algorithm has to notify the oncoming driver. However, it is of little use, for example, to alert an oncoming vehicle when it is 50 or 100 kilometres distant from a breakdown. To be more effective, oncoming drivers have to be notified when they are within a specific practical distance far from the broken vehicle. The current paper refers to this range of distance as a notifiable zone. The notifiable zone, according to this study, is a practical distance at which a driver on the road who is approaching a particular breakdown may begin to receive alerts. It is the role of algorithm to check whether the distance between the broken and oncoming vehicles falls within the notifiable zone. In this context, if the vehicle breakdown has been identified; and is within the notifiable zone, the oncoming driver has to receive notifications regarding the remaining distance between their vehicle and the specific broken-down vehicle.

The crucial issue is how to determine the notifiable zone (RQ). Establishing the notifiable zone must consider various parameters that relate to braking distance. According to Vision Zero (2012), the braking distance depends on the speed of the oncoming vehicle, weather, road surface quality, topography (uphill, downhill), tire and brake condition. Other parameters include the carried load, vehicle weight, visibility of the road scene, the reaction distance required by the driver and the speed of wireless network. According to Vision Zero (2012) and Queensland Government, (2016), the stopping distance for a vehicle moving at 110 km/h should be 154m and 143m respectively. These stopping intervals incorporate only reaction distance under wet weather while ignoring other parameters.

Therefore, while conducting experiments on the created artifact, the present paper seeks to establish the notifiable zone.

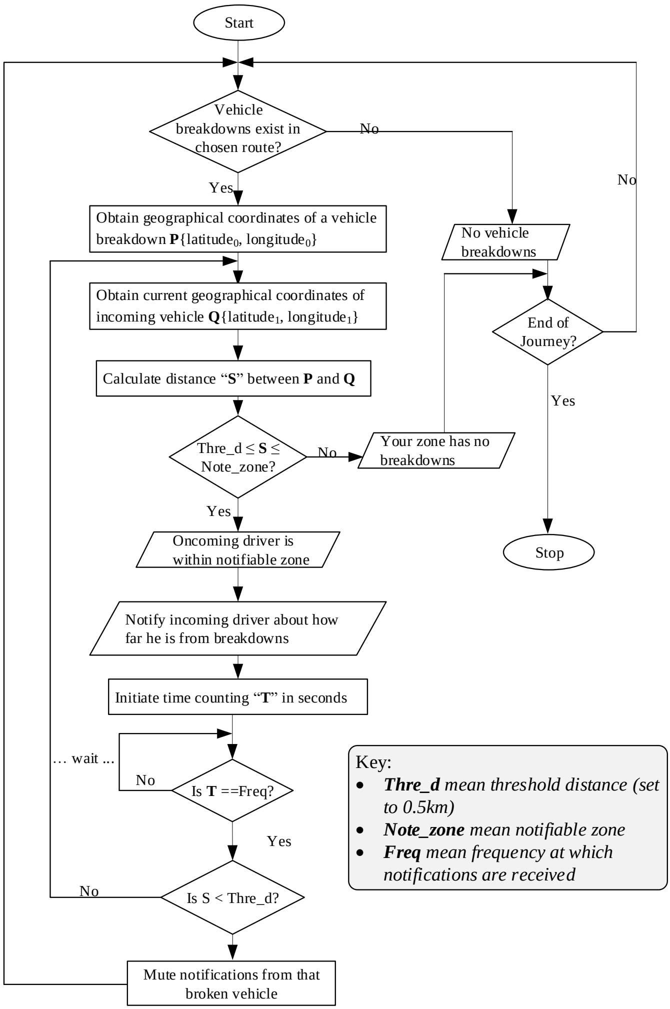


**Fig. 3. An Algorithm for Notifying Oncoming Drivers about**

**Existing Breakdowns**
**Source:** Author

It is also worth noting that as the oncoming drivers approach the broken vehicle, the distance remaining keeps decreasing. When the remaining distance is less than or equal to the threshold distance, the oncoming driver should be warned to take extra caution about the breakdown ahead. The expert judgment and experience gained from many drivers guide the author to set half a kilometre as the threshold distance from which oncoming drivers get alerted to take extra caution because they are almost near the broken vehicle.

In the end, the driver of the broken vehicle will complete fixing the motor vehicle because it is a temporary problem. Upon that completion, the driver has to de-register the breakdown they had reported previously.

### 4.2. Implementation

Implementation, in the context of the present paper, refers to transformation of the DiTRoS algorithm proposed in section 4 into executable computer programs. The objective behind this metamorphosis is to figure out how the developed concept works as well as the extent to which it is useful. Both purposes are fully realized by implementing and, thereafter, testing the DiTRoS algorithm in natural settings. The implementation of the DiTRoS algorithm involves specifying software requirements, designing the system and building (coding) the system. Beginning with software requirement specification, the DiTRoS algorithm offers three main functional requirements as described hereunder:

- *Registration* –the system allows road users (preferably drivers) to create accounts. These accounts enable them to register/deregister vehicle breakdowns and/or receive notifications;

- *Report a breakdown* –this function enables a driver who has encountered a breakdown to report the geographical location of the broken-down vehicle;
- *Choosing a route* –en route drivers wishing to receive notifications choose a specific route they are going to undertake.

Following the outlined functional requirements, the DiTRoS algorithm supports two groups of key users. The first group comprises users who encounter breakdowns and report them, and the second group pertains to oncoming drivers who receive alerts about how far they are from a specific breakdown.

On top of functional requirements, this study considers non-functional requirements as well. The considered non-functional requirements comprise reliability, performance and robustness of the DiTRoS algorithm. However, since this research is on digital reflective triangles, this paper does not go deeper into the outlined non-functional requirements.

Next to the requirement specification is a system design. The design of the DiTRoS algorithm concentrates on the establishment of entity-relationship and sequence diagrams. The design is also extended to development of a database scheme necessary to capture data. This is because the study plans to collect and store data about users and geographical location, as well as calculated values such as dynamic distance between the broken vehicle and oncoming drivers

Regarding the input of data and output of information, the design specifies that drivers may use keyboard input or icon input to select a route and enter other fewer details (Figure 4) except for geographical coordinates, which are captured automatically by the GPS built in smart mobile phones.

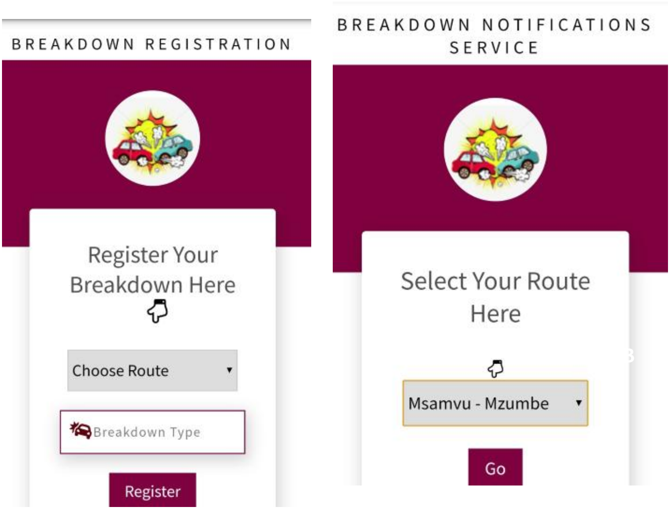


Image A Image B

**Fig. 4. Screenshots of some DiTRoS Algorithm Functionalities**
**Source:** Author

Drivers enter this data when they are not driving. The output information to the oncoming driver is produced primarily in a form of audio. However, the corresponding text is also displayed. Such form of output relieves drivers of reading a text while driving a vehicle. Interactions and data flow underlying a computational instance of the DiTRoS algorithm are specified using sequence diagrams as shown in Fig. ***5*** and Fig. ***6***.

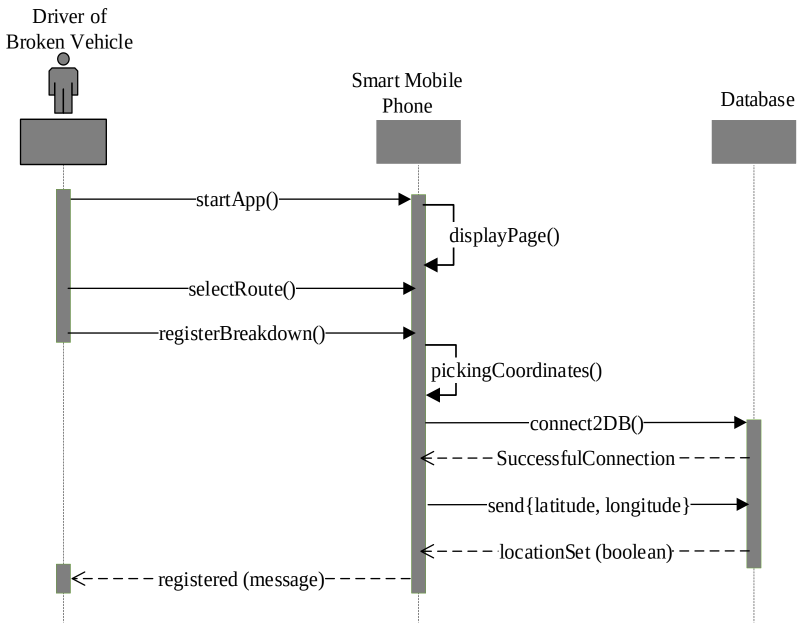


**Fig. 5. Sequence Diagram for Registering Incidence of Broken Vehicle**

**Source:** Author

The DiTRoS algorithm has two types of human actors, namely the driver of a broken vehicle, and the oncoming driver. It uses a smart mobile phone as hardware necessary for input and output functions as well as acquisition of GPS location. To store the data related to particulars of actors and location of the broken vehicle, a database managed by MySQL system is used.

After starting the mobile application, the driver of the broken vehicle selects the route in which the breakdown incidence has occurred (Fig. 5). Afterward, the driver registers the breakdown. During registration, the GPS of the mobile phone captures the longitude and latitude of the broken vehicle location and sends it to the database for storage.

Figure 6 is the sequence diagram for registering for notification.

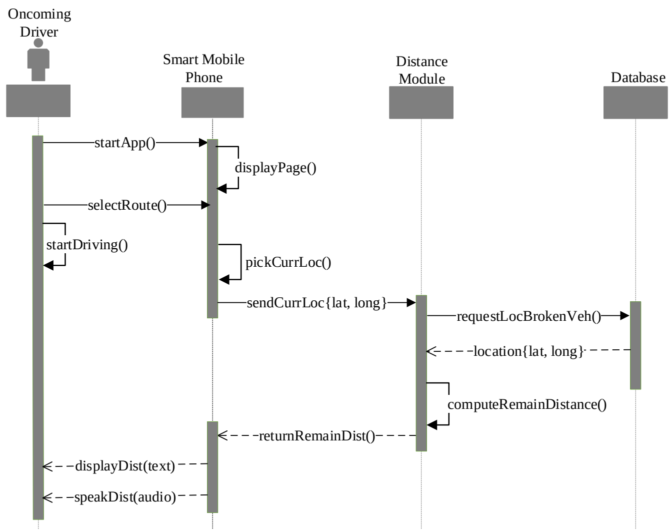


**Fig. 6. Sequence Diagram for Registering to Receive Notification**

**Source:** Author

Based on Figure 6, before starting their journey, oncoming drivers must start the mobile application and select the specific route they are going to take. The mobile application captures the current location of the oncoming driver and passes it to the distance module, which scrutinizes to check for any vehicle breakdowns in the selected route and how far they are. If a breakdown is outside the notifiable zone, the module does not take any action. However, if the distance between the broken vehicle and the oncoming driver lies within the notifiable zone, the mobile app alerts the oncoming driver (in a form of audio). The distance module keeps on calculating the distance remaining based on the current location of the oncoming driver.

In building the DiTRoS, coding is achieved by using Android Studio Development Kit. The building of the DiTRoS algorithm is framed into two forms: control panel, which is both web and mobile-based application; and end-user module, which is a mobile application (see Fig. **4**). The former module is for administration while the latter serves en-route drivers. The screenshot extracted from mobile applications shows the menu for registering the breakdown (image A). The second image (image B) indicates possible options for selection of the specific route the driver undertakes.

## 5. Experimental Design, Setup and Testing

The present study employs natural experiments to demonstrate the effectiveness of the DiTRoS algorithm. A natural experiment is preferred over other methods such as laboratory (prototyping, simulation) and field experiments. On the one hand, laboratory experiments are limited to generalizing resulting findings to other real-life scenarios due to controlled manipulation of variables. On the other hand, field experiment is better than the laboratory experiment but suffers a few manipulations imposed by the researcher, thus its validity and generalization are weak. Therefore, natural experiments break most of the weaknesses of the laboratory and field experiments but sacrifice all manipulative control of variables (Diamond, 1983). The author adds that natural experiment allows selection of sites that differ naturally in the presence or absence of major factors relevant to the dependent variable, and permits examination of conditions that cannot be created experimentally. Equivalently, this study emphasizes employing natural experiments in a realistic environment that offers a reasonable conceptual and operational validity of the DiTRoS algorithm.

In designing the experiment, two vehicles are involved, whereby one assumes the position of the broken vehicle and another assumes the position of an oncoming vehicle. Furthermore, two roads are purposely selected by drawing from the establishment in Diamond (1983), who proposes consideration of presence and absence of key elements. The selection hinges on coverage of internet connectivity to examine the robustness of the DiTRoS algorithm under the elements of full and poor internet coverage. Thus, one of the selected roads has full internet connectivity while the other has a segment in which internet connectivity is poor. These key elements featured in natural settings are also constituents of uncontrolled variables (noises).

Regarding experimental settings, two roads in the United Republic of Tanzania, in Morogoro Region, namely (1) A7 – Iringa Road, and (2) B129 – Dodoma Road were selected. The selection forms two routes that were used to test the DiTRoS algorithm. In addition, for each route taken, a broken-down vehicle was parked at a scenery location whose latitude and longitude were - 6.8057554 and 37.6630266 respectively. After completing settings, testing began. In testing the DiTRoS algorithm system, an oncoming motor vehicle was driven towards the broken vehicle while receiving notification about the distance remaining.

## 6. Results and Discussion of the Findings

The tests conducted in the previous section under natural experiments produced a wide range of results. Subsection 6.1 presents the results followed by discussion of the findings in subsection 6.3.

### 6.1. Results

In this study, two experiments were conducted; the first was conducted along A7 (Iringa) road. The results of the experiment are presented in Table 3 and Figure 7. Table 3 displays tracks of the oncoming driver toward the broken vehicle and portrays diminishing distance with reference to the time at which the driver received alerts. The alerts received match the locations marked in Figure 7.

**Table 3: Paths of Oncoming Driver towards the Breakdown Scene along A7-Iringa Road**

| Coordinates | Time | Distance (km) |
|---|---|---|
| -6.89828, 37.5659 | 15:24 | 14.9 |
| -6.8835, 37.577 | 15:25 | 12.8 |
| -6.88018, 37.5836 | 15:26 | 12.1 |
| -6.87581, 37.5904 | 15:27 | 11.2 |
| -6.8407, 37.627 | 15:32 | 5.6 |
| -6.82921, 37.6411 | 15:33 | 3.6 |
| -6.83066, 37.6358 | 15:35 | 2.9 |
| -6.81744, 37.6485 | 15:36 | 2.1 |
| -6.81287, 37.6505 | 15:37 | 1.6 |
| -6.80496, 37.6593 | 15:38 | 0.4 |

**Source**: Author's Computation

**Table 4: Tracking Oncoming Driver towards the Breakdown Scene along B129- Dodoma Road**

| Coordinates | Time | Distance (km) |
|---|---|---|
| -6.76297, 37.6568 | 14:23 | 4.8 |
| -6.77795, 37.6578 | 14:24 | 3.1 |
| -6.78217, 37.6591 | 14:25 | 2.7 |
| -6.79315, 37.6624 | 14:26 | 1.4 |
| -6.79481, 37.6618 | 14:27 | 1.2 |
| -6.80094, 37.6611 | 14:28 | 0.6 |

**Source:** Author's Computation

As further exemplification, the oncoming driver heading to Morogoro Town was notified at 15:24 (East African Time) through mobile phone about the presence of vehicle breakdowns ahead located at the distance of 14.9km. The oncoming driver continued to receive updates after every sixty (60) seconds for three (3) minutes. Figure 7 displays a satellite view of the oncoming driver's path along A7-Iringa Road, and Figure 8 applies to B129-Dodoma Road.

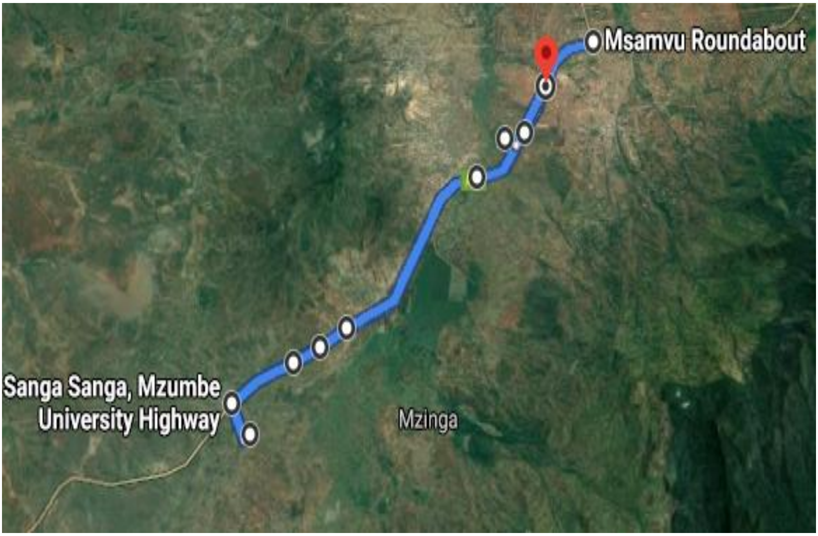


**Figure 7: Satellite View of Oncoming Driver's Path along A7-Iringa Road**
**Source**: Satellite Image


**Figure 8: Satellite View of Oncoming Driver's Path along B129- Dodoma Road**
**Source: Satellite Image**

Afterward, the driver drove for 5.6 kilometres from 15:27 to 15:32 without notifications. Notifications resumed at 15:32, and the oncoming driver continued to receive alerts after every sixty

(60) seconds until 15:38, when the remaining distance was four hundred metres(0.4km) (see Table 3).

The second experiment was carried out along B129- Dodoma Road. In this experiment, the same breakdown was used to study the usefulness of the DiTRoS algorithm. Results presented in

*Table* **4** and Figure 8, again, with

Table **4** indicate diminishing distance toward the broken vehicle. Particular to this experiment, the oncoming driver turned on his mobile app within the proximity of about six (6) kilometres towards the breakdown. The driver started receiving notifications at 14:23 at the distance of 4.8 km from the breakdown. As the driver approached the breakdown, notifications continued after every sixty (60) seconds. The latest notification was received at 14:28 within a notifiable zone of six hundred metres (0.6 km).

Results for the possible threshold distance at which the driver may begin to receive notifications are shown in

Table ***5*** and Table 6. Several experiments were conducted to generate the results, some of which are reported in

Table ***5*** and Table 6.

**Table *5:* Variation in the Distance Covered in Different Experiments**

| Exp. 1 | | Exp. 2 | | Exp. 3 | | Exp. 4 | |
|---|---|---|---|---|---|---|---|
| Time | Distance (km) | Time | Distance (km) | Time | Distance (km) | Time | Distance (km) |
| 13:28 | 2.8 | 18:46 | 1.6 | 14:23 | 4.8 | 15:24 | 14.9 |
| 13:29 | 0.9 | 18:47 | 0.9 | 14:24 | 3.1 | 15:25 | 12.8 |
| 13:30 | 0.2 | 18:48 | 0.9 | 14:25 | 2.7 | 15:26 | 12.1 |
| | | 18:49 | 0 | 14:26 | 1.4 | 15:27 | 11.2 |
| | | | | 14:27 | 1.2 | 15:32 | 5.6 |
| | | | | 14:28 | 0.6 | 15:33 | 3.6 |
| | | | | | | 15:35 | 2.9 |
| | | | | | | 15:36 | 2.1 |
| | | | | | | 15:37 | 1.6 |
| | | | | | | 15:38 | 0.4 |

**Source:** Author’s Computation

A change in distance per minute between consecutive calculated distance is shown for each experiment in Table 6 (which is obtained from

Table *5*).**Table 6: Change in Distance per Minute**

| Exp. 1 Distance (km) | Exp. 2 Distance (km) | Exp. 3 Distance (km) | Exp. 4 Distance (km) |
|---|---|---|---|
| 1.9 km | 0.7 km | 1.7 km | 2 km |
| 0.7 km | 0.0 km | 0.4 km | 0.7 km |
| *1.3 km | 0.9 km | 1.3 km | 0.8 km |
| | *0.53 km | 0.2 km | 0.5km |
| | | 0.6 km | 1.2 km |
| | | ***0.84 km** | ***1.04 km** |

**Source:** Author's Computation

Note: * means average change in distance per minute for specific experiment.

As depicted in Table 6, the average distance traveled in one minute for experiments 1, 2, 3 and 4 was 1.30 km, 0.53 km, 0.84 km, and 1.04 km respectively. The aggregate average of 0.928 km/min was obtained across all experiments.

## 6.2. Evaluation of the DiTRoS Algorithm

This study largely relied on the engineering method as opposed to the scientific method. Instead of developing a theory and evaluating a proposed hypothesis using data from experiments, it developed and tested a solution to a hypothesis while refining the solution (Zelkowitz & Wallace, 1998). Under this context, the evaluation in this subsection seeks to assess the worth of the DiTRoS algorithm, whose implementation results in a tool for use by the community. This study strives to convince the scientific community of the algorithm's soundness by illustrating the algorithm's strengths and limitations (Cohen & Howe, 1988). The following question guides this evaluation, "*Is the computer model a vehicle to prove what we think we already know or is it an honest attempt to find answers that are not predetermined*?" (Oreskes, 1998, p. 1457). In light of this question, the evaluation of the DiTRoS algorithm details both positive and negative feedback.

There are many criteria to evaluate experiments conducted over a particular algorithm. Cohen and Howe (1988) outline various evaluation standards, such as comparing an algorithm's performance to a chosen standard, the algorithm's response to noisy or missing input, and the algorithm's efficiency and usability. Table 7 provides an evaluation of the DiTRoS algorithm based on these criteria.

**Table 7: Evaluation Results of the DiTRoS Algorithm**

| Criteria | Description | Remarks |
|---|---|---|
| Efficiency | nely delivery of otification as per the iterval specified | In many instances, notifications were delivered as per the interval specified |
| | | In fewer cases, notifications were delayed or even missing (see Table 3) |
| | The reality of distance remaining | Can estimate the actual distance remaining |
| Performance in comparison to its standard | How DiTRoS compares to physically installed reflective triangles | It can provide early warning than physically installed triangles |
| Usability | Ease of use | lows for audio output to lessen driving-related distractions |
| Response to noisy/missing input | Preciseness in coordinates (latitudes and longitudes) read as input to the algorithm | Many coordinates as inputs were precisely spotting an exact location (see Fig. 10) |
| | | In fewer cases, coordinates as input were imprecisely spotting a given location (see Fig. 11) |
| Costs | Cost of deployment | Deployment costs are relatively minimal because it makes use of existing user-owned hardware devices |

**Source:** Author

In comparison to its competitors, the DiTRoS algorithm has significant competitive benefits. As mentioned in section 2, the DiTRoS algorithm may be somewhat compared to intelligent imaging systems, night vision cameras, and intelligent vision for automobiles. In this comparison, the DiTRoS algorithm outperforms the named systems in the context of the physically erected reflected triangles issue. A compelling advantage of the DiTRoS algorithm is that it is unaffected by weather, such as rain and fog and environmental constraints, such as curved roads, hills, and valleys. Another benefit is that the DiTRoS algorithm uses existing resources, such as cellphones and cell towers, as opposed to intelligent imaging systems, night vision cameras, and intelligent vision for automobiles, which require mounting cameras on vehicles. That advantage relieves additional costs of purchasing and installing cameras because smartphones are gadgets owned by many drivers.

## 6.3. Discussion of the Findings and Recommendations

The overall objective of the current study was to develop digital reflective triangles to avoid car-to-car collisions attributed to vehicle breakdowns. The results reported in the preceding subsections show that the DiTRoS algorithm is effective in assisting drivers get notifications in advance about the presence of vehicle breakdowns in the course of their directions. For both routes selected and experimented on, the driver was made aware of dangers ahead through notifications delivered to their mobile smartphone.

The DiTRoS algorithm has been evaluated in a natural setting where the experiments had no impact on how variables, particularly dependent variables (geographical coordinates), were manipulated. Both setups with full and limited internet connectivity were intended for testing. The first test was conducted along a path where the computer network failure is likely to occur for the oncoming driver. According to Table 3, there was a network issue that caused the oncoming driver to lose touch with the server for five minutes. However, after that, the driver was able to reconnect and keep getting alerts. The scenario constitutes one of the DiTRoS algorithm shortcomings that results from the underlying route, which leaves some areas without internet connectivity due to weak or lack of cell tower coverage. In the second experiment (Table 3), the chosen route had full coverage of internet connectivity such that notifications were not affected. This study noticed some unusual incidents in which the smartphone GPS occasionally reported coordinates that were a few metres off the path on the chosen road in both experiments. The DiTRoS algorithm has proved to be an effective means to alert oncoming drivers in a more sensible way than conventional reflective triangles that are normally noticed at the distance of forty-five (45) metres.

The current study provides three recommendations in response to the reasonable distance (notifiable zone) at which oncoming traffic may begin to receive alerts. First, it is difficult to define a precise notifiable zone while considering all the factors listed in subsection 4.1. That difficulty arises because the values of those parameters fluctuate throughout time. Second, a smartphone's processing power and network speed are essential factors that could significantly impact how quickly notifications are delivered. In some situations, a more expansive notifiable zone should be considered rather than a fixed, notifiable zone. In some cases, it was found that there was a maximum delay of five minutes in the delivery of alerts to the oncoming driver. Third, the notifiable zone may be derived from data set collected. Such derivation has to put into consideration a delay in delivery of alerts, as well as the overall average change in distance per minute, which is 0.928 km/min. The product of change in distance per minute and maximum delay yields 4.64 km, approximates to 5 km. Under this establishment, the present study recommends 5km to be the minimum distance from which the driver may start to receive notifications. This distance may accommodate vehicles moving at varying speed, and also which bear varying parameters.

## 7. Conclusion and Further Works

Road warnings about vehicle breakdowns signaled through reflective triangles may become ineffective due to bad weather as well as curved road segments and uphill and downhill topography. These factors contribute to the failure of oncoming drivers to notice the presence of broken vehicles ahead of them at a reasonable distance. Such failures may result in motor vehicle collisions that cause loss of lives and properties. This paper has developed a digital approach that notifies oncoming drivers about the existence of broken vehicles earlier enough to enable them to take precautions. Oncoming drivers start getting notifications when they are within a notifiable zone ahead of the broken vehicle. The algorithm has been tested using the natural experiment method and has proved to be effective. The algorithm complements, to a larger part, physically installed reflective triangles.

Though successful, this research has limitations and has thrown some future works. Firstly, the study employed Google location service to obtain the distance between oncoming drivers and vehicle breakdowns scenery. Due to the involved cost, this distance was calculated under assumptions of straight roads that deny the reality that roads are featured with many

curves/corners. Secondly, the proposed DiTRoS algorithm is affected by lack of internet connectivity because some road segments lack cell towers. Therefore, future works should include replicating the current study using Google location services that accommodate real features (curves/corners) of the road.

**Conflict of Interest**

The author declares that there no known conflict of interest.

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## REFERENCES

Abdi, L., Abdallah, F. Ben, & Meddeb, A. (2015). In-Vehicle Augmented Reality Traffic Information System: A New Type of Communication Between Driver and Vehicle. *Procedia Computer Science*, *73*, 242–249. https://doi.org/10.1016/j.procs.2015.12.024

Ahire, A. S. (2014). Night Vision System in BMW. *International Review of Applied Engineering Research*, *4*(1), 1–10.

Calvert, S. C., Heikoop, D. D., Mecacci, G., & van Arem, B. (2020). A human centric framework for the analysis of automated driving systems based on meaningful human control. *Theoretical Issues in Ergonomics Science*, *21*(4), 478–506. https://doi.org/10.1080/1463922X.2019.1697390

Diamond, J. M. (1983). Laboratory, field and natural experiments. *Nature*, *304*, 586–587.

Endsley, M. R. (1995). Toward a Theory of Situation Awareness in Dynamic Systems. *The Journal of the Human Factors and Ergonomics Society*, *37*(1). https://doi.org/10.1518/001872095779049543

FE Online. (2017, April 26). Roads that honk themselves : Smart roads by HP Lubricants and Leo Burnett. *Financial Express*. https://www.financialexpress.com/auto/car-news/roads-that-honk-themselves-smart-roads-by-hp-lubricants-and-leo-burnett-india/643027/

Guerrero-Ibáñez, J., Zeadally, S., & Contreras-Castillo, J. (2018). Sensor Technologies for Intelligent Transportation Systems. *Sensors*, *18*(4), 1212. https://doi.org/10.3390/s18041212

Jermakian, J. S. (2011). Crash avoidance potential of four passenger vehicle technologies. *Accident Analysis and Prevention*, *43*(3), 732–740. https://doi.org/10.1016/j.aap.2010.10.020

Kubota, S., Okamoto, Y., & Oda, H. (2006). Safety driving support system using RFID for prevention of pedestrian-involved accidents. *ITST 2006 - 2006 6th International Conference on ITS Telecommunications, Proceedings*, 226–229. https://doi.org/10.1109/ITST.2006.288860

Ling, C. H., & Huong, A. (2019). Intelligent Imaging System for Optimal Night Time Driving. In N. Ibrahim (Ed.), *Bioengineering Principle and Technology Applications* (Vol. 2, pp. 27–37). Penerbit UTHM.

Luo, Y., Xiang, Y., Cao, K., & Li, K. (2016). A dynamic automated lane change maneuver based on vehicle-to-vehicle communication. *Transportation Research Part C: Emerging Technologies*, *62*, 87–102. https://doi.org/10.1016/j.trc.2015.11.011

Narla, S. R. K. (2013). The evolution of connected vehicle technology: From smart drivers to smart cars to. . . self-driving cars. *ITE Journal (Institute of Transportation Engineers)*, *83*(7), 22–26.

Nishi, T., & Takagi, T. (2001). A proposal of collision avoidance algorithm for driving support system. *IECON Proceedings (Industrial Electronics Conference)*, *3*(C), 80–83. https://doi.org/10.1109/iecon.2001.976458

Parasuraman, R., & Riley, V. (1997). Humans and Automation : Use , Misuse , Disuse , Abuse. *Human Factors and Ergonomics Society*, *39*(2), 230–253. https://doi.org/10.1518/001872097778543886

Parasuraman, R., Sheridan, T. B., & Wickens, C. D. (2000). A model for types and levels of human interaction with automation. *IEEE Transactions on Systems, Man, and Cybernetics - Part A: Systems and Humans*, *30*(3), 286–297. https://doi.org/10.1109/3468.844354

Queensland Government. (2016). *Stopping distances: speed and braking*. https://www.qld.gov.au/transport/safety/road-safety/driving-safely/stopping-distances

Rajkumar, C., & Mahendran, S. K. (2014). Vehicle Detection and Tracking System from CCTV Captured Image for Night Vision. *International Journal of Innovative Science, Engineering & Technology*, *1*(6), 454–456. https://doi.org/https://doi.org/10.1155/2016/8046529

Vision Zero. (2012). *Driving at a suitable speed*. https://visionzero.lu/wp-content/uploads/2019/06/trajet_module_6_en.pdf

WHO. (2018). Global Status Report on Road. In *World Health Organization*. https://www.who.int/violence_injury_prevention/road_safety_status/2018/en/

WHO. (2020). *Road Traffic Injuries*. Fact Sheets. https://www.who.int/news-room/fact-sheets/detail/road-traffic-injuries

Wickens, C. D., Mavor, A. S., Parasuraman, R., & Mcgee, J. P. (1998). *The Future of Air Traffic Control: Human Operators and Automation*. National Academy Press. https://doi.org/10.17226/6018

Yeong, D. J., Velasco-hernandez, G., Barry, J., & Walsh, J. (2021). Sensor and sensor fusion technology in autonomous vehicles: A review. *Sensors*, *21*(6), 1–37. https://doi.org/10.3390/s21062140

Yocco, V. (2015). 5 Characteristics Of An Innovation. *Smashing Magazine.Com*, 1–26. https://www.smashingmagazine.com/2015/01/five-characteristics-of-innovations/

Yu, T. H., Moon, Y. S., Chen, J., Fung, H. K., Ko, H. F., & Wang, R. (2009). An intelligent night vision system for automobiles. *Proceedings of the 11th IAPR Conference on Machine Vision Applications, MVA 2009*, 505–508.

Yusufu, T. (2019, September 2). Road Accidents Down 27 Percent: Report. *THE CITIZEN*. https://www.thecitizen.co.tz/news/1840340-5257278-9bd1ra/index.html