SYSTEM REQUIREMENTS SPECIFICATION

FOR

PEDESTRIAN CRASH AVOIDANCE AND MITIGATION SYSTEM FOR ADAS

Authors:

Spandana Matapathi

Shambhavi Kolte

Utkarsha Fegade

Mariam Jamal

Under Guidance of:

Prof. Erik Kamsties

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5. **Bibliography**

1. Introduction

1.1 System purpose

Over 3 million fatalities were reported in the year 2004 to 2013 according to the data collected by the National Highway Traffic Safety Administration (NHTSA). Due to awareness, campaigns and research programs and safety outreach campaigns the traffic-based fatalities have been significantly reduced over the period of a decade. Every year, more than 1.2 million people in the world die in traffic accidents and among these casualties 22% are pedestrians (WHO, 2013). But the fatalities caused to the pedestrians is increasing at an alarming rate since then. According to the survey, most of the on-road accidents takes place on account of human error. Therefore, advanced driver assistance techniques are taken into consideration to avoid such incidents. Some of the other features that are directed to assure safety and avoid potential accidents arising due to human errors include Adaptive Cruise Control and Collision Avoidance System. The vision statement for Pedestrian Crash Avoidance Mitigation goes in the following way - "*To design a feature for ADAS that is capable of avoiding or mitigating pedestrian crash to achieve Vision Zero Safety Goals*.

Pedestrian Crash Avoidance and Mitigation for ADAS are the systems used to assist the driver to alert him or take necessary actions for preventing fatal accidents or mishaps in order to ensure Pedestrian safety or road safety in general.

As the technology keeps evolving, more and more safety systems are developed to avoid such accidents. One of the salient features of ADAS includes Pedestrian crash avoidance and mitigation system or simply known as Pedestrian Crash Avoiding Mitigation (PCAM). Vehicular crash avoidance systems are mainly of two types, viz. Forward Collision warning and Automatic Brakes system. Collision Mitigation Systems are basically the Radar-based systems that provide audio as well as visual warning while driving the vehicle as soon as any moving or stable object is detected by the radar. As soon as the object is detected, the vehicle attempts to decelerate quickly in order to avoid severe accident. The radar enables to detect objects as far as 500 feet away from the vehicle. Also, the radar is capable of detecting multiple moving objects which makes it more efficient.

1.2 System scope

Collision Avoidance and Mitigation for ADAS are mostly used in the area of Commercial Vehicle Technology that helps to avoid the accidents occurring due to human errors and loss of control crashes and thus making the system more feasible. According to current research, Front Crash Avoiding Systems like Autobraking System and Radar-based techniques are proved to be more efficient than any other techniques in the market yet.

This requirement specification document provides a step by step process of analysing all aspects of the Pedestrian Crash Avoidance systems by considering all the factors that can be fruitful in the long-run.

1.3 Definitions, acronyms and abbreviations

ADAS	Advanced Driver Assistance System
PCAM	Pedestrian Crash Avoidance and Mitigation
DOA	Decision of Action
SDM	Strategic Dependency Model
V2V	Vehicle to Vehicle
V2P	Vehicel to Pedestrain
HMI	Human to Machine
VRU	Vulnerable Road User

1.4 References

Sh.1 Context diagram https://en.wikipedia.org/wiki/System_context_diagram

Sh.2 Goal modelling https://en.wikipedia.org/wiki/Goal_modeling

Sh.3 V2V https://www.its.dot.gov/research_archives/safety/v2p_comm_safety.htm

Sh.4 V2P https://www.its.dot.gov/research_archives/safety/v2p_comm_safety.htm

Sh.5 Road Collision Avoidance
https://casmodeling.springeropen.com/track/pdf/10.1186/s40294-016-0025-8

Sh.6 V2V https://en.wikipedia.org/wiki/Vehicular_communication_systems

Sh.7 Risk assessment based on driving behavior for preventing collisions with pedestrians when making across-traffic turns at intersections
https://www.sciencedirect.com/science/article/pii/S0386111217301188

Sp.1 Estimation of Potential Safety Benefits for Pedestrian Crash Avoidance/Mitigation Systems DOT H812 400 US Department of Transporttation ,Natioanl Highway Safety Administration (NHTSA)April 2017

Sp.2https://www.euroncap.com/en/vehicle-safety/the-ratings-explained/vulnerable-road-user-vru-protection/aeb-pedestrian/

Sp.3http://www.jctconsultancy.co.uk/Symposium/Symposium2011/PapersForDownload/The%20challenges%20of%20using%20radar%20for%20pedestrian%20detection%20Keith%20Manston%20Siemens.pdf

Sp.4 https://en.wikipedia.org/wiki/Pedestrian_crash_avoidance_mitigation

Sp.5 The challenges of using radar for pedestrian Detection by Keith Manston Siemens Mobility, Traffic Solutions

Ma.1
http://www.watchover-eu.org/download/WATCH-OVER_D2.1_Requirements_and_use_cases.pdf

Ma.2 Journal of Intelligent Transport Systems: Technology, Planning and Operations

Ma.3 Tiemann, Nils & Branz, Wolfgang & Schramm, Dieter. (2009). Predictive Pedestrian Protection - Sensor Requirements And Risk Assessment. 21st International Technical Conference on the Enhanced Safety of Vehicles.

1.5 System overview

PCAM extends the functionality of pedestrian safety systems by designing the vehicle to take specific actions during different possible collision scenarios between vehicle and pedestrian. The two main functionalities of our system are:

i) Application of Emergency Brakes: The system is designed to avoid or reduce the severity of the collision.[sp.3] The system will detect if there are any pedestrian in the way .If there is a plausible collision if the vehicle continues moving in same direction, a warning will be provided upon which the user must respond and change the course of the vehicle. If the user fails to do so, the system decides the possible safe action and applies the brake within the time so that collision will be prevented.

ii) Control over Steering: The system should also prevent excess steering. There might be a case where the user has to steer the vehicle to another direction to prevent collision. In this case, applying brake would do more damage than avoid a collision. Therefore, if the driver loses control over the vehicle while trying to avoid a collision, the system controls the steering in order to achieve driver's safety.

1.6 Document overview

This System Requirements Specification document is divided into multiple Subsections. The first section includes descriptions of the Purpose, Scope of the system and also includes Overview of the document. The first section also enlists the description of project specific terms, acronyms and abbreviations that will be further used in the other sections. In addition, we also list the related reference materials used for this document. The second section of the document is divided into the following five different sub sections. Each sub section describes details of the specific features related to the product: Product Perspective, Product Functions, User Characteristics, Constraints, Assumptions and Dependencies, Apportioning of Requirements. The third section is an itemized list of all of the requirements described for this system. The third section includes the use-case diagram which describes the actions to be performed based on the communication between actors and the SDM models the system goals. This document also provides Appendixes and index at the end to help anyone reading this document to easily understand the concepts.

2. General system description

Detailed description of the Pedestrian Crash Avoidance and mitigation system can be found under this section. Here, more focus is given on the factors crucial for the development of the proposed system from the customer point of view. It also emphasises on the assumptions made to create such a system.

2.1 System contexts

The system diagram describes the part of the system and shows how different entities interact with the environment. System context diagrams show a system, as a whole and it's input and output from/to the external factors[wiki].

In the above context diagram, system interaction can be understood with respect to the environmental factors taking part in the system's working. For instance, while driving the car if Pedestrians suddenly comes in between, then the decision-making module will be responsible for taking the decision in fraction amount of time and respond to the scenario accordingly. The decision-making module contains automotive radar sensors and camera inputs and accordingly processes it. It is capable of identifying and differentiating pedestrians between humans and animals. The decision-making module gives audio as well as visual alerts on the notification window to the driver of the car, so that he/she takes actions immediately. Whereas, if the driver fails to take actions within stipulated amount of time, then the decision-making module enables actuators to take control and starts decelerating or applies emergency brakes if necessary. This functionality of the system proves essential for the safety of pedestrians and the driver himself. The situation explained above is the ideal condition of the working of the system. In addition to above condition, the system may encounter many additional scenarios which are mentioned and explained in the section 2.8 of this paper for better understanding.

Fig 2.1.1 Basic context diagram of Pedestrian Crash Avoidance system

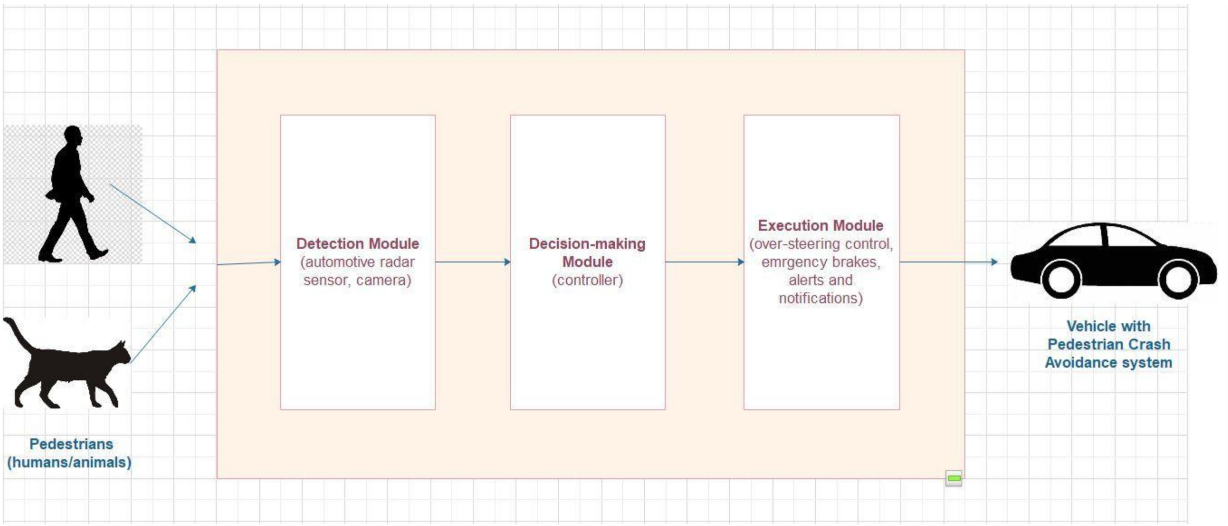
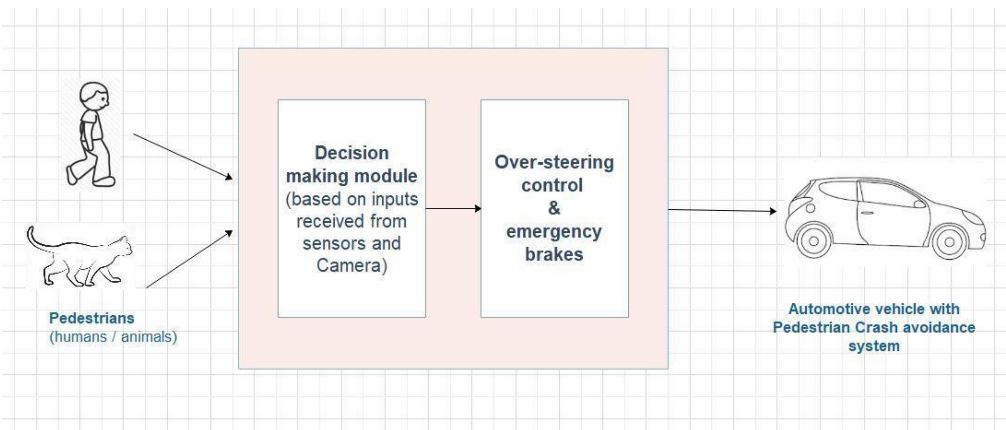


Fig 2.1.2 Detailed context diagram of Pedestrian Crash Avoidance system

2.2 Goal model

Goal modelling expresses a relationship between a system and its environment. Its main emphasis is not only the factors focussing on what the system is supposed to do, but also on why are those actions necessary. Requirements in any system is said to be complete if it satisfies all the goals of the system.



Goal modelling in requirements engineering can be specified using several notations. Out of which the most commonly used notation is the i* notation. The i* notation is further categorized into two categories, viz. SDM (Strategic Dependency Model) and SRM (Strategic Rationale Model). The above goal model is the Strategic Dependency Model used to describe the Pedestrian Crash Avoidance and Mitigation system. The above diagram shows SDM goal modelling approach to explain the system.

The above model shows several aspects and dependencies essential for the crash avoidance system in general. The working of the crash avoidance system is dependent mainly on the detection module which consists of automotive radar sensor placed used to measure distance from the obstacles and camera mounted on the top, used to identify if the pedestrian is a human or an animal. Decision making module takes certain decision based on the analysis of data collected from the detection module. Decision making module consists of a controller which analyses the data and is responsible to take necessary actions based on it. It also alerts the driver regarding the status of the system. If a pedestrian appears suddenly in front of car, then it is responsibility of decision-making module to take action and enable execution module to undertake action if the driver does not respond to the audio and visual alerts for a certain period of time.

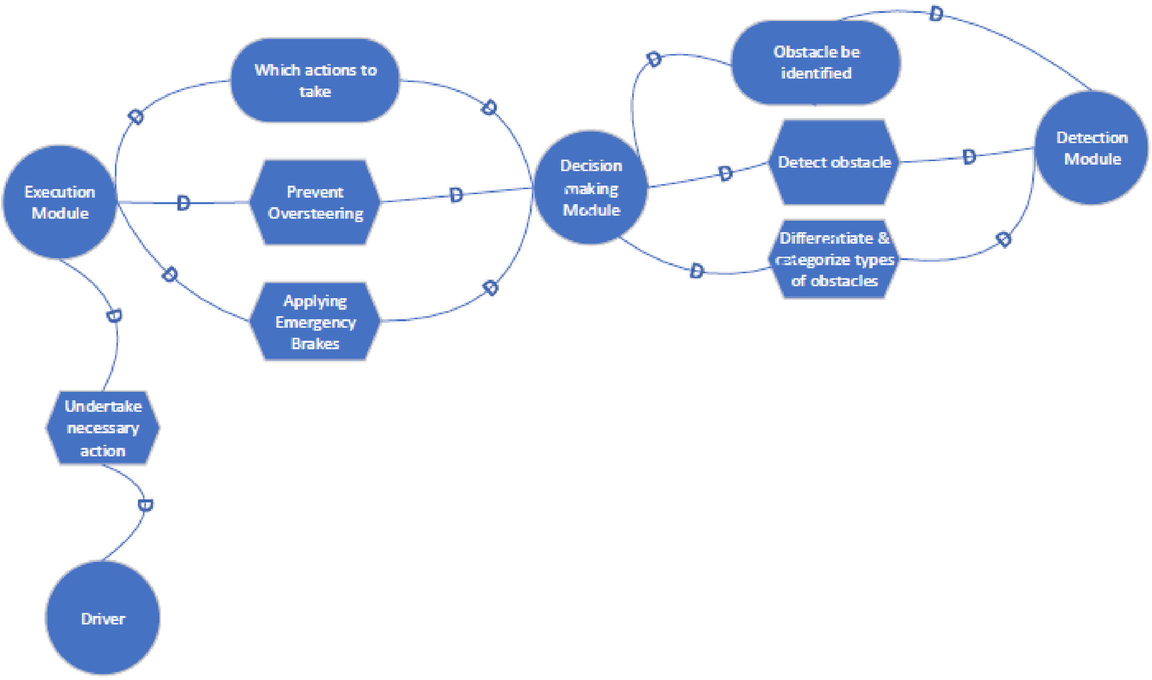


Fig 2.2 Goal Model of Pedestrian Crash Avoidance system

2.3 Major system capabilities

The pedestrian crash avoidance and mitigation system uses ADAS. ADAS stands for Automatic Driver Assistance system and these systems are used mainly to assist driver while driving. These systems are developed to reduce accidents caused by human errors and in turn increasing road safety as well as pedestrian and driver safety. The pedestrian crash avoidance and mitigation system uses artificial intelligence technique to identify between humans, animals, etc. It is also capable of differentiating between living or non-living obstacles. Better the detection and identification of objects, better for making concrete decisions. The radar is also capable of identifying objects single or multiple moving objects as far as 500 feet. Also, the artificial intelligence system can differentiate between rural or urban regions based on the data collected and hence alter the behaviour or the vehicle accordingly. The system can work in kinds of weather.

2.4 Major system constraints

Environmental conditions such as heavy rains, fog, storms etc. can make the design kaput .The system may completely or partially fail to take decisions accordingly in these situations. Selection of radar for implementation is a difficult feat to achieve as there can be compensation in the working in one or more than one combination of following[Sp.4]:

1. Low Performance in low light conditions
2. False detection
3. High Cost of Installation
4. Ability to detect moving and static Pedestrians
5. Reliability

Safety of the users plays a major concern for designing this system. The extent until which the safety of the user should be taken into consideration compared to the pedestrian is difficult to comprehend and may raise disputes among the different stakeholders.

Additionally, morality plays a crucial role in obtaining DOA. It can setback the design decisions because as humans we have to follow certain ethical codes in making decisions which can threaten other lives.

2.5 User characteristics

In general cars, the user is anyone who is driving the vehicle in which the system is installed. In Automated driving cars, there is no driver and hence actions are taken by ADAS system. Our system has to take into consideration of sequence of actions ADAS system performs at every specified interval of time. The passengers in the car are the indirect users of the system.

2.6 Assumptions and dependencies

The Pedestrian Crash Avoidance and Mitigation system has few limits, which are discussed in this section. It is necessary for the system to be operational if and only if the car's speed is in the certain range. If the radar detects obstacle from a distance, then there will be ample of time to decelerate the speed of the car and stop the car in time. But, if the driver is driving the car at large speed crossing the limits, then it will be difficult for the system to suddenly apply brakes and ensure driver's as well as pedestrian safety at the same time. Stopping a car at high speed is risky and may also prove fatal. Therefore, the car's speed is assumed to be less than 60 Km/Hr on the rural street for the system to take actions effectively. Similarly, the speed must be maintained within 30 Km/Hr on urban street where traffic is a bigger problem. Partial or full braking force will be applied if the objects comes suddenly in front of the vehicle when it is just 15 feet away. The ability of the system to prevent crash and ensure pedestrian safety mainly depends on the automotive radar sensor's range resolution to 76 GHz to 81 GHz. This enables the radar to detect far and multiple moving objects. Radar can also help to operate the system effectively during bad weather conditions. Behaviour of the system in certain scenarios is discussed in the next section.

2.7 Operational scenarios

Scenario 1:

Vehicle going straight and pedestrian in the road

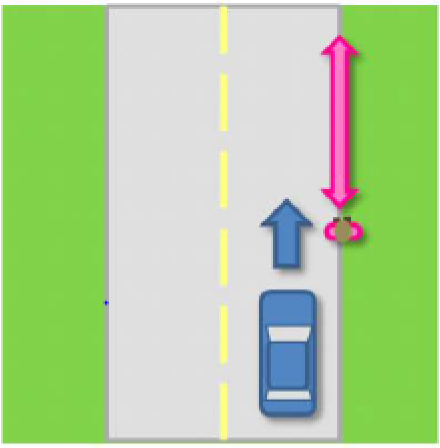


Fig 2.7.1 Scenario 1

This scenario is one of the top priority ones to consider while designing a PCAM System according to the research conducted by [Sp.1] in terms of frequency and crashes statistics. The paper also remarks it is similar to the scenario 'Vehicle going straight and pedestrian adjacent to the road'. Hence, we will consider the situations resulting from both of these.

In this scenario, the vehicle is going straight. Position and moment of pedestrian is of following types:

Pedestrian is in the way of the vehicle and stationary
Pedestrian is adjacent to the vehicle and stationary
Pedestrian is in the way of the vehicle and moving
Pedestrian is adjacent to the vehicle and moving

In this longitudinal scenario, two tests to verify the PCAM Systems are done:
- One with the pedestrian aligned with the center of vehicle

-the other with the pedestrian offset to one side [Sp.2]

Low lights condition needs to be additionally tested as the performance of pedestrian detection in dark is weighed down by few specific disadvantages based on the radar used. There can also be false detections [sp.2] due to shadows and changing light levels. Also the number of pedestrian crashes occurs at low light conditions.

Scenario 2:

Pedestrian or cyclist at cross intersections from the right.

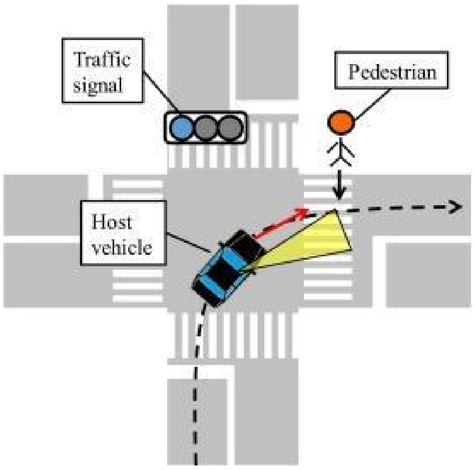


Fig 2.7.2 Overhead view of target driving scenario: a right turn at a signalized intersection in left-hand traffic with no other road users other than a pedestrian walking toward/on the crosswalk.

Description:

In a situation where the vehicle is being driven on a two-way traffic intersection at a fair speed. Here, there may arise a situation in which the driver may just look at the pedestrian and not acknowledge the fact and proceed crossing the intersection. This is because of the fact looking at the pedestrians and noticing the pedestrians are two different things. According to Pedestrian Crash Data Study (PCDS), conducted by National Highway Traffic Safety Administration (NHTSA) in the year 1994-1998, pedestrians hit during straight movement, right turns and left turns were 48%, 32% and 10% respectively. 60% of pedestrians in the left-turn crashes and 67% of pedestrians were injured during right-turn crashes.

Solution:

The vehicle's speed will be eventually reduced in such a scenario giving ample of time to pedestrian to cross the road. If the pedestrian still appears in front of the vehicle, then the system will stop the car until all the pedestrians crosses the road.

Scenario 3:

Pedestrian crossing the road occluded from parked or stopped cars or other obstacles.

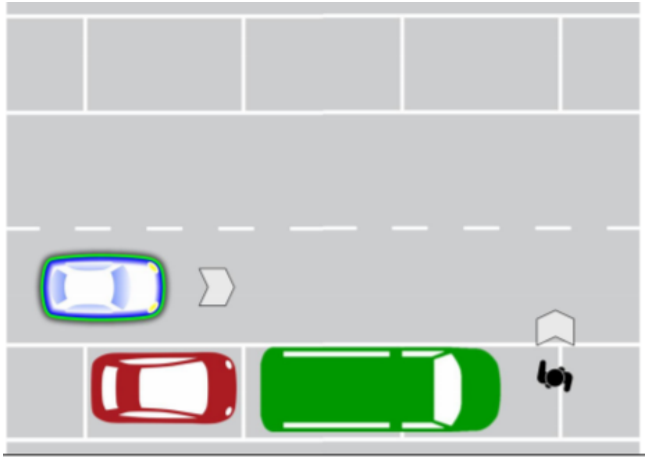


Fig 2.7.3 Overview of Scenario 3: Pedestrian is crossing the road while driver is unable to detect due to occlusion by the parked cars.

This scenario is a high occurrence one where the pedestrian is not visible to the driver due to occlusion by the parked vehicles. It represents one of the most frequent (30.78%) cases in the (Stanzel 2002) survey. This is also supported from PROTECTOR user needs survey that considered, with short distance between car and pedestrian, as the most critical scenario. [Ma.1]

Due to sudden appearance, the timely detection and decision making by the system is of utmost importance. The chances of oversteering by the driver are also high in such a case. If the detection time is less than the time to collision, the crash can be avoided. If it is equivalent, then the collision may or may not be mitigated.

Solution:

This scenario can be avoided through communication channel between the pedestrian and the vehicle(V2P) such that both are warned of the occurrence.

Scenario 4:

3.1 Functional Requirements:

3.1.1 User interface

There should be user button on the dashboard on the system to turn on or turn off the PCAM functionality.

Priority: High
Risk: High
Version: 1
Target Iteration: 1
Comments: Position of button is a part of aesthetics feature of vehicle. Designer can come up with final decision.
Source: Spandana

3.1.2 Detection of VRU

The system shall be able to detect VRU which are prone to collision with the vehicle.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.1.3 Background Classification

The system should be able to differentiate between urban & rural roads with the help of camera & decision module.

Priority: Medium
Risk: Medium
Version: 1
Source: Utkarsha

3.1.4 Detection of more than one VRU

The radar must be capable of detecting more than one VRU or stationary objects.

Priority: High
Risk: High
Version: 1
Source: Shambhavi

3.1.5 Camera Module

The camera should be able to detect objects, both in near and far distances.
3.1.5.1 The system should have a horizontal field of view of about 41° for near distances.
3.1.5.2 The system should have a vertical field of view of about 27° and sufficient resolution for far distances.
3.1.5.3 The camera module should be able to minimize distortions and undesired optical effects such as ghost images, stray lights

Priority: High
Risk: High
Version: 2
Source: Mariam

3.1.6 Classification
The system shall be able to differentiate and classify VRU into either of the categories viz. pedestrians, animals and inanimate objects.

Priority: High
Risk: High
Version: 1
Source: All

3.1.7 Course of action
The decision module shall consider factors like speed of the vehicle, distance from obstacle, type of obstacle, type of road, risk value to drive the course of action.

Priority: Medium
Risk: Medium
Version: 1
Source: Utkarsha

3.1.8 Crash Risk Prediction
The system should be able to predict the crash risk accurately.
3.1.3.1 The system shall be able to track the position and distance of the pedestrians/animals over time.
3.1.3.2 The system shall be able to predict their intended path approximately 5m ahead.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.1.9 Braking force

The system should calculate the precise braking force ideally required when a danger of collision is detected.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.1.10 No danger
The system shall stop deceleration if the VRU moves out of Crash probability range.

Priority: Low
Risk: Low
Version: 1
Source: Utkarsha

3.1.11 Warning to Driver about possible collision
The system shall provide the driver audio and visual warning about possible collision through the user interface.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.1.12 Warning when decision cannot be reached
The system shall warn the driver when DOA cannot be decided due to any of the external factors.

Priority: High
Risk: High
Version: 1
Target Iteration: 1
Source: Spandana

3.1.13 Warning to Pedestrian about possible collision
The system shall provide warning of collision to the VRU through blinking of headlights and honking once.

Priority: Low
Risk: Low
Version: 1
Source: Utkarsha

3.1.14 Crash Avoidance

The system shall be able to decide of applying brakes or steering once the crash risk is detected.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.1.15 Inaction

The system shall switch the apply brake after 2 seconds of inaction from the point of DOA.

Priority: High
Risk: High
Version: 1
Target Iteration: 1
Source: Spandana

3.1.16 Override System

The System shall turn off automatically or override to off state when visibility falls below 50%

Priority: High
Risk: High
Version: 1
Target Iteration: 1
Source: Spandana

3.1.17 Regaining control

The system should be capable of regaining control of the vehicle if the driver loses control while driving.

Priority: High
Risk: High
Version: 1
Source: Shambhavi

3.1.18 Resuming of speed

The system shall resume to the previous speed once the collision is avoided and there is no imminent danger.
Priority: Low
Risk: Low
Version: 1

Source: Mariam

3.2 Safety Requirements:

3.2.1 System activation/deactivation

The system shall be activated only if the vehicle ignition system is on. The system shall be deactivated when the vehicle is turned off.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.2.1 Speed limit

The system shall be operational only if the speed of the vehicle is above 10km/hr and less than 50 km/hr.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.2.1 Height Limit

The system shall be able to take decisions for obstacles varying in height in range of 2 – 7 feet.

Priority: High
Risk: High
Version: 1
Source: Utkarsha

3.2.2 Emergency Full Braking

Emergency Full braking shall only be applied if speed of the vehicle is less than 35km/h to ensure passenger safety.

Priority: High
Risk: High
Version: 1
Source: Utkarsha

3.2.3 Risk Value

The system shall calculate the change in distance of the pedestrian for every 1000µs to determine risk value.

Priority: Medium
Risk: Medium

Version: 1
Source: Utkarsha

3.2.4 Maximum deceleration
The system shall not decelerate at a rate higher than 3.5 m/s^2.

Priority: High
Risk: Medium
Version: 1
Source: Utkarsha

3.2.5 VRU appears suddenly in front of vehicle
The system shall apply partial or full braking force, if the VRU detected by the radar appears suddenly less than 15 feet away from the vehicle.

Priority: High
Risk: High
Version: 2
Source: Shambhavi

3.2.6 Detection and Logging of system failure
The system shall be able to detect and log system and sensor errors, failures, faults and discrepancies.

Priority: High
Risk: High
Version: 1
Source: Mariam

3.2.6 Security
The system shall prevent unauthorized access to the controller.

Priority: High
Risk: High
Version: 1
Comment: Since the brakes can be activated by a controller, external hackers can send incorrect signals to the brakes from other car communication systems, if they exist, so the PCAS needs to be able to detect incorrect messages and prevent them from being sent.
Source: Mariam

3.2.7 Compliance to Standards
The system shall comply with NCAP requirements regarding automatic emergency braking and other reliability standard- ISO26262

Priority: High

Risk: High
Version: 1
Comment: The information provided by the system can save pedestrian life, but if the system is misbehaving or providing incorrect information, that may cause severe injuries or death of pedestrians and passengers of the vehicle. Because of this safety critical nature, the reliability of the system is at most importance
Source: Mariam

3.2.8 Response Time
The system shall provide minimum response time to have real-time feedback.

Priority: High
Risk: High
Version: 1
Comment: Accurate and on time response is extremely important. The time window can be chosen as per the user requirements and current standards.
Source: Mariam

3.2.9 Processing Power
The hardware platform should be carefully chosen to facilitate multi-core Central Pre-processing Unit (CPU) and Multicore Graphics Processing Unit (GPU) support for computationally complex ADAS processing.

Priority: Medium
Risk: Medium
Version: 1
Source: Mariam

3.2.10 Environmental Conditions
The DOA should not be affected by environmental factors like fog or rain.
Priority: High
Risk: High
Version: 1
Target Iteration: 1
Comments: It should be noted that these factors will affect the system. The system should work at its best at these situations.
Source: Spandana

4. System Interfaces

The system interface is given as below:

1. **V2P**

V2P stands for Vehicle-to-Pedestrian communication. These are basically pedestrian detection system which can be implemented in such a way that pedestrians carry a hand-held device with themselves. This will prove beneficial to prevent road accidents by alerting the driver whenever pedestrian is nearby.

2. V2V

V2V stands for Vehicle-to-Vehicle communication. Here, the vehicles communicate with each other in the form of computer network by passing necessary information such as safety warnings and traffic density, etc. They can be effective in avoiding accidents and traffic congestion. Both types of nodes are dedicated short-range communications (DSRC) devices. DSRC works in 5.9 GHz band with bandwidth of 75 MHz and approximate range of 300 m. Vehicular communications is usually developed as a part of intelligent transportation systems (ITS). [wiki]

3. HMI Interface

Notification Panel or Display Screen would act as Human Machine Interface where the user will select the option for switching the system on or off. The DOA will also be displayed on same screen. In addition, any kinds of modification for displaying data would be done through this interface.