Model-Based Systems Engineering Design of an Automobile Collision Avoidance System (ACAS)

Adi Lang, Deepa Jonnagadla, Andy Hammond, Alex Atahua

ISR Advisor: Professor John Baras

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Abstract

According to the National Highway Traffic Safety Administration (NHTSA), over 30,000 fatal automobile crashes occur each year in the United States [1]. An Automobile Collision Avoidance System (ACAS) would prevent deadly collisions, resulting in reduced human suffering and eased financial burden on the economy. This paper focuses on the development of an ACAS using a wide range of model based system engineering tools. Ultimately, we limited the scope of this project so that we could make a satisfactory attempt at implementing the various tools. First, the paper discusses the development of use cases and textual scenarios. Next, the paper introduces system structure and simplified models of system behavior. Third, the paper covers requirements engineering and system level design. Finally, after addressing testing, validation, verification, the paper concludes with a simplified approach to trade-off analysis. Ideally, the system will be implemented in all automobiles throughout the United States. Widespread implementation of the system would create a virtual collision-free bubble around all vehicles.

Part 1. Problem Statement

According to the National Highway Traffic Safety Administration (NHTSA), over 30,000 fatal automobile crashes occur each year in the United States [1]. An Automobile Collision Avoidance System (ACAS) is necessary to prevent such deadly collisions. Ideally, the system will be implemented in all automobiles throughout the United States. Widespread implementation of the system would create a virtual collision-free bubble around all vehicles.

If successful, this project would reduce human suffering caused by automobile accidents. The two main project stakeholders are drivers and automobile manufacturers, and they are concerned with cost, ease of use, and safety. The desire for safer cars and roads will be the main factor driving the economics of development.

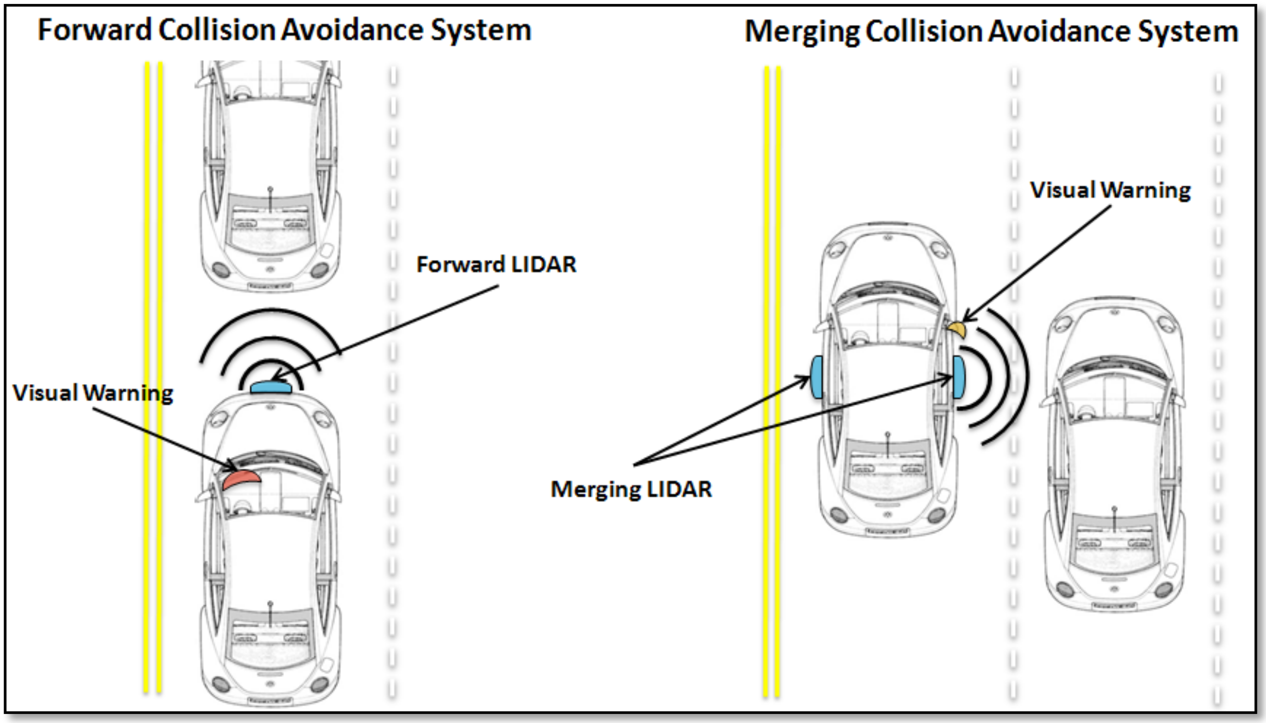


Figure 1 – Forward and Merging Collision Avoidance Systems

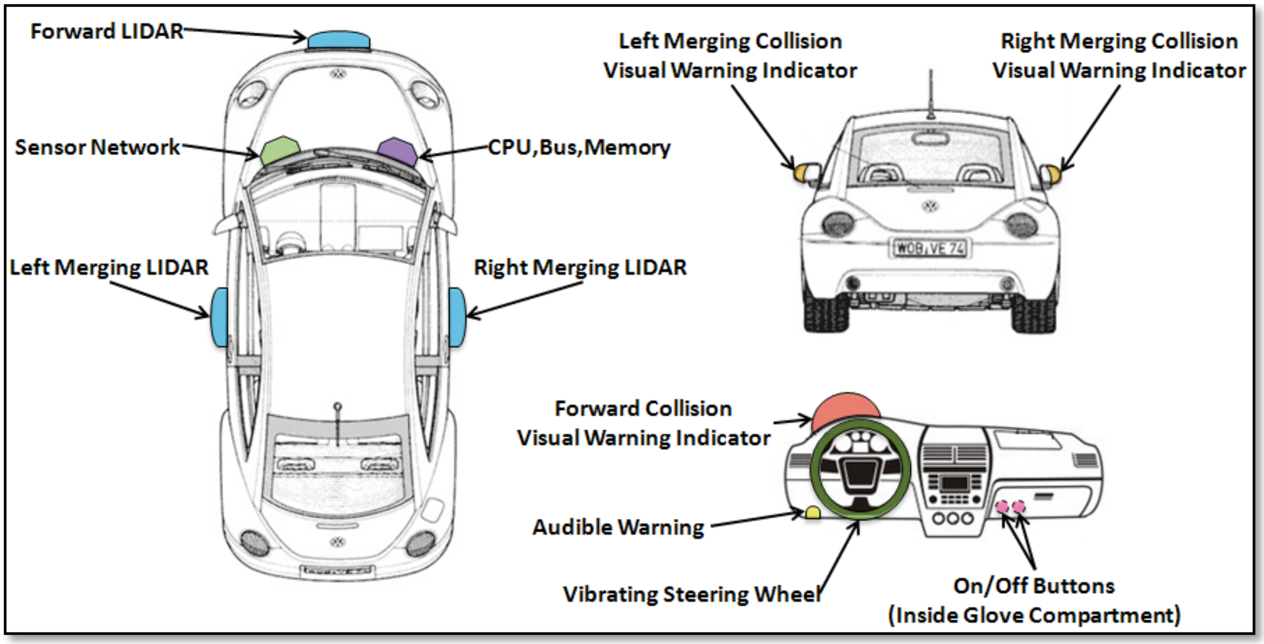


Figure 2 – Overview of System Components

Project Scope and Assumptions

Real world development of an Automobile Collision Avoidance System is an extremely complex task. Systems engineers must consider the infinite number of scenarios in which the system must safely perform. In order to reduce project complexity to a manageable level, the following system development assumes that the host vehicle is traveling forward on a straight stretch of highway. In addition, we only consider scenarios between the host vehicle and one other vehicle or non-vehicle obstacle.

Part 2. Use Case Development

Project Stakeholders

- Drivers
- Automobile Manufacturers

Actors

- Driver
- Host Vehicle
- Other Vehicles
- Non-Vehicle Obstacles

Use Cases

I. System Functionality
    1. Alerting the Driver (Forward Collision)
    2. Alerting the Driver (Merging Collision)
    3. Braking Control
    4. Restricted Steering

II. Driver Functionality
    5. Approaching Another Vehicle or Non-Vehicle Obstacle
    6. Changing Lanes
    7. Turning the System On and Off

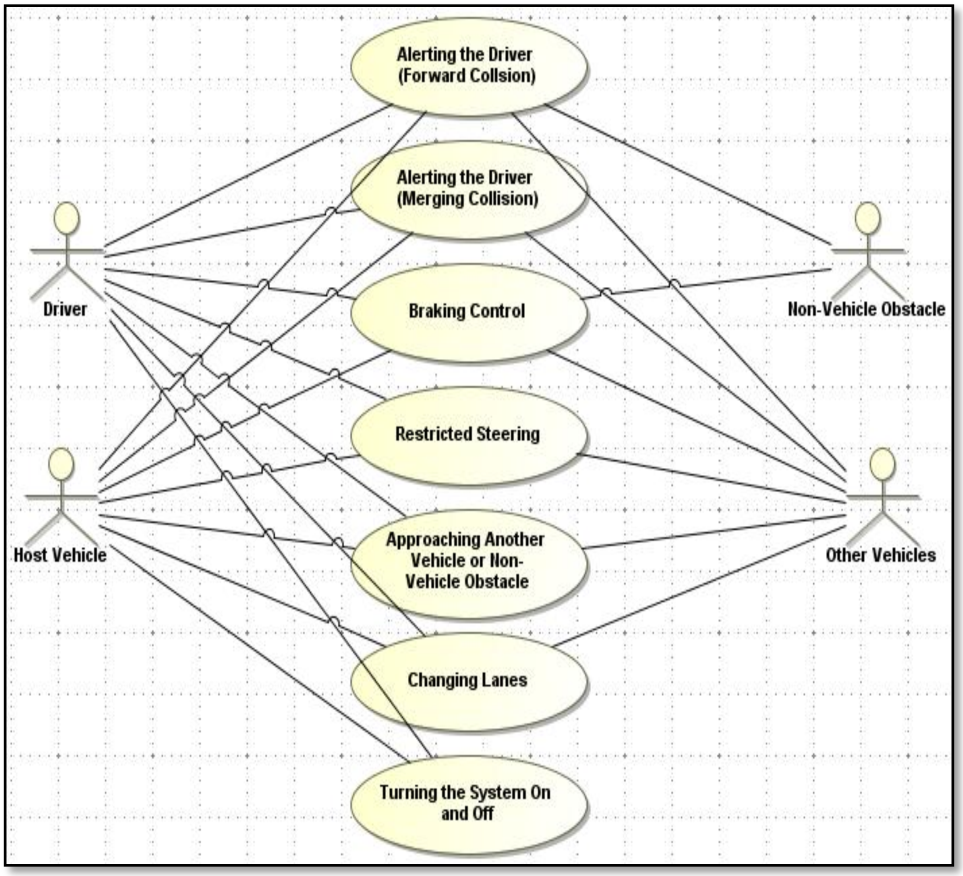


Figure 3 - Use Case Diagram

Part 3. Textual Scenarios

Use Case 1: Alerting the Driver (Forward Collision)

Description: The ACAS alerts the driver when the sensors detect that the host vehicle is on a collision path with another vehicle or non-vehicle obstacle.

Primary Actors: Driver, Host Vehicle, Other Vehicles, Non-Vehicle Obstacles

Pre-Conditions:

1. There is another vehicle or non-vehicle obstacle in the direct path of the host vehicle.

Flow of events:

1. The driver is driving the vehicle forward.
2. The ACAS continuously gathers data about the host vehicle and objects in the host vehicle's path, e.g. the velocity of the host vehicle, the distance from other vehicles and objects, the velocity of other vehicles and objects.
3. From this data, the ACAS determines that the host vehicle is in one of the following states:
    - State 1: Forward collision is not probable (normal driving)
        i. Any alerts are deactivated
    - State 2: Forward collision is probable if no action is taken
        i. The ACAS activates a visual alert

- State 3: Forward collision is imminent
    i. The activates a visual alert and vibrates the steering wheel

Post-Conditions:

1. The driver is alerted of a probable or imminent forward collision.

New Requirements:

a. The Visual Warning Indicator must be highly visible.

Use Case 2: Alerting the Driver (Merging Collision)

Description: The ACAS alerts the driver when the sensors detect a vehicle in the adjacent lane and when a merging collision is imminent.

Primary Actors: Driver, Host Vehicle, Other Vehicles

Pre-Conditions:

1. There is a vehicle in the adjacent lane.

Flow of events:

1. The ACAS system determines if a vehicle is occupying the lane adjacent to the host vehicle.
2. If there is a vehicle occupying the adjacent lane,
    i. The ACAS activates a visual alert.
    ii. The ACAS determines if the host vehicle is in one of the following states.
    - State 1: Merging collision is not probable
    - State 2: Merging collision is probable if no action is taken
    - State 3: Forward collision is imminent
        i. The ACAS activates an audible warning.
3. The ACAS deactivates the visual alert when there is no vehicle occupying the adjacent lane.

Post-Conditions:

1. The driver is warned of a vehicle in the adjacent lane.
2. The driver is warned of an imminent merging collision.

New Requirements:

a. The Visual Warning Indicator must be highly visible.
b. The Audible Warning must be highly audible.

Use Case 3: Braking Control

Description: The ACAS prevents the host vehicle from colliding with other vehicles and non-vehicle obstacles in its direct path.

Primary Actors: Driver, Host Vehicle, Other Vehicles, Non-Vehicle Obstacles

Pre-conditions:

1. The Braking Control System is turned on.
2. There is another vehicle or non-vehicle obstacle in the direct path of the host vehicle.

Flow of events:

1. The host vehicle is approaching another vehicle or non-vehicle obstacle.
2. The driver does not activate the brakes, or activates the brakes not hard and/or quickly enough.
3. The ACAS determines that a collision is imminent.
4. The Braking Control System activates the brakes.
5. The ACAS determines that a collision is no longer imminent.
6. The Braking Control System deactivates.

Post-conditions:

1. Forward collision is not probable or imminent.
2. The driver has full control of the vehicle.

New Requirements:

a. The braking control system should not activate when cars/objects are moving toward the host vehicle.
b. The braking control system must be compatible with vehicle's braking system.

Use Case 4: Restricted Steering

Description: The ACAS prevents the host vehicle from colliding into an adjacent vehicle.

Primary Actors: Driver, Host Vehicle, Other Vehicles

Pre-Conditions:

1. The Restricted Steering System is turned on.
2. There is a vehicle in the adjacent lane.

Flow of Events:

1. The driver turns the steering wheel in the direction of the occupied adjacent lane.
2. The ACAS determines that a collision is imminent.
3. The Restricted Steering System steers the car in the opposite direction.
4. The ACAS determines that a collision is no longer imminent.
5. The Restricted Steering System deactivates.

Post-Conditions:

1. Merging collision is not probable or imminent.
2. The driver has full control of the vehicle.

New Requirements:

a. The restricted steering system must be compatible with the vehicle's steering system.

Use Case 5: Approaching Another Vehicle or Non-Vehicle Obstacle

Description: The driver interacts with the ACAS to avoid a forward collision when the host vehicle is approaching another vehicle or non-vehicle obstacle too quickly

Primary Actors: Driver, Host Vehicle, and Other Vehicles

Pre-Conditions:

1. The Braking Control System is turned on.
2. The driver is driving the host vehicle forward.

Flow of Events:

1. The host vehicle is approaching another vehicle or non-vehicle obstacle too quickly and a collision is probable.
2. The ACAS activates a visual alert.
3. The driver fails to respond or responds inappropriately to the visual alert.
4. The ACAS determines that a collision is imminent.
5. The ACAS activates the Restricted Steering System and vibrates the steering wheel.

Alternate Flow of Events:

1. The host vehicle is approaching another vehicle or non-vehicle obstacle too quickly and a collision is probable.
2. The ACAS activates a visual alert.
3. The driver applies the brakes appropriately.
4. The ACAS determines that a collision is not probable.
5. The ACAS deactivates the visual alert.

Post Conditions:

1. A collision has been avoided.
2. The driver has full control of the vehicle.

Use Case 6: Changing Lanes

Description: The driver interacts with the ACAS to avoid a merging collision.

Primary Actors: Driver, Host Vehicle, and Other Vehicles

Pre-Conditions:

1. The Restricted Steering System is turned on.

Flow of Events:

1. The driver checks to see if the visual alert is active.
2. The visual alert is active (indicating an occupied adjacent lane).
3. The driver attempts to merge into the occupied adjacent lane.
4. The ACAS activates the Restricted Steering System and the audible alert.

Alternate Flow of Events:

1. The driver checks to see if the visual alert is active.
2. The visual alert is active (indicating an occupied adjacent lane).
3. The driver waits for the occupied adjacent lane to clear out.
4. The visual alert is no longer active.

Post Conditions:

1. A collision has been avoided.
2. The driver makes a safe lane change.
3. The driver has full control of the vehicle.

Use Case 7: Turning the ACAS On and Off

Description: The driver can turn the Restricted Steering System and the Breaking Control System on/off.

Primary Actors: Driver, Host Vehicle

Pre-condition:

1. There is a switch for turning each the Restricted Steering and Breaking Control Systems on/off.

Flow of Events:

1. The driver toggles the on/off switches for the Restricted Steering and Breaking Control Systems.

Post-Conditions:

1. The Restricted Steering and Breaking Control Systems of the ACAS are either on or off based on the driver's preference.

New Requirements:

a. There must be a user friendly way to turn on/off the Restricted Steering System.
b. There must be a user friendly way to turn on/off the Breaking Control System.

System Structure

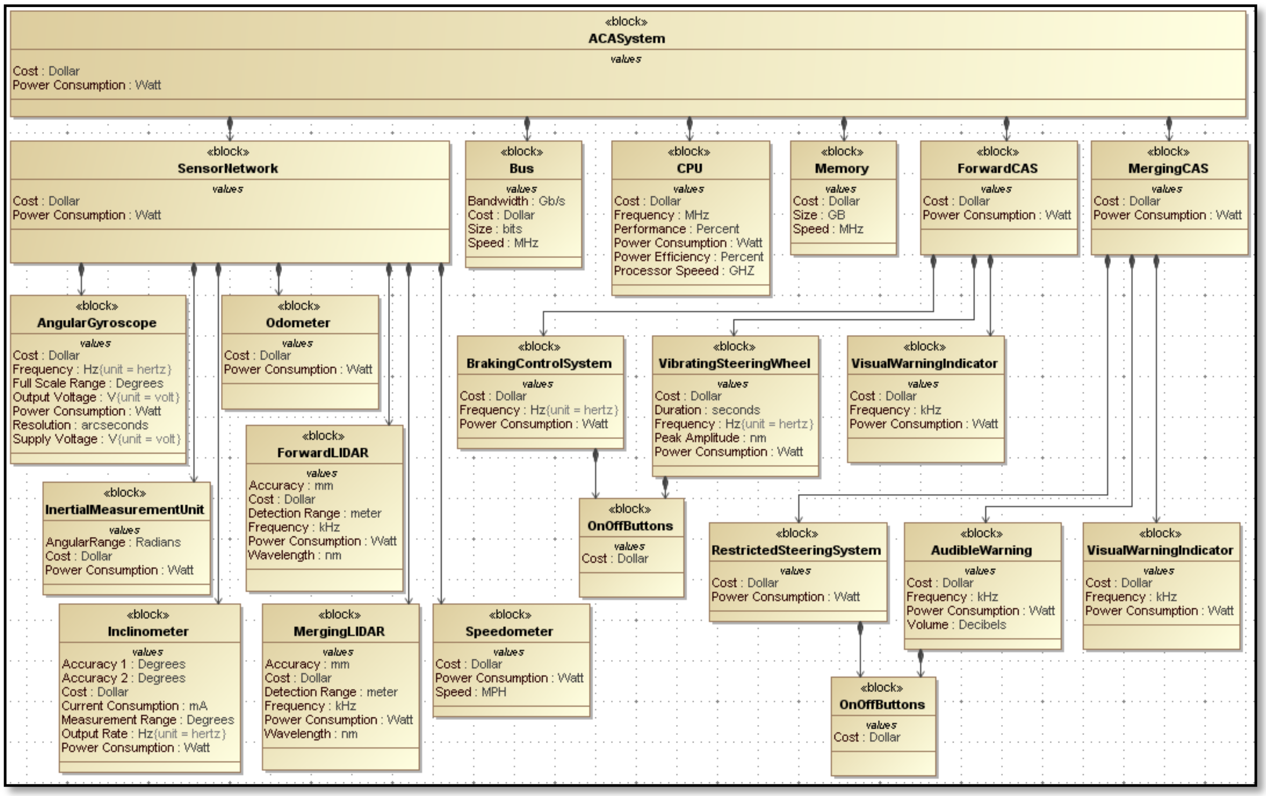


Figure 4 - Automobile Collision Avoidance System Block Definition Diagram

Part 4. Simplified Models of System Behavior

Forward Collision Avoidance System (ForwardCAS) Behavior

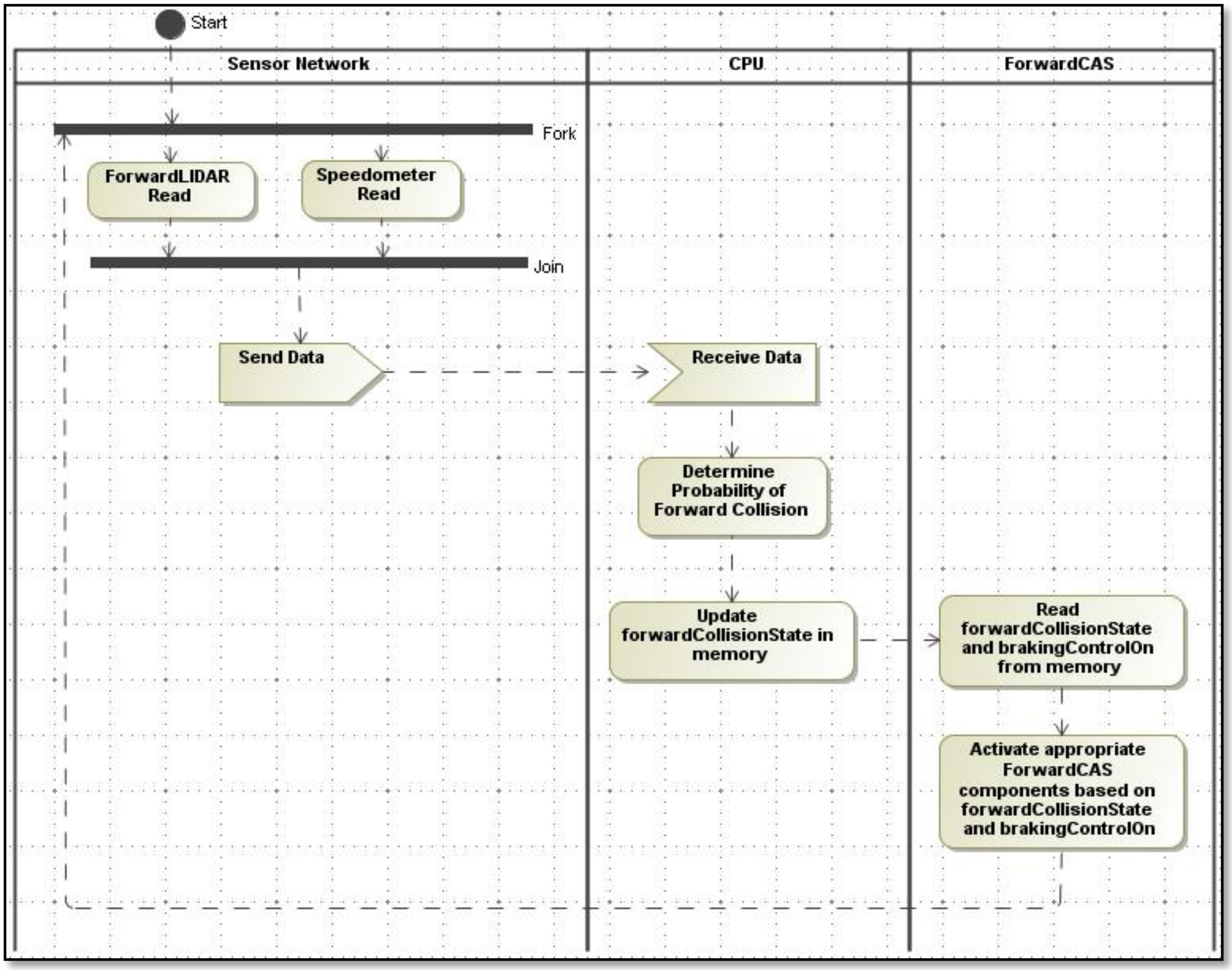


Figure 5 – Forward Collision Avoidance System (ForwardCAS) Activity Diagram

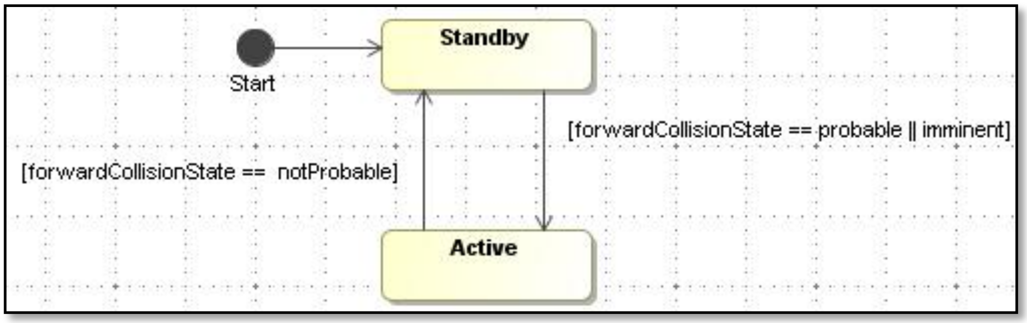


Figure 6 – ForwardCAS Visual Warning Indicator State Machine Diagram

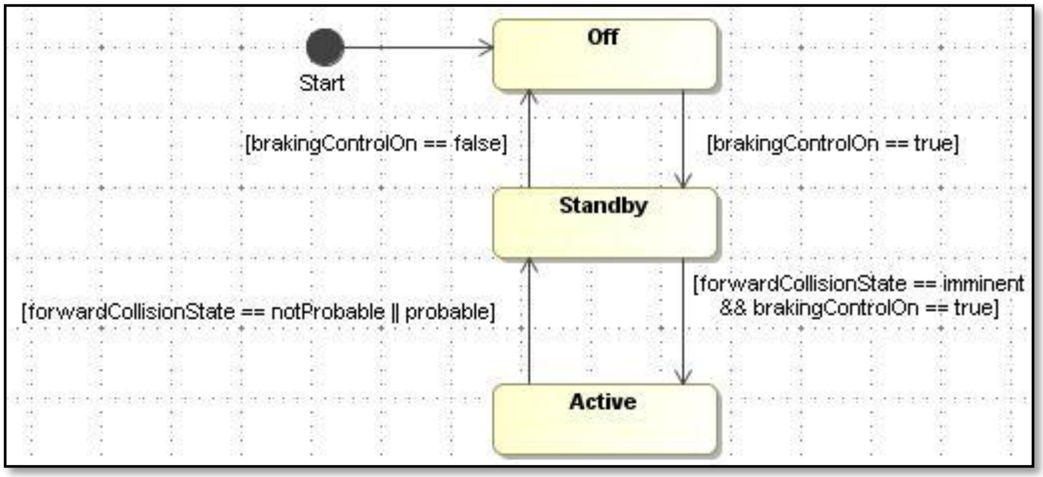


Figure 7 – ForwardCAS Braking Control System and Vibrating Steering Wheel State Machine Diagram

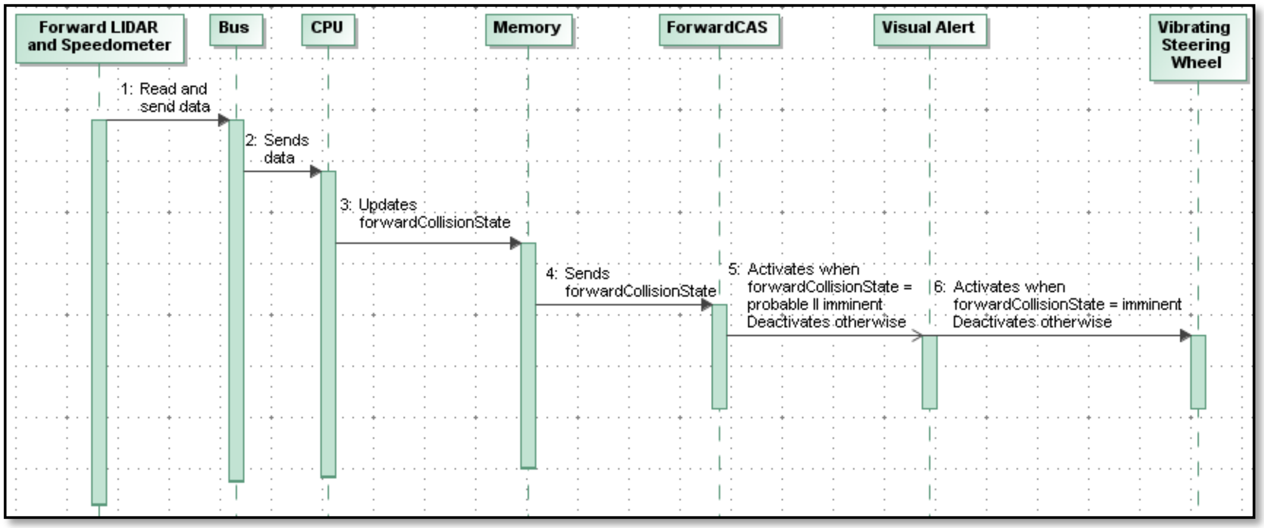


Figure 8 – ForwardCAS Alerting Sequence Diagram

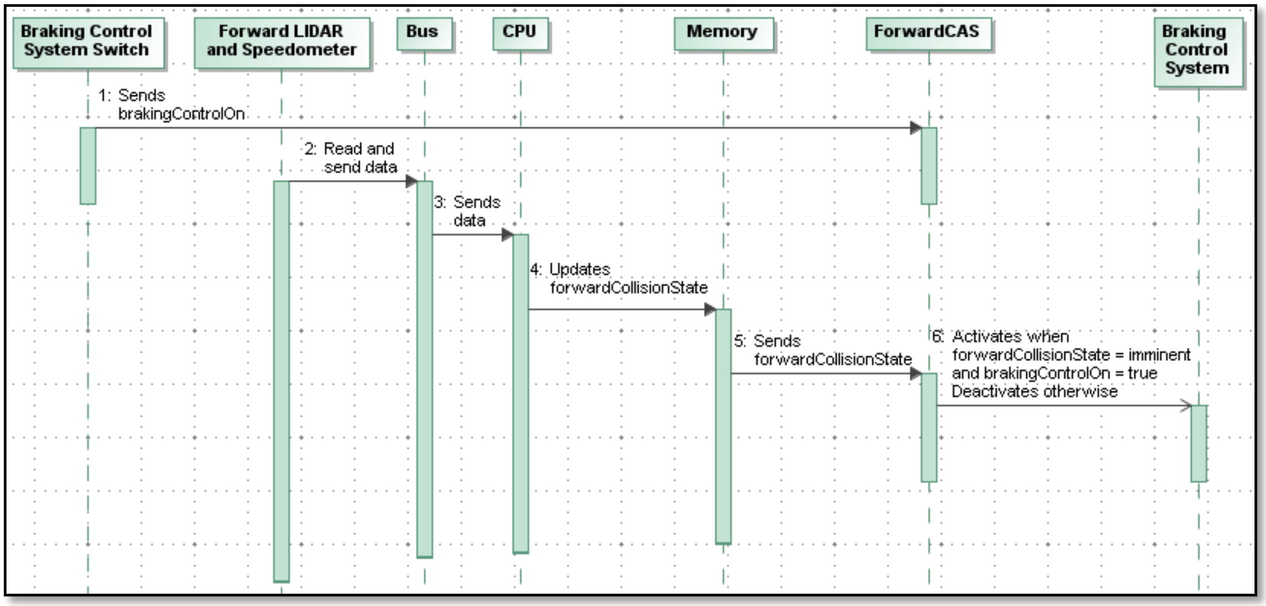


Figure 9 – ForwardCAS Braking Control Sequence Diagram

Merging Collision Avoidance System (MergingCAS) Behavior

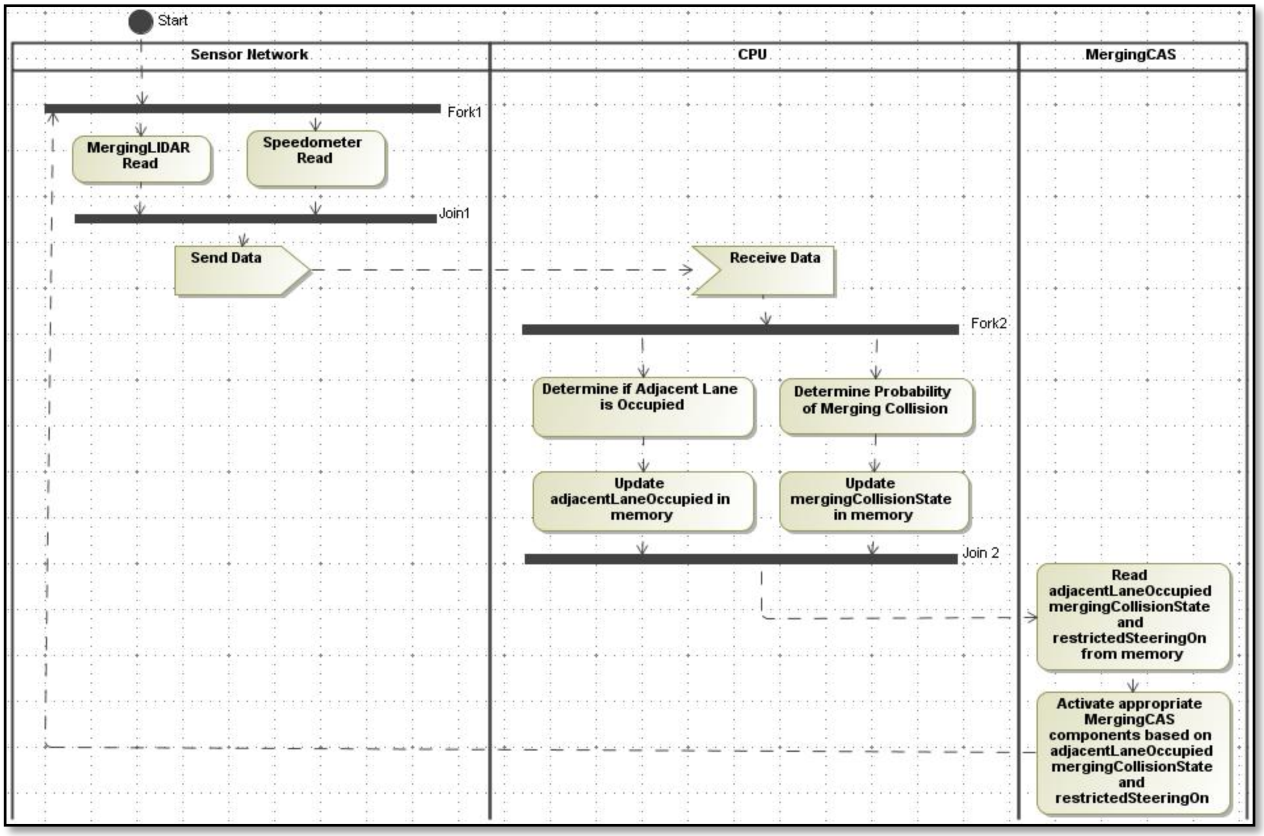


Figure 10 – Merging Collision Avoidance System (MergingCAS) Activity Diagram

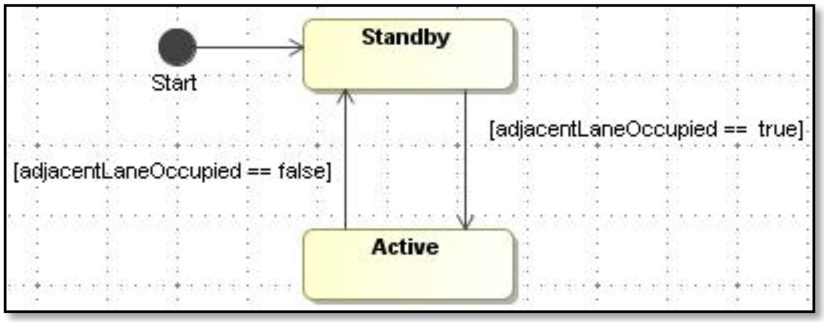


Figure 11 - MergingCAS Visual Warning Indicator State Machine Diagram

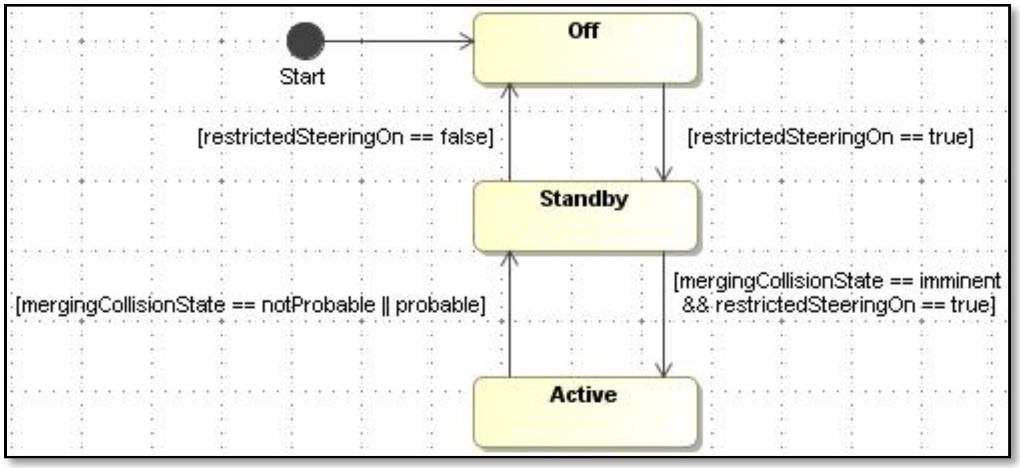


Figure 12 - MergingCAS Restricted Steering System and Audible Warning State Machine Diagram

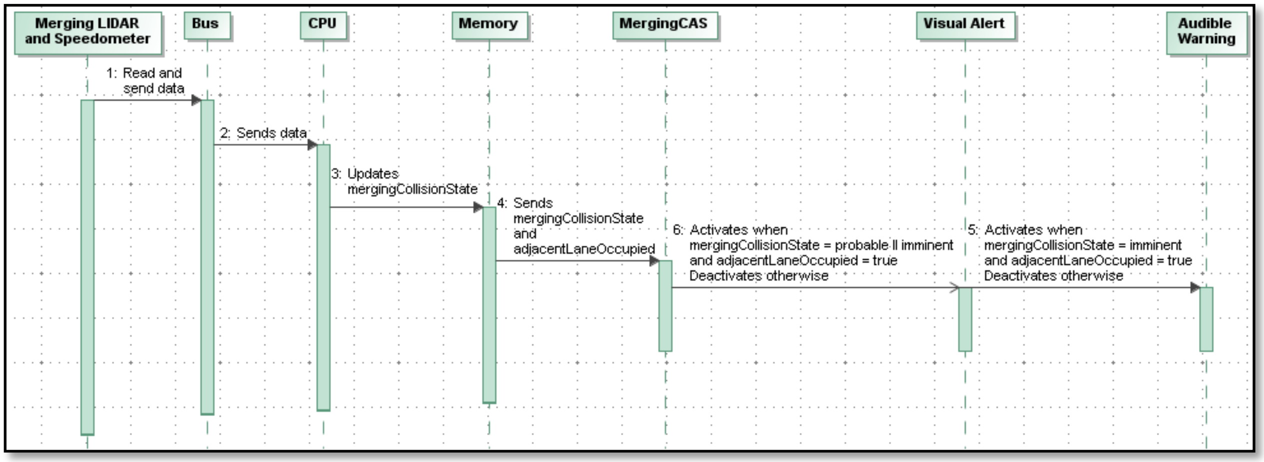


Figure 13 - MergingCAS Alerting Sequence Diagram

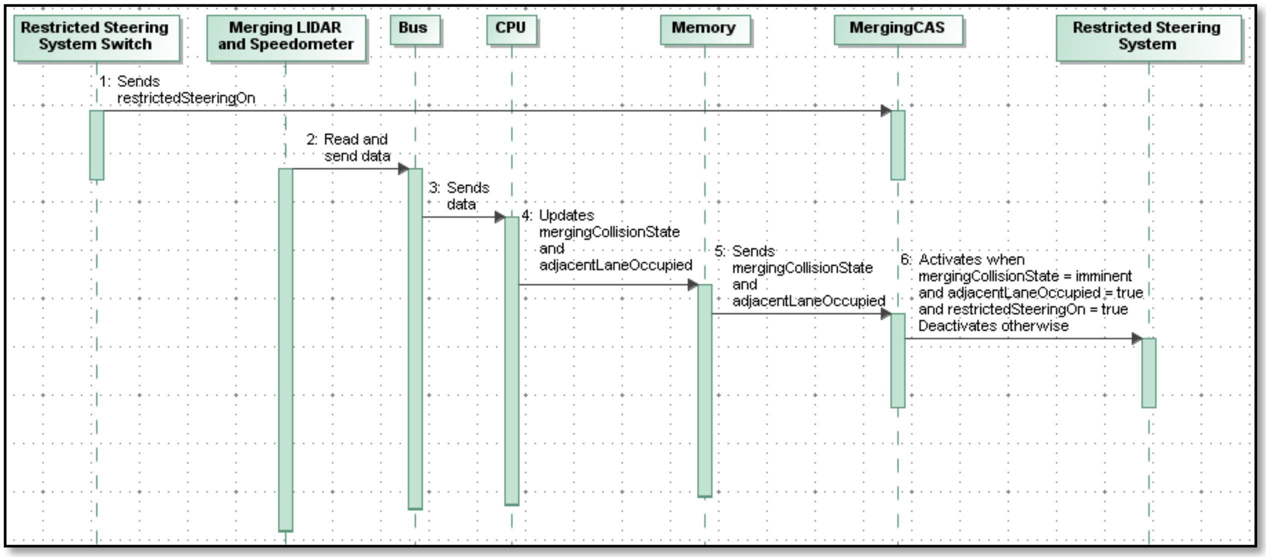


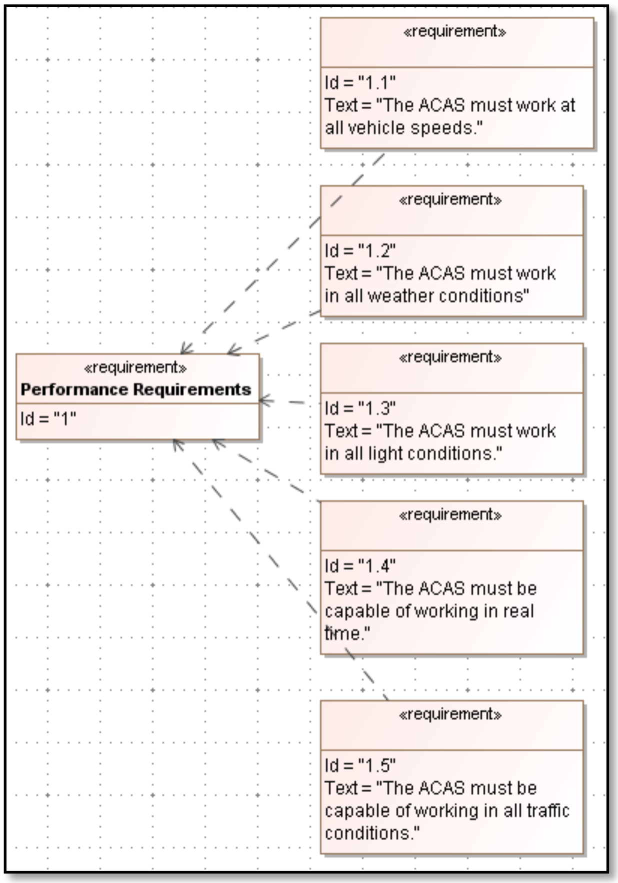
Figure 14 – MergingCAS Restricted Steering Sequence Diagram

Part 5. Requirements Engineering

High Level Requirements

Category	Use case	Requirement	Structure/ Behavior	Description
Performance Requirements	N/A	1.1	Behavior	The ACAS must work at all vehicle speeds
	N/A	1.2	Behavior	The ACAS must work in all weather conditions.
	N/A	1.3	Behavior	The ACAS must work in all light conditions.
	N/A	1.4	Behavior	The ACAS must be capable of working in real time.
	N/A	1.5	Behavior	The ACAS must work in all traffic conditions.
Safety Requirements	N/A	2.1	Behavior	The ACAS must not frighten, disorient, or distract drivers.
	N/A	2.2	Structure	The ACAS must not cause an accident.
Sensor Network, Bus, CPU, and Memory Requirements	N/A	3.1	Structure/ Behavior	The sensor network, bus, CPU, and memory must process large amounts of data at high speeds.
ForwardCAS Requirements	1.a	4.1	Structure	The Visual Warning Indicator must be highly visible.
	3.a	4.2	Behavior	The braking control system should not activate when cars/objects are moving toward the host vehicle.
	3.b	4.3	Structure	The braking control system must be compatible with vehicle's braking system.
	7.b	4.4	Structure	There must be a user friendly way to turn on/off the Breaking Control System.
MergingCAS Requirements	1.a	5.1	Structure	The Visual Warning Indicator must be highly visible.
	1.b	5.2	Structure	The Audible Warning must be highly audible.
	4.a	5.3	Structure	The restricted steering system must be compatible with the vehicle's steering system.
	7.a	5.4	Structure	There must be a user friendly way to turn on/off the Restricted Steering System.

Table 1 – High Level Requirements with Traceability to Use Cases



Id = "1"

Id = "1.1"
Text = "The ACAS must work at all vehicle speeds."

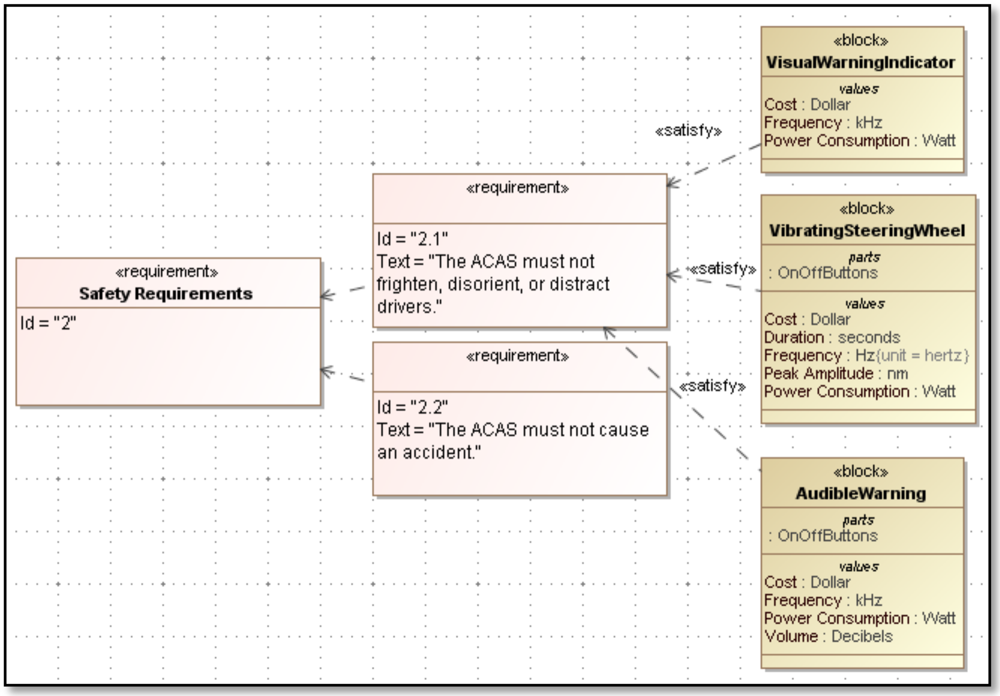
Id = "1.2"
Text = "The ACAS must work in all weather conditions"

Id = "1.3"
Text = "The ACAS must work in all light conditions."

Id = "1.4"
Text = "The ACAS must be capable of working in real time."

Id = "1.5"
Text = "The ACAS must be capable of working in all traffic conditions."

Figure 15 – Requirements Diagram – High Level Performance Requirements



Id = "2"

Id = "2.1"
Text = "The ACAS must not frighten, disorient, or distract drivers."

Id = "2.2"
Text = "The ACAS must not cause an accident."

Cost : Dollar
Frequency : kHz
Power Consumption : Watt

: OnOffButtons
Cost : Dollar
Duration : seconds
Frequency : Hz{unit = hertz}
Peak Amplitude : nm
Power Consumption : Watt

: OnOffButtons
Cost : Dollar
Frequency : kHz
Power Consumption : Watt
Volume : Decibels

Figure 16 – Requirements Diagram – High Level Safety Requirements

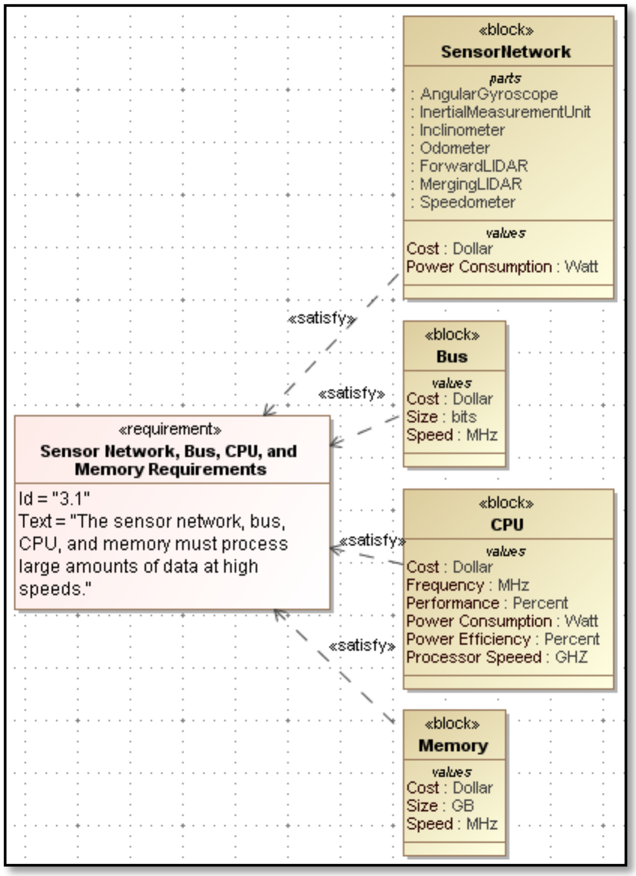


Figure 17 - Requirements Diagram – High Level Sensor Network, Bus, CPU, and Memory Requirements

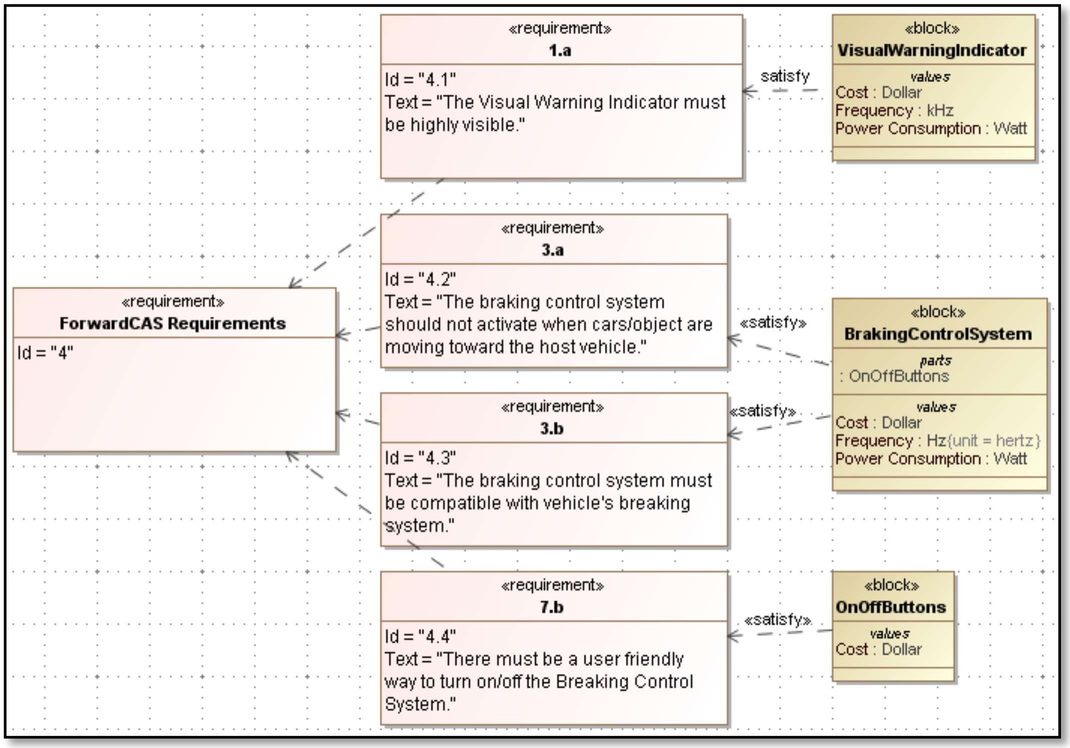


Figure 18 - Requirements Diagram – High Level ForwardCAS Requirements

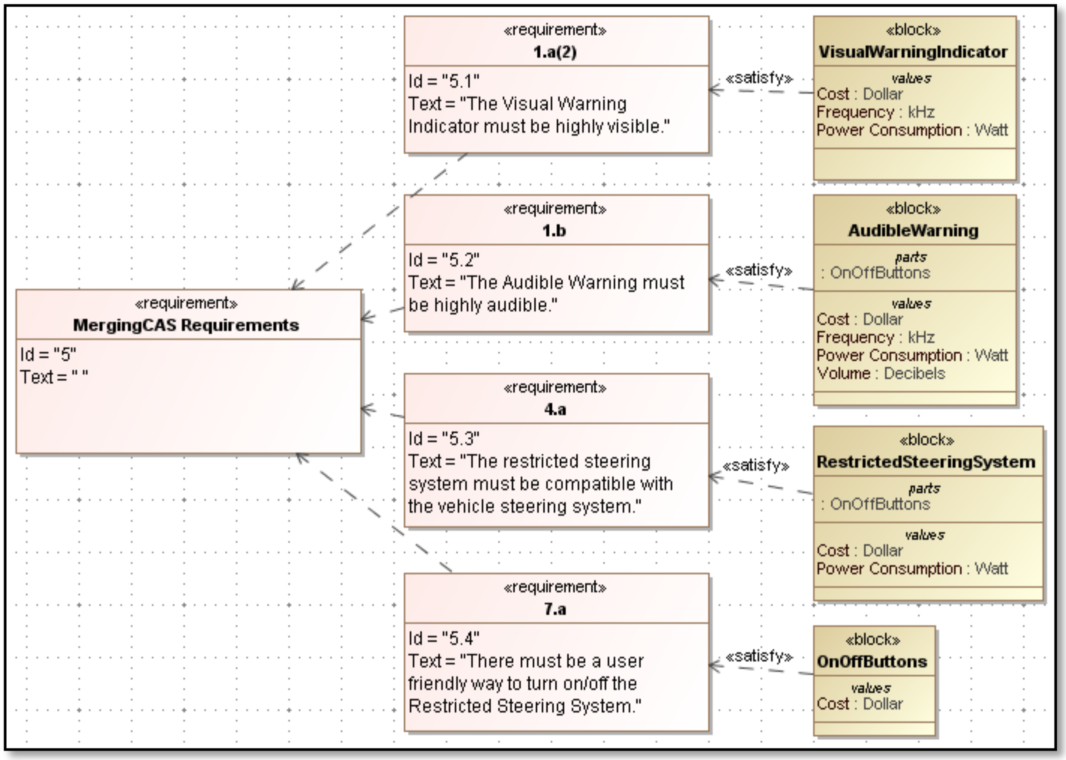


Figure 19 - Requirements Diagram – High Level MergingCAS Requirements

Low Level Requirements

Component	Property	High/Low	Range
CPU	Power Efficiency	High	60% < Power Efficiency < 99%
	Processing Speed	High	2.5GHz < Processing Speed < 5.0GHz
	Performance	High	85% < Performance < 99%
	Cost	Low	$30 < Cost < $200
LIDAR Sensors	Power Consumption	Low	2.5W < Power Consumption < 3.5W
	Detection Range	High	15m < Detection Range < 25m
	Accuracy	High	±2mm < Accuracy < ±5mm
	Cost	Low	$200 < Cost < $500
Bus	Bandwidth	High	1500Mb/s < Bandwidth < 7000Mb/s
	Speed	High	400MHz < Speed < 1000MHz
Memory	Power Consumption	Low	1.5W < Power Consumption < 2.5W
	Access Speed	High	800MHz < Access Speed < 1400MHz
	Size	High	4GB < Size < 9GB
	Cost	Low	$20 < Cost < $87

Table 2 – Low Level Requirements

Part 6. System-Level Design

	Components											
Behavior	On/Off Buttons	Sensor Network	Bus	CPU	Memory	ForwardCAS	MergingCAS	Visual Warning Indicators	Restricted Steering	Braking Control System	Audible Warning	Vibrating Steering Wheel
Read data		X	X									
Send data	X	X	X									
Receive data				X	X							
Determine Probability of Collision				X								
Update Variables in Memory				X								
Store Data					X							
Read Variable from Memory				X		X	X					
Activate Components Based on Variables						X	X					
Control the Vehicle									X	X		
Alert the Driver								X			X	X

Table 3 – System Level Design - Linking Components and Behavior

Part 7. Simplified Approach to Tradeoff Analysis

Tradeoff Analysis of the CPU and Bus

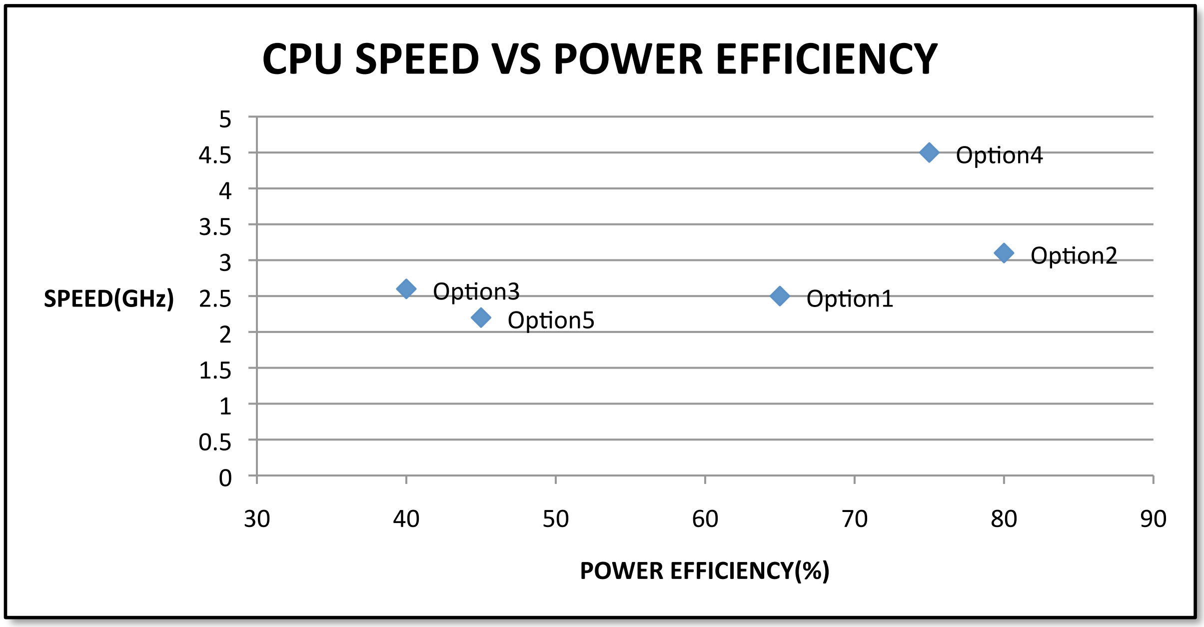


Figure 20 – Tradeoff Analysis – CPU Processing Speed Vs Power Efficiency

It is desired that the Central Processing Unit (CPU) to be used in the Collision Avoidance System (CAS) utilize energy effectively and have the ability to process information quickly. Figure 20 shows a comparison of power efficiency and processing speeds for the five (5) options explored for a choice of the CPU. Options 3 and 5 have relatively low values of power efficiency, and they are dominated by Option 1 which has high power efficiency at approximately the same speed. Option 2 dominates Option 1 as it has more power efficiency and more speed. Option 2 is dominated by Option 4 which has the highest speed though it has slightly lower power efficiency than Option 2. The loss in power efficiency between Option 2 and Option 4 is acceptable in the proposed design since the higher speed is highly desirable and the power efficiency is small enough to be tolerated.

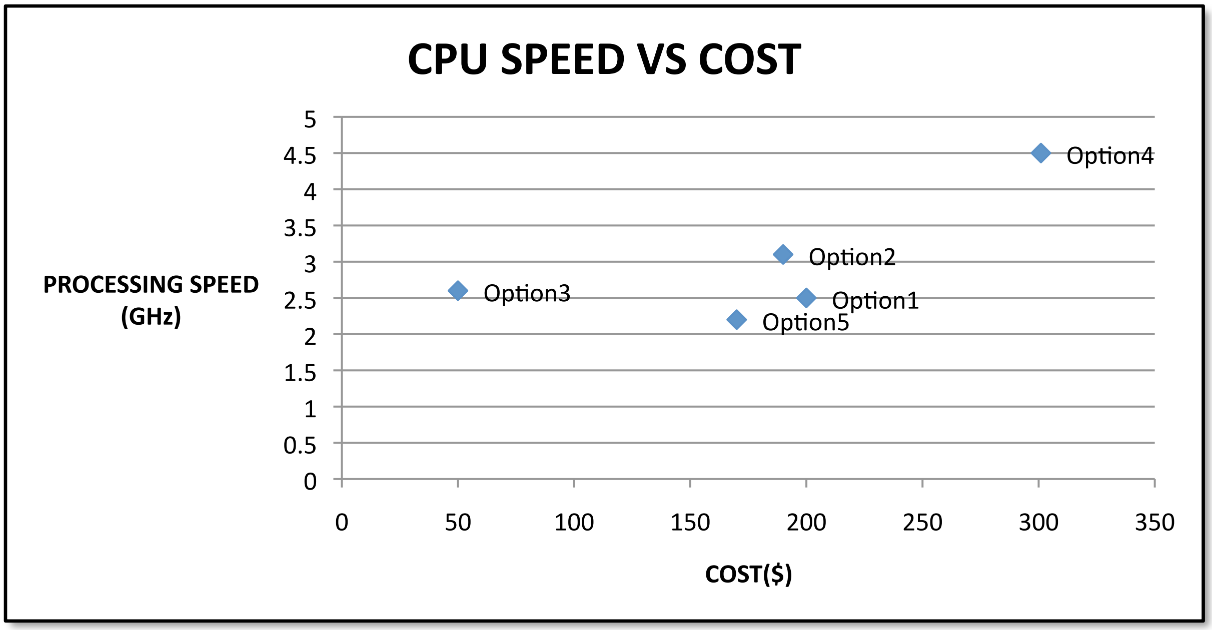


Figure 21 – Tradeoff Analysis – CPU Processing Speed Vs Cost

The constraint on the cost of the CPU was that:

$30<   <$200

Looking at Figure 21, the best option would be the one that has the lowest cost and the highest speed. Option 4 is neglected in this scenario as it does not satisfy the cost requirements for the CPU. Option 1 is dominated by Option 2 since Option 2 offers more speed for less money. Option 5 is also dominated by Option 2 since the increase in speed 71% for a $19 difference. The competing options are then Option 3 and Option 2. Option 3 offers an 83% speed increase over Option 2. Option 3 costs much less than Option 2. However, since both options fall within the acceptable cost for the CPU, Option 2 dominates over Option 3 because of its higher desirable speed.

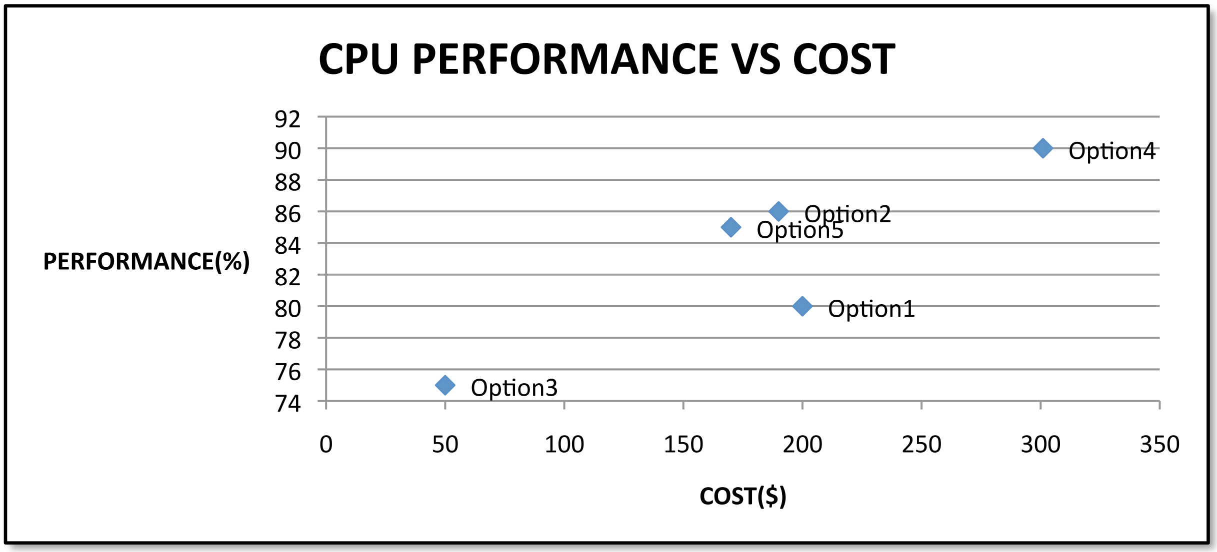


Figure 22 – Tradeoff Analysis – CPU Performance Vs Cost

The performance of the CPU is measured by a series of standard tests that include a measurement of how fast the CPU can accomplish algebraic accumulation operations, how well the CPU is able to perform compression on data, encryption tests and tests to determine the amount of time the CPU can operate in a consistent manner (without noticeable decline in speed). The performance rating of each CPU is as a percentage to achieve an equal standard in measurement. The design of the CAS calls for a CPU with a high performance rating and low cost. This rules out the possibility of Option 4 because even though it has high performance, it is above the cost allowable for the CPU. Options 3 and 1 have low performances as compared to Options 2 and 5 and can also be ruled out. This leaves Options 5 and 2 as likely candidates. The 1% increase in performance in going from Option 5 to Option 2 does not justify the 20 dollar increase in cost, and so Option 5 dominates in this analysis (Figure 22).

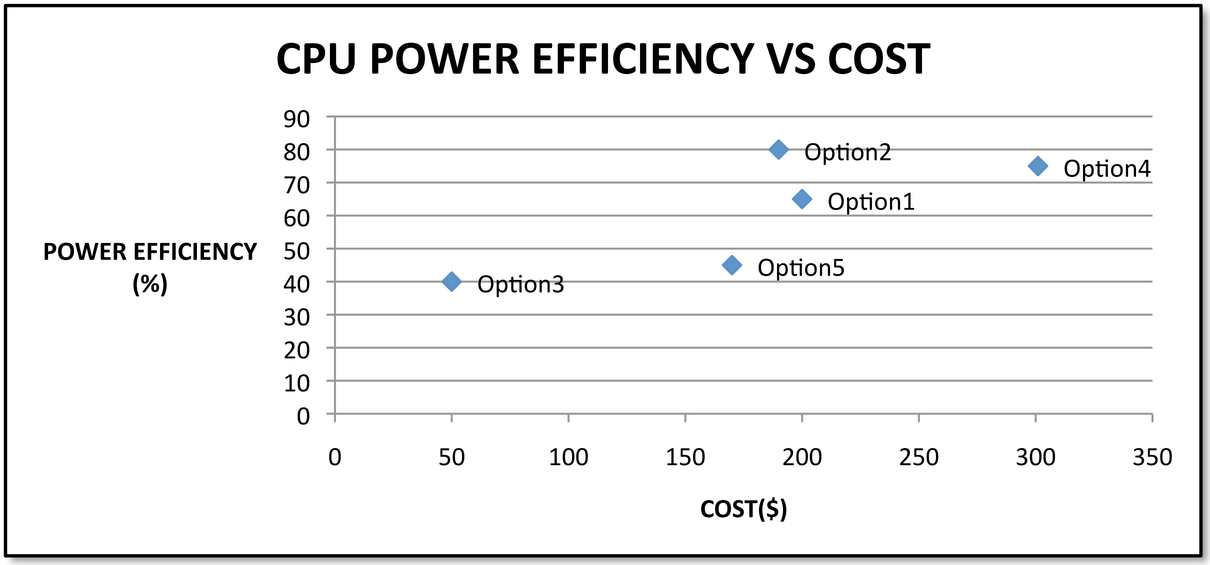


Figure 23 – Tradeoff Analysis – CPU Power Efficiency Vs Cost

Power efficiency is a measure of how much energy that is put into the CPU is not lost to heat dissipation and other forms of losses. It is desired that the CPU have high power efficiency, and as such Options 3 and 5 can be neglected in the analysis. The constraint on the cost still holds and this allows Option 4 to be neglected also. Option 2 and Option 1 are the two competing options, but as Option 2 is cheaper than Option 1 and has higher power efficiency, Option 2 dominates and is selected (Figure 23).

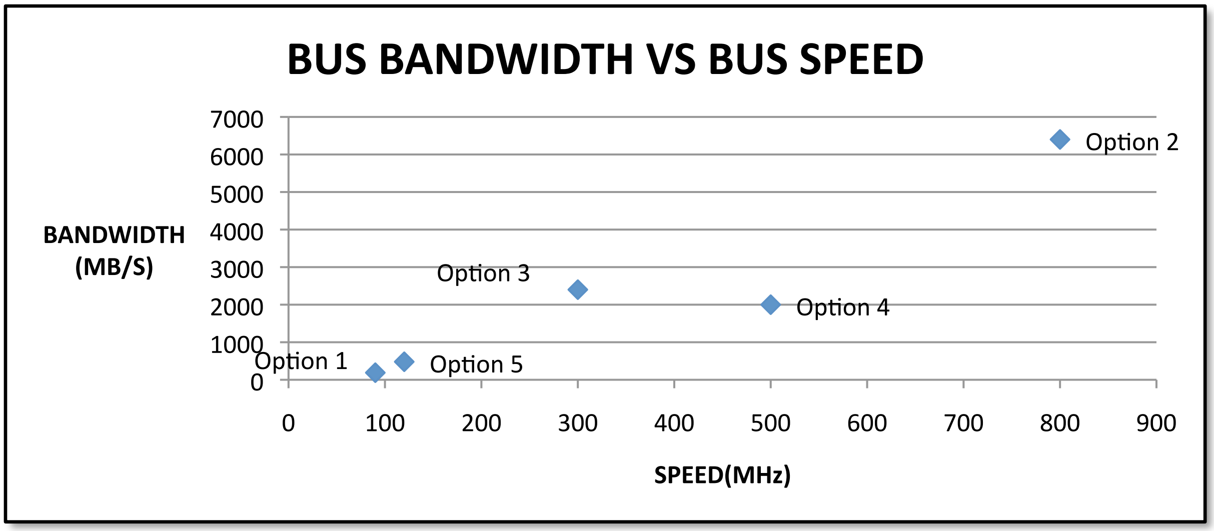


Figure 24 – Tradeoff Analysis – Bus Bandwidth Vs Speed

Since a requirement on the system is that it operates in real time, the best option for a bus would be the one that has the highest bus speed. Bus bandwidth describes the amount of data that can be transferred in a unit of time, and as such, it is required that the value for bus bandwidth be as high as possible. Figure 24 shows a comparison of 5 different options for buses that can be potentially implemented in the CAS. Option 2 and Option 4 are likely candidates since they have the highest bus bandwidths. However, in comparing Option 2 and 4, Option 2 dominates since it has a higher value of Bus bandwidth and a considerably higher bus speed than Option 4.

	SP,PE	SP,C	P,C	PE,C	BS,BB
Option 1					
Option 2		**X**		**X**	**X**
Option 3					
Option 4	**X**				
Option 5			**X**		

Table 4 – Tradeoff Analysis – Choosing the Best CPU and Bus

SP = Speed; PE = Power Efficiency; C = Cost; P = Performance; BS = Bus Speed; BB = Bus Bandwidth

From Table 4, Option 2 is the best overall choice for CPU and Bus.

Tradeoff Analysis of the Memory

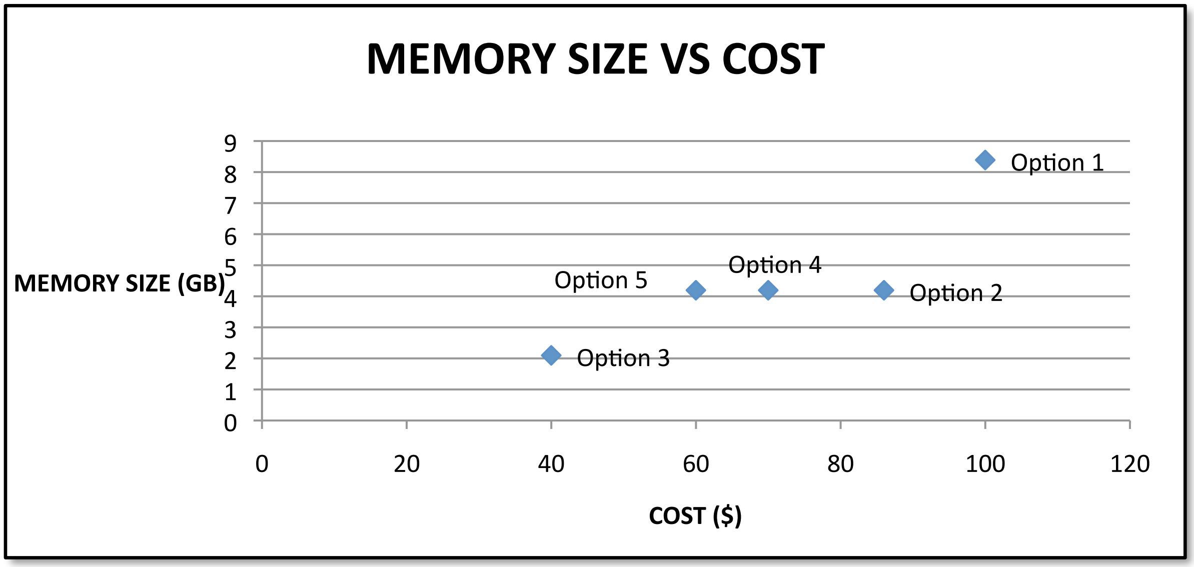


Figure 25 – Tradeoff Analysis – Memory Size Vs Cost

Constraint on the cost of memory:

$$\$20< \qquad <\$87$$

The memory serves as a storage device where values are stored for easy access by the various components of the CAS. It also serves to store the various algorithms to be implemented, and thus it is required that the memory be large so that there is no competition between the memory resident variables and algorithms for space. A good choice for memory would be one with a low cost and high storage capability. From Figure 25, Option 1 can be neglected since it does not satisfy the constraint requirement. The good choices in this case are Options 5, 4 and 2. Option 5 dominates these options since it offers the same amount of memory as Options 4 and 2 but at a lower cost.

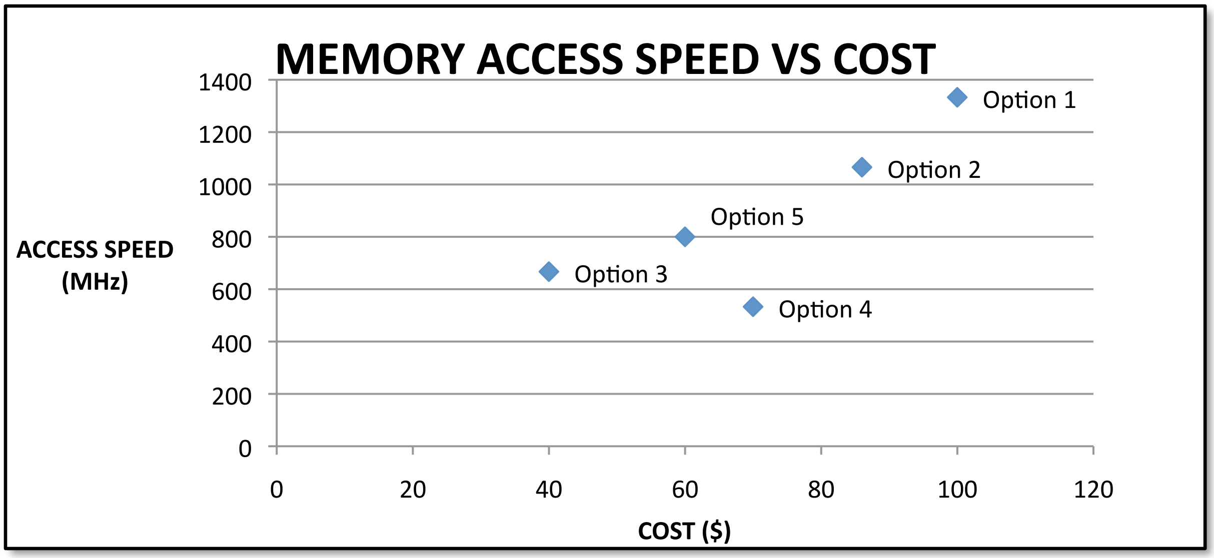


Figure 26 – Tradeoff Analysis – Memory Access Speed Vs Cost

The access speed is defined to be how quickly data can be read or written to memory. This is often stated in nanoseconds but can be easily converted to Megahertz. Since timing is very critical in the CAS, it is important that the access speed be high so that there is no lag in accessing information stored in memory. The competing choices in Figure 26 above are Options 1 and 2 since they offer the highest access speeds. Option 2 dominates Option 1 since Option 1 falls out of the cost range allowable for memory.

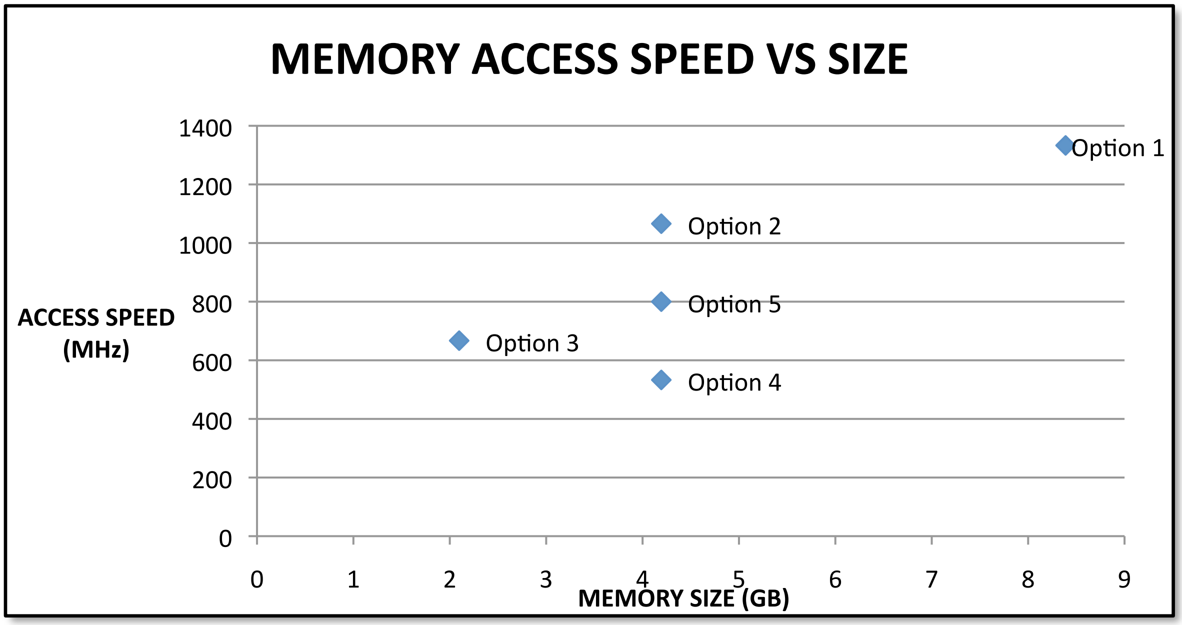


Figure 27 – Tradeoff Analysis – Memory Access Speed Vs Size

To satisfy the requirements of having a fast access speed and a high memory size, the ideal option would be toward the upper right hand of the diagram in Figure 27. Option 1 and Option 2 are the likely choices which would satisfy the requirements. However, Option 1 dominates over Option 2 since it has a bigger memory size and a faster access speed.

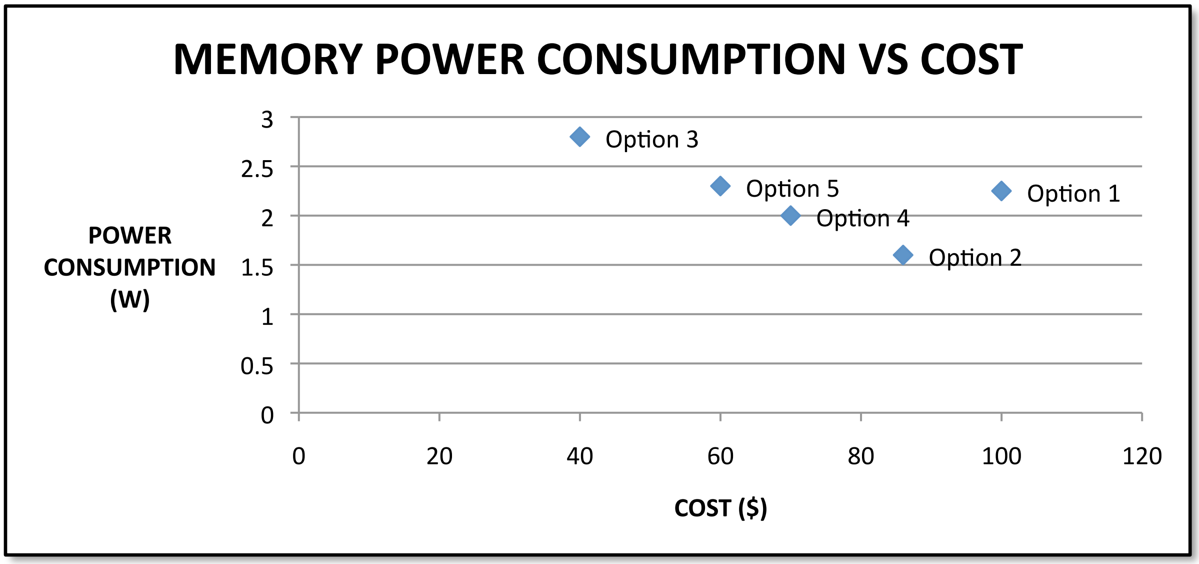


Figure 28 – Tradeoff Analysis – Memory Power Consumption Vs Cost

The best choices for memory will have low power consumption and low cost. Looking at Figure 28, it can be seen that the points of interest are Options 4 and 2. Option 2 dominates over Option 4 since it has lower power consumption.

	DR,A	AS,C	AS,MS	PC,C
Option 1			**X**	
Option 2		**X**		**X**
Option 3				
Option 4				
Option 5	**X**			

Table 5 – Tradeoff Analysis – Choosing the Best Memory

DR = Detection Range; PC = Power Consumption; C = Cost; A = Accuracy; AS = Access Speed

From Table 5, Option 2 is the best overall choice for memory.

Tradeoff Analysis of the LIDAR Sensors

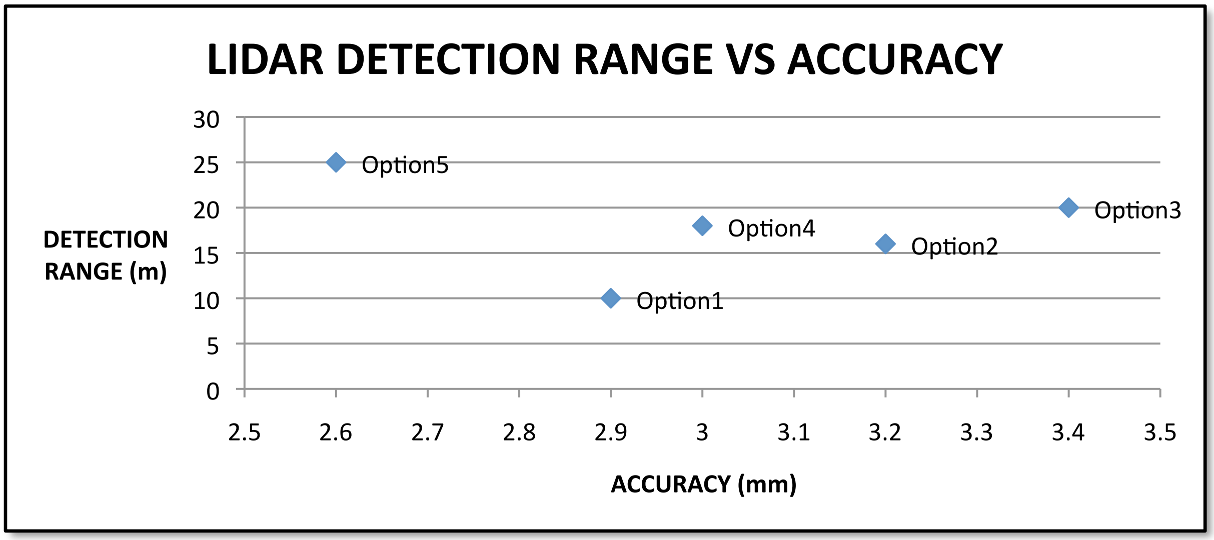


Figure 29 – Tradeoff Analysis – LIDAR Detection Range Vs Accuracy

A measure of accuracy of the Light Detection and Ranging (LIDAR) sensor indicates how well the LIDAR measures the distance between two objects (in this case the host car and another object). The values of accuracy used in Figure 29 are ranges around the assumed true value that the LIDAR is measuring. For instance an accuracy of 3.1 means ±3mm. For this reason, it is desired that the value of accuracy be small so that the error in measuring the true value is low. A higher range is also necessary so that detection of other objects around the host vehicle can occur over greater distances, hence allowing enough time for appropriate actions to be taken in anticipation of an issue. Option 5 dominates over all the other options in this case since it has the best accuracy over a longer range.

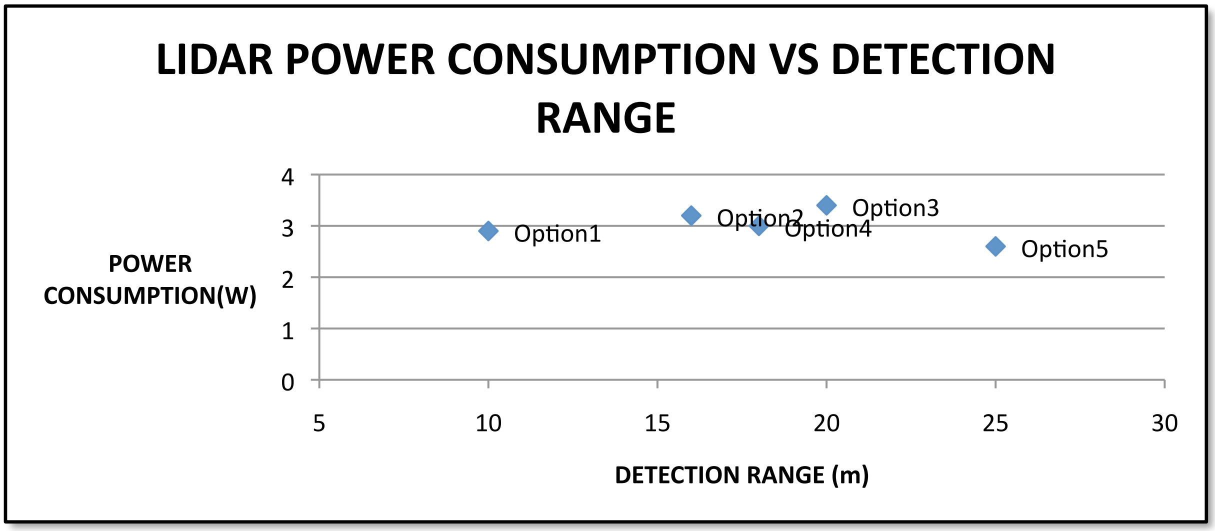


Figure 30 – Tradeoff Analysis – LIDAR Power Consumption Vs Detection Range

A requirement for the entire CAS is that it be power efficient. To help achieve this aim, a requirement on the LIDAR sensors is that they have low power consumption. It is also required that the LIDAR sensors have a wide range so that they can detect obstacles from a distance and give the driver or the system enough reaction time in case of a probable or imminent collision. Looking at Figure 30, Option 1 has a low detection range and is dominated by Option 2 which has a higher detection range and a 30% increase in power consumption. Option 3 dominates Option 2 since it has a better range and not a significant increase in power consumption. Option 5 has both the best range and the lowest power consumption and thus dominates all the other Options.

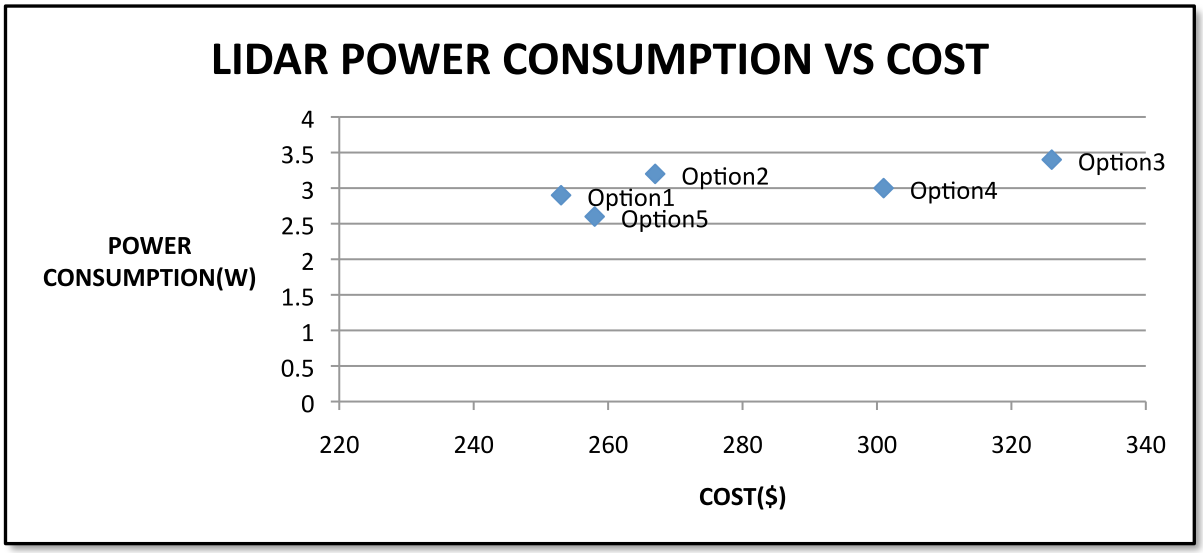


Figure 31 – Tradeoff Analysis – LIDAR Power Consumption Vs Cost

Constraint on Cost of LIDAR sensors:

$200< <$500

All options for the LIDAR sensor fall within the price range agreed upon. The best option would be the one which has relatively low cost and low power consumption. This rules out Option 3 (Option 3 is dominated by Option 4 which has a lower power consumption for less money). Option 4 is dominated by Option 2 which has a lower cost for a small increase in power consumption. The competing options for best choice are Options 1 and 5 since they have the lowest costs and power consumption. Though Option 1 is cheaper than Option 5, Option 5 offers lower power consumption for $5 more which is acceptable in this analysis. Therefore, the best option is Option 5 (Figure 31).

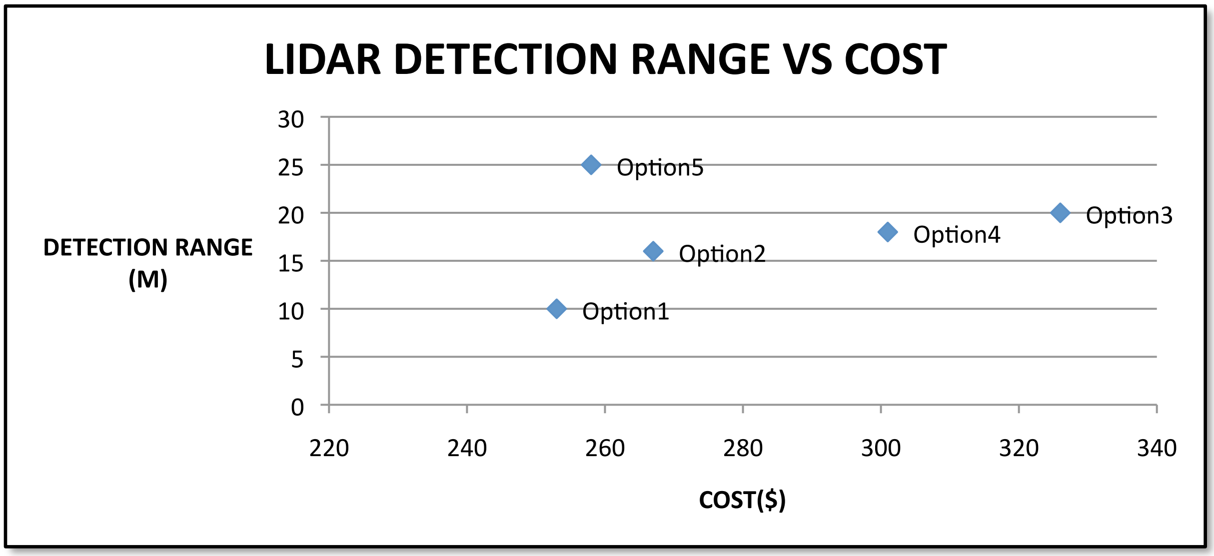


Figure 32 – Tradeoff Analysis – LIDAR Detection Range Vs Cost

The best option would be the one which has the lowest cost and the highest detection range. Looking at Figure 32, the best options would be Options 5 and 2. Option 5 dominates since it has the higher detection range for less money.

	DR,A	PC,DR	PC,C	DR,C
Option 1				
Option 2				
Option 3				
Option 4				
Option 5	X	X	X	X

Table 6 – Tradeoff Analysis – Choosing the Best LIDAR Sensors

DR = Detection Range; PC = Power Consumption; C = Cost; A = Accuracy

From Table 6, Option 5 is the best overall choice for the LIDAR sensors.

Example Verification of Component Based Tradeoff Analysis

In order to determine whether the options selected for the CPU/Bus and LIDAR sensors met our system requirements of low cost and high power efficiency, we summed their costs and multiplied their efficiencies.

CPU: Option 2

Cost = $189.99

Power Efficiency = 80%

LIDAR sensor: Option 5

Cost = $258

Power Efficiency = 88%

Total Cost = $189.99 + $258 = $447.99

Total Power Efficiency = (.80 * .88)*100 = 70.4%

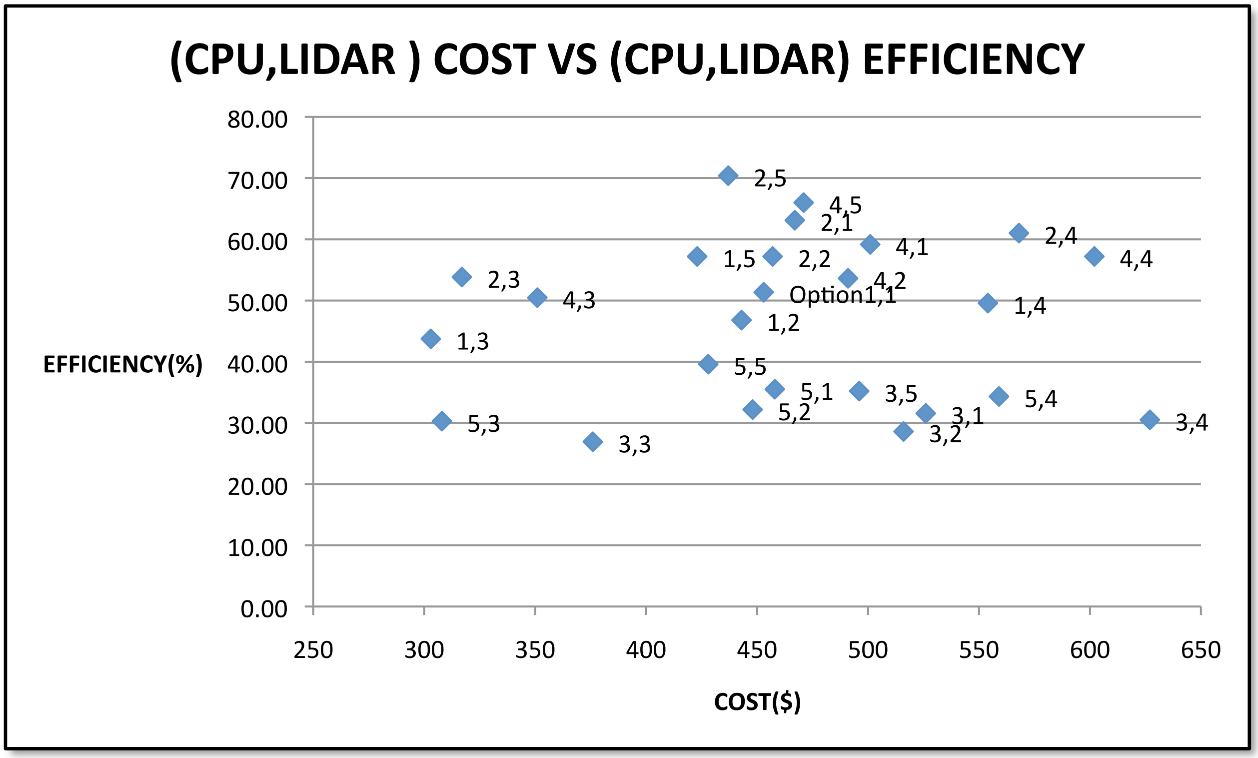


Figure 33 – Verification of Component Based Tradeoff Analysis

The combination of CPU/Bus Option 2 and LIDAR Option 5 has the highest power efficiency and mid-range cost. If lower cost is desired and some power efficiency can be sacrificed, CPU/Bus Option 2 and LIDAR Option 3 would be a good option. This analysis only takes into account two attributes of two components. A similar and much more complex analysis would need to be performed on a system-wide level in order to truly choose the best components.

Part 8. Testing, Validation, and Verification

Requirement	Description	Testing, Validation, and Verification
1.1	The ACAS must work at all vehicle speeds	The performance of the system at various vehicle speeds will be tested with simulation software and in the field. The speeds to be tested will range from 0mph to 110mph.
1.2	The ACAS must work in all weather conditions.	The performance of the system in various weather conditions will be tested in the field. We will simulate a variety of weather conditions (precipitation, temperature, humidity, poor road conditions).
1.3	The ACAS must work in all light conditions.	The performance of the LIDAR sensors will be tested outdoors under various light conditions.
1.4	The ACAS must be capable of working in real time.	The sensor network, bus and CPU operations will be integrated so that 555 timer chips are attached to both inputs and outputs. Time measurement for both 555 chips will be compared making sure the error does not exceed 0.01%.
1.5 4.2	The ACAS must work in all traffic conditions. The braking control system should not activate when cars/objects are moving toward the host vehicle.	The reaction of the system to a variety of vehicle and non-vehicle obstacles will be tested with simulation software and in the field. The system will also be tested with a range of traffic densities.
2.1	The ACAS must not frighten, disorient, or distract drivers.	A survey of a large group of individuals (variety of age, sex, background) will be conducted in order to ensure that the visual alerts, audible alert, and vibrating steering wheel do not frighten, disorient, or distract drivers.
2.2	The ACAS must not cause an accident.	The system will be field tested with a large variety of scenarios. The system will log tens of thousands of road-testing hours before mass implementation.
3.1	The sensor network, bus, CPU, and memory must process large amounts of data at high speeds.	The performance of the sensor network, bus, and CPU will be bench tested to make sure that they can handle large amounts of real-time data.
4.1	The Visual Warning Indicator must be highly visible.	A survey of a large group of individuals (variety of age, sex, background) will be conducted in order to ensure that the visual warning

Requirement	Description	Testing, Validation, and Verification
		indicator is highly visible.
4.3	The braking control system must be compatible with vehicle's braking system.	The compatibility of the braking control system with the vehicle's braking system will be tested with simulation software and in the field.
5.1	The Visual Warning Indicator must be highly visible.	A survey of a large group of individuals (variety of age, sex, background) will be conducted in order to ensure that the visual warning indicator is highly visible.
5.2	The Audible Warning must be highly audible.	A survey of a large group of individuals (variety of age, sex, background) will be conducted in order to ensure that the audible warning is highly audible. The frequency of the tone will be measured to ensure that it falls well within the range of normal human hearing.
5.3	The restricted steering system must be compatible with the vehicle's steering system.	The compatibility of the restricted steering system with the vehicle's steering system will be tested with simulation software and in the field.
4.4 5.4	There must be a user friendly way to turn on/off the Breaking Control System. There must be a user friendly way to turn on/off the Restricted Steering System.	A survey of a large group of individuals (variety of age, sex, background) will be conducted in order to ensure that the on/off switches are in fact user friendly.

Table 7 – Testing, Validation, and Verification of High Level Requirements

Part 9. Summary and Conclusions

Designing an Automobile Collision Avoidance System is truly a monumental task. Beyond dealing with the complexity of the system itself, systems engineers must consider the infinite number of scenarios in which the system must safely perform. In addition, systems engineers must consider the most complicated factor of all: the human factor. Because automobiles are piloted by individuals who have a wide range of backgrounds and skills, the human factor is especially complex in this case.

Ultimately, we had to severely limit the scope of our project so that we could properly attempt to implement the wide range of system engineering tools that we learned about. The model based systems engineering techniques that we studied throughout the semester are invaluable tools for managing the design of any complex system.

Part 10. References

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Part 11. Credits.

Adi Lang

- Driving force behind use case and textual scenario development
- Compiled, formatted, and edited final report
- Compiled PowerPoint presentation
- Created activity and state machine diagrams
- Created the use case diagram
- Created graphics
- Assisted with high level requirements
- Assisted with structure diagram

Deepa Jonnagadla

- Created structure diagram
- Created sequence diagrams
- Created requirements diagrams
- Created system level design chart
- Created activity and state machine diagrams
- Assisted with use case development
- Assisted with high level requirements

Andy Hammond

- Driving force behind tradeoff analysis
- Created low level requirements
- Developed part of PowerPoint presentation
- Assisted with use case development
- Assisted with high level requirements

Alex Atahua

- Driving force behind tradeoff analysis
- Driving force behind testing, validation, and verification
- Created high level requirements
- Assisted with use case development