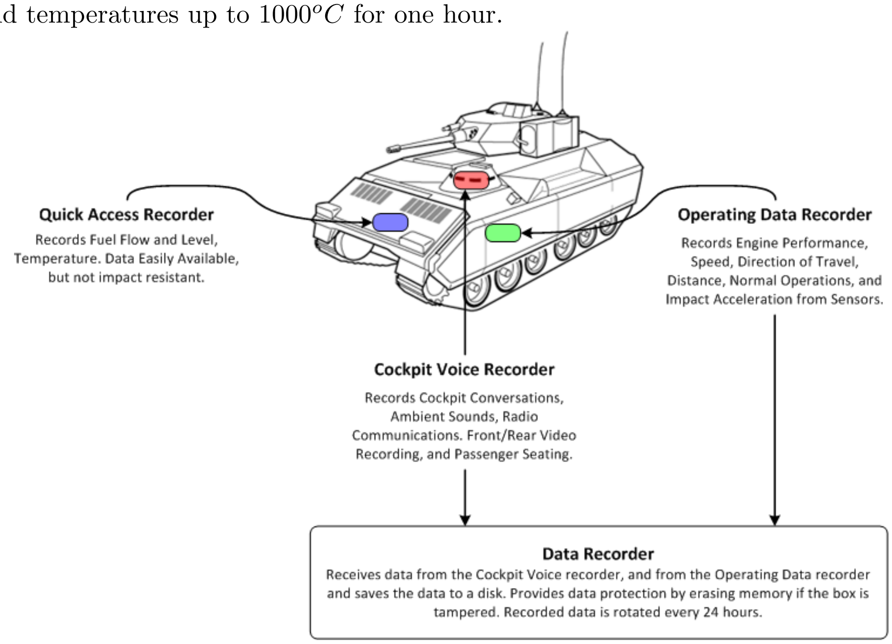
Black Box System Design

Ahmad Asi, Benjimin Chang, Mehdi Dadfarnia, Serge Kamta, and Ifzalul Khan

December 14, 2010

Abstract

Create a System-Level design representation for a “black box” system tailored to the functional needs of an Army Transportation Vehicle. A black box design should include both a vehicle data recorder and also a voice and visual recorder so that an incident can be accurately reconstructed from the vehicle’s status and visual recordings. This particular design will allow analysts to determine whether the cause of the incident was a vehicle error, operating error, or environmental factors. This design is similar to Flight Data Recorder and Cockpit Voice Recorder with the addition of a similar On-Board Diagnostics (OBD) II design in modern automotive vehicles. A typical black box should have the capability to withstand 3400g for 6.5ms and temperatures up to 1000^oC for one hour.



The basic functions of a black box should include continuous audio/visual recording for both the front and rear of the vehicle. This will be part of the voice and visual recorder. Because this design must withstand 3400g in the event of an incident, a typical disk drive will not suffice. A 512 GB solid-state drive (SSD) (approx $2000) has the capability to withstand 1500g and provide enough space to record at least 24 hours of audio and video at 640x480@15 FPS with voice quality audio. In order for the SSD to withstand 3400g padding and springs can provide shock resistance to the disk and a mirroring redundancy will be designated for fault tolerance.

The second part of the black box is the vehicle data recorder including the status of the vehicle (vehicle speed, engine health, ...), environmental status (outside temperature, climate), and passenger seating arrangement. Pressure sensors will be used to determine where each passenger is seated, and the number of passengers in the vehicle. Pressure sensors will also be placed on the chassis of the vehicle in order to determine the location of the incident if an explosion, or side/head-on collision are to occur. GPS and time/date data will also be recorded in order to determine the location of the incident.

A Data Rotator software will help refrain from data loss. Wireless communication can also be used in order to provide vehicle monitoring with a monitoring station. As part of this design, tamper resistance is crucial to this design. Memory can be wiped when the case is open, or if the device is not attached to a module. During normal operation, a module is attached to the vehicle. This module contains a signature unique to the vehicle. When the vehicle is destroyed, the module will also be destroyed. In order to access the data, a module with the same signature must also be attached to the black box, otherwise the device will return null data. If the black box is opened, fuses in the SSD will break the connection thus destroying the data. This way when retrieving the data, and the operator forgets to plug in the module, the data will not be destroyed as the operator should not need to open the box.

Contents

Chapter 1

Problem Statement

1.1 Why is the black box needed?

The Black Box will give us feedback about health of vehicle and crashes/accidents and allow for accessibility to data involving the vehicle's mechanical and electrical status. The Black Box will give us instant feedback for any physical anomalies, and will also give the command center access to the data on the Black Box. Because the Black Box is designed to withstand a large impact, it will also secure the data in the Black Box.

1.2 Who will use it?

The Black Box will be used by Field Technician Soldiers, and Command Center mechanic to diagnose and repair any issues that may arise while out on the field or at home base. If an accident were to occur, a Data Analyst can use the Black Box to determine the cause of the accident, and provide ways to prevent a future accident.

1.3 Where will they use it?

Field technicians and passengers in the vehicle can use the Black Box on the field to determine vehicle status. At the Command Center, mechanics and analysts will use the Black Box to identify any anomalies with the vehicle, record normal operation data, and to determine the causes of accidents if any should occur.

1.4 Who are the project stakeholders and what are their concerns?

- **ENES489P Black-Box Team and Advisors**: Improvement of vehicles, functional integration of a single model of the Black Box into multiple vehicle classes
- **Military Logistics Agency**
- **Soldier**: Field Technician Soldiers, Command Center Mechanics
- **Budget**: Finances for research and development, manufacturing, and usage
- **Military Doctrine**
- **Manufacturers**: Manufacturing of the Black Box system, software system testing and design

1.5 If successful, what are the potential benefits of this project?

Several potential benefits of this project include:

- Vehicle Tracking through GPS
- Remotely monitoring vehicle status
- Detect and report the reliability of the vehicle
- Efficiency data to improve vehicle and overall system performance
- Modular versatility that allows integration into several types of vehicles

1.6 What factors are likely to drive the economics of development?

- Safety and accident prevention
- Vehicle maintenance
- Cost of black-box maintenance
- Hardware and software costs

Chapter 2

Use Case Development

2.1 Project Stakeholders

- The Black Box system project stakeholders include: ENES489P Black-Box Team and Advisors, Military Logistics Agency, Soldier, Budget, Military Doctrine, Manufacturers
- Figure 2.1 shows a graphical layout of each stakeholders and their relationship with the Black Box system design.

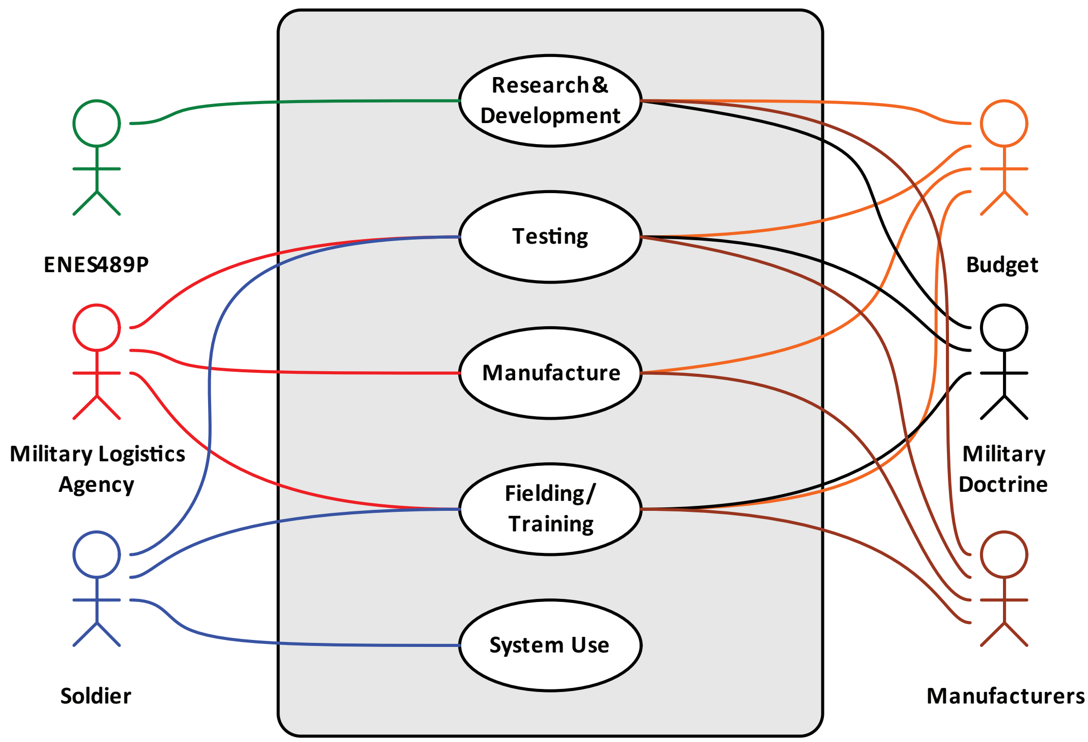


Figure 2.1: Relationship between Stakeholders and their Concerns

2.2 Actors

- **Environment (Vehicle)**: The vehicle to be used for the Black Box system

- **Command Center Mechanic**: During installation and testing, the mechanic needs to know where each sensor is located so that issues with the vehicle and black box is easier to diagnose.
- **Data Analysts**: Receive accurate crash data, and system efficiency
- **Field Technicians Soldiers**: Be able to determine the health of the vehicle, computer systems, and sensors
- **System/Component Level Tester**: Testing for Black Box algorithms and analysis scripts
- **Threats and Terrorists (Environmental Destruction and Human)**: Determine ways to destroy and/or hack Black Box data
- **Passengers**: Provides seating arrangement data
- **Sensor Subsystem**: A sensor network including the OBD-II sensor network, pressure sensors, and GPS to collect vehicle status data for the black box.

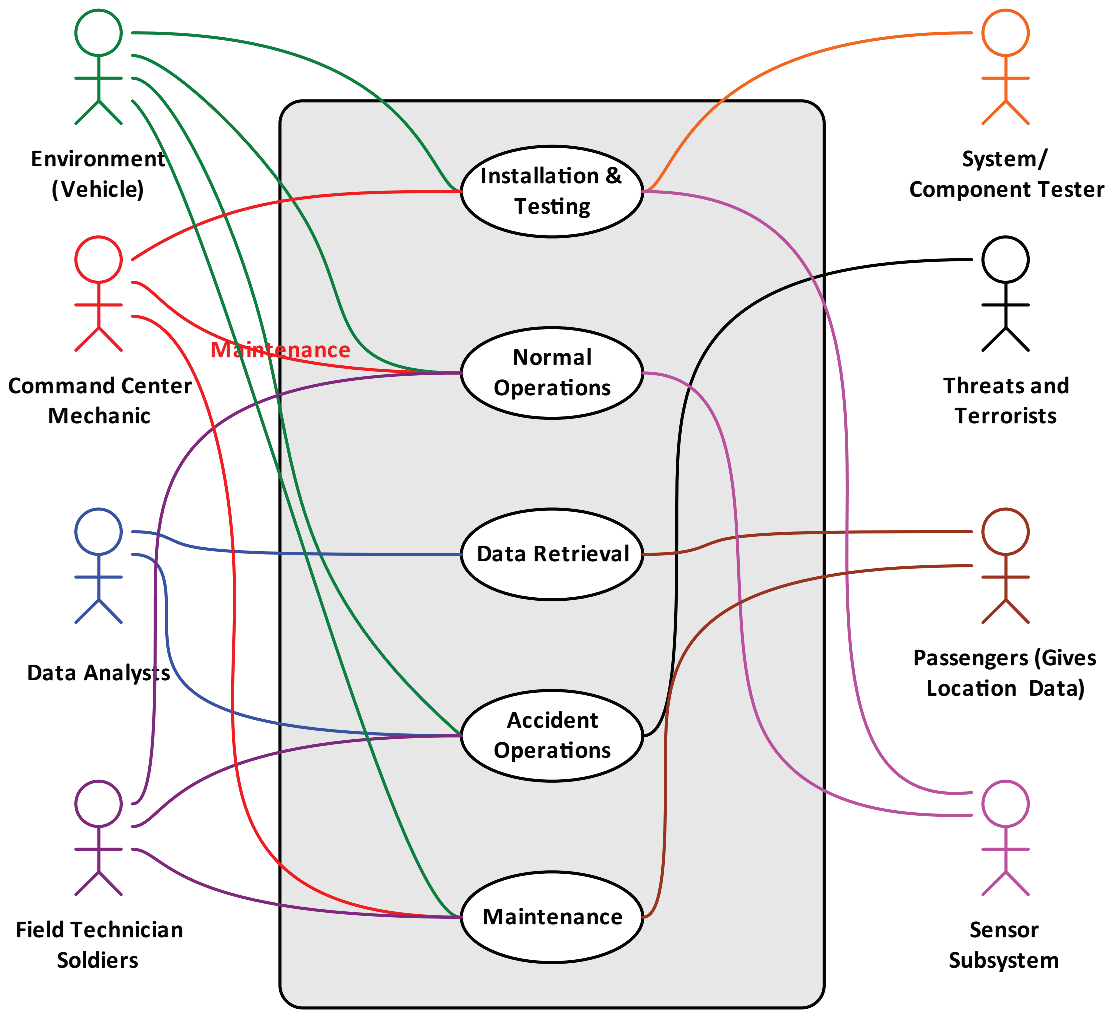


Figure 2.2: Relationship between Use Cases and Actors

2.3 Use Case 1: Installation and Testing

- **Description**: System tester performs component testing. The mechanic installs black box and performs component and system testing

- **Primary Actors**: Vehicle, System Tester, Sensor Subsystem, Command Center Mechanic
- **Pre-Conditions**: Vehicle, black box, and sensor systems are assembled, and the sensor system and vehicle have been tested by manufacturer
- **Flow of Events**:
  - System Tester checks that the black box is functional and meets the general physical and behavioral requirements set by designers (ENES489P design team)
  - Mechanic checks that vehicle and sensor system are in working order before installing the black box. Also performs his own simulation on the black box to check that it is functional and meets behavioral requirements.
  - Mechanic installs black box and integrates the three subsystems into one system.
  - Mechanic performs an overall system test to check if the black box is securely located, and is functioning in accordance with the sensor network.
- **Post-Conditions**:
  - Black box is installed and integrated with vehicle and sensor network. Follows the behavioral requirements set by design team
- **Alternative Flow of Events**:
  - Component tester finds fault in design requirements in black box, components must be reprogrammed or replaced, if this cannot be accomplished, a fundamental redesign is necessary.
  - Mechanic finds fault in black box, vehicle, or sensor network, and the damaged system must be repaired or replaced before installation is possible.
  - Mechanic finds that after installation and integration, black box does not function properly with sensor network and is not secure within the vehicle, reprograming or repositioning of black box is necessary. If the system test still fails, replacement may be necessary.
- **New Requirements**:
  - Manufacturer provides location of black box placement inside vehicle
  - Black box must be compatible with given sensor network, and the two systems must be tested together before installation.
  - Accurate measurements for the placement of the black box within the vehicle must be taken before installation

2.4 Use Case 2: Normal Operation (Recording and Interpreting Data)

- **Description**: Records engine control unit data (including fault codes), power supply, seatbelts, seats, location of vehicle, temperature outside vehicle, and also audio/video data. Audio/video data can be used as Vehicle Boundary Recording, where the vehicle operator can use the outside viewing area video footage for normal operations.
- **Primary Actors**: Sensor Subsystem, Vehicle, and Field Technician Soldiers
- **Pre-conditions**: The sensor subsystem is set and computer software is available on black box computer. Sufficient power is suppliled to the black box and sensor subsystem.
- **Flow of Events**:

- Records OBD-II PID (Parameter Identification Numbers) which includes data from the engine control unit and non-standard PID (eg. power, seatbelts, passenger location, temperature) via data acquisition software (similar software to Baravian Technic[2]) on a computer. Fault codes are included in the recordings.
- Records vehicle location via GPS computer software,
- Records audio and video data via cameras (connected to USB ports) on a computer.
- Save data on solid-state disk for data redundancy
- Data Rotator software is implemented. Data is saved in one-minute packets, designated as 'bad' for problematic/malfunctioning/error data and 'good' for nonproblematic data, and the data rotator deletes the oldest 'good' data if the solid state drive's capacity reaches 70%

- **Post-Conditions**: Data saved in hard drive for data retrieval (Use Case 3)
- **Assumptions**: Pre-Conditions have been met.
- **New Requirements:**
  - *Computer Type*: Includes wireless connectivity capability
  - Additional solid-state disk for data redundancy
  - Power Supply
  - Backup Battery
  - Command center data requesting and retrieval
  - Tamper resistance for both computer and additional solid-state disk
  - Vehicle layout, boundaries, and limitations

2.5 Use Case 3: Retrieving Data

- **Description**: This use case (process) is needed when there is the necessity to monitor the health of the vehicle in the normal basis or to research the causes of failure in case any incident happens to the vehicle. Data retrieving can be done on site or remotely from the command center through wireless communication. Here we are concerned with on-site data retrieving.
- **Primary Actors**: Data Analysts, Field technician
- **Pre-Conditions**:
  - Black box is powered ON, and is functioning properly
  - Decision on the retrieving mode
- **Flow of Events (On-Site)**:
  - Verify that the black box is powered ON
  - Connect the Reader Device to the black box
  - Pass the system security-access (Authentication)
  - Download the data from the black box hard drive
  - Log out when download is completed
  - Disconnect the reader device
- **Alternative Flow of Events (Remote access):**
  - Identify the vehicle location

- Launch wireless communication
- Pass security access (Authentication)
- Initiate data download
- Log out when download is completed

- **Post-Conditions:**
  - Register log-in information and operation time
  - Black box remains powered ON

- **New requirements:**
  - The black box does not lost data after the retrieving process
  - The black box does not interfere with the vehicle's functions

2.6 Use Case 4: Accident/Abnormal Operations

- **Description**: This scenario occurs when the black box is subject to external factors such as human and environment threats. The black box hardware must be able to withstand extreme temperatures and forces, while the software must be resilient to human threats by encrypting data and through various security features.
- **Primary Actors**: Terrain (Outside Environment), Human Threats
- **Pre-Conditions:** System is installed in vehicle
- **Flow of Events:**
  - System withstands High Temperatures (i.e. Desert Temperatures)
  - System withstands Low Temperatures (i.e. Arctic Temperatures)
  - System withstands high forces
  - System functions underwater
- **Post-Conditions**: System still functions
- **Alternative Flow of Events**: System fails to withstand any of the conditions listed above.
- **New Requirement**s:
  - The black box must withstand any vibration while driving in the field.
  - The black box must survive explosion if any should occur
  - Trusted Platform Module (TPM) hardware and software
  - After an accident, the data rotator does not delete data and records until full. If there is a main power loss, the system performs Normal Operations (see Use Case 2: Normal Operations) for 30 minutes, using the backup battery as power source, and then switches to work as a locator beacon. This will allow an additional 30 minutes of post-accidental data to be recorded.

2.7 Use Case 5: Maintenance (Black Box System Maintenance and Physical Data)

- **Description**: The BlackBox will alert the operator that there is an error with the vehicle components, the sensors, or the BlackBox itself
- **Primary Actors**: Vehicle, Command Center Mechanic, Field Technician, Operator, Passenger
- **Pre-Conditions**: The vehicle components, all sensors and the black box is operating normally and is under normal operating conditions.
- **Flow of Events**:
  - During normal operation, the black box will use previous data to determine any abnormal operation.
  - If the black box detects erroneous data being recorded, the black box will alert the vehicle operator or passenger that there is an error in the system, and the particular sensor(s) that is being reported.
- **Post-Conditions**: If the vehicle is out in the field a field technician will perform a brief check to determine if it is a major issue. If it is a major issue, then the vehicle will return to the command center. If it is not a major issue, the vehicle can continue.
- **Alternative Flow of Events**:
  - If the vehicle is at a non-operating stage, the command center will dispatch a field technician to retrieve the passengers and vehicle.

2.8 Black Box System Outline

Our Black Box System design consists of a black box hardware and a sensor subsystem. Figure 2.3 describes the location of the OBD-II system, sensors location, and the location of the black box. The black box consists of hardware to prevent data failure, secure data, resist external factors, wirelessly request data, and perform normal operations. In Figure 2.4 we describe how the black box hardware is laid out.

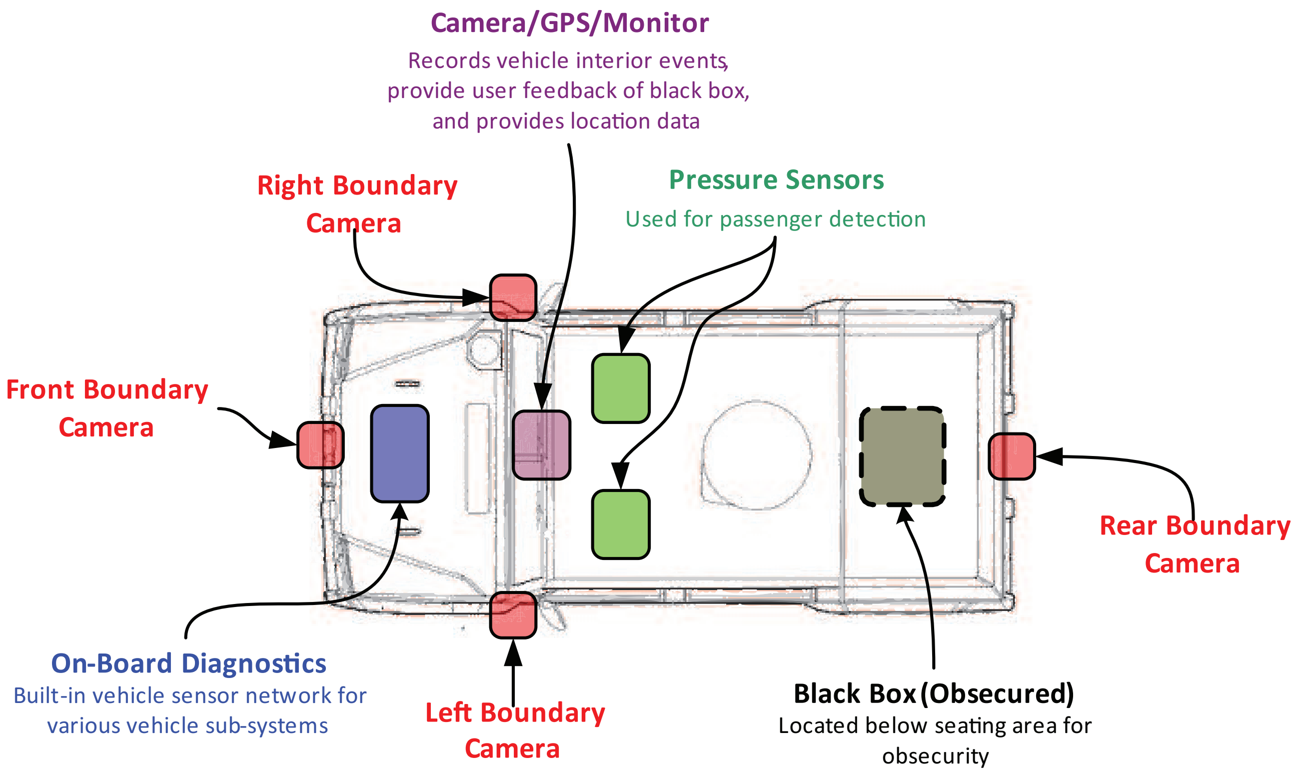


Figure 2.3: Complete Black Box system layout diagram showing the location of each subsystem

- Sensors
  - **Microphone**: Cockpit audio recording
  - **Camera**: Vehicle boundary (left, right, front, rear), and cockpit video recording
  - **OBD-II**: Vehicle Condition Recording and Monitoring
  - **GPS**: Vehicle Geo-Tracking
  - **Pressure Sensor**: Passenger Location
- Vehicle (environment)
  - **Vehicle Layout**: Diagram of the vehicle and the location of each sensor
- Black Box
  - **Back-Up Battery**: To provide power if main power is lost. Used as a post-accident auxiliary power for GPS and 30 minutes of recording
  - **Command Center Data Requesting**: The command center can request data from the vehicle wireless by assigning a unique ID to each individual vehicle
  - **Environmental Condition**: Records conditions of the environment
  - **Data Analyzing**: Black-box must also be able to analyze input data and output accurate system information for use by analysts and technician (use baselines, past data, etc)
  - **Tamper Resistance**: Prevents unauthorized access by requiring a dongle for data access, destroys data if Black Box is opened
  - **Solid State Disk**: For shock resistant data storage
  - **Data Acquisition Unit**: Receives data from sensors to be recorded onto disk

– **Data Redundancy**: Provides redundant data so that if one disk is damaged, a mirrored data is available

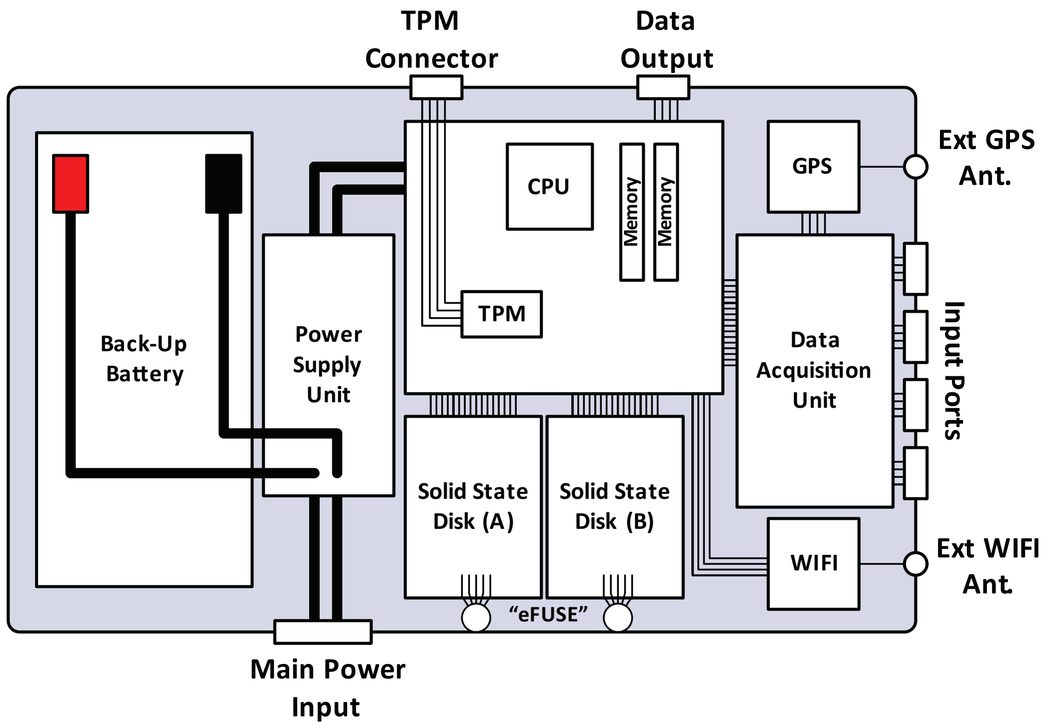


Figure 2.4: Black Box hardware layout

2.9 System Boundary

- Vehicle
  - Climate conditions and Vibrations
- Black Box
  - Sufficient Power
  - Mounting locations, mounting support
  - Security by obscurity
  - Theft or loss of the box due to threats or accident
  - Internal shock greater than 3400g
  - Internal temperature greater than $1000^{o}C$

2.10 Relationship Between Each Actor and Use Cases

- **Data Analysts**
  - View the audio/video recording of the vehicle interior to determine the situation within the vehicle that led to the accident; analyze conversations
  - View whether the accident was caused by an impact or other factors

  - Determine the condition of the vehicle before and during the accident
  - Locate the geographic location of the accident
  - Determine whether the environment play a role in the accident
  - Being able to understand the standard operating condition compared to the data acquired during accident
  - Requires a dongle to be inserted with the correct unique key for the black box, none or invalid keys will prevent data from being retrieved

- **Field Technician Soldiers**
  - Preview the boundaries of the vehicle to determine any potential threats
  - Being able to acknowledge the conditions of the vehicle and report issues to technicians
  - Being able to know the geographic location
  - The passenger can request to send data to the command center or base station to verify vehicle condition
  - Determine if the environment is safe (eg. climate, and weather)
  - Determine possible repairs and maintenance issues with black-box, vehicle, sensors, and physical systems

- **Command Center Mechanics**
  - Determine malfunctions within the system that could lead to catastrophic failure
  - Use analysis from black-box to determine efficiency of systems, software, hardware, and sensor networks.
  - Passengers (Pressure Sensor)
  - The black box knows where each passenger is seated
  - The mechanic installs the black box inside the vehicle
  - Passengers can preview the boundaries of the vehicle and determine the geographic location

- **Vehicle**
  - Records vehicle interior audio/video every 24 hours (if an accident has occurred, data will not be erased after 24 hours)
  - Records the boundaries of the vehicle every 24 hours (if an accident has occurred, data will not be erased after 24 hours)
  - Collect data from sensors within the vehicle for report generation
  - Keep track of where the vehicle navigational path so that the user can determine where the vehicle has been
  - Receive requests from Command Center to transmit data from the Black Box to the substation.
  - Records the temperature, humidity, and other environmental factors that may [have] contribute(d) to the accident
  - Generate a operating report for the vehicle operators or accident report for analysts
  - Prevent unauthorized access to the black box
  - Provide data redundancy to prevent data loss if one disk in the array is damaged

- **Human Threats**
  - Determine the location of the Black Box that is retrieved by enemy
  - Deny access to the data if no dongle is detected (TPM); data is destroyed (eFUSE) if the black box is opened.

2.11 Dependencies Among the System Functionalities

- Sufficient Power must be available for the black box
- During installation, the technician should know where each sensor is located for troubleshooting

Chapter 3

Textual Scenarios

3.1 Use Case 1: Installation and Testing

During installation, the technician must know the number of sensors used, types of sensors, and the location of each sensor. After installation phase is completed, the black box will need to be tested for compatibility with the vehicle. Figure 3.1 shows an activity diagram of this use case.

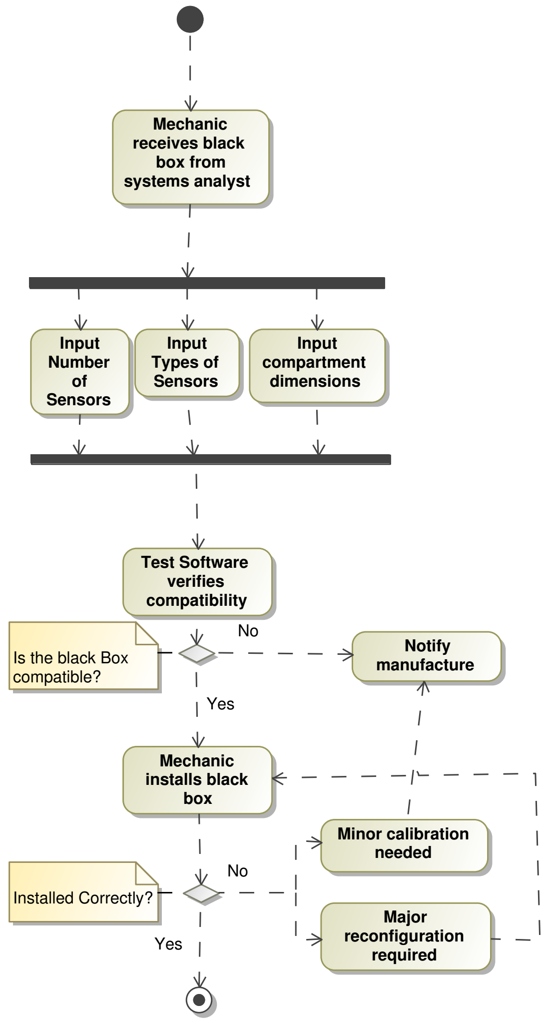


Figure 3.1: Activity Diagram for Installation and Testing

- Installation
  - Component-Level Testing
  - *Black Box Location*: System-Level Testing
- Figure 3.2 is the block definition diagram to describe the test software.

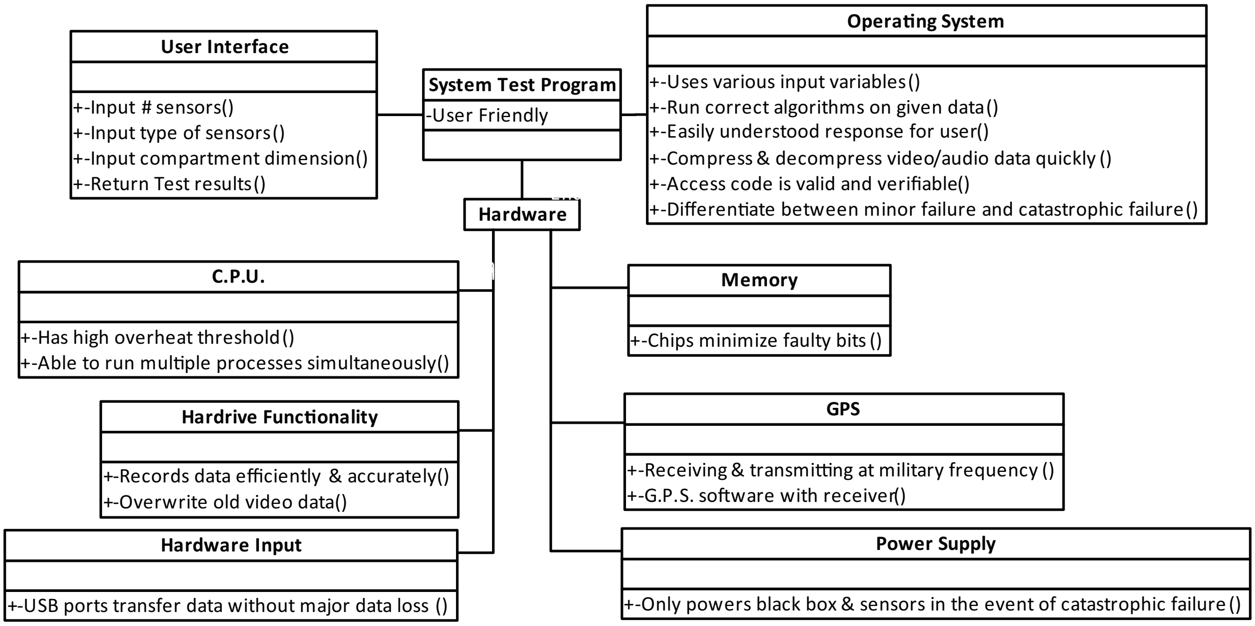


Figure 3.2: Test Software Block Definition Diagram

3.2 Use Case 2: Normal Operation (Recording and Interpreting Data)

- Streams in data from Cameras, GPS Receiver, and OBD-II Parameter ID's (sensor systems). Figure 3.3 describes a more generalized view of the normal operation of the black box. In Figure 3.4 we describe the parallel processes of the OBD-II, GPS, and cameras sensors for the black box.
- Cockpit Recording
  - Always on, the cockpit will be recorded constantly and saved onto the disk array. Records cockpit conversations, ambient sounds (internal and external), radio communications between base/command center and vehicle, time of each radio message transmission, continuously record cockpit instrumentation, engine sounds, radio communications, and ambient cockpit sounds
- Vehicle Boundary Recording
  - The vehicle operator can use the cameras during normal operation, Records outside viewing area.
- Vehicle Condition Recording
  - Always On, the Black Box will be able to record data from the Black Box and monitor for any faults within the vehicle
- Records conditions of the environment
  - temperature and humidity for both interior and exterior of the vehicle
  - fuel tank levels, vehicle tilt, direction of travel, throttle position, location

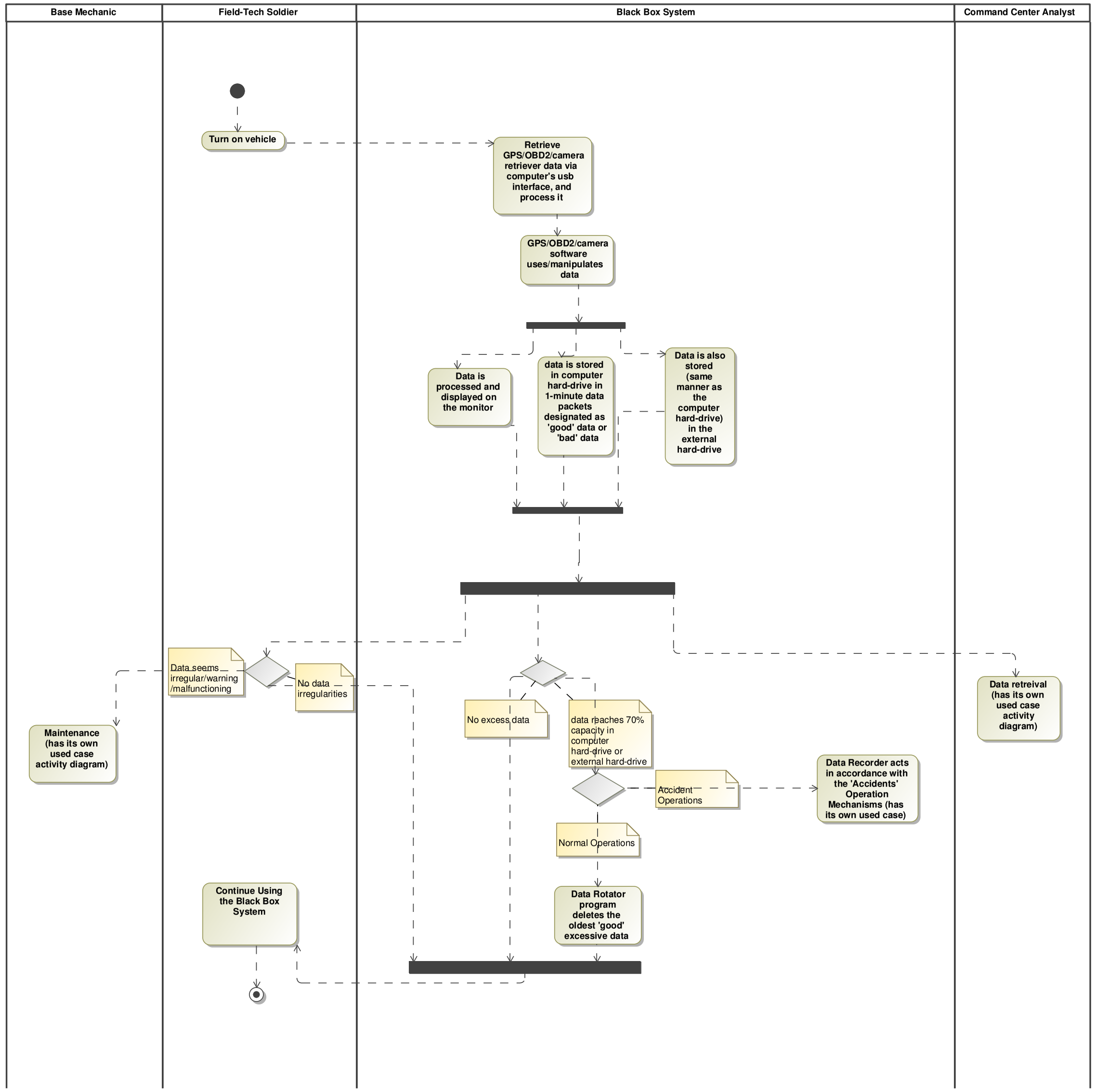


Figure 3.3: General Activity Diagram for Operation

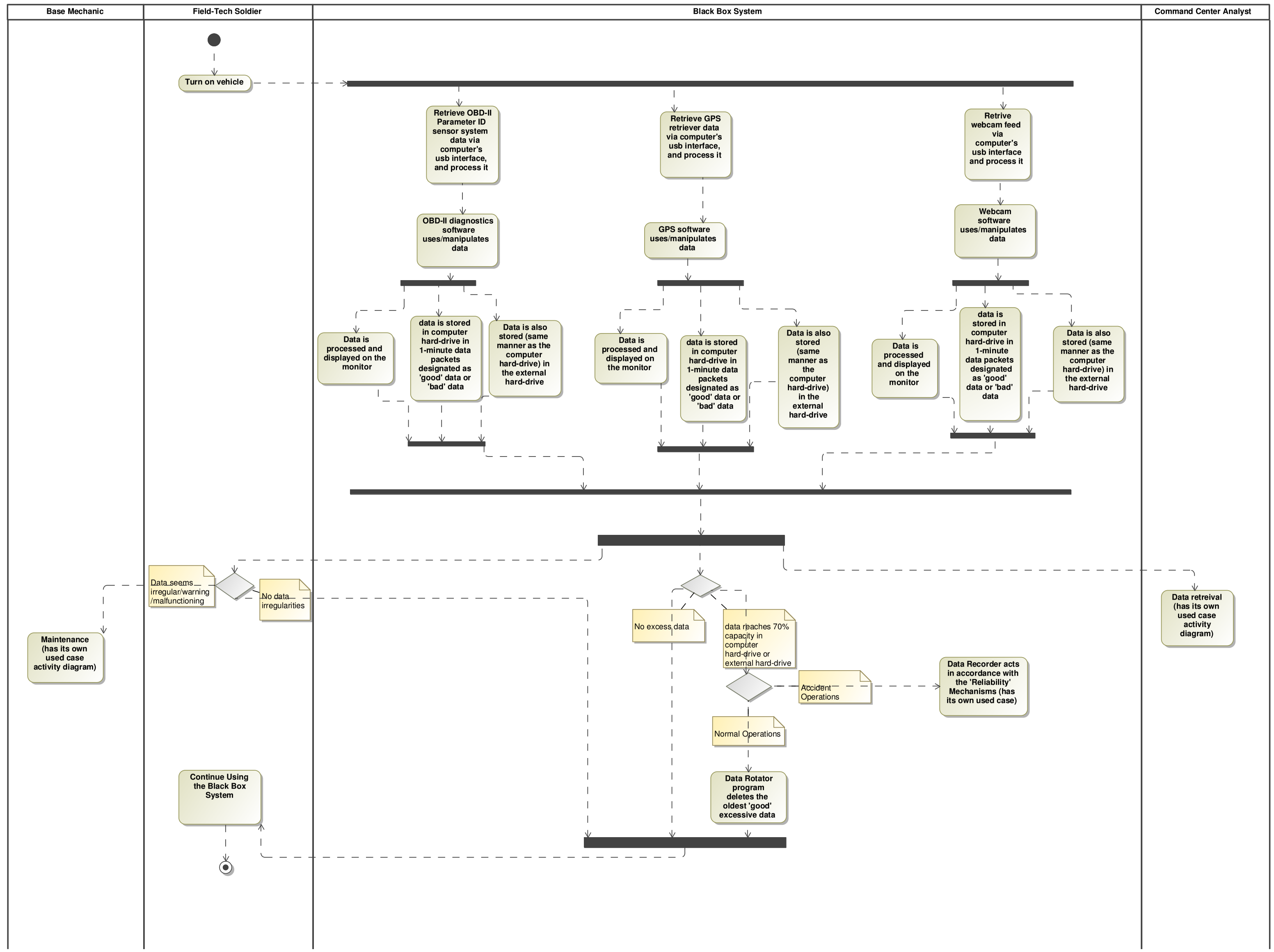


Figure 3.4: Activity Diagram for Operation

3.3 Use Case 3: Retrieving Data

- Modes of Data Retrieval: Figure 3.5 the process in which data is retrieved from the black box.
  - The Command Center can request data remotely and be able to monitor the vehicle's health.
  - For local access, a technician can insert a reader containing the unique ID for authentication to retrieve data

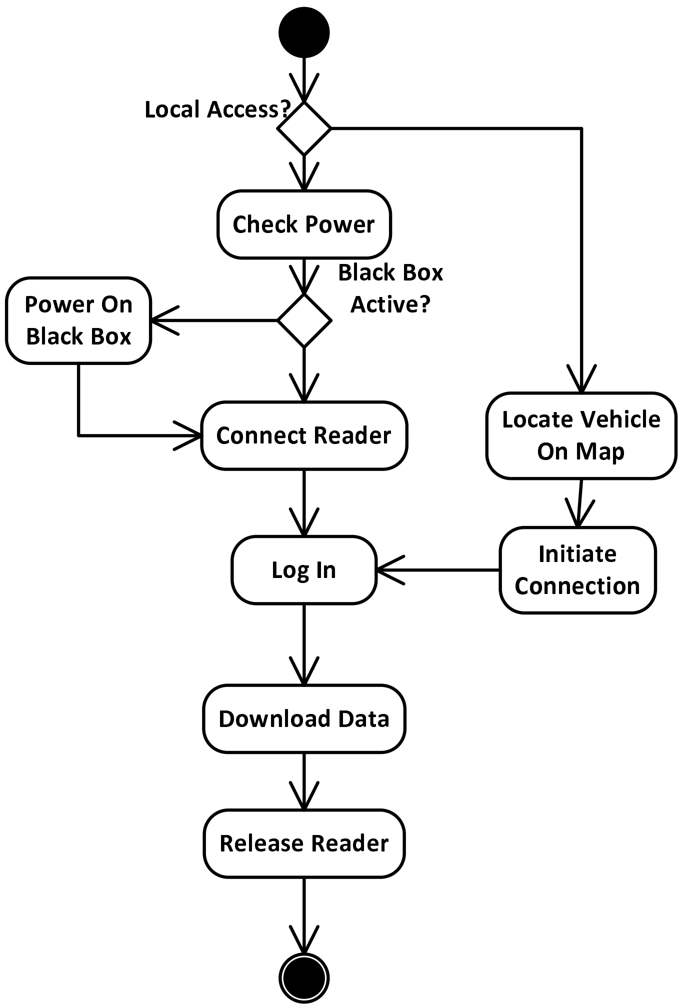


Figure 3.5: Activity Diagram for Retrieving Data

3.4 Use Case 4: Accident/Abnormal Operations

When an accident has occurred and the vehicle is damaged, the black box must be resilient to external threats as it acts as an independent hardware. Figure 3.6 shows the process after an accident has occurred.

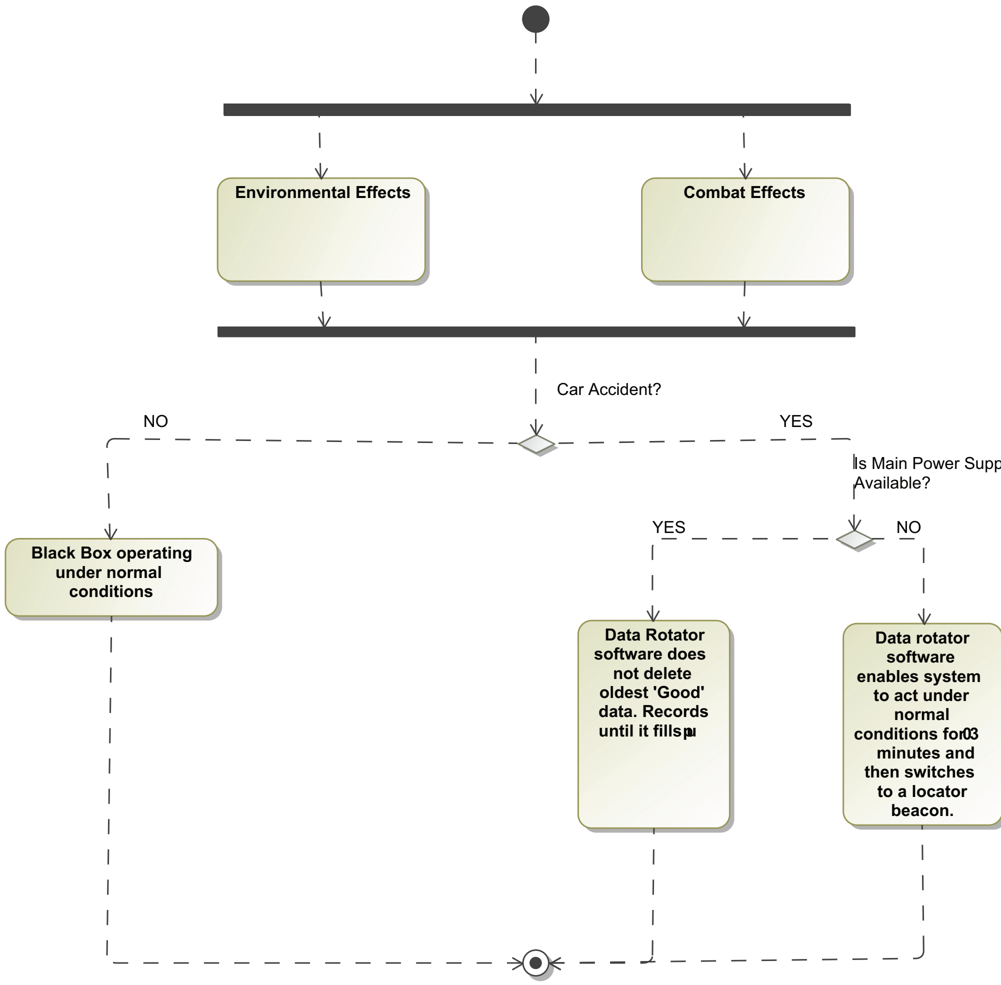


Figure 3.6: Activity Diagram for Threats and Reliability

- Reliability of the Black Box
- If vehicle is destroyed, the GPS will act as a beacon to provide the location of the Black Box

3.5 Use Case 5: Maintenance

This use case describes the maintenance of the vehicle and the black box system. If an error has occurred, the black box will notify the passenger and will also send a signal to the command center. Figure 3.7 describes how this is achieved.

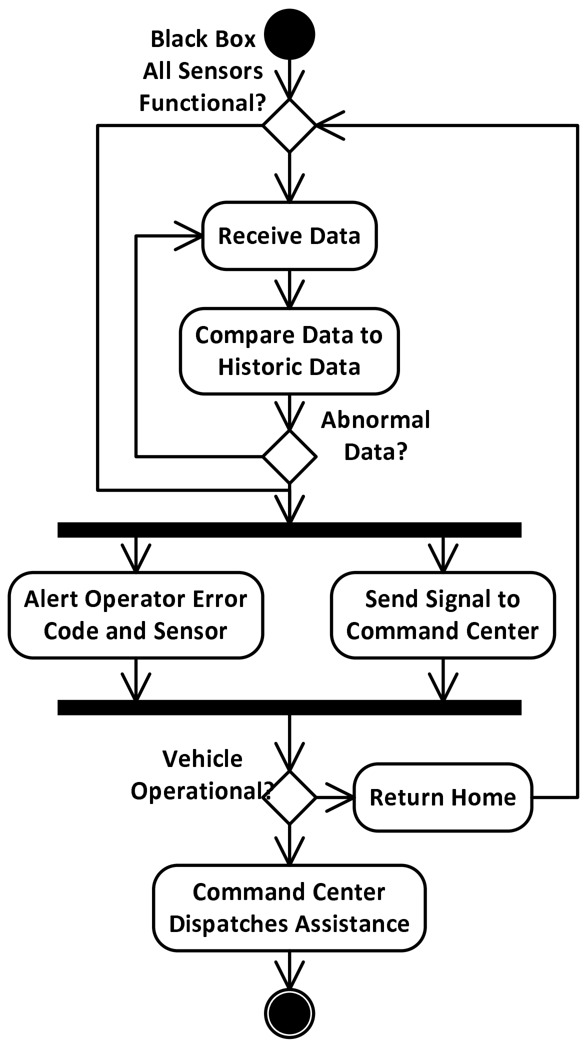


Figure 3.7: Activity Diagram for Maintenance

- Vehicle/Black Box Tracking
  - Command Center can use the integrated GPS in the Black Box to locate the vehicle
- Analyze Data and Generate Report

Chapter 4

Simplified Models of System Behavior

4.1 Use Case 1: Installation and Testing

- See Figure 4.1. This figure describes a 'timeline' of how installation and testing is performed on the Black Box system.

4.2 Use Case 2: Normal Operation (Recording and Interpreting Data)

- Figures 4.2, 4.3, 4.4 describes a generalized sequence diagram of each individual sensor system (OBD-II, GPS, camera) used for operation.
- Figures 4.5, 4.6, 4.7 describes the sequence of events achieved by each sensor system.

4.3 Use Case 3: Retrieving Data

In Figure 4.8 we describe two ways of retrieving data from the black box. The sequence of physically accessing the data, and remotely accessing the data is described in 4.8.

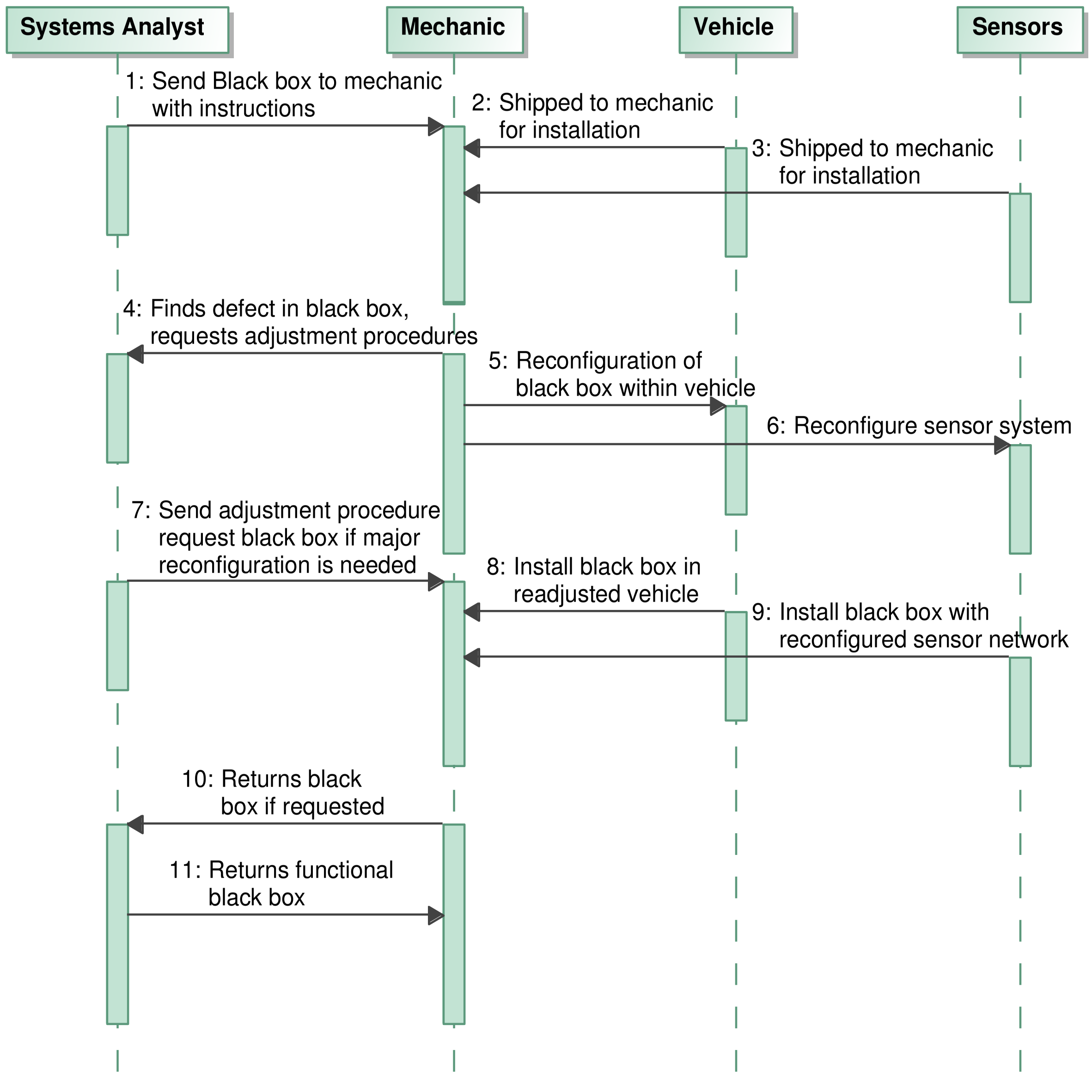


Figure 4.1: Sequence Diagram of Installation and Testing

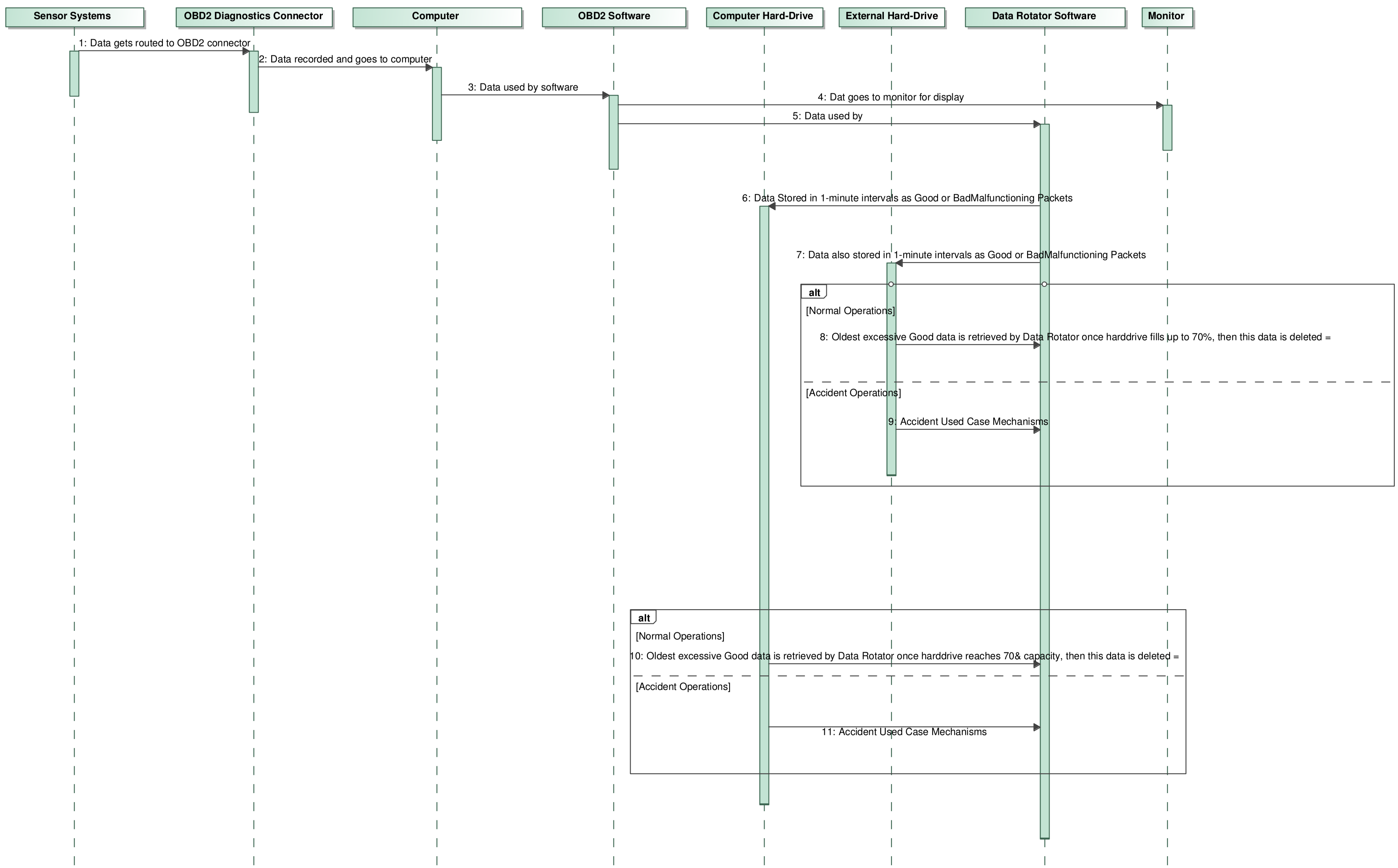


Figure 4.2: General OBD-II Operation Sequence Diagram

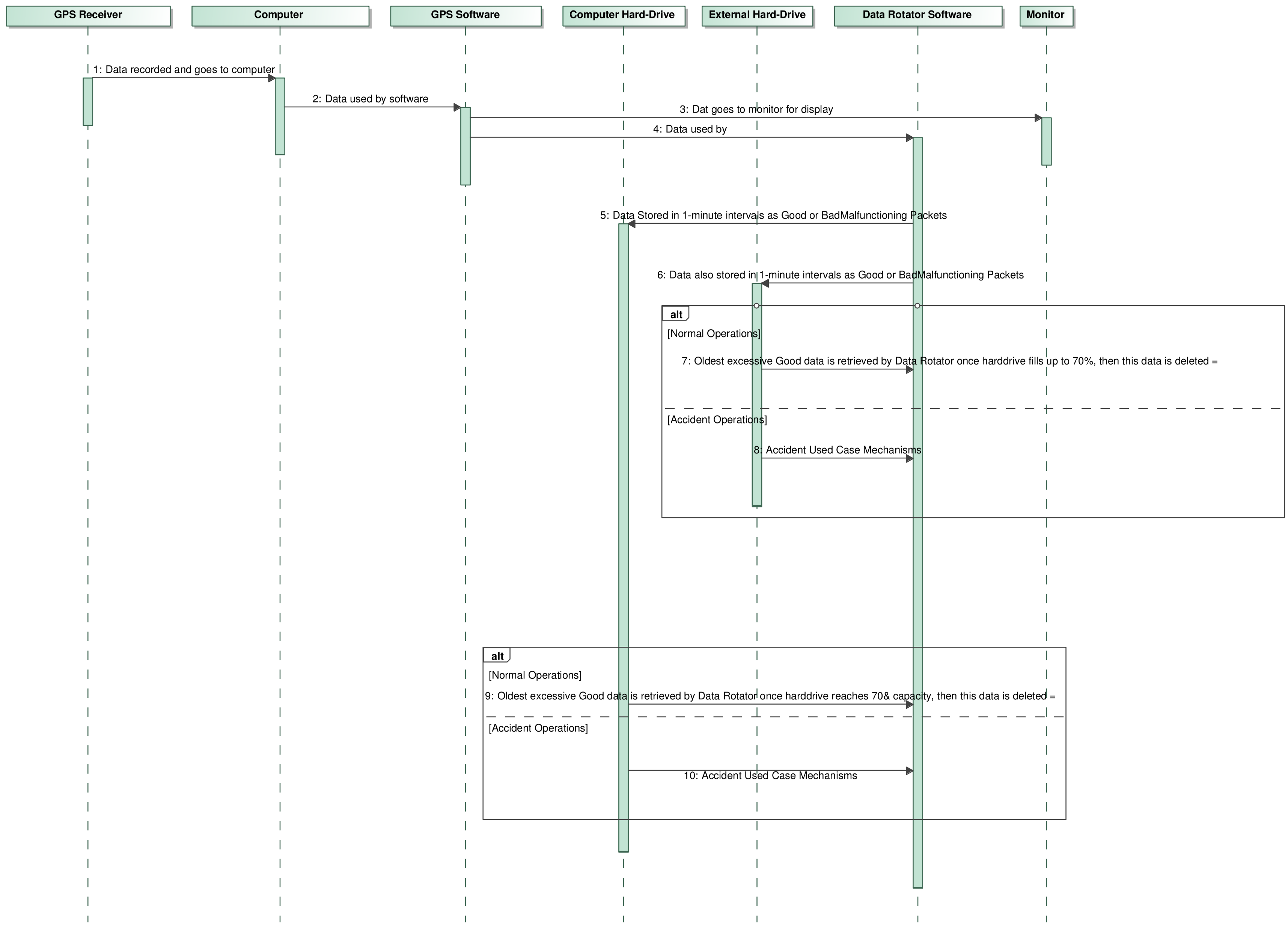


Figure 4.3: General GPS Operation Sequence Diagram

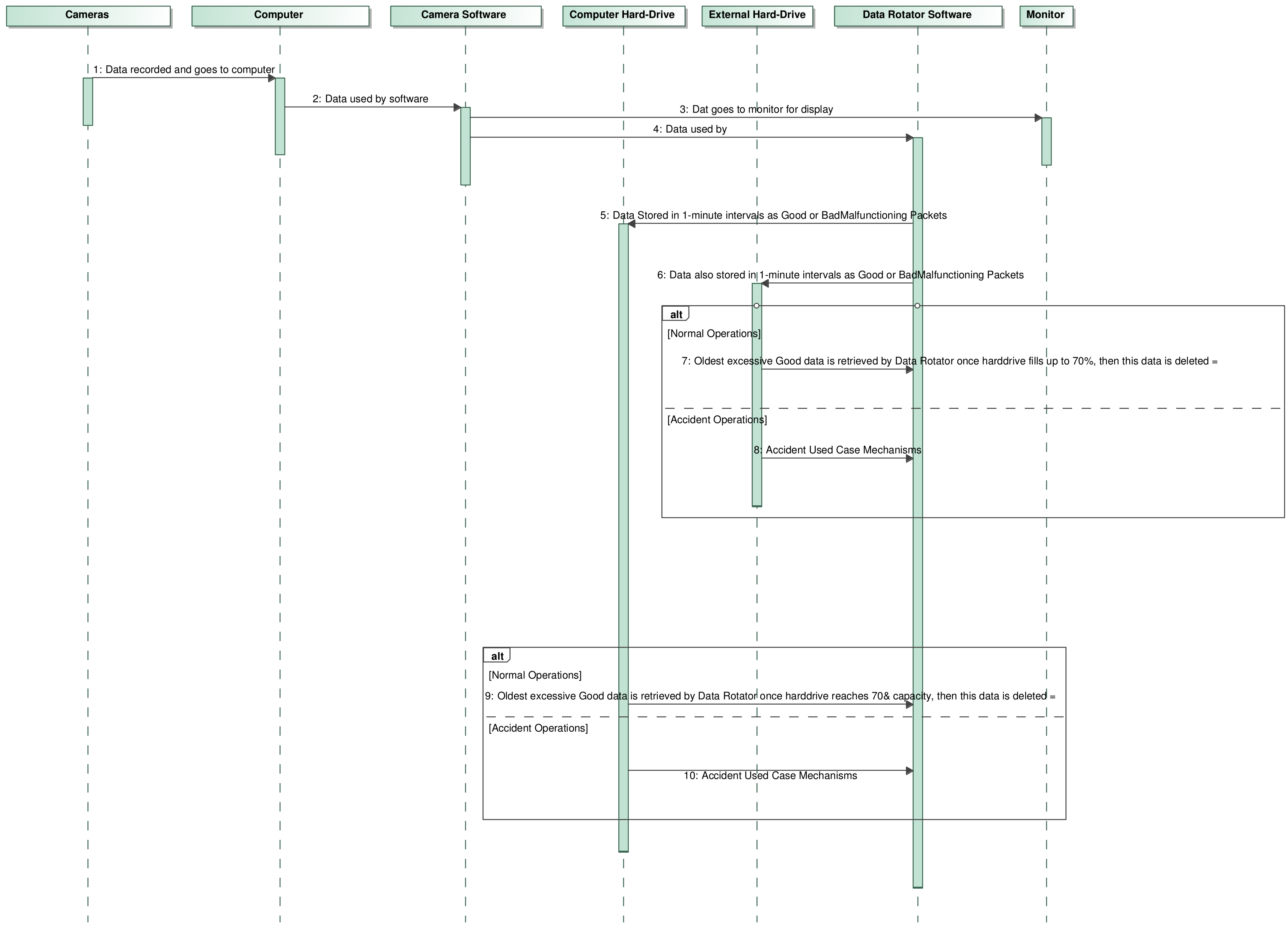


Figure 4.4: General Camera Operation Sequence Diagram

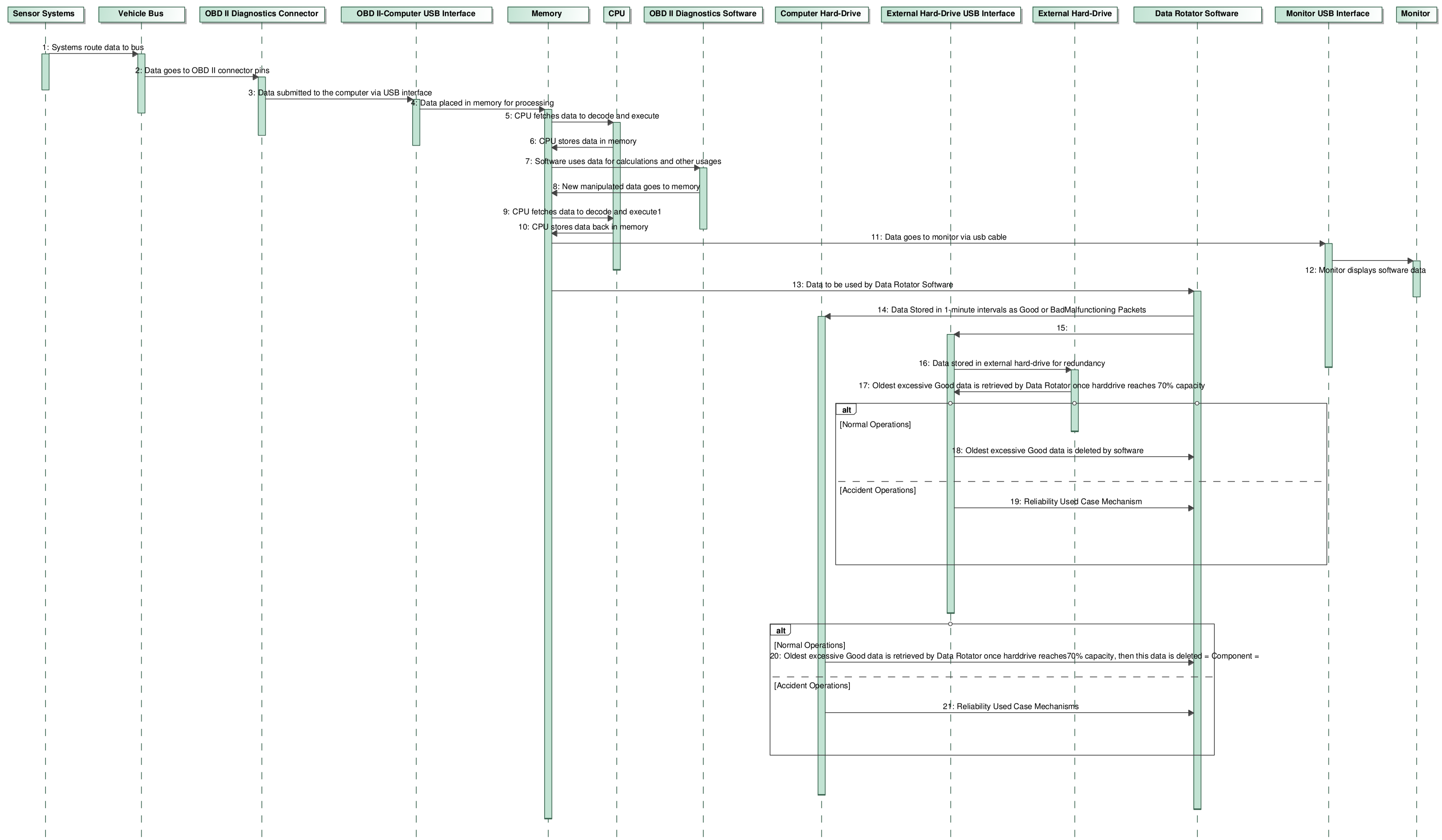


Figure 4.5: Sequence Diagram of On-Board Diagnostics Operation

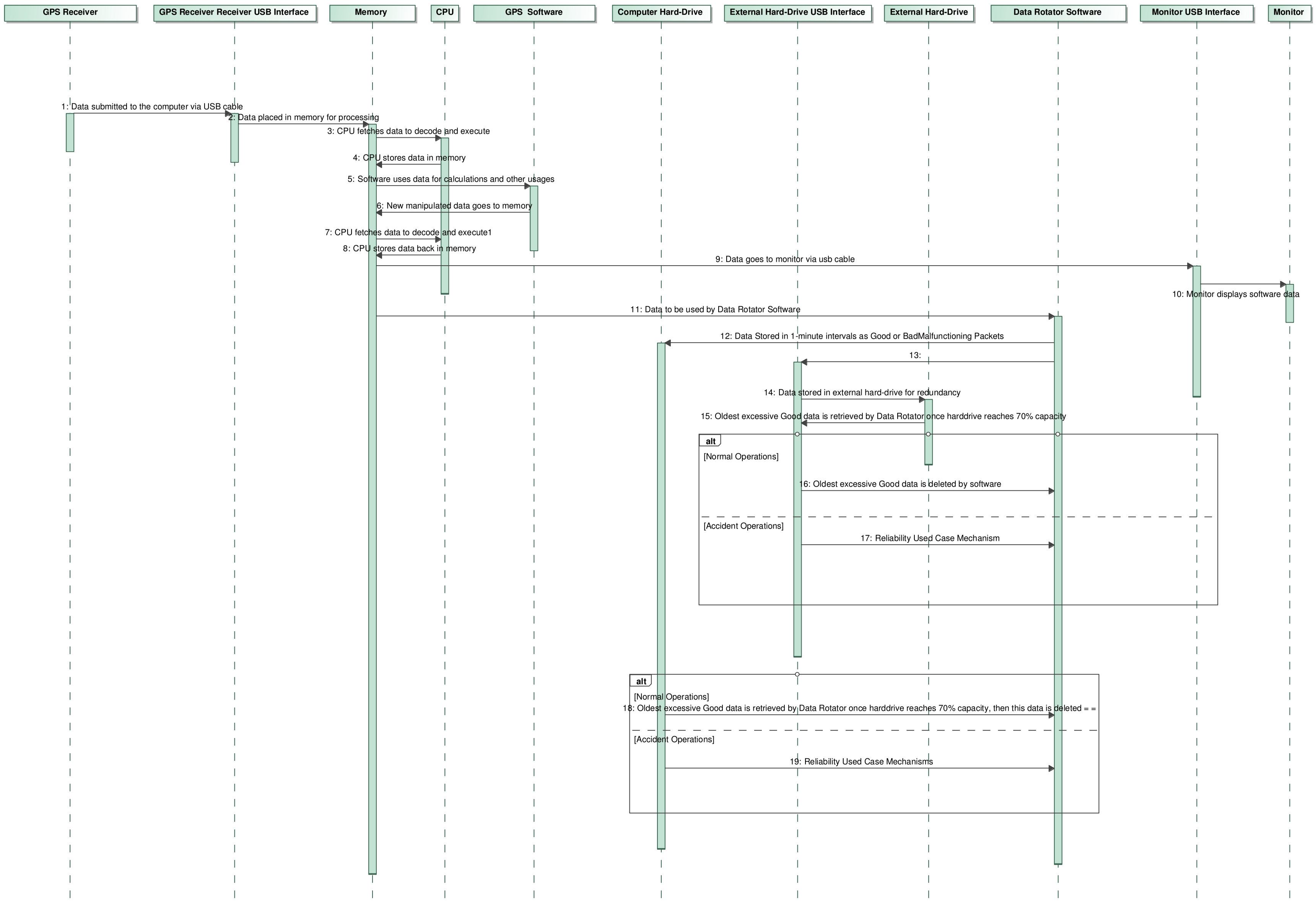


Figure 4.6: Sequence Diagram of GPS Operation

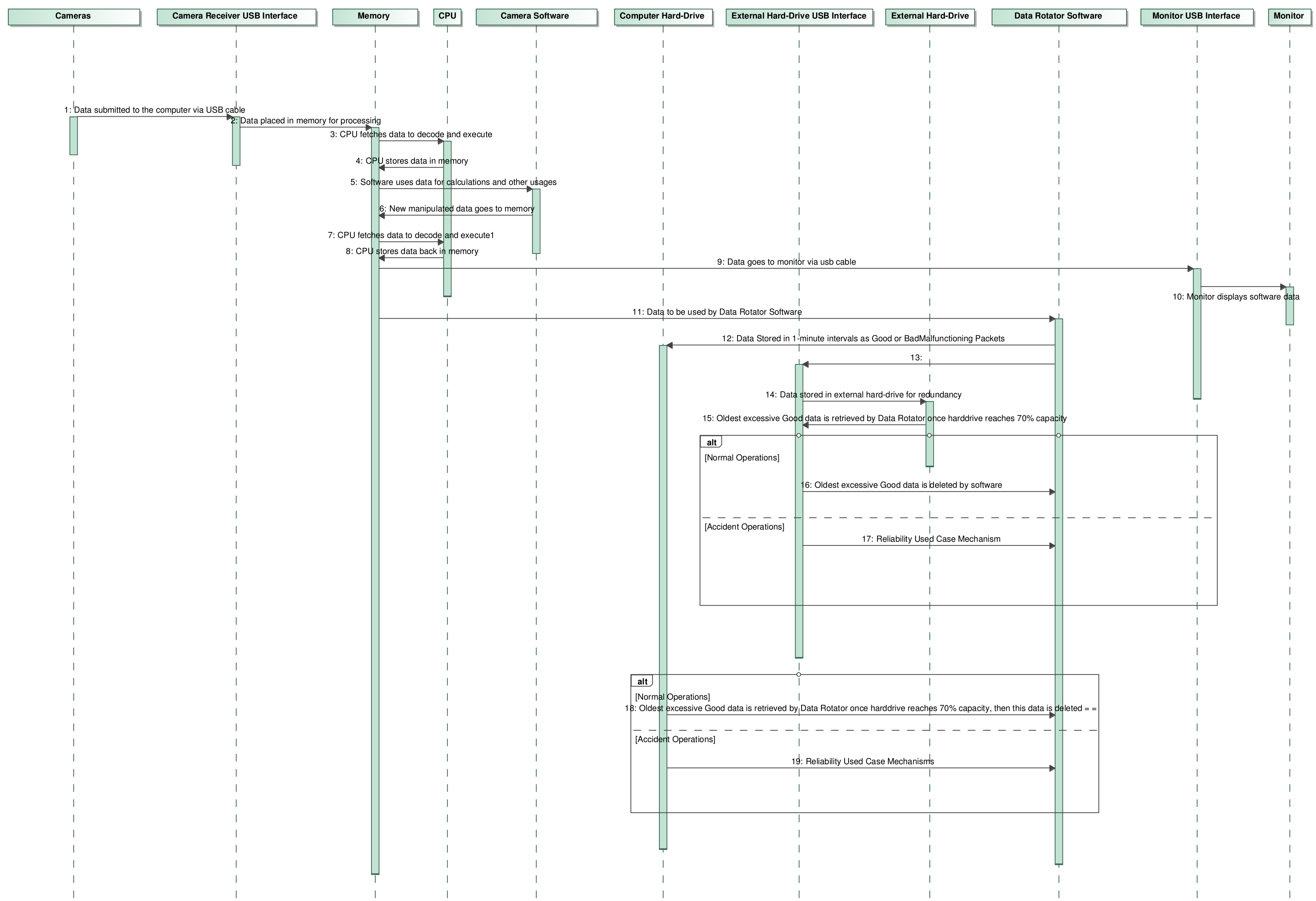


Figure 4.7: Sequence Diagram of Camera Operation

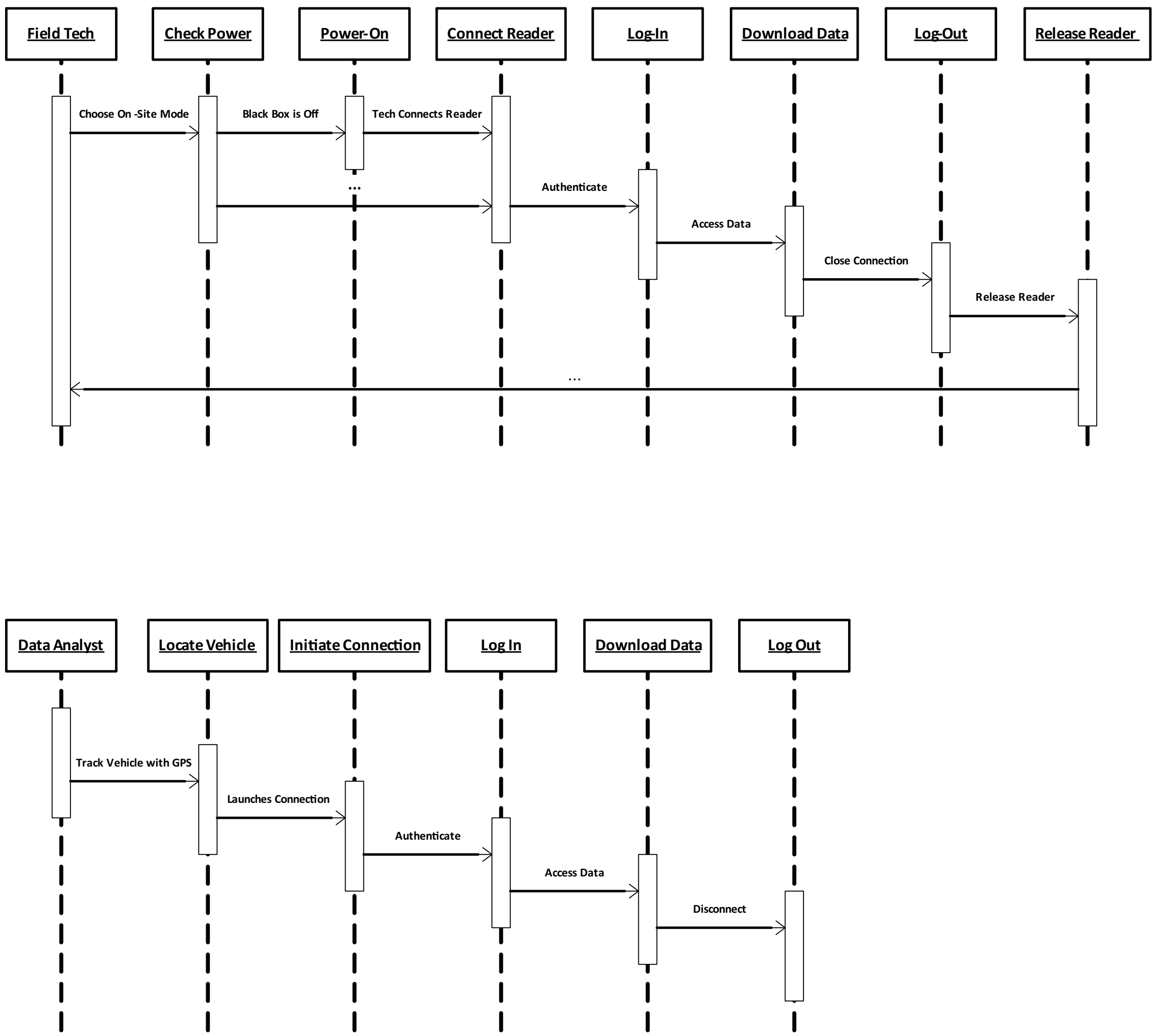


Figure 4.8: Sequence Diagram of Retrieving Data

4.4 Use Case 5: Maintenance (Black Box System Maintenance and Physical Data)

In Figure 4.9 we describe the sequence when the vehicle has malfunctioned.

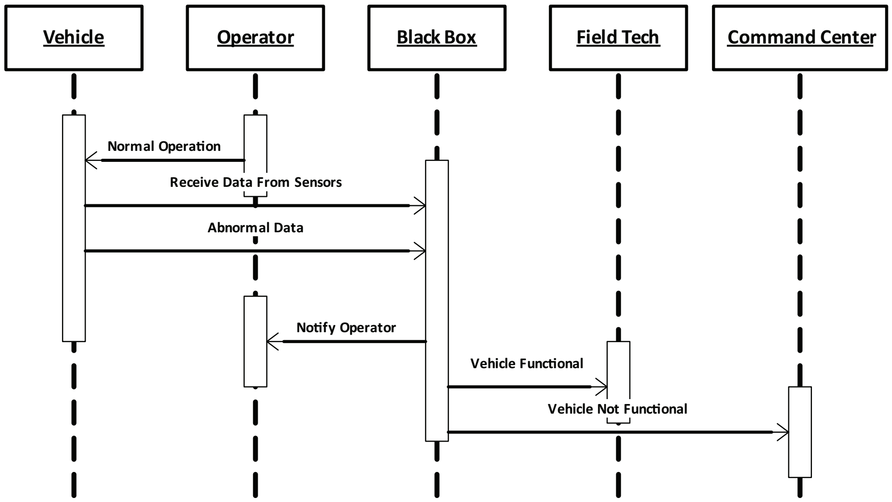


Figure 4.9: Sequence Diagram of Maintenance

Chapter 5

Requirements Engineering

First we reiterate on the high-level requirements for our Black Box system. The following tables (Tables 5.2-5.11) dwelves into our focus on the hardware of the black box itself.

High Level Requirements	
Requirement 1	Be as indestructible as possible
Requirement 2	Be mountable to army vehicles
Requirement 3	Store data from camera, vehicle sensors, and location (GPS)
Requirement 4	Have accessible data for army command and base centers
Requirement 5	Be tamper-resistant
Requirement 6	Accommodate accident-scenarios
Requirement 7	Have accessible data displayed for Field-Technician Soldiers
Requirement 8	Must be power-efficient

Table 5.1: Table of High Level Requirements

Requirement	Structure (Objects, Attributes)	Behavior (Time, Performance, Sequence)
Requirement 1	'Indestructable' container	Withstand acceleration of 3400g for 6.5 ms
Requirement 2	>1.8 GHz processor	Fetch, Decode, Execute, Store Data
Requirement 3	Solid-State Disk, >200GB	Store Data
Requirement 4	Input Ports (USB 2.0)	Data receiver/transmitter-to-computer interface
Requirement 5	PSU/Battery, 9-36V DC Range	Wide Input Range (mountable to various vehicles), >10 days standalone
Requirement 6	External SDD >200GB	Store Data
Requirement 7	Memory, >2GB	Primary Storage
Requirement 8	GPS Receiver, TBD after talks with U.S. ARL advisor	navigation, search and rescue, etc TBD after talks with U.S. ARL advisor
Requirement 9	Wideband Wifi Link, TBD after talks with U.S. ARL advisor	internet access to transmit data when/if necessary

Table 5.2: Table of Requirements

Index	Requirement
CT1	Withstand >3400g of force
CT2	Withstand 3400g force for at least 6.5 milliseconds
CT3	Be at least 99% reliable
CT4	Cost < TBD

Table 5.3: Container Requirements

Index	Requirement
PRC1	Be at least 99% reliable
PRC2	Processor Speed >1.8 GHz
PRC3	Able to run several processes at once
PRC4	Cost <$600

Table 5.4: Processor Requirements

Index	Requirement
CHD1	Be at least 99% reliable
CHD2	Storage >200GB
CHD3	Dependence from Trusted Platform Module Software (additional cost)
CHD4	Cost < $3000

Table 5.5: SSD Requirements

Index	Requirement
IP1	Be at least 99% reliable
IP2	USB 2.0
IP3	DC Connector

Table 5.6: Input Port Requirements

Index	Requirement
PSU1	Standalone battery only power black box/cameras (for first 30 minutes) and locator beacon (after 30 minutes) upon car battery failure
PSU2	Power system for at least >10 hours standalone
PSU3	Black box is compatible with at least 9V-36V battery input range
PSU4	Cost <$1000
PSU5	Be at least 99% reliable

Table 5.7: PSU/Battery Requirements

Index	Requirement
EHD1	Be at least 99% reliable.
EHD2	Storage >200GB
EHD3	Dependence from Trusted Platform Module Software (additional cost)
EHD4	Cost <$3000

Table 5.8: External/Redundant SSD Requirements

Index	Requirement
RAM1	Be at least 99% reliable
RAM2	Primary Storage >2 GB
RAM3	Cost <$200

Table 5.9: Memory Requirements

Index	Requirement
GPS1	Be at least 99% accurate in navigation
GPS2	Dependence from GPS software (additional cost)
GPS3	Cost <$1000
GPS4	Be at least 99% reliable in air/vacuum/precipitation medium
GPS6	Useful for Search and Rescue (specifics TBD)

Table 5.10: GPS Requirements

Index	Requirement
WWL1	Be at least 99% reliable in air/vacuum medium
WWL2	Be at least 40% reliable in rain/water medium
WWL3	Average upload rate >128 kbps
WWL4	Average download rate >512 kbps
WWL5	Coverage >100km
WWL6	Customer-Premises Equipment <$1500
WWL7	Dependance from (Optional) Real-Time Data Streaming Software (optional additional cost)

Table 5.11: Wide-Band Requirements

5.1 Traceability

In Table 5.12 we link the necessary high-level requirements to the Normal Operations use case. High-level requirements 3 and 8 are effected by the memory, processor, and solid-state disk drives. We will attempt to optimize the black box hardware in terms of performance, power efficiency, and cost in Chapter 7.

Used Case	High-Level Requirement	Component Requirement	Description	Components
Normal Operations	Requirement 3 Requirement 8	RAM 1, 2; PRC 1, 2, 3; CHD 1,2; EHD 1, 2	Black box must store data and it must do so as efficiently (eg speed, power) as possible.	Memory, Processor, SSD and Redundant SSD

Table 5.12: Traceability Table

5.2 Effectiveness Analysis: A Brief Description

Looking at a list of components, we will measure their effectiveness in meeting with these requirements by looking at their:

- Costs

- Performance (ability of component to accomplish requirement)
- Power Efficiency

Our trade-off analysis will look forward to accomplish the 3 following variables:

- Minimum Cost of System Implementation
- Maximum Power Efficiency of System Components
- Maximum Performance of System Components

5.3 Library

Here is a library of components that we have available. Using these components, we will be doing a trade-off analysis between the memory, processor, and the SSD as there are a few different options for them.

Component	Performance	Normalized Performance	Normalized Power Efficiency	Cost
WiFi Link (A)	Coverage (km)			
WWL1	2000	1	1	$300.00
Input Ports (B)	Speed (MB/s)			
IP1	480	1	1	$20.00
Container (C)	Force (g)			
CT1	3400	1	1	$8,000.00
PSU (D)	Lifetime (days)			
PSU1	30	1	1	$1,000.00
SSD/ExternalSSD (E)	Storage (GB)			
HD1	960GB	1	0.6	$2,900.00
HD2	480GB	0.5	0.8	$1,300.00
HD3	200GB	0.21	1	$600.00
Processor (F)	Processing Speed (GHz)			
PRC1	3	1	0.72	$550.00
PRC2	2.66	0.89	0.85	$270.00
PRC3	2.26	0.75	1	$210.00
Memory (G)	Primary Storage (GB)			
RAM1	8GB	1	0.63	$200.00
RAM2	4GB	0.5	0.81	$130.00
RAM3	2GB	0.25	1	$65.00
GPS Receiver (H)	Mapping Accuracy (%)			
GPS1	99.00%	1	1	$500.00

Table 5.13: Library of System Components

Chapter 6

System-Level Design

6.1 System Structure

Figure 6.1 shows the general structure of the whole black box system, whereas Figure 6.2 focuses on the black box itself (inside the 'indestructable containter') and all the hardware/software involved in it

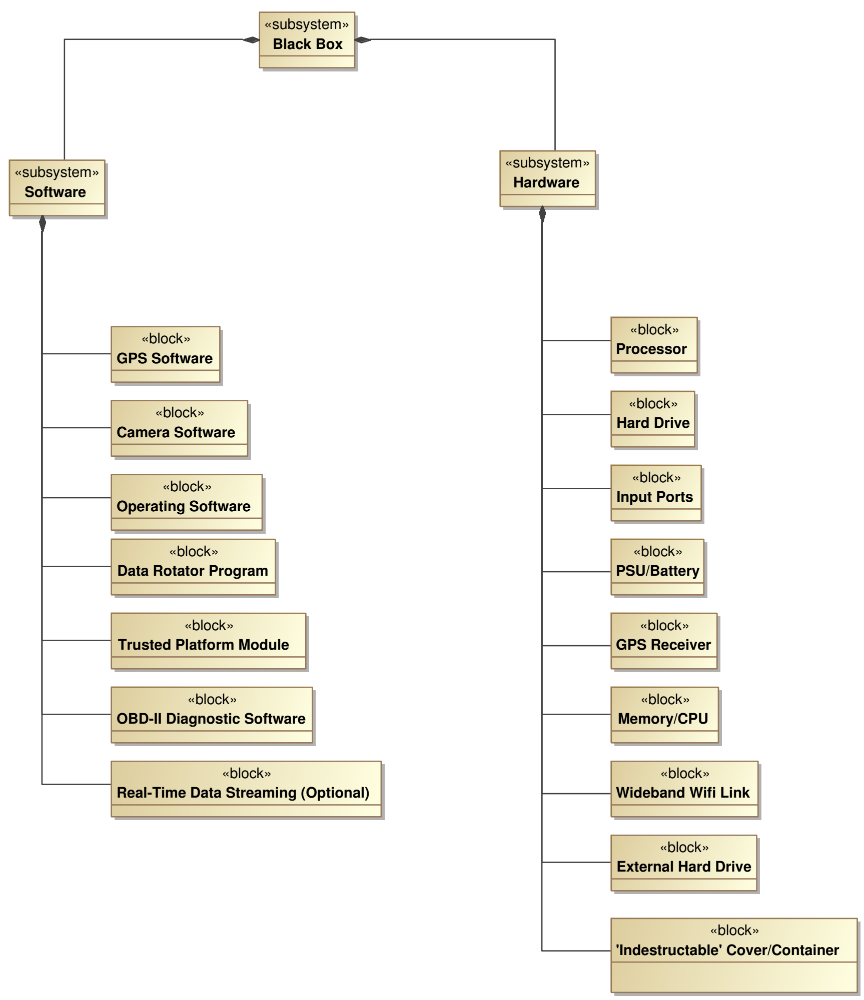


Figure 6.2: Black Box Structure Diagram

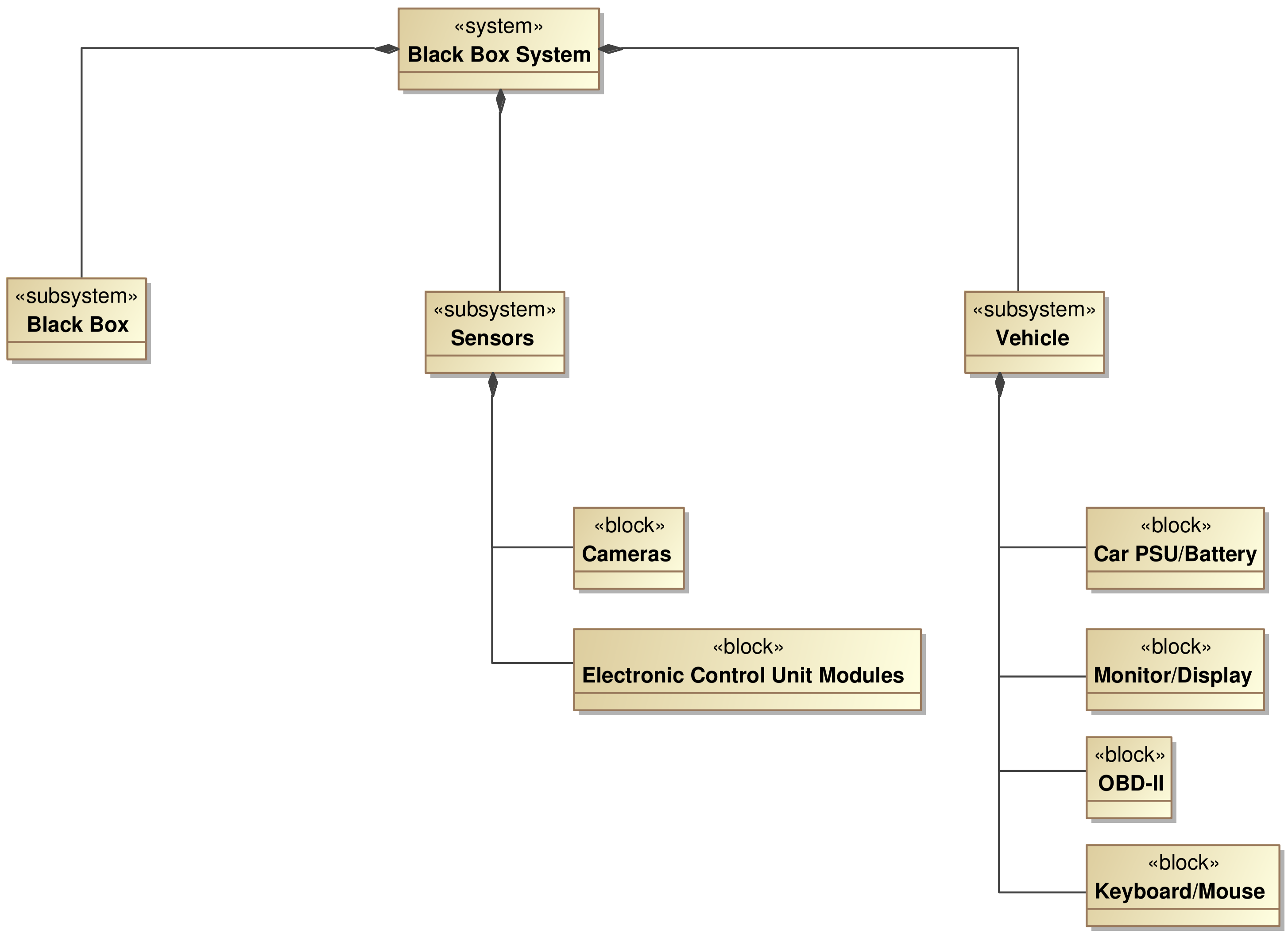


Figure 6.1: Black Box System Structure Diagram

Chapter 7

Simplified Approach to Tradeoff Analysis

In the following sections, we list the equations we used to optimize the black box hardware.

7.1 Total System Cost

Cost = Wifi Link(A) + Input Ports(B) + Container(C) + PSU(D) + HD/RedundantHD(E) + Processor(F) + Memory(G) + GPS Receiver(H)

- Selection of wifi link is represented by variables A
  - $A_i = 1$ for only one value of $i = 1$. Otherwise $A_i = 0$.
- Selection of input ports are represented by variables B
  - $B_i = 1$ for only one value of $i = 1$. Otherwise $B_i = 0$.
- Selection of container is represented by variables C
  - $C_i = 1$ for only one value of $i = 1$. Otherwise $C_i = 0$.
- Selection of PSU is represented by variables D
  - $D_i = 1$ for only one value of $i = 1$. Otherwise $D_i = 0$.
- Selection of HD/Redundant is represented by variables E
  - $E_i = 1$for only one value of $i = 1, 2, 3$. Otherwise $E_i = 0$.
- Selection of processor is represented by variables F
  - $F_i = 1$for only one value of $i = 1, 2, 3$. Otherwise $F_i = 0$.
- Selection of memory is represented by variables G
  - $G_i = 1$for only one value of $i = 1, 2, 3$. Otherwise $G_i = 0$.
- Selection of GPS receiver is represented by variables H
  - $H_i = 1$for only one value of $i = 1$. Otherwise $H_i = 0$.

7.2 Formula for System Cost

- $CostC = C_{WWL1}A_1 + C_{IP1}B_1 + C_{CT1}C_1 + C_{PSU1}D_1 + C_{HD1}E_1 + C_{HD2}E_2 + C_{HD3}E_3 + C_{PRC1}F_1 + C_{PRC2}F_2 + C_{PRC3}F_3 + C_{RAM1}G_1 + C_{RAM2}G_2 + C_{RAM3}G_3 + C_{GPS1}H_1$
- $CostC = 300A_1 + 20B_1 + 8000C_1 + 1000D_1 + 2900E_1 + 1300E_2 + 600E_3 + 550F_1 + 270F_2 + 210F_3 + 200G_1 + 130G_2 + 65G_3 + 500H_1$

7.3 System Performance

- $P = P_{WWL1}A_1 + P_{IP1}B_1 + P_{CT1}C_1 + P_{PSU1}D_1 + P_{HD1}E_1 + P_{HD2}E_2 + P_{HD3}E_3 + P_{PRC1}F_1 + P_{PRC2}F_2 + P_{PRC3}F_3 + P_{RAM1}G_1 + P_{RAM2}G_2 + P_{RAM3}G_3 + P_{GPS1}H_1$
- $P = 2000A_1 + 480B_1 + 3400C_1 + 30D_1 + 960E_1 + 480E_2 + 200E_3 + 3.0F_1 + 2.66F_2 + 2.26F_3 + 8G_1 + 4G_2 + 2G_3 + 0.99H_1$

7.4 Constraints

- $\$10000 < Cost < \$14000$
- $6 < norm(Performance) < 8$
- $6.5 < norm(PowerEfficiency) < 8$
- $A_1 = 1$
- $B_1 = 1$
- $C_1 = 1$
- $D_1 = 1$
- $E_1 + E_2 + E_3 = 1$
- $F_1 + F_2 + F_3 = 1$
- $G_1 + G_2 + G_3 = 1$
- $H_1 = 1$

7.5 Minimize

- $290E_1 + 130E_2 + 60E_3 + 55F_1 + 27F_2 + 21F_3 + 20G_1 + 13G_2 + 6.5G_3$

7.6 Subject To:

- $1.2 \leq 1E_1 + 0.5E_2 + 0.21E_3 + 1F_1 + 0.887F_2 + 0.75F_3 + 1G_1 + 0.5G_2 + 0.25G_3 \leq K_1$
- $K2 \leq 0.6E_1 + 0.8E_2 + 1E_3 + 0.72F_1 + 0.85F_2 + 1F_3 + 0.63G_1 + 0.81G_2 + 1G_3 \leq 3$
- $E_1 + E_2 + E_3 = 1$
- $F_1 + F_2 + F_3 = 1$
- $G_1 + G_2 + G_3 = 1$

7.7 Bounds

- $0 \leq A_1 \leq 1$
- $0 \leq B_1 \leq 1$
- $0 \leq C_1 \leq 1$
- $0 \leq D_1 \leq 1$
- $0 \leq E_1 \leq 1$
- $0 \leq E_2 \leq 1$
- $0 \leq E_3 \leq 1$
- $0 \leq F_1 \leq 1$
- $0 \leq F_2 \leq 1$
- $0 \leq F_3 \leq 1$
- $0 \leq G_1 \leq 1$
- $0 \leq G_2 \leq 1$
- $0 \leq G_3 \leq 1$
- $0 \leq H_1 \leq 1$

7.8 Value Constraints

- $A_1, B_1, C_1, D_1, E_1, E_2, E_3, F_1, F_2, F_3, G_1, G_2, G_3, H_1$ are integers
- Change to value of K_1 and K_2 to get various points with different costs, power factors, and performance

7.9 Trade-Off Analysis

For the black box hardware, we can perform trade-off analysis on the memory, processor, and solid state drive to optimize performance, power efficiency, and cost.

Point	Cost	Performance	Power Factor
1	3650	3.00	1.95
4	3370	2.89	2.08
7	3310	2.75	2.23
10	2050	2.50	2.15
13	1770	2.39	2.28
17	1640	1.75	2.61
22	1070	2.10	2.48
24	935	1.35	2.85
27	875	1.21	3.00

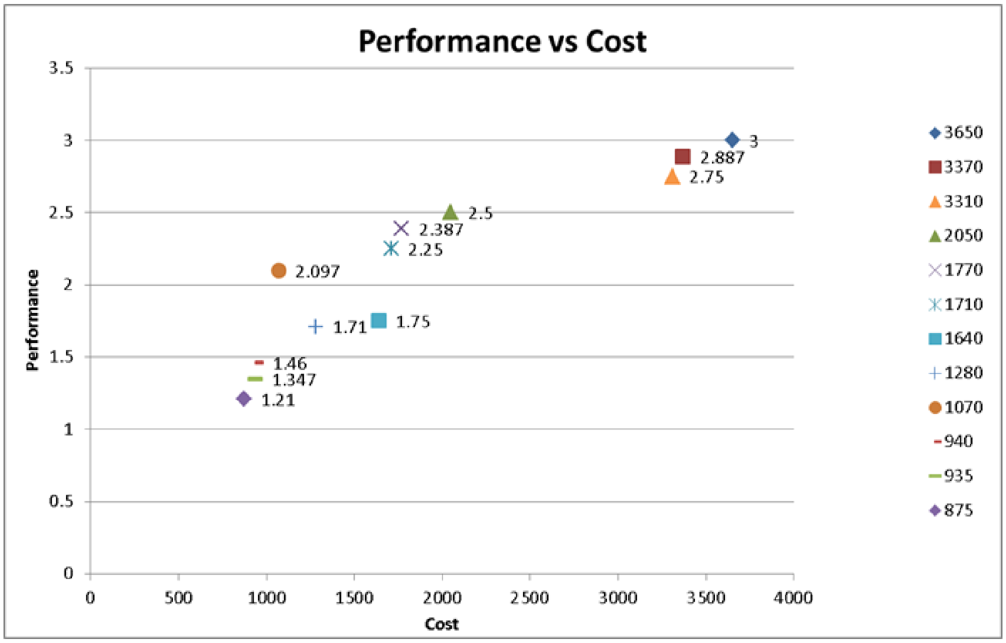


Figure 7.1: Performance vs. Cost

Here in Figure 7.1 we perform trade-off analysis on performance of the system, and the cost of the system. We see that Point 22 (Performance: 2.097, Cost: 1070) is the dominating choice for optimizing performance and cost. Points 27 (Performance: 1.21), and 24 (Performance: 1.347) should not be chosen since these points have lower performance than point 22 with similar costs. If no constraint is placed on cost, we can then choose point 1 for the highest performance and highest cost.

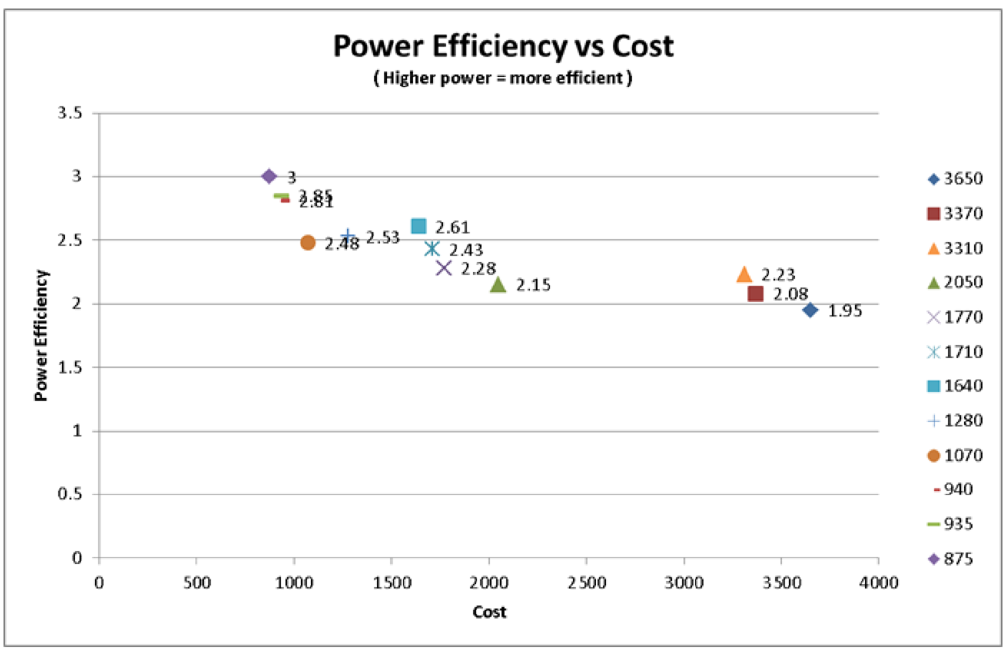


Figure 7.2: Power Efficiency vs. Cost

Since, after an accident, the black box will need to be powered independently from the vehicle using the built-in back up battery, power efficiency is necessary so that the black box can function after main power is lost. In Figure 7.2 we attempt to optimize power efficiency of the hardware and cost of the black box. We see in 7.2 no points are dominating, however, since we want to maximize power efficiency, we can choose point 27 as this has the lowest cost, and highest power efficiency.

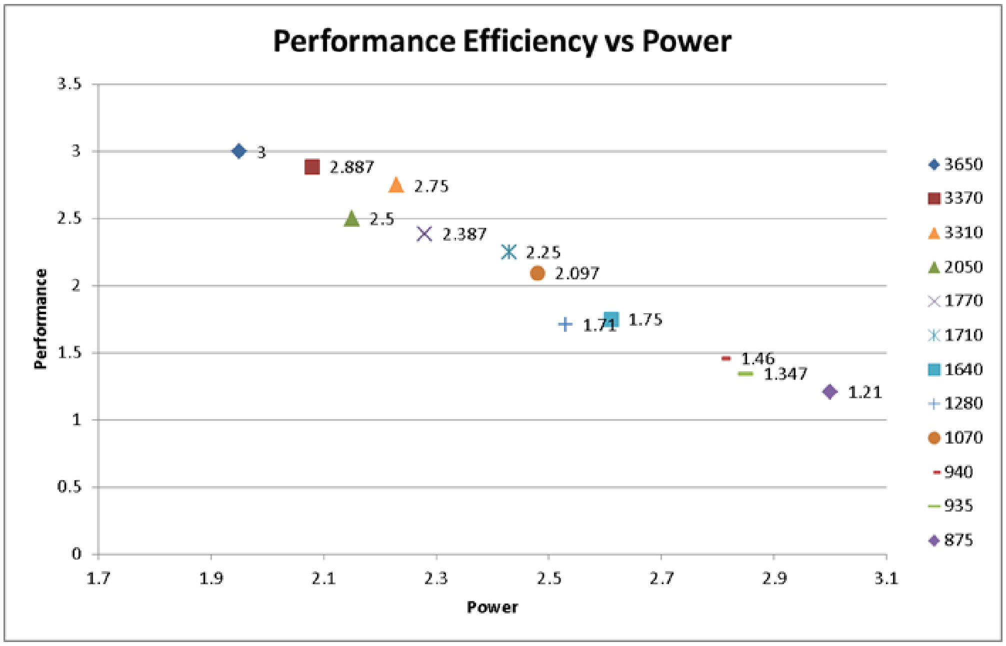


Figure 7.3: Performance vs. Power Efficiency

In Figure 7.3 we analyze performance and power efficiency. Since components with lower performance uses less power, whereas components with higher performance uses more power we see that there is no dominating point in 7.3.

As a complete system, we see that point 22 is the optimal design as that particular design has dominance in performance vs. cost, power efficiency is only about 0.5 point lower than the most efficient components. This analysis is summarized in Table 7.1.

7.10 Summary

Based on our evaluations of performance, power efficiency, and cost the points we chose to be the best combination of options.

Trade-Off Curve	Points of Interest
Performance vs Cost	22, 1, 10, 27, 17
Power Efficiency vs Cost	27, 22, 24, 17, 13, 1
Performance vs Power	1, 7, 27, 17, 22
Overall System	22, 1, 27, 17

Table 7.1: Summary of Trade-Off Analysis

Chapter 8

System-Component Testing (Validation/Verification)

The two questions that we will try to answer:

- Are we building the right product?
- Are we building the product right?

We will do a brief system-component testing on the requirements from our traceability matrix that have to deal with our trade-off analysis. These are requirements RAM2, PRC2, PRC3, CHD2, and EHD2.

- **RAM2: Primary Storage > 2GB**
  - *Testing RAM2*: test the memory with a computer to make sure it reaches requirement
- **PRC2: Processor Speed > 1.8 GHz**
  - *Testing PRC2*: test the processor's speed with a computer to make sure it reaches req.
- **PRC3: Able to run several processes at once**
  - *Demonstration PRC3*: demonstrate that the processor meets this req. with a computer.
- **CHD2: Storage > 200GB**
  - *Testing CHD2*: Check the storage amount with a computer to make sure it reaches req.
- **EHD2: Storage > 200GB**
  - *Testing EHD2*: Same as Testing CHD2

Design Reqirements	Testing	Analysis	Demonstration	Examination	Verification Require-ments	Level of Application
RAM2	Yes	–	–	–	Testing RAM2	High-Level Requirement 3
PRC2	Yes	–	–	–	Testing PRC2	High-Level Requirement 3
PRC3	–	–	Yes	–	Demonstration PRC3	High-Level Requirement 3
CHD2	Yes	–	–	–	Testing CHD2	High-Level Requirement 3
EHD2	Yes	–	–	–	Testing EHD2	High-Level Requirement 3

Chapter 9

Appendix

9.1 Key Terms and Definitions

- **Cockpit Recorders**: Records vehicle interior conversations, ambient sounds (internal and external), radio communications between base/command center and vehicle, time of each radio message transmission, continuously record cockpit instrumentation, the outside viewing area, engine sounds, radio communications, and ambient cockpit sounds
- **Data Recorder**: Records speed, direction of travel, tilt, distance, throttle position, impact/shock (from impact sensors), operation of horns/headlights, seat belts, air bags, impact acceleration, material degradation, engine performance, control and actuator positions, time of day, geographical position(from GPS and/or beacon), ECU data, OBD-II data, passenger sensors, weaponry system data, tire pressure
- **Data Rotater Software**: A theoretical software that stores data in 1-minute bundles, designated as 'bad' for problematic/malfunctioning/error data and 'good' for non-problematic data. The data rotater deletes the oldest 'good' data if the solid state drive's capacity reaches 70%. In case of an accident, it does not delete data and records until full if there is a main car power loss but enables system to act under Normal Operations (see used case 'normal operations') for 30 minutes and then switches to work as a locater beacon if the main car power is not cut off'
- **Disk Redundancy**: A set of two disks to provide data reliability
- **GPS/Navigation**: Provides location data of the vehicle
- **Impact Sensor Network**: A network of pressure sensors located on the vehicles exterior frame to determine the impact location
- **OBD II**: Vehicles sensor network to provide vehicle's health and status information
- **Power Supply**: Provides power to the backup battery and to the internal components of the Black Box
- **Pressure Sensors**: Provides passenger seating arrangements
- **Quick Access Recorder**: Records fuel flow, cockpit and outside temperatures, fuel tank levels
- **Sensor Subsystem**: The different sensor systems in the vehicle, coming from the vehicle's various electronic control unit modules, is routed to the OBD-II, which we connect our black box system to read off the data.
- **Trusted Platform Module (TPM)**: Data security requiring a dongle when retrieving data with physical access to the Black Box

- **Wireless Link**: Provides a communication link between the vehicle and the Command Center. Allows for secure remote access to the vehicle's Black Box data through the use of a unique identifier.

Bibliography

[1] Class Notes

[2] http://www.bavariantechnic.com/