Smart Grid Integrated Digital License Plate

Capstone Project Report #2

Team Members:

Abdul Bhutta - 100785884

Yussef Elzein - 100641407

Emran Soltani - 100618333

Kumail Syed - 100661596

Walid Ayub - 100695612

Report #2 submitted in partial fulfillment for the final year Capstone Project in the Faculty of Engineering and Applied Science.

Project Advisor: Dr. Tarlochan Sidhu, P.Eng.

Capstone Coordinator: Dr. Vijay K. Sood, P.Eng., ECSE

Submitted to Ontario Tech University

November 8th, 2022

Abstract

In recent years, it has become evident that traditional license plates have many flaws such as security, durability, and functionality. Current license plates have proven time and time again that it is time for an update. The world is quickly going digital as technological advancements are being made every day. License plates have not yet caught up to the times. A smart digital license plate would be a tremendous upgrade moving into this electric and digital world. Current technologies such as displays, communications, and electric vehicles have created a possibility for revolutionary smart digital license plates with features such as theft detection, renewal updates, smart grid integration, and web information access. The following capstone project report is a follow-up of report 1. It includes all the design aspects of the smart grid-integrated digital license plate. It contains all the test cases that will be conducted to ensure the proper function and safety of the product. Furthermore, during the concept generation, we found it feasible to program the digital license plate on a Raspberry Pi. It was also found logical to power the system using a rechargeable power bank. The system will also utilize a GPS module alongside a RFID tag and reader to support anti-theft measures. Moreover, the assembly of the product will be enclosed in a 3D-printed case designed using SolidWorks. Finally, the integration of a website will be included to manage all the features. According to the Gantt chart, the product is currently on track to be fully established by April 2023.

Dedication

We would like to dedicate this report to each of our group members' families who have continuously supported us throughout the university in both moral and material needs. Moreover, we would like to dedicate this report to all our professors, peers, and friends for their consistent encouragement and motivation.

Acknowledgments

We would like to express our gratitude to our supervisor Dr. Tarlochan Sidhu who made this project possible. With his guidance, we were able to get a thorough understanding of the project and how to execute our ideas. His continuous support fed our ambition to take this project above and beyond.

We would also like to acknowledge our capstone coordinator Dr. Vijay Sood. He was able to give us a strong detailed understanding of producing reports and how to have a complete presentation on our project.

Our sincere appreciation to Dr. Sheldon Williamson for offering his knowledge and guidance with this project. In our first meeting, he provided us with many ideas on smart grid technology and possible recommendations on how to implement them.

Lastly, we would like to thank our friends and family for their continued support, especially Siear Lutfi for attending one of our meetings and encouraging us throughout.

We will be forever grateful for this capstone project as it has not only challenged us but helped us understand the process of designing, testing, building, and implementing a product from start to finish.

Table of Contents

List of Figures

List of Tables

List of Acronyms Used

Acronym	Meaning
3D	Three Dimensional
BMS	Battery Management System
BMS	Battery Management System
CVV	Card Verification Value
EV	Electric Vehicle
GB	Gigabyte
GPS	Global Positioning System
HDMI	High-Definition Multimedia Interface
HTTP	Hypertext Transfer Protocol
ID	Identification
IESO	Independent Electricity System Operator
IP	Internet Protocol
IT	Integration Test
kWh	Kilowatt-hour
LTE	Long-Term Evolution
MW	Megawatt
RFID	Radio-Frequency Identification
SD	Secure Digital
TCP	Transmission Control Protocol
USB	Universal Serial Bus
USB-A	Universal Serial Bus Type A
USB-C	Universal Serial Bus Type C
Wi-Fi	Wireless Fidelity

1 Introduction

This capstone project aims to create a smart digital license plate that will present an innovative design for displaying all the requirements needed for a traditional license plate on a digital screen with the integration of smart grid and various other improvements. Given current technological advancements, it is highly possible to add features that allow clients to be kept updated on all current information and alerts such as theft, battery life, plate renewal, etc., all while being visually appealing. The digital license plate will be used to display the characters needed for a legal license plate, clearly for any law enforcement to read and customize in any way of the owner's choosing. A website is available for all the services a user might need, such as fulfilling the requirements to renew a vehicle owner's license plate, tracking where the license plate is and whether it has been removed/stolen.

This report will include a concept analysis to show the required key components for our prototype and some viable options we can eliminate. A system design will be provided to clearly outline the software aspect of the project, with diagrams explaining how everything will operate and coordinate for the system to run. Furthermore, visuals for a website example, using a wireframe, will show how the actual website will look and specify how a user can navigate around the services. An electrical design will give a visual representation of how the license plate circuit will operate and the connections it has with every component, along with other circuit diagrams of how the plate features will work. Multiple integration testing will be done to explain where the software aspects can be logically integrated and tested. The test will describe the scenario, and procedures being taken, alongside the expected result. A cost breakdown will also be provided with information on all parts.

Problem Statement

Many advancements have been made in technology and there is no reason for vehicles today not to be equipped with smart license plates. The current license plates endure issues such as peeling, theft, and readability. Moreover, the province of Ontario had recently updated its plates to blue ones with a new slogan. The goal was to refresh the plates and solve the peeling issue but, instead, it made matters worse as law authorities found it difficult to see the plates at night as they were not reflective. These new plates cost the province about 1 million dollars and shortly after were discontinued [1]. Introducing a smart digital license plate would automatically eliminate all the problems with the current license plates. Furthermore, designing, integrating, and implementing digital license plates would not only save the province issues like legibility at night, but also create cost-effective solutions for plate updates in the future.

Overview of the Report

The remaining portion of this report is structured as follows. Section 2 is the concept generation & analysis, where it explains how and why the specific parts were chosen. Section 3 includes design schematics for both the website and the digital license plate. Section 4 includes all the integration testing that will take place to ensure the proper function of the license plate. Section 5 reports our budget and the amount spent. Lastly, section 6 explains the project plan and section 7 explains our contribution to this report.

2 Concept Generation & Analysis

2.1 Initial Concept Generation

In order to have an efficient and functional smart grid integrated license plate, our product will require many key components. The main components we will need to have include: a controller, a power source for the plate, a digital display screen, a security method, a user interface, and a method for GPS tracking. In **Table 1.0** below, we list our top picks for each of the main components.

Table 1.0: Prototype Main Component Options

Controller	Plate Power Source	Display Screen	Security	User Interface	GPS
Raspberry Pi 3 Model B+ (1GB Only)	Rechargeable Li-Battery Pack	Portable Monitor from Amazon	Pressure Switch	Website	Apple AirTag
Raspberry Pi 4 Model B (2GB)	Rechargeable Power Bank	Portable Monitor from a Chinese Manufacturer	RFID RC522	Mobile Application	Location Services
Raspberry Pi 4 Model B (4GB)	Connection to Vehicle's 12V Battery	Laptop Screen Replacement			GT-U7 GPS Module
LattePanda 2G/32GB	Solar Rechargeable Power Bank				

After reviewing the list of options for our prototype's main components, we eliminated several options due to the cost or their complexity of integration. For the controller, we have chosen to proceed with a Raspberry Pi 4 Model B for our controller as it would have ample processing power for our prototype. The LattePanda was also a reasonable option, but we decided not to select it as we are not very familiar with it and are more comfortable with the Raspberry Pi. For the plate's power source, we quickly eliminated the option of having a direct connection to the vehicle's 12V battery. This is because it would rapidly discharge the battery causing it to fail when the vehicle is not in motion. For the display screen, we discarded the laptop screen option due to the difficulty of connection. We decided to either go with the portable monitor from Amazon or from a Chinese Manufacturer. The Amazon screen is higher quality than the China sourced screen however, it is comparatively expensive. Moreover, upon deciding the user interface, we chose to create a website and if time permits, a mobile application as well for the user. Finally, we abandoned the idea of using an Apple AirTag as it is costly and would require us to send the user to a 3rd party app for GPS tracking making it difficult to integrate.

2.2 Model Creation

The following table shows 4 different models that we have created which we will analytically compare in order to determine which model is best suited for our project. Each model contains a different combination of options for the main components.

Table 2.0: Model Alternatives

Concept Model	Controller	Power Type	Display Screen	User Interface	Security	GPS
Model 1	Raspberry Pi 4 Model B (2GB)	Solar Rechargeable Power Bank	Portable Monitor from Amazon	Website	Pressure Switch	Location Services
Model 2	Raspberry Pi 4 Model B (2GB)	Rechargeable Power Bank	Portable Monitor from a Chinese Manufacturer	Website	RFID RC522	GT-U7 GPS Module
Model 3	Raspberry Pi 4 Model B (4GB)	Rechargeable Li-Battery Pack	Portable Monitor from a Chinese Manufacturer	Website	Pressure Switch	GT-U7 GPS Module
Model 4	Raspberry Pi 4 Model B (4GB)	Rechargeable Power Bank	Portable Monitor from Amazon	Website	RFID RC522	Location Services

2.3 Model Analysis

This section contains tables where all 4 models are compared in regards to their complexity, cost, as well as strengths and weaknesses. These comparisons will prove useful in the model decision making process.

Table 2.1: Complexity Comparison

Concept Model	Software Complexity Level 0 (Simple) to 100 (Complex)	Electrical Complexity Level 0 (Simple) to 100 (Complex)
Model 1	30	50
Model 2	40	20
Model 3	35	40
Model 4	35	35

Table 2.2: Estimated Cost of Models

Concept Model	Estimated Cost of Parts	Total Estimated Cost
Model 1	Raspberry Pi 4 Model B Starter Kit (2GB) – $192 Solar Rechargeable Power Bank – $70 Portable Monitor (Amazon) – $382 Pressure Switch – $14 Location Services – $0 Various Small Parts/Cables – $40	$698
Model 2	Raspberry Pi 4 Model B Starter Kit (2GB) – $192 Rechargeable Power Bank – $44 Portable Monitor (Chinese Manufacturer) – $191 RFID RC522– $16 GT-U7 GPS Module – $29 Various Small Parts/Cables – $40	$512
Model 3	Raspberry Pi 4 Model B (4GB) – $271 Rechargeable Li-Battery Pack – $232 Portable Monitor (Chinese Manufacturer) – $191 Pressure Switch – $14 GT-U7 GPS Module – $18 Various Small Parts/Cables – $60	$786
Model 4	Raspberry Pi 4 Model B (4GB) – $271 Rechargeable Power Bank – $44 Portable Monitor (Amazon) – $382 RFID RC522 – $16 Location Services – $0 Various Small Parts/Cables – $60	$773

[the remainder of this page has been intentionally left blank]

Table 2.3: Model Strength & Weakness Comparison

Concept Model	Strengths	Weaknesses
Model 1	• Self-rechargeable with sunlight • Easy to implement security features • No cost associated to GPS • Easily replaceable power bank	• Difficult to implement solar power bank • High cost • Low theft security • Easy to trick security pressure switch • Lower computing power
Model 2	• Very cost-effective • Least complex to design • Minimal points of failure • High security with RFID • Accurate GPS location • Easily replaceable power bank	• Lower computing power • Connection to vehicle's electrical required
Model 3	• Easy to implement security Feature • Accurate GPS location • Higher computing power	• Very high cost • Low theft security • Easy to trick security pressure switch • Li-Battery is very large • Connection to vehicle's electrical required
Model 4	• High security with RFID • Accurate GPS location • Higher computing power • Easily replaceable power bank	• Very high cost • Connection to vehicle's electrical required

[the remainder of this page has been intentionally left blank]

2.4 Model Ranking

2.4.1 Pairwise Comparison Matrix

In order to decide on which model is the best for our project, we must analyze them analytically based on predetermined selection criteria. For the purposes of our project, we have chosen 4 unique criteria for selection: Simplicity, Cost, Size, and Security. **Table 2.4** compares the selection criteria and computes their individual weights for the decision-making process. Assume that the scale ranges from 1 to 7 where 1 means both criteria are of equal importance up to 7 where the first criterion is extremely more important.

Table 2.4: Pairwise Comparison Matrix

	Simplicity	Cost	Size	Security	Total	Weight
Simplicity	1	3	5	1/3	9.33	0.315
Cost	1/3	1	3	1/5	4.53	0.153
Size	1/5	1/3	1	1/5	1.73	0.059
Security	3	5	5	1	14	0.473
Total:					**29.59**	**1**

2.4.2 Selection Criteria Per Model Weighting

In the following tables, we will be calculating our selection criteria's normalized weighting in order to be able to eventually score each model to determine the best model for our established needs and criteria.

Table 2.5: Simplicity Weighting Calculation Table

	Model 1	Model 2	Model 3	Model 4
Simplicity Score	80	60	75	70
Total	80 + 60 + 75 + 70 = 285			
Normalizing	80/285	60/285	75/285	70/285
Normalized Weighting	**0.281**	**0.210**	**0.263**	**0.246**

Table 2.6: Cost Weighting Calculation Table

	Model 1	Model 2	Model 3	Model 4
Estimated Cost ($)	698	512	786	773
Lowest Cost to Model Ratio	512/698= 0.734	512/512 = 1	512/786 = 0.651	512/773 = 0.662
Total	0.734 + 1 + 0.651 + 0.662 = 3.047			
Normalizing	0.734/3.047	1/3.047	0.651/3.047	0.662/3.047
Normalized Weighting	**0.241**	**0.328**	**0.214**	**0.217**

Table 2.7: Size Weighting Calculation Table

	Model 1	Model 2	Model 3	Model 4
Estimated Casing Size for All Parts (cm^3)	2520	2520	4410	2520
Ratio to Lowest Size	1	1	2520/4410 = 0.571	1
Total	1 + 1 + 0.571 + 1 = 3.571			
Normalizing	1/3.571	1/3.571	0.571/3.571	1/3.571
Normalized Weighting	**0.280**	**0.280**	**0.160**	**0.280**

In order to calculate the weighting for security, we came up with the original security score by rating the efficiency for each of the security components from 0 to 100. We then continued by adding the total up for each model. The first model has a pressure switch which we rated at 25 and uses location services for GPS tracking which we rated at 50. Therefore, the total for Model 1 equates to 75. Model 2 uses an RFID reader which we rated at 90 along with a GT-U7 GPS module which we rated at 80. This makes Model 2's security score equal to 170. Model 3 contains a pressure switch rated at 25 and a GPS module rated at 80 adding to a total of 105. Model 4 contains a RFID reader (90) and uses location services (50) totalling to a score of 140. These scores can be seen in **Table 2.8** below.

Table 2.8: Security Weighting Calculation Table

	Model 1	Model 2	Model 3	Model 4
Security Score	75	170	105	140
Total	75 + 170 + 105 + 140 = 490			
Normalizing	75/490	170/490	105/490	140/490
Normalized Weighting	**0.153**	**0.347**	**0.214**	**0.286**

[the remainder of this page has been intentionally left blank]

2.4.2 Decision Matrix

The model decision matrix in **Table 2.9** above suggest that Model 2 would be the optimal design for our prototype as it aligns best with our selected criteria.

Table 2.9: Model Decision Matrix

		Model 1	Model 2	Model 3	Model 4
Simplicity	0.315	0.281	0.210	0.263	0.246
Cost	0.153	0.241	0.328	0.214	0.217
Size	0.059	0.280	0.280	0.160	0.280
Security	0.473	0.153	0.347	0.214	0.286
Score		**0.214**	**0.297**	**0.226**	**0.262**

For the purposes of our project, we have thus decided to use Model 2 for the initial design of our product. The subsequent sections in this report will be completed using the components outlined in the Model 2 concept in **Table 2.0**.

[the remainder of this page has been intentionally left blank]

3 Conceptual System Design

The following section will include designs for Model 2 that was chosen in section 2 of this report.

3.1 Software Design

3.1.1 Deployment Diagram

The diagram below represents a deployment diagram for the embedded system, which shows a high-level abstraction of the interaction and links among the physical components at run-time. A solid line within the system indicates an association relationship, and a dotted line represents a dependency. The RFID tag is dependent on the reader to authorize access to the microcontroller, and the microcontroller is dependent on the RFID reader to allow access and fetch the licence plate number from the database. Please note in the diagram that cloud service will have its physical infrastructure somewhere in the world, but the system acts as one rather than individual components through transparency. Each physical module contains an artifact or a component. An artifact is displayed by the following syntax <<Artifact>> and described by the product or information generated from the software. A component is shown by two rectangular tabs and represents a software element.

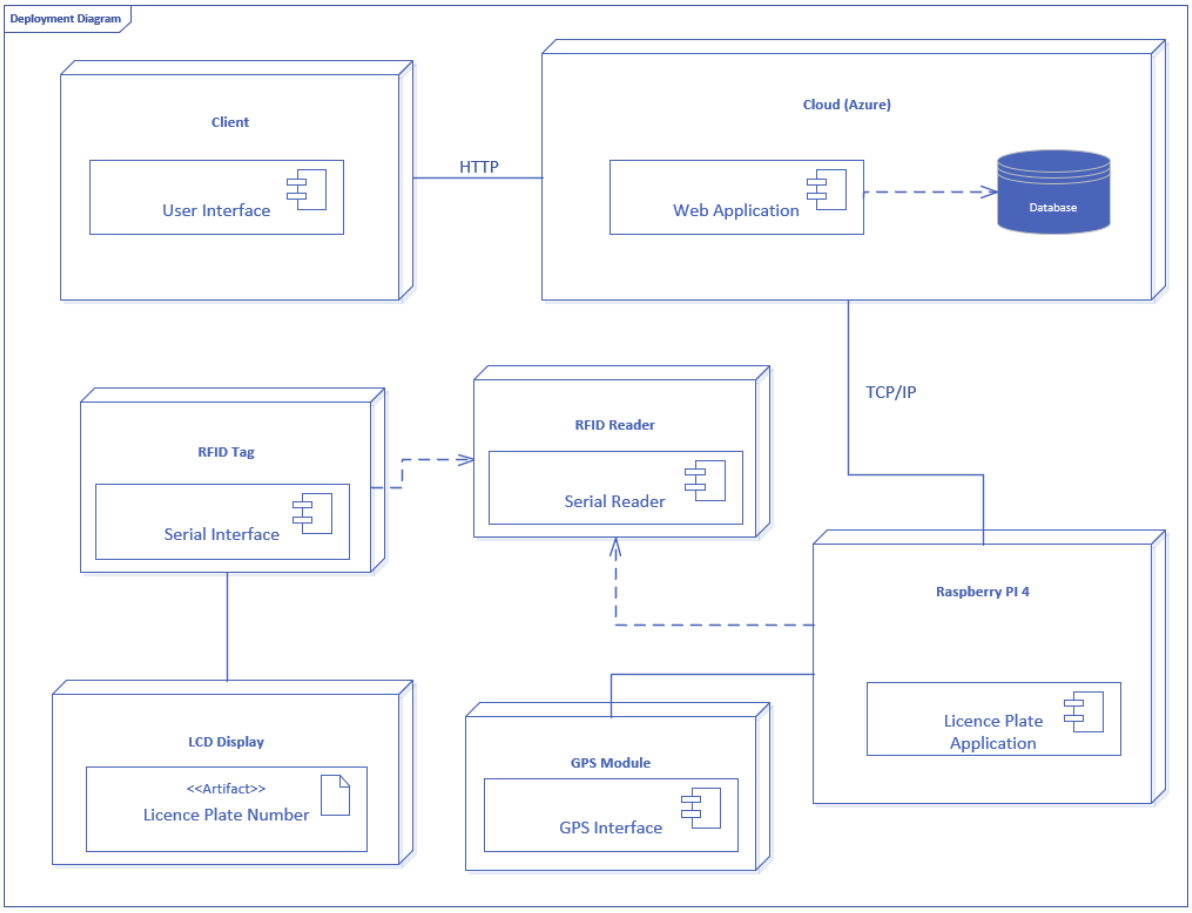


Figure 1: Deployment Diagram

3.1.2 Functional Decomposition Conceptual Model

The diagram below shows a conceptual model of the functional decomposition for our smart license plate application. This model's outline will be followed when designing the application.

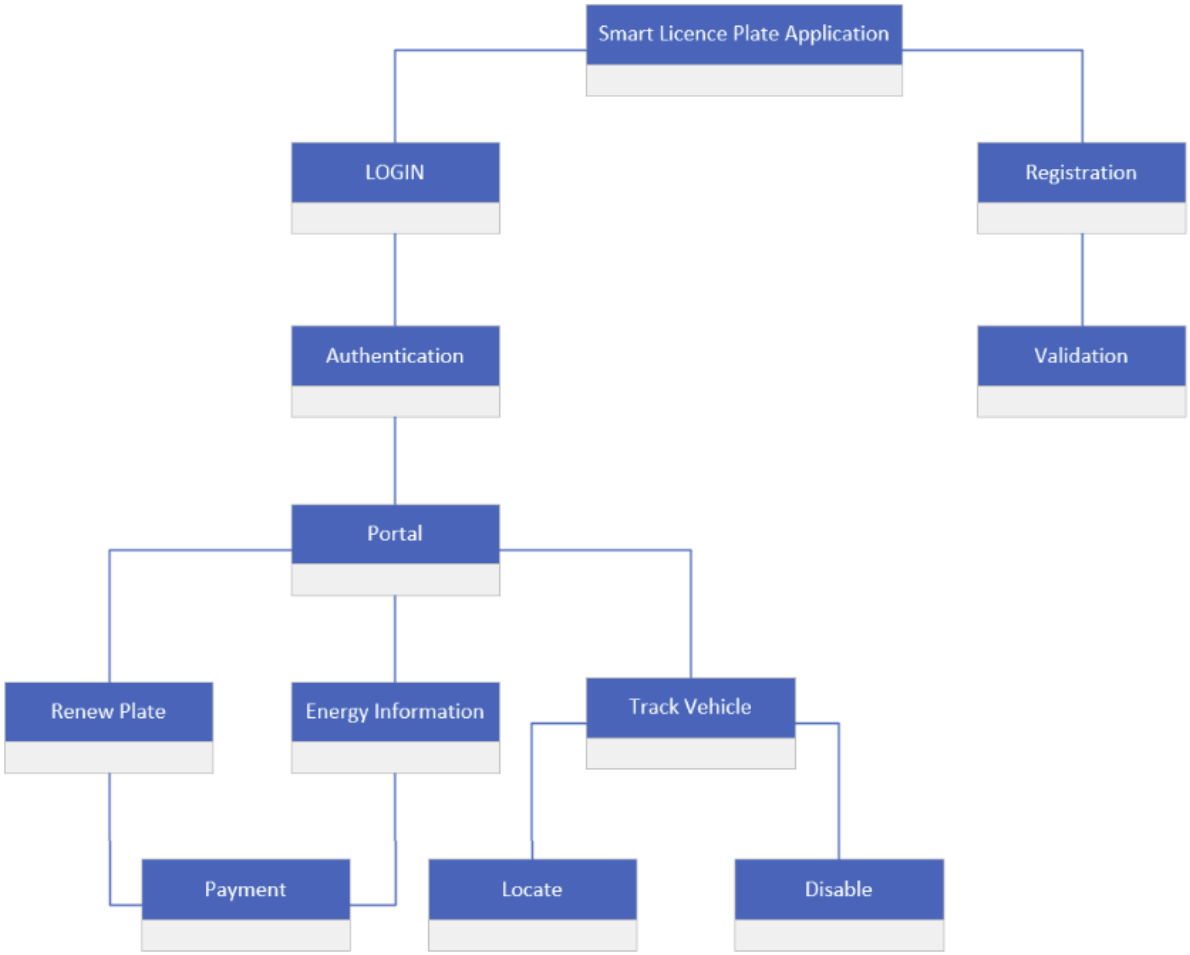


Figure 2: Functional Decomposition of Software System

[the remainder of this page has been intentionally left blank]

3.1.3 Architecture (3-Tier)

The diagram below shows our system's 3-Tier architecture.

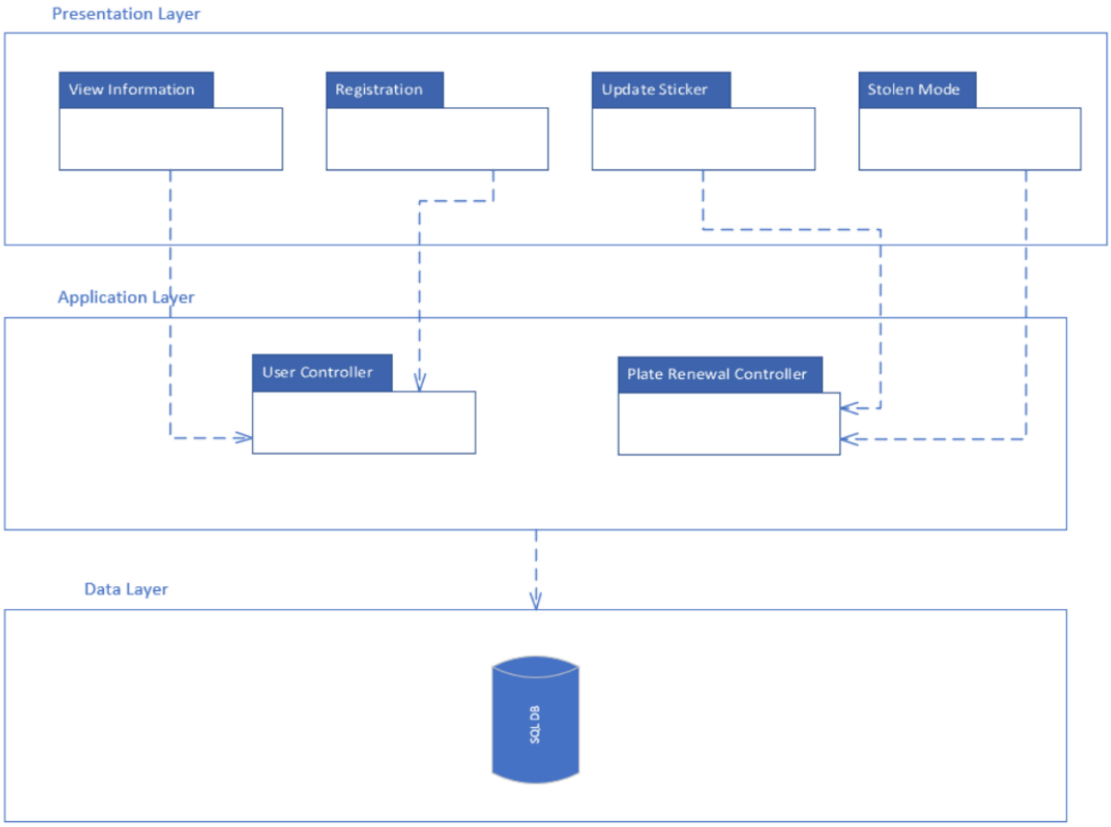


Figure 3: 3-Tier Architecture Diagram

[the remainder of this page has been intentionally left blank]

3.1.4 Website Wireframe

In this section, we will show the basic wireframes for each of the fundamental pages on our website.

3.1.4.1 User Portal

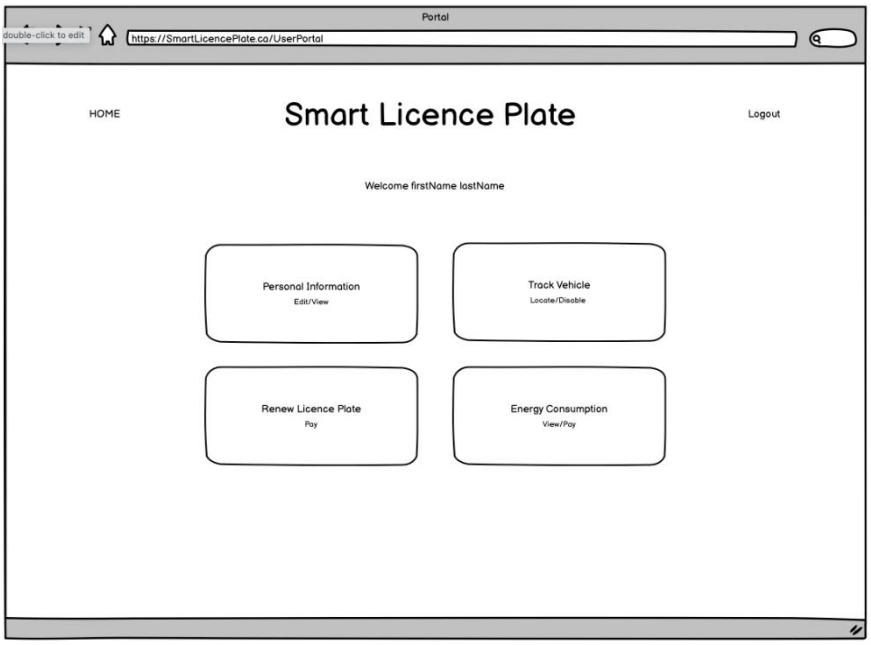


Figure 4: User Portal Wireframe

3.1.4.2 Registration Page

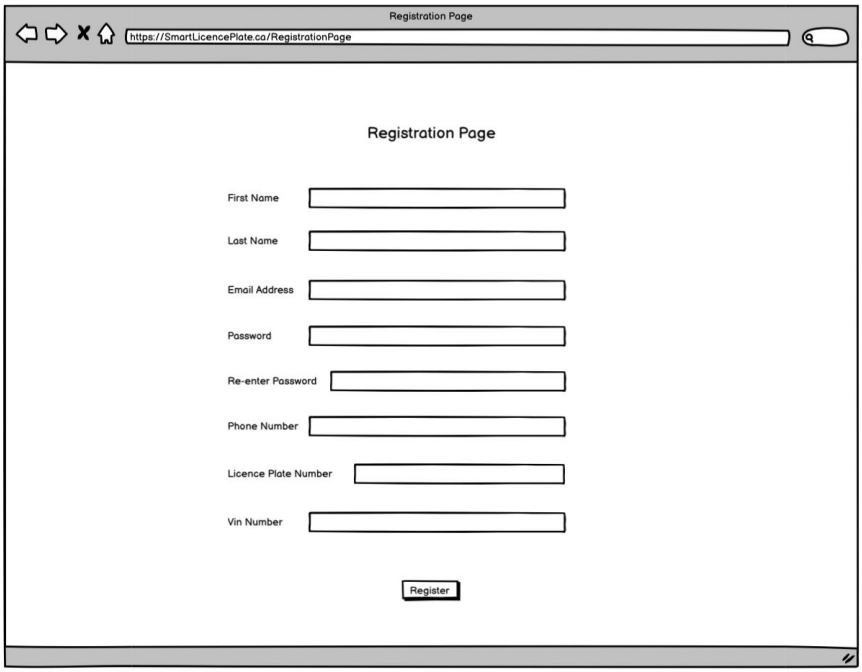


Figure 5: Registration Page Wireframe

3.1.4.3 Login Page

Figure 6: Login Page Wireframe

3.1.4.4 Tracking Page

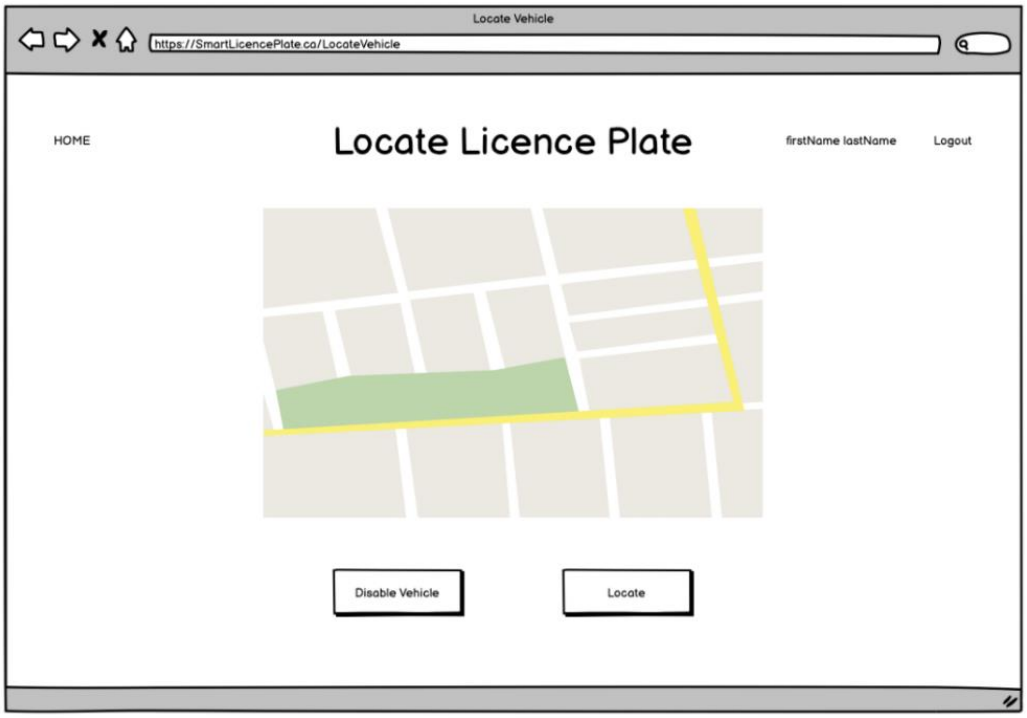


Figure 7: Location Page Wireframe

3.1.4.5 Renewal Page

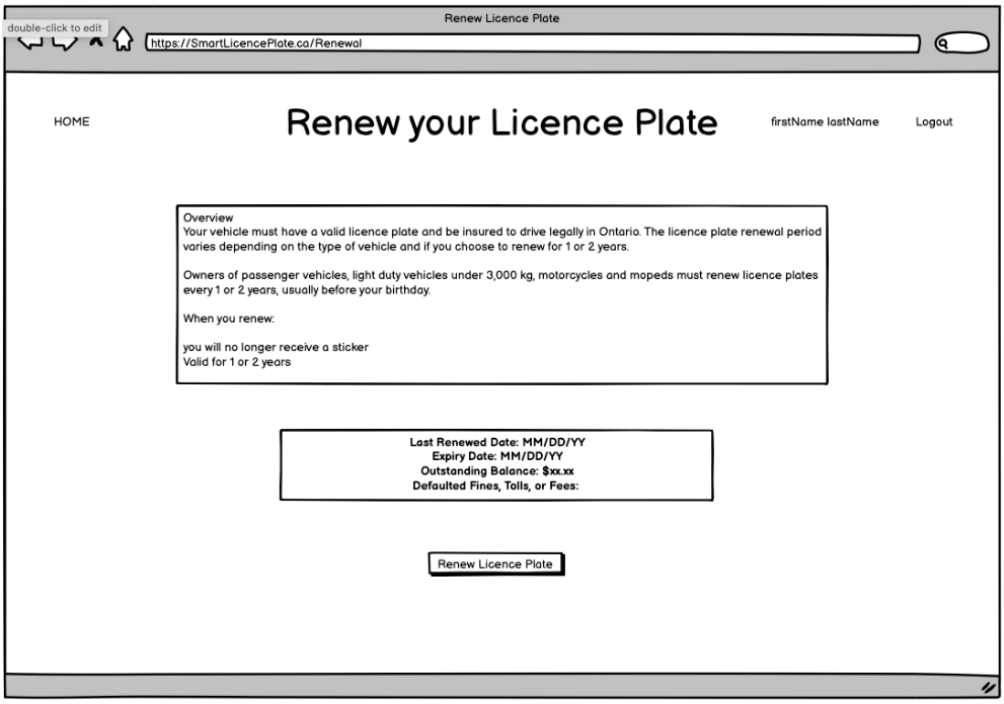


Figure 8: Renewal Page Wireframe

3.1.4.6 Energy Consumption Page

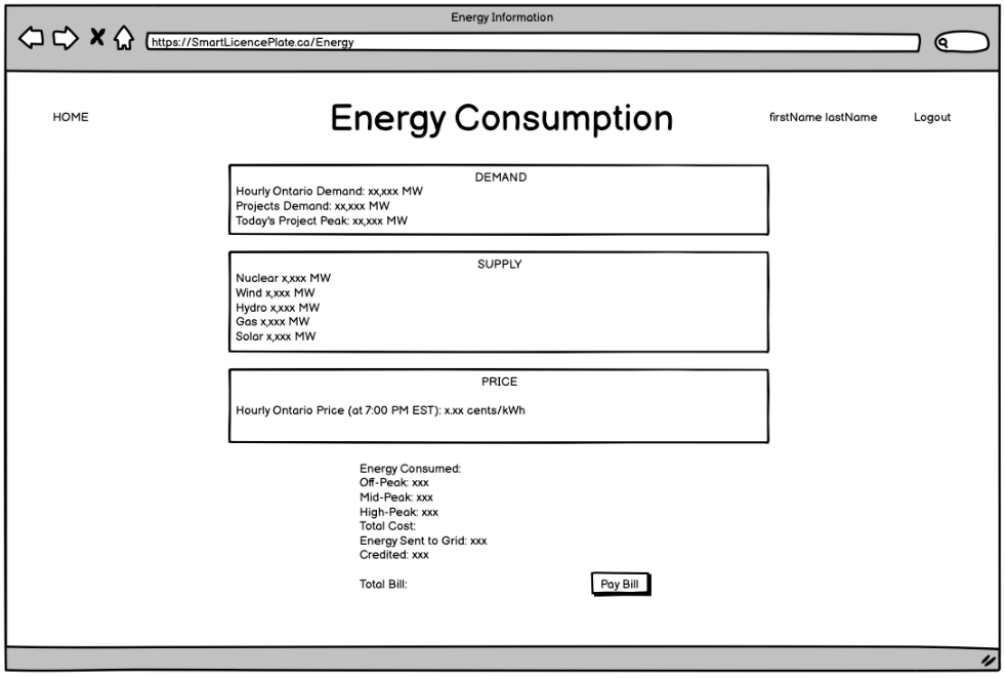


Figure 9: Energy Consumption Wireframe

3.1.4.7 Payment Page

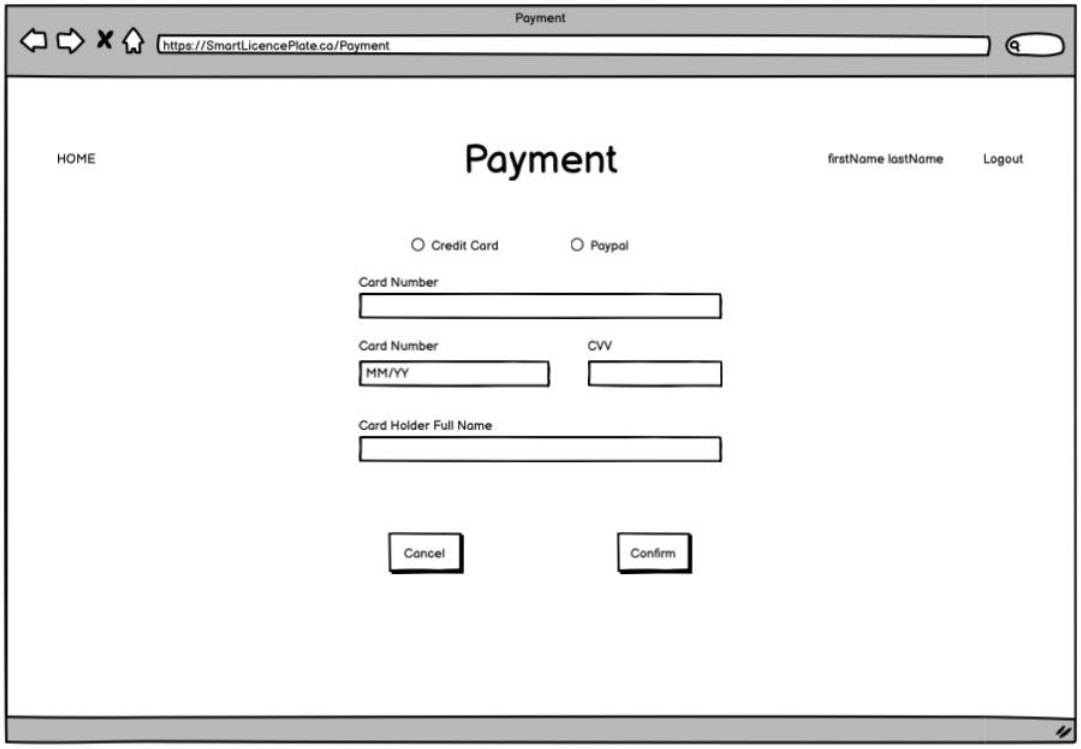


Figure 10: Payment Page Wireframe

[the remainder of this page has been intentionally left blank]

3.2 Electrical Design

3.2.1 Plate Display Connection Diagram

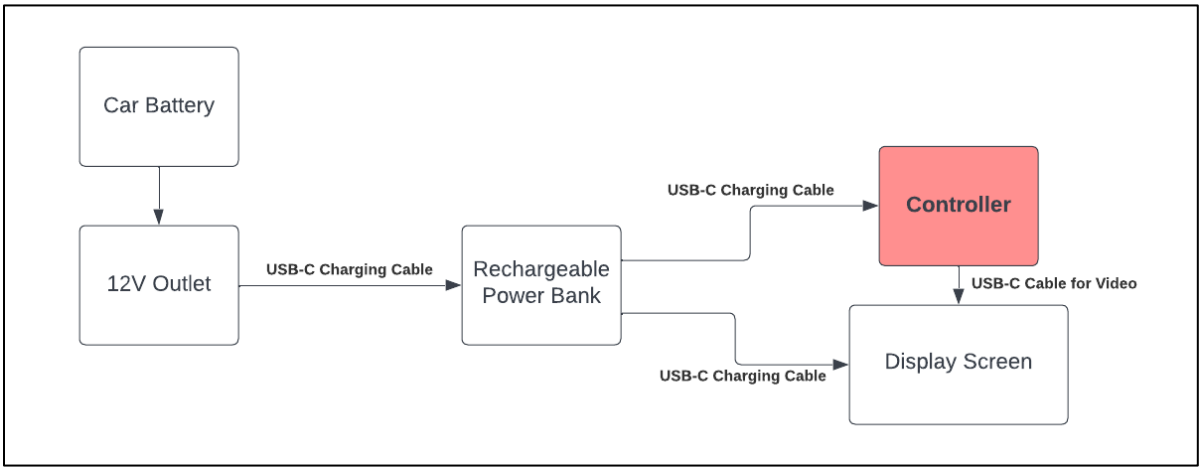


Figure 11: Plate Display Connection Diagram

Figure 11 shows a diagram of the connections for our plate's display. The car battery will be plugged into the 12V power outlet which gives power to the rechargeable power bank using the USB-C charging cable. This provides a connection to the controller (Raspberry Pi) as well as the display screen for the output.

3.2.2 Security Connection Diagram

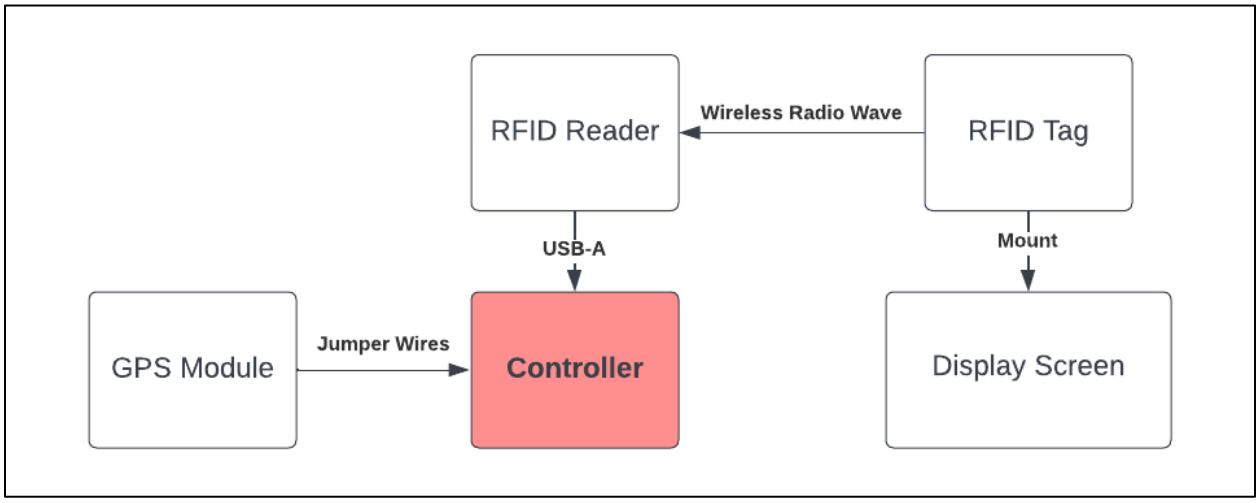


Figure 12: Security Connection Diagram

Figure 12 displays a basic connection diagram for the security components in our circuit. An RFID tag attached to the backside of our display screen will wirelessly send a signal to the RFID reader via wireless radio wave. When the display screen is removed, the controller will be notified which will prompt an alert to the user that the plate has been dismounted from the backplate. The GT-U7 GPS module is also connected directly to the Raspberry Pi controller via jumper wires.

3.2.3 EV Diagram

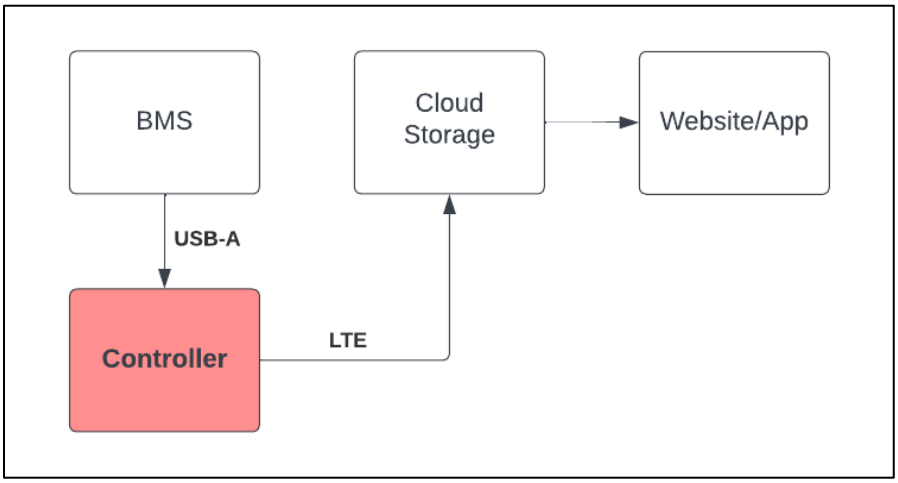


Figure 13: EV Connection Diagram

Figure 13 demonstrates the smart grid electrical setup for electric vehicles. The EV's battery management system, or BMS for short, is connected to the controller through a USB-A input. The BMS will provide real-time battery data and pass it to the controller. The controller will then communicate the data to our cloud storage system using an LTE connection and ergo to our website. The website will be available to users who want to check their vehicle's electrical consumption data along with its battery health and state information. Note that this circuit can only be implemented into EV vehicles.

3.2.4 Complete Electrical Connection Diagram

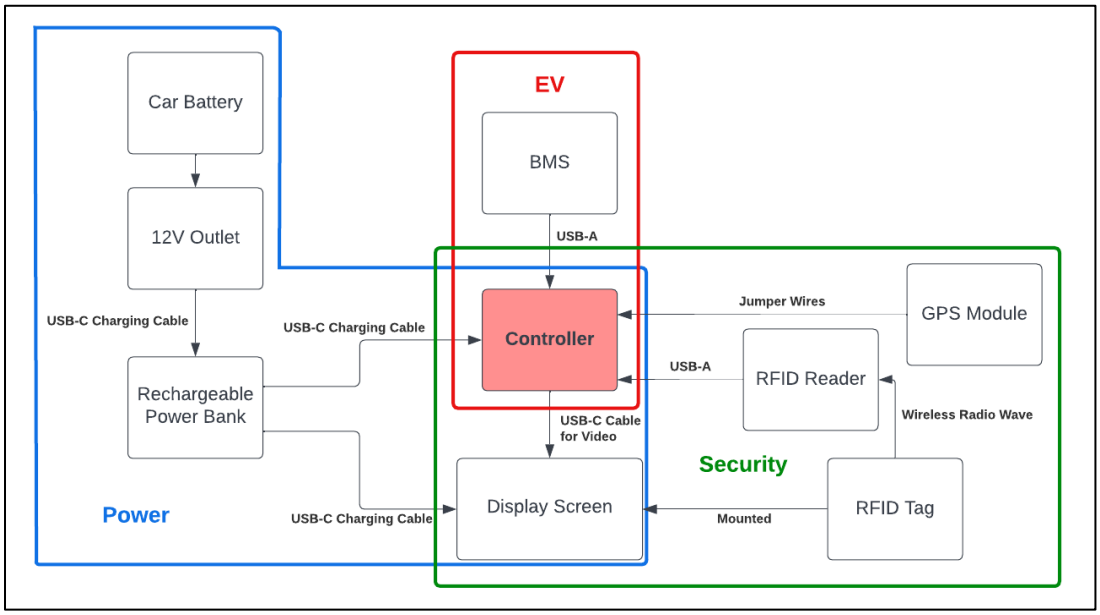


Figure 14: Complete Electrical Diagram

Figure 14 represents the complete electrical connection diagram. There are three major components presented in the diagram: Power (blue), Security (green) and EV (red).

3.3 Functional Decompositions

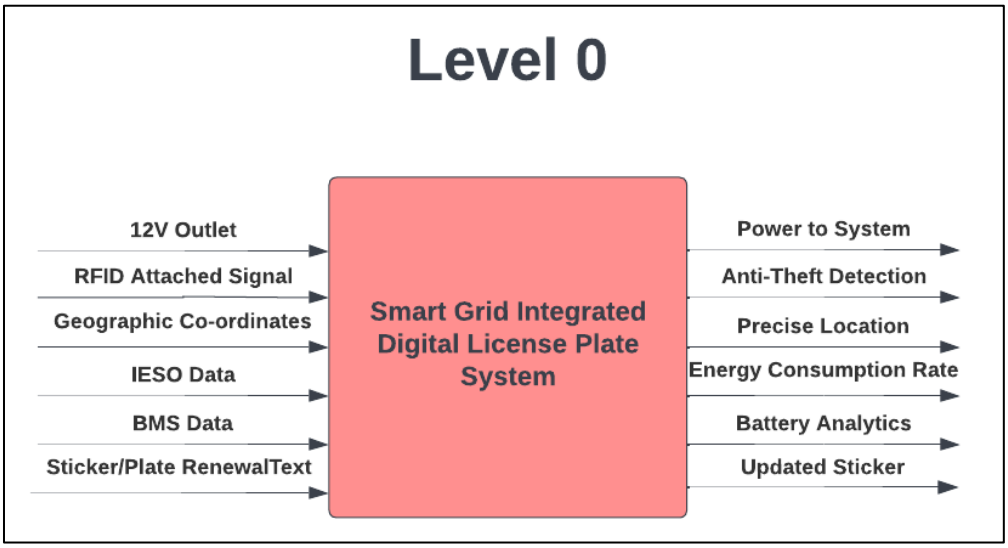


Figure 15: Level 0 Functional Decomposition

Table 3.0: Functional Decomposition for Level 0 System

Module	**Smart Grid Integrated Digital License Plate**
Inputs	**12V Outlet –** Power source for providing energy to the controller and plate. **RFID Attach Signal –** The plate would receive a signal from the RFID Reader to indicate whether the plate (display) is attached to the vehicle or not. **Geographical Co-ordinates –** The controller will use a GPS module for location services. **IESO Data –** Data from this website will help determine electricity costs and current conditions. **BMS Data –** The BMS will help provide real time EV battery analytics. **Sticker/Plate Renewal -** The user through the website will pay any renewal fees.
Outputs	**Power to System –** The power would allow the controller and the system to turn on and function. **Anti-Theft Detection –** The user would be notified immediately of a possible plate theft or removal. **Precise Location –** The precise location will be displayed on the website when requested. **Energy Consumption Rate –** The user would be able to see the peak electricity hours and costs as well as the demand and supply data. **Battery Analytics –** The user would benefit from this feature and keep a track of their battery health, range, and state. **Updated Sticker –** After the payment has been the sticker will be updated.
Functionality	The Smart Grid Integrated Digital License Plate will utilize specific parts to output a futuristic digital license plate.

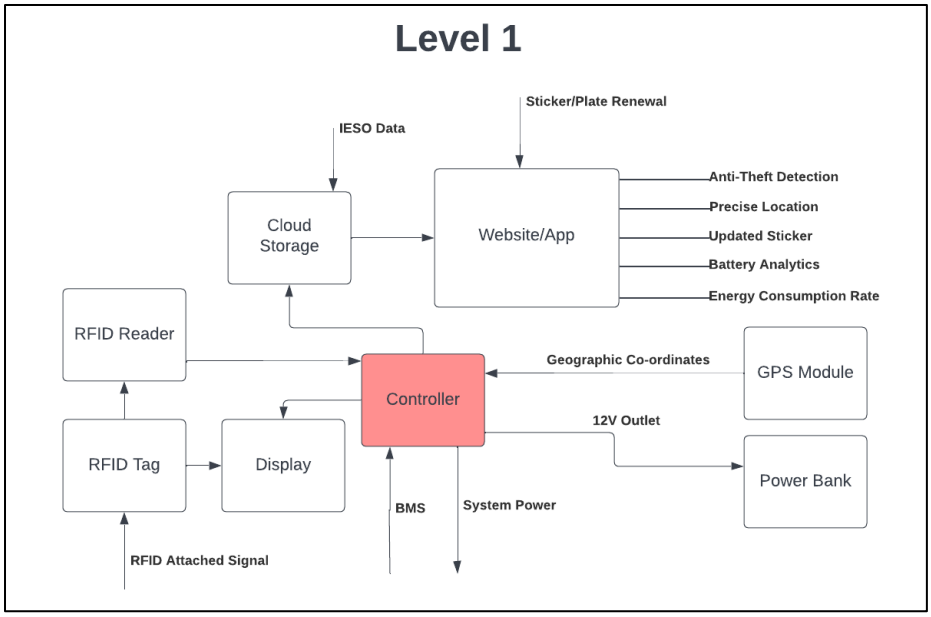


Figure 16: Level 1 Functional Decomposition

Table 3.1: Functional Decomposition for Level 1 System

Module	**Total Decomposition of License Plate**
Inputs	**12V outlet –** The 12V outlet is connected to the rechargeable power bank which powers the whole system through the controller (Raspberry Pi). **RFID Attached Signal –** The RFID reader is connected to the controller and is in communication with the RFID tag. **IESO Data –** The data is pulled from the IESO website and stored in the cloud storage. The data is then displayed on the website for the user. **Geographic Co-ordinates –** The geographic co-ordinates will be acquired through a GPS module. The information will be sent to the cloud through the controller. **Sticker/Plate Renewal –** The user will make their plate/sticker renewal fee through the website. **BMS –** The battery information will be drawn from the EV's BMS.
Outputs	**Power to System** – The power connected to the controller (Raspberry Pi) provides power to the whole system. **Anti-Theft Detection** – The user would be notified immediately of a possible plate theft or removal. **Precise Location** – The license plate will be continuously tracked using the GPS module. **Energy Consumption Rate** - The user would be able to see the peak electricity hours and costs as well as the demand and supply data. **Battery Analytics** – The user would benefit from this feature and keep track of their battery health, range, and state. **Updated Sticker –** The sticker will be updated and displayed on the screen.
Functionality	This level 1 function decomposition reveals all the parts that support the features.

3.3.1 Level 1 Functional Decomposition Module Descriptions

Table 3.2: Module Description for Raspberry Pi Controller

Module	**Controller (Raspberry Pi)**
Inputs	Power, BMS, RFID Reader, GPS Module
Outputs	Display, Power to GPS Module, Power to RFID Reader
Functionality	The Raspberry Pi will be powered by a rechargeable power bank which would be connected to the Battery Management System and RFID Reader to provide battery information and security. It will also have a GPS module attached to provide location services.

Table 3.3: Module Description for Rechargeable Power Bank

Module	**Rechargeable Power Bank**
Inputs	Power
Outputs	Power to Controller, Power to Display
Functionality	The rechargeable power bank will be connected to a 12V outlet. This will allow the power bank to recharge when the vehicle is in motion. Furthermore, utilizing this method will allow for an efficient recharge all while efficiently providing power to the controller and display screen.

Table 3.4: Module Description for Display Screen

Module	**Display Screen**
Inputs	Video, Power
Outputs	License Plate Display
Functionality	The display screen will be powered directly from the power bank and receive a video signal from the controller (Raspberry Pi). The RFID tag will be mounted on the display screen to security measures.

Table 3.5: Module Description for RFID Reader

Module	**RFID Reader**
Inputs	Unique Digital ID (Wireless Radio Frequency)
Outputs	Pass Signal to Controller (Raspberry Pi)
Functionality	The RFID reader would communicate with the controller via a USB A cable to notify the user of the status of the license plate for anti-theft detection purposes.

Table 3.6: Module Description for BMS

Module	**BMS**
Inputs	EV Battery System
Outputs	Power Consumption and Battery State
Functionality	The BMS system would connect to the controller (Raspberry Pi) and retrieve all necessary data to display battery analytics.

Table 3.7: Module Description for RFID Tag

Module	**RFID Tag**
Inputs	None
Outputs	Unique Digital ID (Wireless Radio Frequency)
Functionality	If the license plate is stolen, the RFID tag will send a radio frequency signal to the RFID reader which would then notify the user of a stolen license plate.

Table 3.8: Module Description for GT-U7 GPS Module

Module	**GPS Module**
Inputs	Satellite Location
Outputs	Precision Location
Functionality	The GPS module will obtain precise geographical co-ordinates via satellite. The co-ordinates will then be transferred to the data base (cloud storage) via the controller, allowing the user to view the exact location when requested.

3.4 Casing Design

The license plate will have a casing to enclose all parts for a clean and complete look. The case will eventually be designed using SolidWorks and then printed using a 3D printer. Currently, the design for the case cannot proceed as parts of the plate are not completely assembled. Once all parts are received and assembled, we will take measurements and design a backplate that will fit all our smart license plates elements in a single casing. All components including the Raspberry Pi, power bank, and other main parts should be condensed and have a spot to be securely mounted in our backplate. The goal is to have the most thin and sleek backplate possible for the plate (display screen) to be mounted onto. The **Figure 17** below shows a rough idea of the look of our backplate.

A full 3D model and breakdown of the casing measurements will be included in a future report.

Figure 17: License Plate Back Plate Concept [2]

[the remainder of this page has been intentionally left blank]

4 Integration Tests

4.1 List of Integration Tests

Below, **Table 4.0** lists the integration test cases that will be described in the next section.

Table 4.0: List of Integration Tests

Integration Test Case Name	Test ID	Description
IT #1	Plate-IT-01	Test the interface link between the login and the portal module
IT #2	Plate-IT-02	Test the interaction between the RFID tag and Raspberry Pi 4
IT #3	Plate-IT-03	Test interaction between LCD display and Raspberry Pi 4
IT #4	Plate-IT-04	Test the interaction between the LCD display and renewal module.
IT #5	Plate-IT-05	Test the interaction between Raspberry PI and power bank.
IT #6	Plate-IT-06	Test the interaction between energy consumed and payment module.

[the remainder of this page has been intentionally left blank]

4.2 Definition of Integration Tests

Table 4.1: Integration Test Case #1

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #1	**Test ID:**	Plate-IT-01
Description:	Test the interface link between the login and the portal module	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:	The user accessing the login page must be within the database.		

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Enter Login Information	No error messages should be displayed				
2	Click on login button	Redirected to the portal page				
3						
4						
Test Result:						

Table 4.2: Integration Test Case #2

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #2	**Test ID:**	Plate-IT-02
Description:	Test the interaction between the RFID tag and Raspberry Pi 4	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:	The Raspberry Pi 4 must have the RFID unique ID authorized within the microcontroller. The RFID reader must be installed and running on the Raspberry Pi.		

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect the LCD onto the case	The RFID reader should validate the RFID tag.				
2	Remove the LCD from the case	The RFID reader should disable the microcontroller and will enter sleep mode				
3						
4						
Test Result:						

Table 4.3: Integration Test Case #3

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #3	**Test ID:**	Plate-IT-03
Description:	Test interaction between LCD display and Raspberry Pi 4	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:	The Raspberry Pi 4 must have the RFID unique ID authorized within the microcontroller. The RFID reader must be installed and running on the Raspberry Pi.		

Step	Action	Expected Results	Pass	Fail	N/A	Comments
1	Remove LCD from the case	Raspberry Pi should enter sleep mode				
2	Connect LCD on the case	Raspberry Pi should turn on and validate LCD display				
3	Verify output on the LCD	The LCD will display the linked plate number				
4						
Test Result:						

Table 4.4: Integration Test Case #4

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #4	**Test ID:**	Plate-IT-04
Description:	Test the interaction between the LCD display and renewal module.	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:	The Raspberry Pi must be running the application and the RFID unique ID should be authorized to access the microcontroller. The Raspberry Pi must be connected to a reliable Wi-Fi network.		

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Login as “user”	The webpage will display the personal portal				
2	Access renewal plate	The webpage will be updated to the renewal page while allowing the user to pay the fee				
3	Pay the amount	A confirmation update will appear				
4	Verify updated sticker	The expiry date on the sticker will be updated				
Test Result:						

Table 4.5: Integration Test Case #5

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #5	**Test ID:**	Plate-IT-05
Description:	Test the interaction between Raspberry Pi and power bank.	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:			

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Connect the Raspberry PI to the power bank	The Raspberry Pi should be powered on.				
2	Remove source power	No change on the Raspberry Pi and power bank.				
3	Verify battery usage	The Raspberry Pi should stay powered on for 72-96 hours.				
4						
Test Result:						

Table 4.6: Integration Test Case #6

Test Writer(s):	Abdul Bhutta, Emran Soltani, Kumail Syed, Walid Ayub, Yussef Elzein		
Test Case Name:	IT #6	**Test ID:**	Plate-IT-06
Description:	Test the interaction between energy consumed and payment module.	**Type:**	Black Box: ✓ White Box: ☐
Tester Information			
Tester Name(s):	Abdul Bhutta, Walid Ayub	**Date:**	-
Hardware Version:	V1.0	**Time:**	-
Setup:	The user must exist within the database and have an outstanding balance.		

Step	**Action**	**Expected Results**	**Pass**	**Fail**	**N/A**	**Comments**
1	Login as “User”	The webpage will display the personal portal.				
2	Access the Energy Consumption page	The webpage will display the outstanding payment.				
3	Click on payment	The webpage will be redirected to the payment page.				
4	Confirm payment	A confirmation message will appear, and the outstanding balancing will be updated.				
Test Result:						

5 Estimated Project Cost

5.1 Project Part Cost Breakdown

Below is a table breaking down each the parts to be used for our protype and their cost.

Table 5.0: Purchased Part Cost Breakdown

Part	Part Cost	Total Running Cost	Purchase Date
13.3" Display	$159.73	$159.73	09/29/2022
13.3" Display Import Fee	$32.07	$191.80	09/30/2022
Raspberry Pi w/ SD Card	$192.09	$383.89	10/21/2022
Rechargeable Power Bank	$44.06	$427.95	11/06/2022
Right Angle USB-A to USB-C Charging Cables (3-Pack)	$11.29	$439.24	11/06/2022
RFID Tag & Reader	$15.68	$454.92	11/07/2022
Mini Breadboards	$12.42	$467.34	11/07/2022
Jumper Wires	$16.94	$484.28	11/07/2022
GT-U7 GPS Module	$29.32	$513.60	11/07/2022
HDMI Cable	$11.29	$524.89	11/07/2022
3D Printed Case	$0 (Estimated)	$524.89	Not Yet Purchased
	Total:	**$524.89**	
	Total Budget Remaining:	**$475.11**	

[the remainder of this page has been intentionally left blank]

6 Project Plan

6.1 Fall Semester Deliverable Breakdown

Table 6.0 below shows a breakdown of the remaining Fall semester deliverables from Report #2 onwards.

Table 6.0: Remaining Fall Semester Deliverable Breakdown

Deliverable	Report Section Name	Section Deliverables	Assigned Team Member(s)	Duration (Days)
Report #2	**Report Introduction**	Abstract, Dedication, Acknowledgements, Report Introduction	All Members	2
Report #2	**Concept Generation/Analysis**	Concept Generation Table Creation	All Members	5
Report #2	**Conceptual System Design**	Software System Designs Electrical System Design Overall System Design Design Review	All Members	10
Report #2	**Definition of Integration Tests**	Creation of Integration Tests Review of Tests	Abdul Kumail Walid	4
Report #2	**Estimated Project Cost**	Cost Estimation Cost Analysis Cost Tracking	Emran Yussef Walid	2
Report #2	**Project Plan**	Updated Task Breakdown Update Gantt Chart	Abdul Yussef	2
Report #2	**Contribution Matrix**	Matrix Creation and Completion	Yussef	1
Report #2	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	1
Report #2	**Report Formatting**	Format Report Naming/Organizing Tables & Figures Table of Contents	Yussef	1
Report #2	**Report Submission**	Submission to Capstone Advisor	Yussef	>1
Team Presentation & Demo	**Presentation Assembly**	Construction of PowerPoint Presentation	All Members	5
Team Presentation & Demo	**Presentation Proofreading and Formatting**	Proofreading Consistency Check General Flow Check	Emran Kumail Walid	1

Team Presentation & Demo	**Prototype Assembly**	Assembly of Prototype	Abdul Yussef	5
Team Presentation & Demo	**Presentation Rehearsals**	Assign Sections for Presentation Practice Presenting	All Members	3
Team Presentation & Demo	**Final Presentation**	Present to Capstone Advisor/Coordinator	All Members	1
Team Retrospective Report	**Report Preparation**	Write Team Report	All Members	10
Team Retrospective Report	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	2
Team Retrospective Report	**Report Formatting**	Format Report Naming/Organizing Tables & Figures Table of Contents	Yussef	1
Team Retrospective Report	**Report Submission**	Submission to Capstone Coordinator	Yussef	>1
END OF FALL SEMESTER				

6.2 Winter Semester Deliverable Breakdown

Table 6.1: Winter Semester Deliverable Breakdown

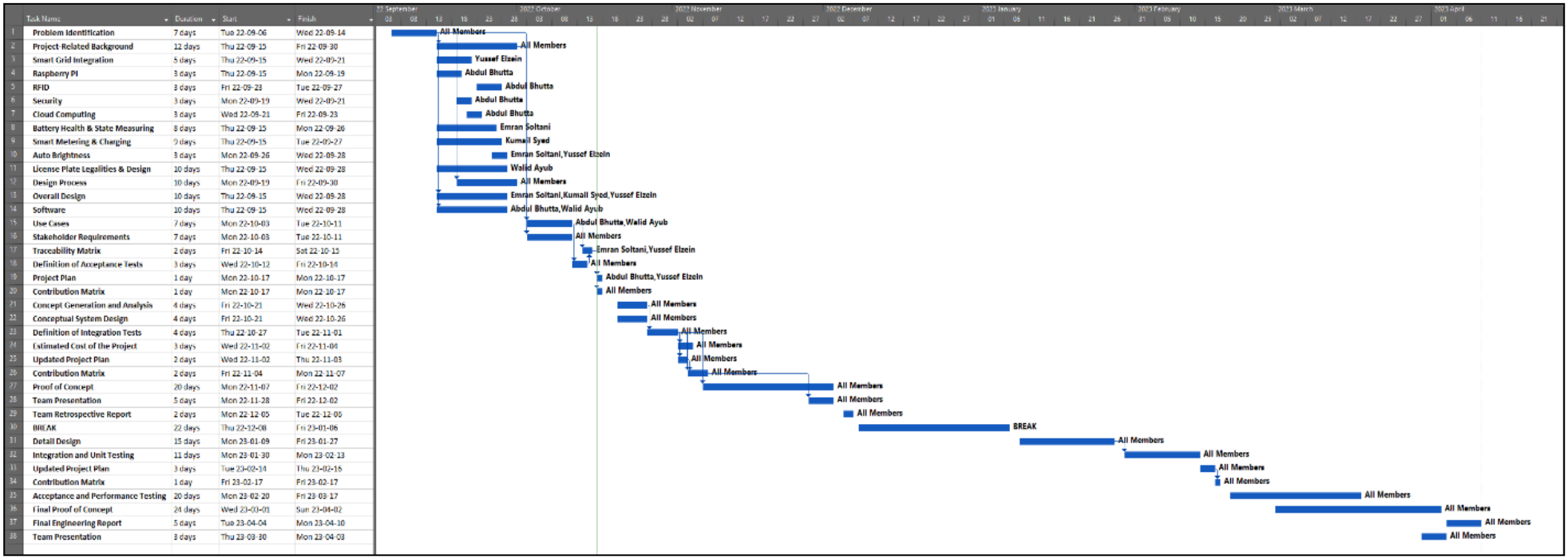
Deliverable	Report Section Name	Section Deliverables	Assigned Team Member(s)	Duration (Days)
Detail Design & Integration Testing Report	**Report Introduction**	Abstract, Dedication, Acknowledgements, Report Introduction	All Members	2
Detail Design & Integration Testing Report	**Detail Design**	Diagram Creation Design Analysis Detailed Schematics	All Members	7
Detail Design & Integration Testing Report	**Integration Testing / Unit Testing**	Refine Integration Tests Complete Integration Tests	All Members	5
Detail Design & Integration Testing Report	**Project Plan**	Updated Task Breakdown Update Gantt Chart	Abdul Yussef	2
Detail Design & Integration Testing Report	**Contribution Matrix**	Matrix Creation and Completion	Yussef	1
Detail Design & Integration Testing Report	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	2
Detail Design & Integration Testing Report	**Report Formatting**	Format Report Organizing Tables & Figures Table of Contents	Yussef	1
Detail Design & Integration Testing Report	**Report Submission**	Submission to Capstone Advisor	Yussef	>1
Acceptance Test Demonstration Report	**Acceptance Testing**	Complete Acceptance /Performance Testing Refine Acceptance Tests	All Members	3
Acceptance Test Demonstration Report	**Demonstration Rehearsals**	Assign Sections for Presentation Practice Presenting	All Members	2
Acceptance Test Demonstration Report	**Acceptance Test Demonstration**	Present to Capstone Advisor	All Members	>1
Acceptance Test Demonstration Report	**Report Introduction**	Abstract, Dedication, Acknowledgements, Report Introduction	All Members	2

Acceptance Test Demonstration Report	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	2
Acceptance Test Demonstration Report	**Report Formatting**	Format Report Organizing Tables & Figures Table of Contents	Yussef	1
Acceptance Test Demonstration Report	**Report Submission**	Submission to Capstone Advisor	Yussef	>1
Final Engineering Report	**Report Introduction**	Title Page, Abstract, Dedication, Acknowledgements, Report Introduction Executive Summary	All Members	3
Final Engineering Report	**Addition of Previous Reports**	Add Report #1 Add Report #2	Yussef	1
Final Engineering Report	**Revised Design Report**	Revise Designs	All Members	4
Final Engineering Report	**Ethical Considerations**	Comments of Ethical Considerations of Project	All Members	3
Final Engineering Report	**Safety Considerations**	Comments of Safety Considerations of Project	All Members	3
Final Engineering Report	**Report Conclusion**	Write Project's Closing Remarks	All Members	1
Final Engineering Report	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	2
Final Engineering Report	**Report Formatting**	Format Report Organizing Tables & Figures Table of Contents	Yussef	1
Final Engineering Report	**Report Submission**	Submission to Capstone Advisor	Yussef	>1
Team Presentation & Video Clip	**Presentation Assembly**	Construction of Presentation	All Members	5
Team Presentation & Video Clip	**Presentation Rehearsals**	Assign Sections for Presentation Practice Presenting	All Members	2

Team Presentation & Video Clip	**In-Class Final Presentation**	Present to Class / Faculty Advisors	All Members	>1
Team Presentation & Video Clip	**Video Clip Planning**	Writing of Script Review of Script Overall Plan of Video	All Members	4
Team Presentation & Video Clip	**Video Clip Filming**	Filming of Prototype Clips	Yussef	2
Team Presentation & Video Clip	**Video Clip Editing**	Assemble Clips Overall Video Editing	Yussef	4
Team Presentation & Video Clip	**Video Compilation & Review**	Finalize Video Review Final Video	Yussef	2
Capstone Design Annual Exhibition	**Presentation Assembly**	Construction of Presentation	All Members	5
Capstone Design Annual Exhibition	**Presentation Rehearsals**	Assign Sections for Presentation Practice Presenting	All Members	3
Capstone Design Annual Exhibition	**Poster Creation**	Design of Poster Assembly of Poster	All Members	5
Capstone Design Annual Exhibition	**Preparation of Final Prototype**	Test Final Prototype Ensure All Parts Assembled	Yussef	2
Team Retrospective Report	**Report Preparation**	Write Team Report	All Members	10
Team Retrospective Report	**Report Corrections**	Proofreading Consistency Check General Flow Check	Emran Kumail	2
Team Retrospective Report	**Report Formatting**	Format Report Naming/Organizing Tables & Figures Table of Contents	Yussef	1
Team Retrospective Report	**Report Submission**	Submission to Capstone Coordinator	Yussef	>1
END OF WINTER SEMESTER				

6.3 Project-Long Gantt Chart

Figure 18 below shows a Gantt chart demonstrating the project plan deliverables throughout to the end of the project and a timeframe for their completion.



	Task Name	Duration	Start	Finish
1	Problem Identification	7 days	Tue 22-09-06	Wed 22-09-14
2	Project-Related Background	12 days	Thu 22-09-15	Fri 22-09-30
3	Smart Grid Integration	5 days	Thu 22-09-15	Wed 22-09-21
4	Raspberry PI	3 days	Thu 22-09-15	Mon 22-09-19
5	RFID	3 days	Fri 22-09-23	Tue 22-09-27
6	Security	3 days	Mon 22-09-19	Wed 22-09-21
7	Cloud Computing	3 days	Wed 22-09-21	Fri 22-09-23
8	Battery Health & State Measuring	8 days	Thu 22-09-15	Mon 22-09-26
9	Smart Metering & Charging	9 days	Thu 22-09-15	Tue 22-09-27
10	Auto Brightness	3 days	Mon 22-09-26	Wed 22-09-28
11	License Plate Legalities & Design	10 days	Thu 22-09-15	Wed 22-09-28
12	Design Process	10 days	Mon 22-09-19	Fri 22-09-30
13	Overall Design	10 days	Thu 22-09-15	Wed 22-09-28
14	Software	10 days	Thu 22-09-15	Wed 22-09-28
15	Use Cases	7 days	Mon 22-10-03	Tue 22-10-11
16	Stakeholder Requirements	7 days	Mon 22-10-03	Tue 22-10-11
17	Traceability Matrix	2 days	Fri 22-10-14	Sat 22-10-15
18	Definition of Acceptance Tests	3 days	Wed 22-10-12	Fri 22-10-14
19	Project Plan	1 day	Mon 22-10-17	Mon 22-10-17
20	Contribution Matrix	1 day	Mon 22-10-17	Mon 22-10-17
21	Concept Generation and Analysis	4 days	Fri 22-10-21	Wed 22-10-26
22	Conceptual System Design	4 days	Fri 22-10-21	Wed 22-10-26
23	Definition of Integration Tests	4 days	Thu 22-10-27	Tue 22-11-01
24	Estimated Cost of the Project	3 days	Wed 22-11-02	Fri 22-11-04
25	Updated Project Plan	2 days	Wed 22-11-02	Thu 22-11-03
26	Contribution Matrix	2 days	Fri 22-11-04	Mon 22-11-07
27	Proof of Concept	20 days	Mon 22-11-07	Fri 22-12-02
28	Team Presentation	5 days	Mon 22-11-28	Fri 22-12-02
29	Team Retrospective Report	2 days	Mon 22-12-05	Tue 22-12-06
30	BREAK	22 days	Thu 22-12-08	Fri 23-01-06
31	Detail Design	15 days	Mon 23-01-09	Fri 23-01-27
32	Integration and Unit Testing	11 days	Mon 23-01-30	Mon 23-02-13
33	Updated Project Plan	3 days	Tue 23-02-14	Thu 23-02-16
34	Contribution Matrix	1 day	Fri 23-02-17	Fri 23-02-17
35	Acceptance and Performance Testing	20 days	Mon 23-02-20	Fri 23-03-17
36	Final Proof of Concept	24 days	Wed 23-03-01	Sun 23-04-02
37	Final Engineering Report	5 days	Tue 23-04-04	Mon 23-04-10
38	Team Presentation	3 days	Thu 23-03-30	Mon 23-04-03

Figure 18: Smart Grid Integrated Digital License Plate Project Gantt Chart

7 Contribution Matrix

The contribution matrix in the table below displays how the work for report #2 was divided.

Table 7.0: Report #2 Contribution Matrix

Report #2 Sections	Group Members				
	Abdul Bhutta	**Yussef Elzein**	**Emran Soltani**	**Kumail Syed**	**Walid Ayub**
Section 1: Introduction					
			✓	✓	✓
Section 2: Concept Generation & Analysis					
Initial Concept Generation	✓	✓	✓	✓	
Model Creation	✓	✓			
Model Analysis		✓			
Model Ranking		✓			
Section 3: Conceptual System Design					
Software Design	✓				✓
Electrical Design		✓	✓	✓	
Functional Decompositions	✓	✓	✓	✓	
Casing Design			✓	✓	
Section 4: Integration Tests					
List of Integration Tests		✓			
Definition of Integration Test Cases	✓				✓
Section 5: Estimated Project Cost					
Project Cost Breakdown	✓	✓	✓	✓	✓
Section 6: Project Plan					
Updated Fall Task Breakdown		✓			
Winter Task Breakdown		✓			
Gantt Chart	✓				
Section 7: Contribution Matrix					
Contribution Matrix		✓			
Other:					
Report Formatting		✓			
Report Corrections			✓	✓	

References

1. J. Wood, “Despite Ford promises, failed Ontario licence plates increased costs by 26 per cent,” Newsroom, 16-Jun-2021. [Online]. Available: https://www.taxpayer.com/newsroom/despite-ford-promises,-failed-ontario-licence-plates-increased-costs-by-26-per-ent#:~:text=Throughout%20the%20entirety%20of%20the,have%20added%20up%20to%20%24913%2C867. [Accessed: 10-Oct-2022].

2. “Cruiser vault license plate frame, black/smoke | Canadian tire,” *Cruiser - Vault License Plate Frame*. [Online]. Available: https://www.canadiantire.ca/en/pdp/cruiser-vault-license-plate-frame-black-smoke-0379870p.html. [Accessed: 06-Nov-2022].