ADVANCED VEHICLE FIRE SAFETY AND MONITORING WITH RAPID EMERGENCY DISPATCH SOLUTIONS

R24-058

Project Proposal Report

Glen.N.Anthick

B.Sc. (Hons) Degree in Information Technology specializing in Information Technology

Department of Information Technology

Sri Lanka Institute of Information Technology

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DECLARATION

We declare that this is our own work, and this proposal does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any other university or Institute of higher learning and to the best of our knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.

Name	Student ID	Signature
Glen.N.Anthick	IT21096266	

The supervisor/s should certify the proposal report with the following declaration.

The above candidates are carrying out research for the undergraduate Dissertation under my supervision.

Signature of the Supervisor:	2024.02.	
Signature of the Co-Supervisor:	2024.02.	

ABSTRACT

In response to the critical need for rapid emergency services in urban environments, this study suggests the development of an AI-driven routing system that gives the optimum path a firetruck or the fireman should take in case of a vehicle fire. Addressing the research problem of lack of existing routing solutions, the system integrates real-time traffic data, vehicle telemetry, and advanced routing algorithms to facilitate swift and safe navigation through congested metropolitan areas.

The study employs a hybrid AI model combining the predictive power of Graph Neural Networks (GNNs) with the efficiency of A* and Dijkstra algorithms. This model is designed to interpret complex traffic conditions and dynamically adjust routes in real-time. The research encompasses the collection and preprocessing of data from IoT devices within vehicles, the development and integration of the AI model into existing emergency dispatch systems, and the simulation of scenarios to test system efficacy.

Initial interpretations indicate that the proposed system significantly reduces response times by adapting to changing traffic patterns and road conditions, outperforming traditional static routing methods. The conclusions suggest that implementing such an AI-driven system could enhance the operational capabilities of fire departments, potentially saving lives and mitigating property damage more effectively during vehicular fire incidents.

Keywords: AI-driven routing system, Emergency services, Urban environments, Vehicle fires, Graph Neural Networks (GNNs), A* algorithm, Dijkstra algorithm, Emergency dispatch systems .

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LIST OF ABBREVIATION

AI - Artificial Intelligence

IoT - Internet of Things

GNN - Graph Neural Network

GPS - Global Positioning System

A - A-Star Algorithm*

ML - Machine Learning

CNN - Convolutional Neural Network

ESP32 - Espressif Systems 32-bit Microcontroller

AWS - Amazon Web Services

API - Application Programming Interface

SUMO - Simulation of Urban MObility

OSRM - Open-Source Routing Machine

UI - User Interface

SDK - Software Development Kit

HTTP - Hypertext Transfer Protocol

HTTPS - Hypertext Transfer Protocol Secure

QGIS - Quantum Geographic Information System

REST - Representational State Transfer

MQTT - Message Queuing Telemetry Transport

1 INTRODUCTION

1.1 Background and Literature Survey

The escalation of urban density and the ensuing vehicular congestion pose significant challenges for emergency response units, particularly fire services. The need for rapid and reliable navigation to incident sites is hampered by traditional routing systems that cannot accommodate the dynamic and often unpredictable urban traffic flows. To address these shortcomings, there's an increasing focus on leveraging real-time traffic data and vehicle telemetry within advanced routing algorithms. The integration of such data streams is crucial for developing responsive and efficient navigation solutions.

Graph Neural Networks (GNNs) have emerged as a promising avenue for enhancing the adaptability and accuracy of routing systems. When combined with traditional algorithms like A* and Dijkstra, GNNs offer a nuanced understanding of traffic patterns, allowing for the prediction of optimal routes that can dynamically adjust to changing conditions. The literature indicates, however, a distinct lack of routing systems that are specifically designed for the operational needs of emergency vehicles, such as fire trucks, which must maneuver quickly yet safely, often against the flow of regular traffic.

This study seeks to bridge the identified gap by developing a hybrid AI model that capitalizes on the strengths of GNNs, A*, and Dijkstra algorithms. The proposed system will assimilate real-time and historical traffic data, along with vehicle-specific telemetry, to compute the most efficient paths for fire trucks during emergencies. The AI model will be trained to prioritize routes based on various parameters, including the shortest distance, the fastest time, and the least congestion, while also considering the physical constraints of fire trucks.

The innovative aspect of this research lies in its real-time data integration capability. By continuously updating the routing model with live traffic information, the system promises to deliver more accurate and timely route optimizations. This real-time adaptability is crucial for emergency vehicles that operate in highly fluid and time-sensitive situations.

Furthermore, the system will undergo rigorous testing through simulations that replicate a wide range of emergency scenarios. This approach will not only validate the model's effectiveness but also refine its predictive algorithms to cater to the exigencies of urban emergency response. Upon successful simulation testing, the system will be integrated with emergency dispatch protocols to ensure that it can operate seamlessly within the existing framework.

In conclusion, this study aims to contribute a novel, AI-driven routing system that is tailored to the specific needs of fire trucks. By combining real-time data analytics with advanced computational models, the research aspires to enhance the operational efficiency of fire services, potentially reducing response times and saving lives. The integration of this system into emergency services holds the promise of setting a new benchmark for intelligent transportation systems in urban emergency management.

1.2 Research Gap

The research gap identified for the development of an AI-driven routing system for fire trucks addresses a crucial deficiency in current emergency response strategies. While recent advances in machine learning and traffic management have led to improved general routing algorithms, these solutions often do not fully cater to the urgent and specific needs of emergency services. The existing systems typically do not incorporate real-time traffic data and vehicle telemetry in a manner that allows for the instantaneous rerouting of emergency vehicles, such as fire trucks, in response to rapidly changing traffic conditions.

Moreover, although some studies have explored the use of AI in traffic management, there is a paucity of research that combines the real-time analytical capabilities of Graph Neural Networks (GNNs) with traditional routing algorithms like A* and Dijkstra specifically for emergency vehicles. The integration of these technologies promises to enhance the decision-making process for emergency route optimization, yet this potential remains largely untapped in existing literature and practice.

Current routing systems also tend to neglect the distinct operational constraints of fire trucks, such as the need to navigate through traffic while adhering to safety protocols and maintaining high speed. The AI-driven routing system proposed in this study seeks to fill this gap by providing a solution that not only improves response times but also ensures adherence to safety standards.

Additionally, there is a lack of scalable and adaptable AI-driven routing models that can be customized for various urban environments and integrated seamlessly with existing emergency dispatch systems. This research aims to bridge this gap by developing a model that is both flexible and easily integrated, thus representing a significant step forward in the application of AI to public safety and emergency response logistics.

The study is poised to contribute to the existing body of knowledge by presenting a comprehensive, real-time, AI-driven routing framework that addresses the unique challenges faced by fire trucks. This gap, once filled, could lead to more effective emergency responses, potentially saving lives and reducing the economic impact of fire-related incidents.

2 RESEARCH PROBLEM

Expanding on the outlined research problems, this study aims to develop an AI-driven system that fundamentally transforms the routing capabilities of emergency response vehicles. The first research problem is the real-time adaptability of routing systems. With urban traffic becoming increasingly unpredictable, there is a critical need for a system that can learn and adjust in real-time. The integration of GNNs with conventional routing algorithms proposes a solution that assimilates a vast array of dynamic traffic data to create a responsive and intelligent routing framework. This system must not only discern the optimal paths through congested cityscapes but also anticipate and circumvent emerging traffic events that could hinder emergency response.

The second research problem focuses on the practical integration of this AI system within the operational protocols of emergency services. The challenge lies in ensuring that the transition to an AI-enhanced routing protocol is frictionless and that the system interfaces seamlessly with existing communication and dispatch channels. This necessitates a design that foregrounds reliability and user-friendliness, ensuring that first responders can interpret and trust the AI-generated routing directives.

This research contends with the intricacies of designing a system that is robust enough to handle the computational demands of processing real-time data, yet intuitive enough for seamless human-machine interaction. The development process must be rigorous, involving simulation, real-world testing, and continuous feedback loops with emergency personnel. The goal is to deliver a system that not only improves response times but also becomes an indispensable tool in the arsenal of emergency services, leading to safer, more efficient urban environments.

3 OBJECTIVES

3.1 Main Objectives

The primary objective of this study is to develop an AI-driven system capable of utilizing real-time and historical traffic data, vehicle telemetry, and advanced routing algorithms to accurately predict the most efficient routes for fire trucks. This system aims to significantly improve response times to vehicle fires in urban environments, ultimately enhancing public safety and minimizing property damage.

3.2 Specific Objectives

- To implement and assess the effectiveness of A*, Dijkstra, and GNN algorithms within the routing system, ensuring optimal path selection based on varied criteria including distance and traffic conditions.
- To design, train, and refine an AI model that integrates the strengths of the selected routing algorithms, capable of adjusting to dynamic traffic scenarios for real-time route optimization.
- To conduct extensive simulations and field tests in collaboration with fire departments, validating the AI model's accuracy and reliability in predicting optimal emergency routes under diverse conditions.
- To leverage cloud computing resources for scalable data storage, processing power, and enhanced model accessibility, ensuring the system's reliability and performance across diverse urban environments.
- To develop a user-friendly interface for emergency services, ensuring the seamless delivery of routing information and compatibility with existing dispatch systems.

4 METHODOLOGY

4.1 System Architecture

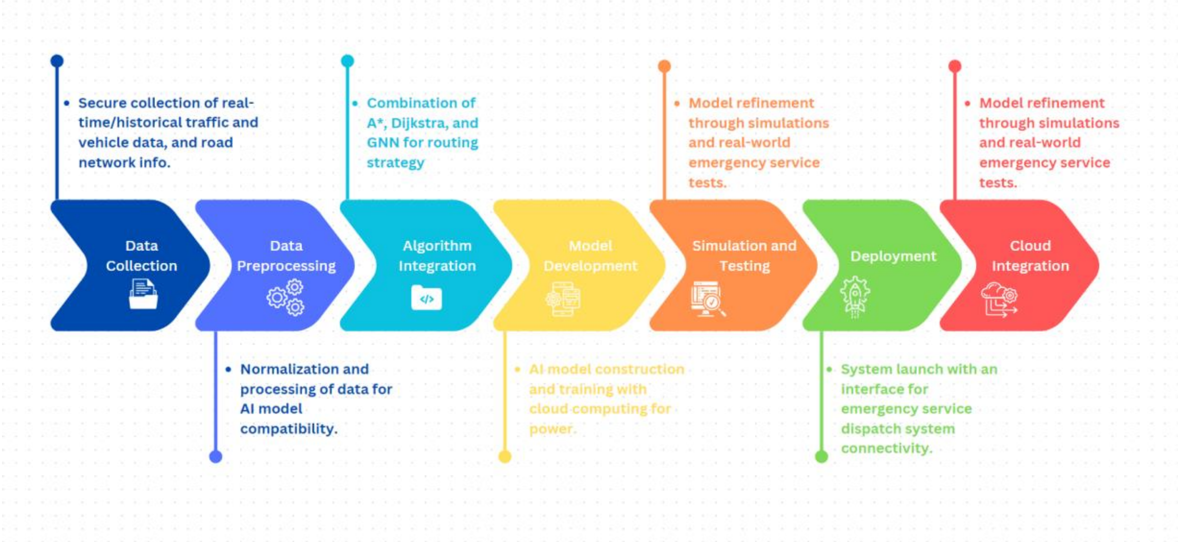


Figure 1:Component Architecture Diagram

The proposed AI-driven routing system is a multi-layered architecture designed to enhance the efficiency of firetruck responses in urban environments. At its foundation, the system commences with the Data Collection phase, meticulously gathering both live and historical traffic data alongside intricate details of the road network. This collection phase prioritizes the security and integrity of data, ensuring a reliable base for subsequent processes. During Data Preprocessing, this raw data undergoes rigorous cleaning and normalization to ensure uniformity and accuracy, which is critical for the reliability of AI predictions. Algorithm Integration is a pivotal phase where time-tested routing algorithms like A* and Dijkstra are combined with advanced GNNs, crafting a sophisticated and comprehensive routing logic that is sensitive to both static and dynamic traffic elements. In Model Development, cloud computing resources come into play, offering substantial computational power necessary for training the AI models. These models are designed to assimilate the diverse data inputs and evolve through machine learning to predict the most efficient routes. Simulation and Testing involve virtual and real-world scenarios to fine-tune the model's accuracy and to ensure its robustness in actual emergency situations. Collaboration with emergency services during field tests is key to validating model predictions. Deployment sees the introduction of a user-friendly interface seamlessly integrated with the emergency dispatch systems, ensuring that the optimized routes are effectively communicated to the firetruck crews. Lastly, Cloud Integration guarantees scalability and robustness, with cloud platforms providing the backbone for data storage and additional computational power, ensuring the system's performance is maintained across various scales and conditions. This holistic approach aims to revolutionize emergency response routes, making them faster and more efficient.

4.2 Commercialization of the Product

Automotive Integration: This system could be integrated into vehicle navigation systems at the manufacturing stage, providing an advanced feature that enhances the safety and value of new vehicles. Collaborations with car manufacturers would not only be a selling point but could also standardize emergency response technology across the industry.

Consultancy Services: Using the data collected from the system, we could offer consultancy services to vehicle manufacturers and emergency response equipment providers, aiding them in developing features that enhance safety and response capabilities.

Data Monetization: The system could generate valuable data on traffic patterns and emergency incident responses. This data, once anonymized to protect privacy, could be a critical asset for urban development agencies, helping to plan and improve city infrastructure.

5 SOFTWARE / HARDWARE METHODOLOGY

5.1 Software methodology

Requirements Gathering and Analysis:

This phase is crucial for understanding the exact needs of the emergency services in terms of routing efficiency, data accuracy, and system integration. It would involve discussions with emergency responders to identify critical system features, desired outcomes, and constraints such as compatibility with existing communication and navigation systems.

Market Research:

An in-depth market analysis would be conducted to assess existing emergency routing solutions, potential gaps in the market, and areas where innovation can provide significant advantages. This also involves identifying potential competitors and understanding their product offerings to ensure that the new system offers unique and superior capabilities.

Use Case Scenarios:

Crafting detailed scenarios that the system will encounter is key to ensuring its effectiveness. This includes simulating high-traffic conditions, different times of day, urban versus rural routes, and various emergency types to ensure the AI model is robust and versatile.

System Architecture:

The architecture of the system must be designed for scalability and resilience, capable of handling large volumes of real-time data and integrating seamlessly with multiple data sources. It should also be adaptable to incorporate future advancements in AI and routing algorithms.

Technology Selection:

Selecting the right technology stack is critical for the success of the system. This includes choosing programming languages known for performance and reliability, robust frameworks for AI and data processing, and tools that support agile development and collaboration.

Sprint Planning:

Create task list and break it down into sprints. One sprint means 2 weeks. Allocate the tasks according to the weight of the task into sprints. And always monitor the sprint plan and the actual work done during the sprint. And plan the remaining work to complete in the upcoming sprint and adjust the sprint plan accordingly.

Code Reviews:

A systematic code review process would help maintain high-quality standards, facilitate knowledge sharing among developers, and ensure that all code commits are aligned with the project's coding standards and architecture.

Software Development:

The development phase involves writing clean, efficient, and well-documented code to implement the core functionalities of the routing system, the user interface, and the integration mechanisms with real-time data sources.

Data Gathering and Model Training:

Gathering a diverse set of traffic and incident data is vital for training the AI model to accurately predict optimal routes under a variety of conditions. This data needs to be cleaned, normalized, and structured before being used for model training.

5.2 Tools and Technologies

Jupyter Lab: for exploratory data analysis and model prototyping. Its interactive environment is particularly useful for visualizing data flows within the system and sharing findings with the development team.

Microsoft Azure: Utilize Microsoft Azure to host the AI models and manage the data infrastructure. Azure's scalable computer and storage options ensure that the system can handle variable loads and data volumes during emergency situations.

TensorFlow: TensorFlow can be used to develop machine learning models that analyze patient data and categorize them into safe, cautious, or danger zones. The models can be trained to provide personalized recommendations based on the patient's specific health conditions and medical history.

Python: Leverage Python's extensive ecosystem for all stages of software development, from writing backend services to processing data and machine learning.

Microsoft Azure: Utilize Microsoft Azure to host the AI models and manage the data infrastructure. Azure's scalable compute and storage options ensure that the system can handle variable loads and data volumes during emergency situations.

Graph Neural Networks (GNN): Implement GNNs to effectively learn and model the complex patterns in the road network data, enabling the system to make informed routing decisions in dynamic traffic scenarios.

A* Algorithm: Integrate the A* search algorithm to efficiently calculate the optimal route for emergency vehicles, factoring in various constraints such as road types, traffic conditions, and incident locations.

Dijkstra's Algorithm: Use Dijkstra's algorithm for route optimization tasks that require finding the shortest path without considering dynamic traffic conditions, serving as a foundational component for more complex routing strategies.

OpenStreetMap: Use OpenStreetMap for access to free and editable maps of the road network, which can be continuously updated with new information relevant to routing.

6 DESCRIPTIONS OF PERSONAL AND FACILITIES

Table 1-Description of personal facilities

Member	Component	Tasks
Glen.N.Anthick IT21096266	Optimal path, the firetruck can take. Using GNN, Dijkstra, and A*	Develop a system to gather and curate extensive datasets of traffic, vehicle telemetry, and road network information for AI model training and validation. Select and configure an advanced AI framework, such as TensorFlow, to build a neural network capable of processing complex traffic data, incorporating graph neural network (GNN) methodologies for spatial data processing and multimodal fusion techniques for integrating diverse data sources. Train the neural network using the acquired dataset with advanced machine learning strategies like transfer learning for leveraging pre-trained models on similar tasks, data augmentation to enrich the dataset, and hyperparameter tuning for model optimization to ensure the most efficient routes for emergency vehicles. Embed the trained machine learning model into the application using lightweight libraries and frameworks suitable for the intended platform (e.g., TensorFlow Lite), ensuring smooth performance and low latency in real-world emergency scenarios. Execute rigorous testing of the application and the AI model under various scenarios, including unpredictable traffic conditions and emergency incidents, to refine the system's accuracy and reliability.

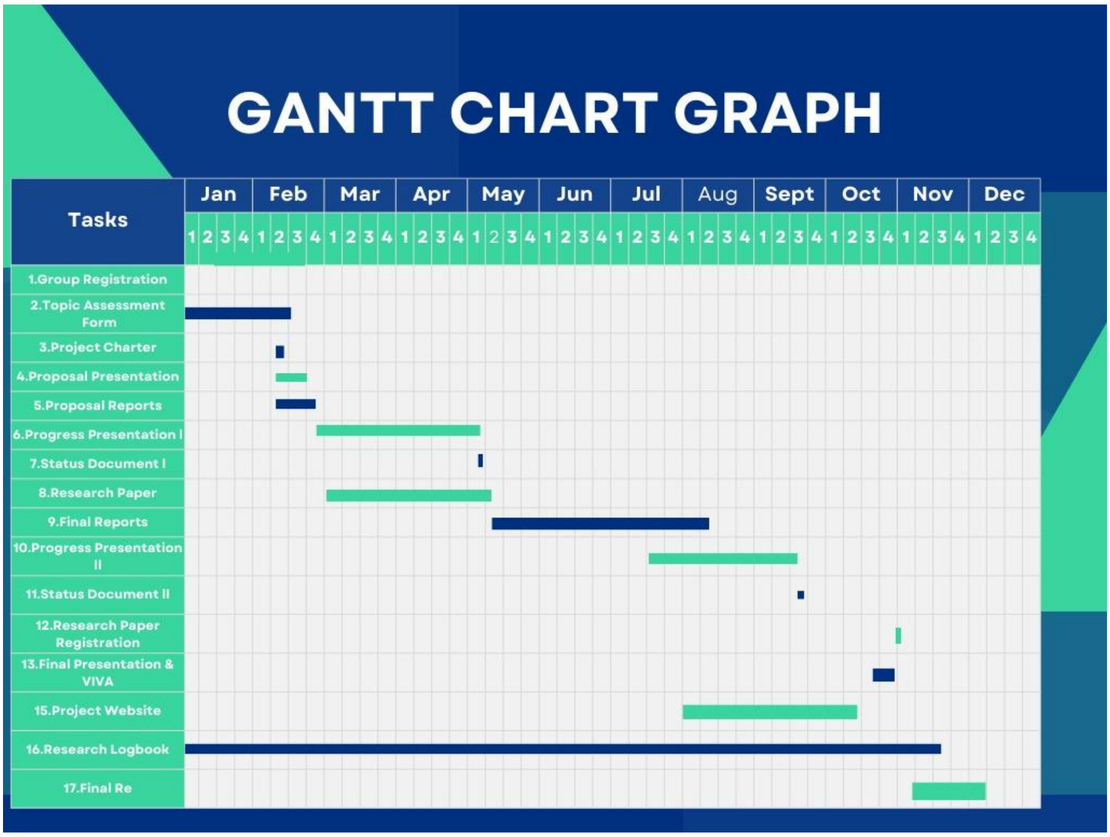
7 BUDGET AND BUDGET JUSTIFICATION

Resources	Estimated Price (LKR)
Cloud server host	25,000.00
Travelling	10,000.00
Internet	5,000.00
Stationery	2,000.00
Total	**42,000.00**

Table 2-Expected Expenditure

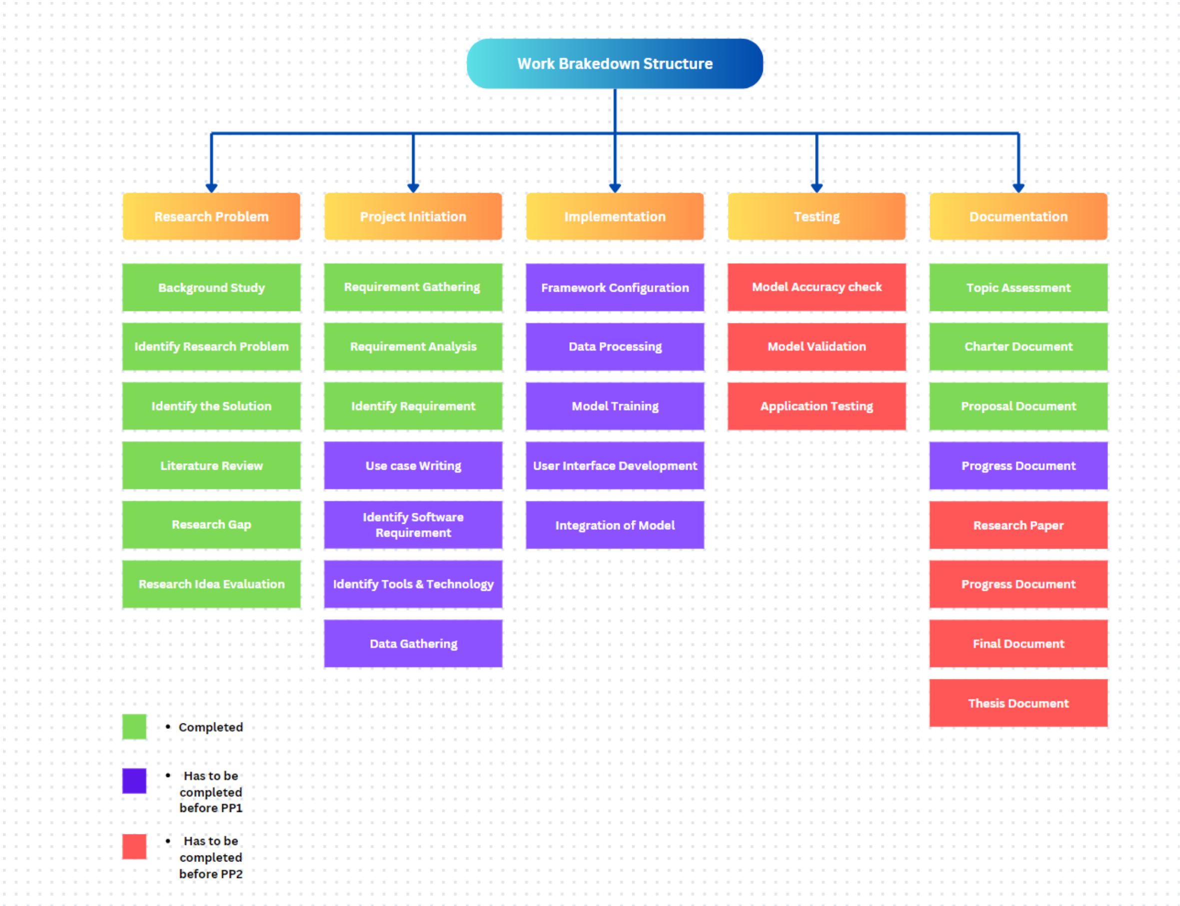
The proposed budget total cost amount is LKR 42000. To cover this expenditure, our group plans to collect funds from group members. The budget table should detail all the project expenses, including any necessary equipment, materials, or services required to complete the project. These costs might change in the future due to unforeseen circumstances or unexpected expenses, but with a clear budget plan and contributions from group members, the project can be completed successfully.

8 GANTT CHART



Our suggested plan for the research project, with an emphasis on my component, is shown in the Gantt chart above. Up until this week, we have made progress since January. Our research plan would not be the same without this Gantt chart, which allows us to efficiently allocate our time and resources. It displays the project schedule as well as the deadlines for each task and their dependencies.

9 WORK BREAKDOWN CHART



The Work Breakdown Structure for this project is methodically divided into five pivotal stages: Research Problem, Project Initiation, Implementation, Testing, and Documentation, each with distinct tasks that contribute to the development of an IoT-based water quality monitoring system. In the Research Problem stage, tasks like Background Study, Identification of the Research Problem, Solution, Literature Review, Research Gap, and Idea Evaluation are thoroughly addressed to establish a solid foundation for the project's objectives and needs. The Project Initiation phase encompasses Requirement Gathering, Analysis, Use Case Writing, and the identification of Software Requirements and Tools & Technology, ensuring a robust blueprint for the system's hardware and software design. During the Implementation stage, Framework Configuration, Data Processing, Model Training, User Interface Development, and Integration of the Model are diligently executed to construct the IoT framework and synchronize it with Machine Learning algorithms for accurate water quality assessment.

The Testing phase is systematically structured to carry out Model Accuracy Checks, Validation, and Application Testing, facilitating the meticulous evaluation and optimization of the system's performance with verified water samples, and integrating with the mobile application dashboard for enhanced accessibility. Finally, the Documentation stage is dedicated to the meticulous compilation of the Topic Assessment, Charter, Proposal, Progress Documents, Research Paper, and ultimately, the Thesis and Final Documents, encapsulating all the technical specifications, operational guidelines, and comprehensive reporting of the project's trajectory.

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