ComFix 2024 Stage 2

Project Proposal

Autonomous Traffic Management System

Group Name:	**LinkSquad**
Members:	Senum Dondangoda
	Thaveesha Wathudura
	Warren Jayakumar
Date of Submission:	2024.04.28

1 Introduction

The rapid urbanization and increasing vehicle population have led to significant challenges in managing traffic congestion, particularly in densely populated cities like Colombo. The traditional traffic management systems, often based on fixed-time schedules, fail to adapt to dynamic traffic conditions, resulting in prolonged waiting times, increased fuel consumption, and heightened emissions. To address these issues, we propose an innovative project, the Autonomous Traffic Management System (ATMS), which leverages computer vision, data analytics, Artificial Intelligence (AI), and communication technologies.

The ATMS is designed to create a dynamically responsive and adaptive traffic control system that can minimize roadblocks, reduce waiting times, and optimize traffic flow. The system will utilize computer vision technology and data analytics from traffic monitoring sources to monitor and analyze real-time traffic conditions, AI algorithms to predict traffic patterns and make intelligent decisions and advanced communication technology to obtain data and control traffic signals in a coordinated manner.

This project aims to revolutionize the traditional traffic management paradigm by introducing a self-governing system that can adapt to dynamic traffic conditions, thereby improving traffic efficiency, reducing environmental impact, and enhancing the overall commuting experience. The proposed system aligns with the vision of smart cities, where technology is harnessed to create sustainable, efficient, and citizen-friendly urban environments.

2 Problem Description

Traffic congestion in urban areas has become an increasingly pressing issue, leading to a multitude of challenges that negatively impact the quality of life for city dwellers. The inefficiencies in current traffic management systems, particularly those employing fixed-schedule traffic lights, exacerbate these problems, resulting in unnecessary delays, commuter frustration, and heightened accident risks.

Studies have consistently demonstrated the correlation between traffic congestion and the frequency of fatal and serious injury accidents. For instance, research conducted by Wang (2010) found a significant positive relationship between traffic congestion and the occurrence of road accidents, suggesting that as congestion levels increase, so does the likelihood of accidents. Similarly, a more recent study by Sharmilaa & Ilango (2022) highlighted that congested traffic conditions contribute to a higher incidence of rear-end collisions, pedestrian accidents, and other types of road crashes, further underscoring the importance of addressing this issue.

Moreover, traffic congestion has significant environmental implications. Vehicles stuck in traffic consume more fuel and emit higher levels of pollutants, contributing to poor air quality and exacerbating climate change. The World Health Organization (WHO) has identified air pollution as a major public health concern, with traffic-related emissions being a significant contributor to this problem. Prolonged exposure to these pollutants can lead to a range of health issues, including respiratory problems, cardiovascular diseases, and even premature death.

In addition to the safety and environmental concerns, traffic congestion also imposes substantial economic costs on commuters and society at large. The time spent idling in traffic translates into lost productivity, while increased fuel consumption due to stop-and-go traffic patterns results in higher operational costs for vehicle owners. According to a report by the Texas A&M Transportation Institute, the annual cost of traffic congestion in the United States alone amounts to over $160 billion, highlighting the immense economic burden of this issue.

Furthermore, traffic congestion contributes to noise pollution, which has been linked to various health problems, such as sleep disturbances, stress, and cognitive impairment. The World Health Organization (WHO) estimates that at least one million healthy life years are lost every year due to traffic-related noise in Western Europe alone.

Given the challenges associated with traffic congestion, it is evident that addressing this issue is of paramount importance for improving road safety, reducing travel times, minimizing environmental impact, and enhancing the overall quality of life in urban areas. The urgency of finding effective solutions to mitigate traffic congestion cannot be overstated, as the costs of inaction are substantial and far-reaching.

3 Proposed Solution

The solution we propose consists of three main components as follows:

1. Data aggregation
2. Data processing
3. Control

The following figure shows the block diagram of the proposed solution.

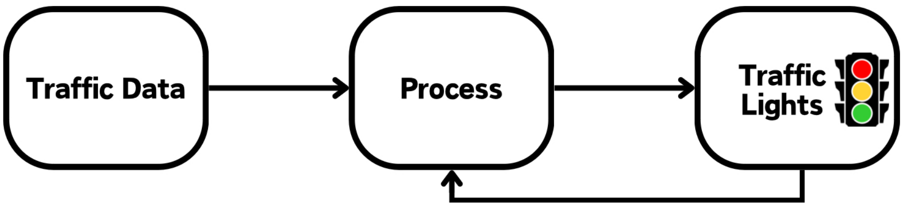

Figure 1: Block Diagram of the system

Communication technology is used to connect all these individual components together.

3.1 Data Aggregation

In order to control the traffic lights and enable a smooth traffic flow, data on current traffic congestion and possible areas of future congestion would need to be obtained. We propose two methods to obtain this data. One would be the use of cameras in strategically placed locations with vision processing algorithms and the other would be the use of traffic data sources such as Google Maps. Cameras can be installed afresh or existing traffic cameras that are used to check for traffic violations could also be used. The use of two sources would enable a more consistent approach to model traffic data. Data captured from cameras would more accurately represent the actual situation if vision processing algorithms were designed with a minimum error. However, it is not practical to use cameras at every point as the cost would be high. Therefore, the use of an existing service such as Google Maps to obtain traffic data would prove beneficial. Both inputs would be weighted and added to obtain an estimate of the traffic at a point.

Another advantage of using traffic data sources is the ability to detect traffic jams in areas where they are usually not expected. As an example, there may be areas where traffic jams usually don't occur. However, due to a motor accident at a particular time, the road may be blocked. Since events such as these are not common, it would not have been practical to have placed a camera at the location. Instead, the use of such traffic data services would be able to detect a heavy traffic jam. Additionally, this would be extremely useful in situations such as road works as well.

We propose to place cameras just before the main intersections facing away from the junction. This would enable us to obtain data about the traffic density leading up to an intersection. Obtaining this data would be important as the system would be able to obtain details about roads that need to be cleared. For example, if traffic leading up to a particular intersection from one side is high, the traffic light facing this side would need to be on for most of the time, Though this might seem like a sufficient solution, it is not as easy as clearing one intersection as one intersection might lead to the next intersection becoming jammed. This issue is addressed by the AI algorithm which is discussed later.

Even though the system seems capable, as a fail-safe mechanism, we propose to store the data regarding traffic at a given point and time in a database centrally. This data can be obtained by observing traffic patterns over a period of time and filling in the database.

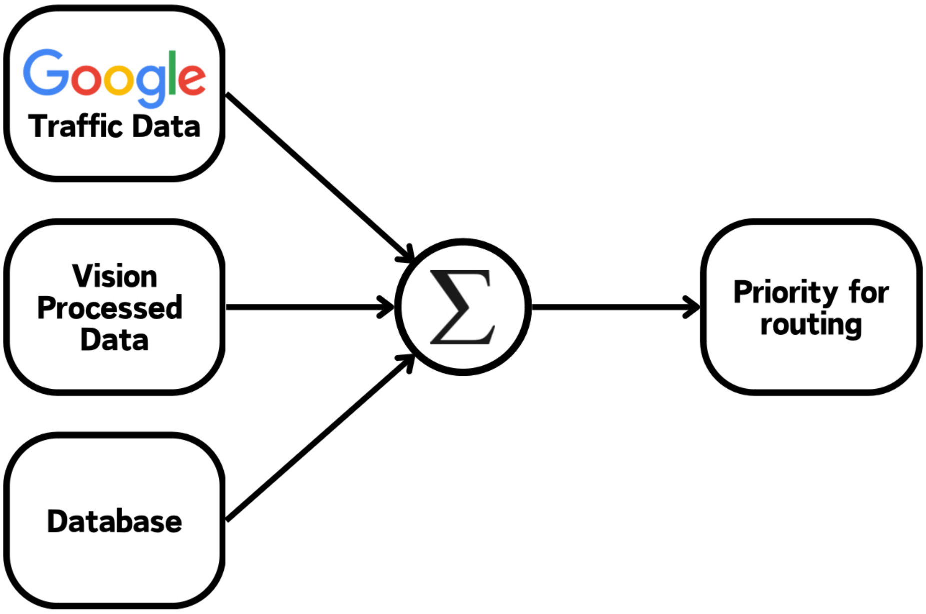

Figure 2: Diagram of traffic calculation for proposed system

3.2 Data Processing

To enhance the efficiency of traffic management, our proposed system utilizes data from two primary sources: traffic APIs such as Google Maps for work and traffic cameras connected to a server equipped with vision processing algorithms. Firstly, by leveraging traffic APIs, we obtain travel time data along main roads as shown in Figure 3, allowing us to gauge the level of traffic congestion along a road. Simultaneously, traffic cameras capture visual information about road conditions, which is processed by vision algorithms to assess traffic density and movement. Integrating these two sources of data by performing a weighted summation enables us to generate a comprehensive estimate of traffic conditions along roads, factoring in both real-time travel time data and visual assessments of traffic density.

At intersections, the system employs this aggregated traffic data to determine optimal traffic light timings. By comparing traffic volume from each road entering the intersection, the system calculates the most efficient allocation of green and red light phases. This localized optimization ensures smoother traffic flow at individual intersections. However, to address broader traffic management challenges across the urban area, the system goes beyond localized optimizations. In addition, as a failsafe, a database is maintained containing the usual traffic at a given point and time and that could also be used. It integrates data from multiple intersections and road segments to gain an understanding of traffic dynamics city-wide. This enables the system to make informed decisions that minimize congestion and roadblocks on a larger scale. Unlike static traffic light management systems, our proposed solution dynamically responds to changing circumstances such as accidents or roadworks. By continuously analyzing real-time traffic data, the system adapts traffic light timings in real-time to mitigate disruptions and optimize traffic flow across the urban network.

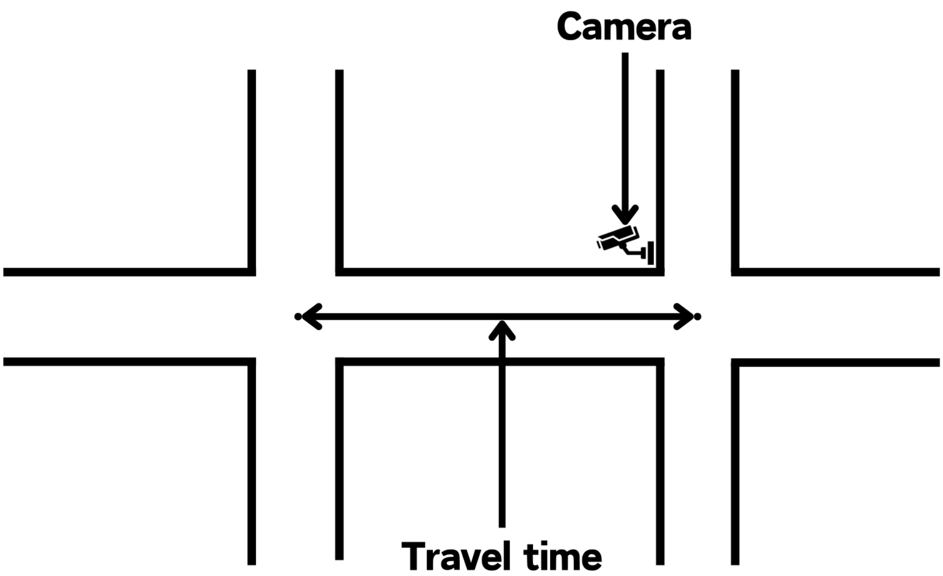

Figure 3: Diagram suggesting camera placement and the length for which travel time needs to be calculated

3.2.1 Algorithms

The first part of the processing is obtaining a value for the traffic at a particular point. This is obtained by the following equation:

$$T(x) = w_1.F(t(s)) + w_2.C(x) + w_3.D(x,t)$$

where $F(t(s))$ is a function that calculates the traffic based on the time taken to travel according to Google Maps API and $C(x)$ is a function that that calculates a value for the traffic based on the camera's data. $D(x,t)$ is a function that returns the usual traffic value stored in a database. w_1, w_2, and w_3 are weights for each of the inputs. However, it should be noted that the system frequently would have to send probing messages to the cameras and if a camera is unreachable, it would have to change the weights by increasing w_1 and setting w_2 to 0. Similarly, if the API is not reachable, it would have to increase w_2 and set w_1 to 0. If both are unavailable, the database value is used. In a usual situation, the contribution of the database would be minimal and its main purpose is a fail-safe option.

3.3 Control

The next part is the allocation of time-based on the traffic value. This can be done proportionally based on the traffic from each road approaching an intersection as follows:

$$Time_k\% = \frac{T(x_k)}{\sum_{i=1}^{n} T(x_i)}$$

This is possible as the algorithm allocates a value for the traffic linearly. Additionally, the performance of this algorithm can be monitored as feedback is continuously obtained from the data collection sources. Additionally, at each junction, a module would be present which would periodically probe the central station to see if it is online. If it doesn't receive a reply, it will use the previous values until a timeout after which it will revert to a default timing system.

4 Use of Communication Technology

Communication is used in three scenarios. The first is between the cameras and the central processing stations. The second is between the processing station and servers from traffic services such as Google Maps. This can be easily achieved via a fibre optic internet connection as it provides the greatest speed. Adding redundancy via a 4G or 5G internet connection would also prove to be beneficial. The final is between the central processing station and the traffic lights. The communication medium would need to be reliable irrespective of environmental conditions as failure to switch would increase traffic congestion and would be risky.

Two solutions are fiber optic cables and wireless mesh networks. The main differences are compared in the following table: Fiber optic cables offer high-speed data transmission and enhanced

Aspect	**Fibre Optic Cables**	**Wireless Mesh Networks**
Key advantage	Speed, Reliability	Scalability, Flexibility
Suitability	Critical components	Non critical components
Cost	High	Low
Latency	Low	High
Interference or Congestion	Minimal	Present

reliability. The wireless mesh network will consist of WiFi and 4G/5G technology. Utilizing WiFi access points within the mesh network extends wireless coverage, allowing seamless connectivity for various devices.

Our suggestion is to use fibre optic cables for the core network consisting of main intersections and the central control station. This is due to the reliability of the communication medium. However, due to its lack of scalability, we suggest having wireless access points connected to traffic lights and cameras in areas of less congestion as shown in Figure 4. The fibre optic cables would need to be placed along the road. We suggest placing the side or the middle as placing them underground would incur a large cost.

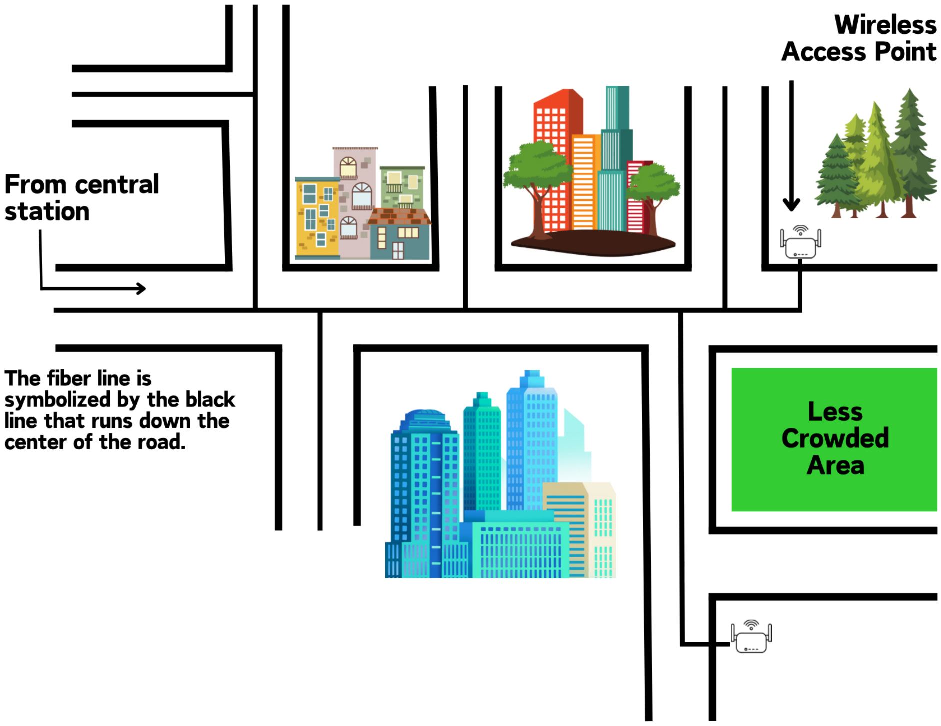

Figure 4: Use of fibre optic cables and wireless access points

5 Implementation

The implementation of this system can be broken down into the following sections.These would take place after conducting feasibility studies by an external agent and obtaining relevant approval for such a project.

1. Identification
   - Identify key intersections and road segments for installing traffic cameras
   - Identify key road sections to calculate traffic time
2. Development
   - Develop and fine-tune vision processing algorithms for analyzing traffic conditions captured by cameras.
   - Establish protocols for collecting real-time traffic data from cameras, sensors, and external APIs.
   - Implement mechanisms to handle data transmission errors and ensure data integrity.
   - Set up data logging mechanisms for storing historical traffic data in the centralized database.
   - Calculate suitable weights for the model's three inputs.
   - Implement algorithms for predicting traffic patterns and estimating future congestion levels based on historical data.
   - Develop user interfaces for system administrators to monitor traffic conditions, configure settings, and manage alerts.

3. Testing and Validation:
    - Conduct thorough testing of individual system components, including data collection devices, algorithms, and control mechanisms.
    - Perform integration testing to validate the interoperability of different modules and components.
    - Simulate various traffic scenarios to evaluate the system's responsiveness and effectiveness in managing congestion.
4. Pilot Deployment
    - Select a pilot area or route for initial deployment to assess the system's performance in a real-world setting.
    - Gather feedback from pilot users and stakeholders to refine system parameters and algorithms.
    - Monitor traffic to evaluate the effectiveness of the system.
5. Full-Scale Deployment
    - Gradually expand the deployment to cover additional intersections and road networks based on the success of the pilot phase.
    - Monitor traffic to evaluate the effectiveness of the system.
6. Ongoing Monitoring and Maintenance
    - Implement continuous monitoring of system performance and traffic conditions.
    - Set up automated alerts for detecting anomalies or system failures.
    - Establish a maintenance schedule for regular inspection, calibration, and repair of hardware components.
7. Continuous Performance Evaluation
    - Periodically evaluate the impact of the system on traffic congestion, travel times, and environmental factors.
    - Identify areas for optimization based on performance metrics and feedback.

As seen above, the implementation is not just a one-time process as the system needs to be continuously maintained and improved. Continuous improvements to the system are crucial and would also be beneficial in the future if fully self-driving cars became more popular and were legally able to drive themselves without a qualified driver.

6 Evolution of the System

This section covers the initial idea of the system and improvements made to the proposal.

6.1 Initial Model

The initial system proposed by us consisted of just cameras, a vision processing algorithm, and a central controller for controlling the traffic lights. This model faced the problem of not having a complete view of traffic and also the failure of the model in cases where situations like an accident occurred or roadworks were underway. As an example, consider the following scenario: The roads

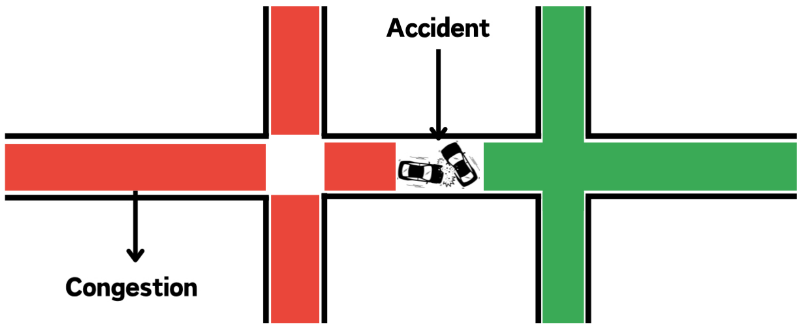

Figure 5: Traffic jam due to accident

marked here in red are the roads leading up to the collision and the roads marked in green are the roads leaving away from the collision. Additionally, the colours also represent the level of traffic along the roads, with red being high traffic and green being low traffic. Our initial model would see the traffic at the first junction on the left and try to clear all traffic towards the accident. This would cause more congestion along that road. Additionally, as the intersection on the right, less time would be allocated as the road leading up to it from the left wouldn't be busy. This in turn would cause congestion at the second intersection as well. This model suffered from the problem that it lacked data beyond an intersection.

Another problem would be when a road is closed. The traffic cameras would output the lack of traffic along that road and try to send as many vehicles as possible along that road. Therefore, the solution needs more information for more effective traffic management.

6.2 Addition of traffic API

In order to get a more holistic view of the traffic, we added a component to obtain data from traffic API services such as Google Maps. Obtaining data from such a service would give data to the system regarding places outside an intersection. In the above-discussed example. it would be possible to get data about the road where the accident took place and hence adjust traffic light timings at the second intersection based on this data as well. It would also be possible to obtain data regarding road closures from Google Maps and hence divert traffic away from that road. Additionally, it would also be possible to manually enter data about a road closure. This was the new feature set added in the second model.

6.3 Addition of traffic database and prediction algorithms

The model discussed in the above section would fail when Google Maps data or traffic vision data was unavailable. To combat this issue, we added the database where usual traffic details are maintained. Additionally, communication protocols were also added to the central processing station to find out whether data from each three of these sources is available and adjust the weights based on availability. In the event of a failure in the communication media to the traffic lights, it was also proposed to add a module to the traffic lights to see if data was being received from the central controller. If not, it would have to keep using the previous values for the timing until a certain timeout and then revert to the default timing values.

6.4 Addition of driver indications to traffic lights

Even though the current model has access to whether there is an unpredicted delay along a road, there is no way to indicate to drivers to avoid that road. Drivers would have to check on their phones if there is an unusual delay which is unsafe. Therefore, we propose adding indications to traffic lights telling drivers to avoid a certain road. These can be simple indicators such as a cross over a green light discouraging drivers from using that road.

7 Conclusion

In conclusion, this system proposes a proactive solution to urban traffic congestion by utilizing advanced communication technology, real-time data analysis and vision processing. The proposed project has the potential to revolutionize traffic management for a more efficient, safer, and environmentally friendly transportation network.

8 References

1. Wang, Chao. (2010). The relationship between traffic congestion and road accidents: an econometric approach using GIS. 10.13140/RG.2.1.3180.0087.

2. Sharmilaa, G., & Ilango, T. (2022). Vehicular air pollution based on traffic density - A case study. Materials Today: Proceedings, Volume 52, Part 3.

3. A. Hazarika, N. Choudhury, M. M. Nasralla, S. B. A. Khattak and I. U. Rehman, “Edge ML Technique for Smart Traffic Management in Intelligent Transportation Systems,” in IEEE Access, vol. 12, pp. 25443-25458, 2024, doi: 10.1109/ACCESS.2024.3365930.

4. N. Nishanthan, K. Thiruthanigesan, and P. Georgakis, “Towards the Development of Intelligent Transportation Systems in Sri Lanka,” International Journal of Scientific & Technology Research, vol. 6, 2017.