CSAI 498 / CSAI 499 – Graduation Project Proposal

- **GitHub link**:https://github.com/ranna-waleed/sumoflow-ai-traffic-optimization)
- **Project Title:** SUMOFlow AI: AI-Driven Traffic Optimization for Next-Generation Smart Cities: A YOLO-SUMO Integration Approach
- **Team Members:**

Student Name	ID	Program
Rana Waleed Gindy	202201737	DSAI
Roaa Raafat	202202079	DSAI
Mariam Alhaj	202200529	DSAI

- **Supervisor**: DR. Mohamed Maher
- **Semester / Year**: Fall 2025
- **Date of Submission**: Week 6 (10/25/2025)

Abstract

The congestion of cities and highways is a massive and costly transportation challenge that generates burdens on contemporary metropolises in terms of billions of lost productivity, huge wasted energy, and the explosion of urban carbon dioxide (CO_2) emissions. The entire problem is that classic fixed-time traffic lights cannot dynamically adapt to the changing flow patterns, this project proposes SUMOFlow AI, an intelligent traffic manager system to the optimization of signal timing through a combination of real-time computer vision and optimization theory. Our method takes YOLO (You Only Look Once) to be able to detect and count the number of vehicles based on simulated video streams. The above information instantly feeds a multi-objective fitness (minimizing vehicle delay and CO_2 emissions) to be solved by nature-inspired optimization algorithms, like Genetic Algorithms (GA) or Particle Swarm Optimization (PSO) running on a SUMO (Simulation of Urban MObility) environment.This innovation is that they establish a real-time feedback loop between the traffic control system and a multi-objective fitness. Our goal is to obtain a tangible decrease in the average vehicle waiting time and carbon emissions in respect to conventional fixed-timing systems and deliver to the city planners a solid, fact-based, and eco-friendly solution.

Problem Statement & Motivation → (SO 1)

The real-world problem is non-adaptive traffic light control which is inefficient and expensive to the environment. An urban traffic jam is a significant structural breakdown that has cost the developing economies billions of dollars of wasted productivity and also a major pollutant of air. Traffic lights that are fixed in time are non-adaptive in nature. They work by historical averages and do not consider spontaneous events, dynamic pattern of flows and the immediate density of traffic. Such inflexibility leads to undue delays, road rage among commuters, and a colossal wastage of fuel as a result of long periods of idleness. The elevated localized CO_2 emissions have direct influence on the quality and health of the local people living near big cross-intersections, and the economic drain has the overall effect on all commuters and the operation budgets of all the municipalities. The issue is relevant and is worth resolution since the fast development of AI computer vision (YOLO) and nature-inspired optimization offers a newer and advanced solution that can help to achieve real-time situational awareness. Our project in particular aims at maximizing efficiency (waiting time/throughput) as well as the environment (emissions) which is a very essential solution that is green and will be used in the next generation smart cities.

Proposed Solution → (SO 1 & SO 2)

The Proposed solution is SUMOFlow AI, a hybrid AI-based traffic control system developed in the environment of the SUMO simulation and integrated three main elements:

- **YOLO** (You Only Look Once): It is a vehicle detector and counter applied in simulated video streams and provides high-density data in real-time and with accuracy and low latency.
- **Nature-Inspired Optimization** (e.g., GA, PSO): These algorithms are used as the logic of the core to identify the most efficient dynamic timing plan of traffic lights. Their fitness operation is multi-objective and aims at reducing the average vehicle waiting time and CO_2 emissions at once.
- **Real-Time Feedback Loop** (The Innovation): The most important innovation is the close integration. The features (current queue length, density) that are to be used in the decision making process of the optimization algorithm are the real-time detection output of YOLO, which is an immediate input in each time step of the simulation. This enables the system to learn and dynamically adapt its signal policy, which is a major improvement over reactive systems or fixed-policy systems which are pre-trained.

This data-driven, adaptive solution will be strictly tested by measuring its performance against a conventional fixed-timing system on key metrics and prove the superiority of the methodology.

Project Scope → (SO 2)

In Scope:

- Creating a SUMO model of a simulated intersection of a few cities.

- Autonomous vehicle recognition on simulated video streams (generated by SUMO) using YOLO.

- Application and benchmarking of nature optimised algorithms in signal control.

- Evaluating the effect of systems on efficiency and emissions of traffic with fixed-timed signals.

- Detailed description of methodology, results and discourse.

Out of Scope:

- Physical implementation or integration with actual road infrastructure or city networks.

- Development of in-the-field hardware (sensors, actuators).

- Integration of the solution to the existing municipal traffic systems.

- Processing of live or real-time camera feeds from actual intersections.

Assumptions & Limitations:

- Assumption One (Simulation Fidelity): SUMO simulator is capable of simulating the physics and behavior of vehicles, as well as their emissions, in the real world to be used in comparative analysis.

- Assumption Two (YOLO Performance): The YOLO model can reach a high minimum accuracy and low latency with the input data consisting of simulated traffic data so as to deliver credible real-time traffic density characteristics.

- Limitations: The testing of the model is only done on a simulated single intersection topology and is not expected to scale to an actual city wide network within the project time frame.

High-Level Timeline → (SO 2)

Phase	**Description**	**Duration** (weeks)	**Deliverables**
Research & Requirement Analysis	Research on AI-controlled proxies and traffic control	Weeks 1–2	Document of summary of research and requirement specification.

	systems Code Learn SUMO environment Characterize system requirements.		
Design & Planning	Layout of Design SUMO simulation and YOLO integration plan and optimization algorithm architecture.	Weeks 3–5	System architecture diagrams and project plan.
Implementation Part 1	Apply vehicle detection in YOLO and SUMO configuration with baseline fixed-time control.	Weeks 6-10	SUMO simulation environment and functional YOLO model.
Testing & Evaluation	Compare the model suggested with the fixed-timing system based on the established measures of success (waiting time, CO2 emissions, throughput).	Week 11-14	Results of performance evaluation and analysis charts.

Technology Stack & Theoretical Basis → (SO 6 – Program Specific)

Technology	**Purpose**	**Justification**	**Program Focus**
SUMO (Simulation of Urban MObility)	Simulate real-world traffic flow and emissions	Gives realistic and customizable traffic flow and emission simulation.	**DSAI / SWD**- Simulation and performance analysis- Model based.
YOLO (You Only Look Once)	Detection of vehicles and information about traffic.	real-time object identification to get the accurate numbers of traffic.	**DSAI** - A computer vision based on deep learning.
Python	SUMO integration and development of algorithms.	AI/optimization libraries, and SUMO API compatibility	**SWD**-System integration, implementation.

PyTorch	YOLO application, training of the model.	Powerful ML/DL library with robust support for YOLO architectures.	**DSAI**–AI model development
Matplotlib/Seaborn	Visualization of results and trends	Plotting performance indicators to study.	**DSAI** - Data report and data visualization.
Nature-Inspired Algorithms	Core Optimization Logic	Algorithms, which are efficient in locating near-optimal, dynamic signal timing plans in response to real time traffic input.	**DSAI** - Intelligence and control systems.

Success Metrics & Evaluation Plan → (SO 2 & SO 6)

The dynamic SUMOFlow AI system will be evaluated based on success against a conventional fixed-timing benchmark in different scenarios involving traffic.

- Decrease in the Average Vehicle Waiting Time: The primary indicator of traffic effectiveness will be the average waiting time of vehicles at the intersection. The target is to show a statistically significant decrease, aiming for at least a 25% reduction in average waiting time compared to the fixed-timing baseline under moderate to high traffic scenarios.

- Decline in the Total Carbon Dioxide Emissions: An important environmental indicator, which is calculated as the total amount of carbon dioxide that has been emitted throughout the simulation period. The goal is a measurable decrease, targeting at least a 15% reduction in total CO_2 emissions compared to the baseline when operating under moderate to high traffic conditions.

- Throughput Consistency Improvement: This is the number of vehicles transported across the intersection in an hour and this indicates the flow rate that remains stable and is enhanced with more reliability through an increment in the throughput regardless of traffic levels.

- Model Accuracy and Reliability: Test of the YOLO detection module to determine that it can be highly accurate in analyzing the video frames on the simulated environment.

- Performance Evaluation: The performance of the proposed model and the fixed-timing baseline will be evaluated by running a series of randomly selected traffic scenarios (varying volumes and turn ratios). The statistical significance of the observed performance improvements will be done with the help of a statistical analysis of the results.

Team Roles & Responsibilities → (SO 5 & SO 3)

Team Member	Program	Primary Role	Technical Contribution (SO 6 Focus)
Rana Waleed	DSAI	YOLO integration & system design	Computer vision model and integration
Roaa Raafat	DSAI	SUMO setup & data interface	Environment setup and baseline design
Mariam Alhaj	DSAI	Optimization model & performance tracking	Nature-inspired algorithm development

Communication Plan:

- Meeting Schedule: Team meetings every week, either on a Tuesday or Wednesday, on a Zoom. Duration: 1-2 hours per session. Progress reports to the supervisor on a weekly basis.

- Tools and Platforms: Zoom (Online meetings), GitHub (Version control, code repository and task tracking through Issues/Projects), Google Docs (Shared documentation, meeting minutes and drafting reports), and WhatsApp (Daily quick communication and updates).

- Documentation Strategy: After every session, meeting notes were documented in Google Docs. Commit messages at Github should be descriptive.

- Teamwork Structure: The branching approach of GitHub will implement a main branch protection that will enforce all mergers to undergo code review by at least one other team member. The feature development will be done on a feature branch.

REFERENCES

[1] "SUMO Documentation," German Aerospace Center (DLR), Institute of Transportation Systems. [Online]. Available:https://sumo.dlr.de/docs/index.html. [Accessed: Oct. 25, 2025].

[2] "YOLO Documentation - Ultralytics," Ultralytics, 2024. [Online]. Available: https://yolo-docs.readthedocs.io/en/latest/. [Accessed: Oct. 25, 2025].

[3] "Python 3 Documentation," Python Software Foundation, 2025. [Online]. Available: https://docs.python.org/3/. [Accessed: Oct. 25, 2025].

[4] "PyTorch Documentation," PyTorch Foundation, 2025. [Online]. Available: https://pytorch.org/docs/stable/index.html. [Accessed: Oct. 25, 2025].