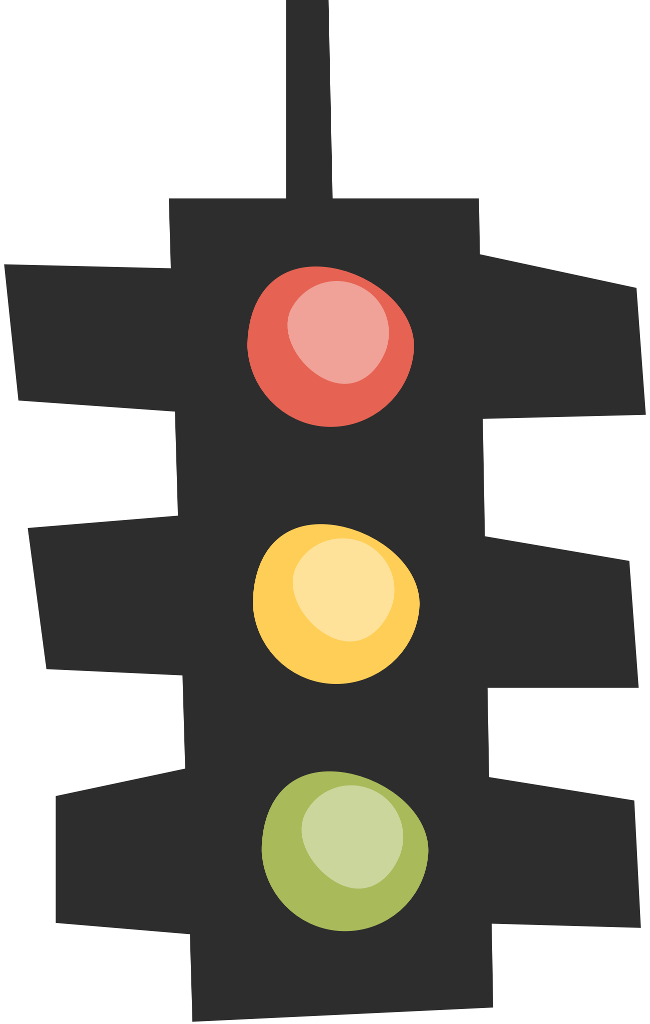


BRAUDE
College of Engineering, karmiel

Innovating Traffic Control – Smart Traffic Lights Powered by Digital Twin Models

Advisor :
Mr. Uzi Rosen

Amni Abo Samra
Hamza Abu Nimer

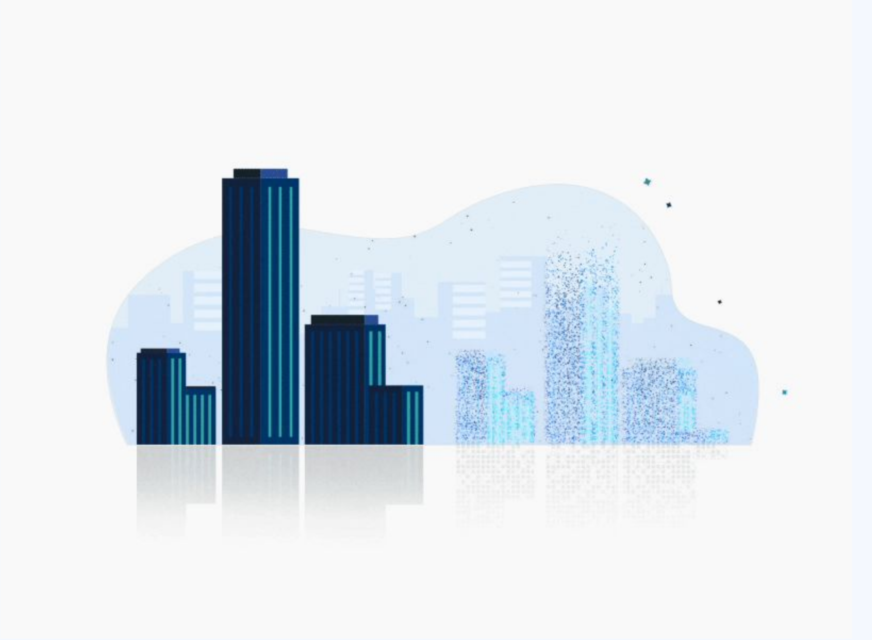
Digital Twin Technology

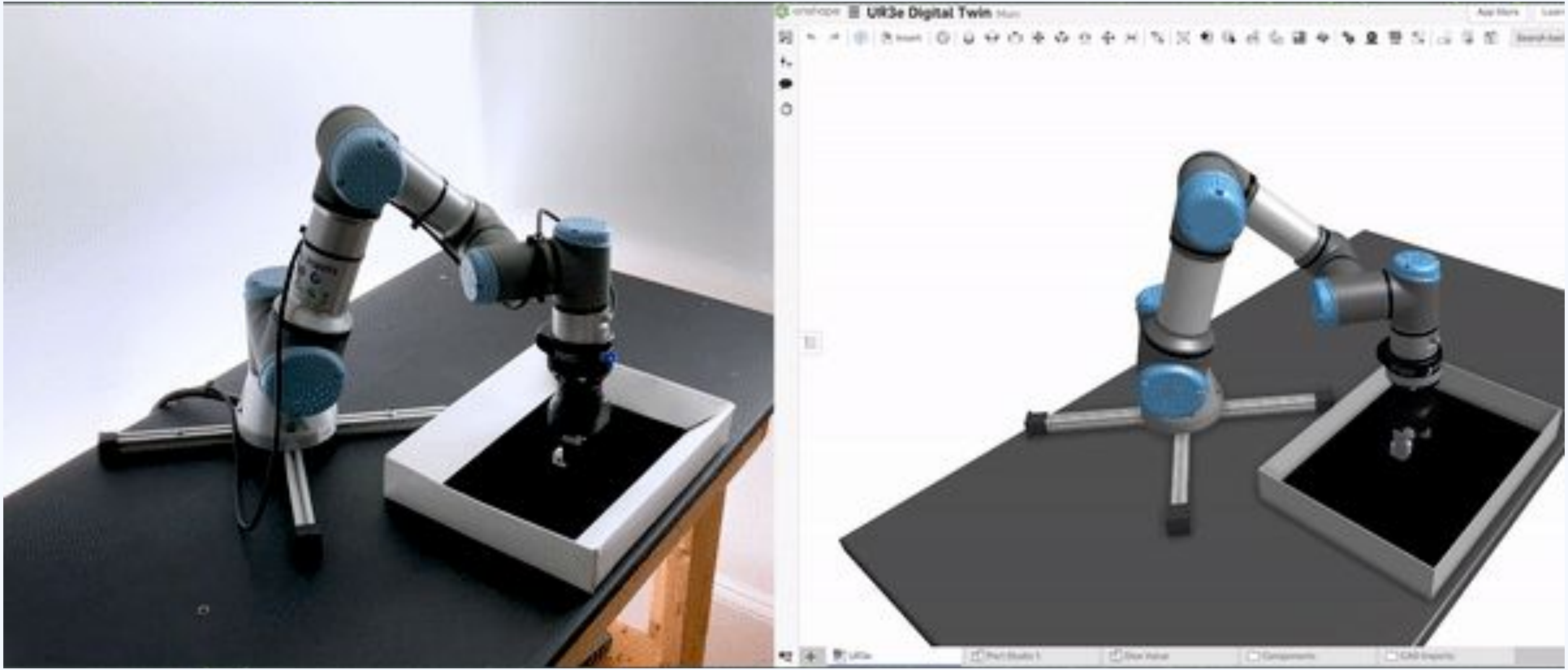
Digital Twin: A Live Virtual Mirror

A digital twin is a virtual model of a real-world object, system, or process. It continuously updates using data from sensors and other sources to reflect real-time conditions.

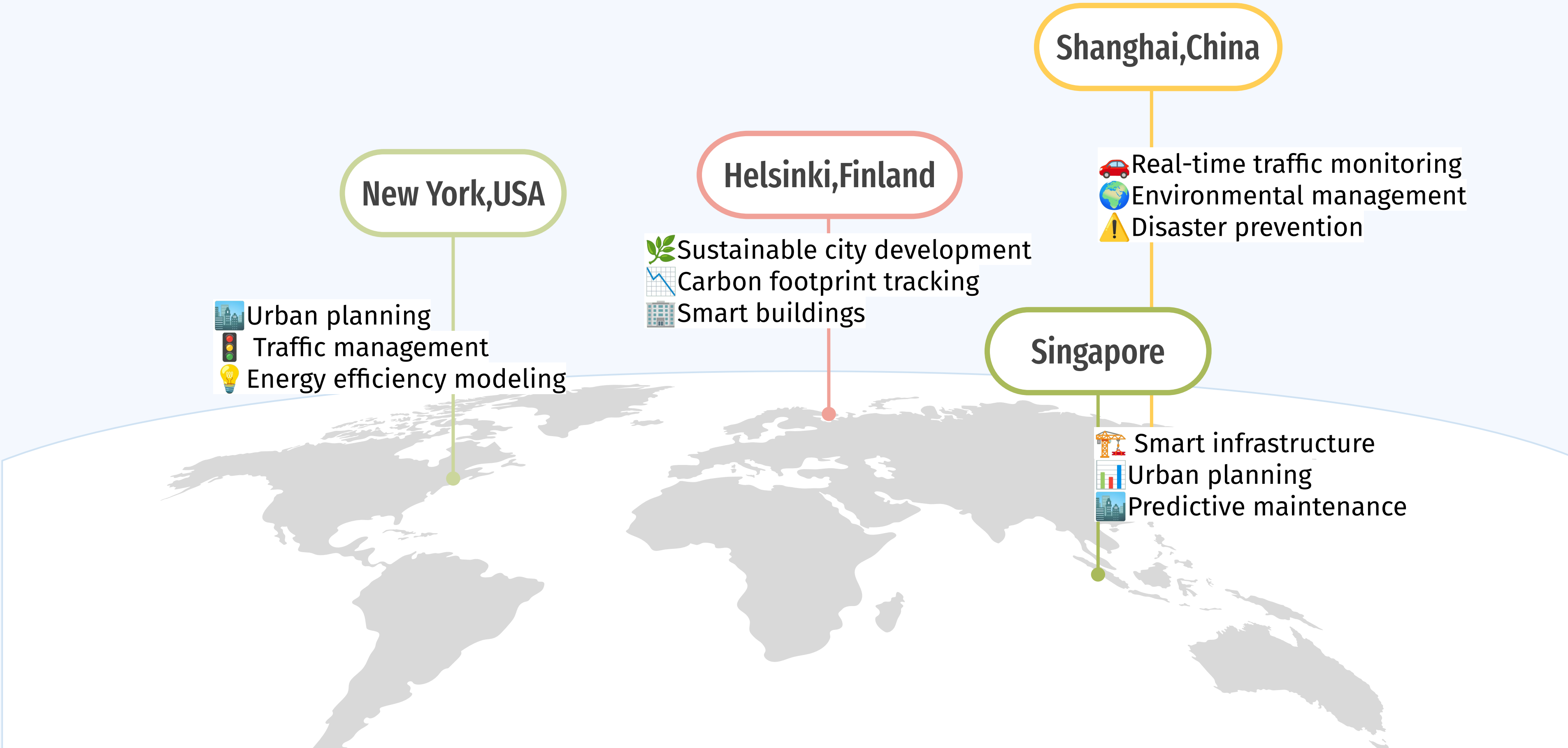
How it Works

1. **Data Collection:** Sensors and devices collect real-time information.
2. **Simulation:** The system analyzes and models behavior in a digital environment.
3. **Bi-Directional Flow:** Updates in the real world are reflected in the digital model, and insights from the model help improve real-world decisions.




UR3e Digital Twin

Leading Cities DT Implementations



Why Traffic Management

🚦 Traffic Congestion & Pedestrian Safety

- Every day, drivers experience long delays due to inefficient traffic management.
- Pedestrians struggle with unsafe crosswalks and extreme weather conditions, making city travel difficult.

🔧 Feasibility & Implementation

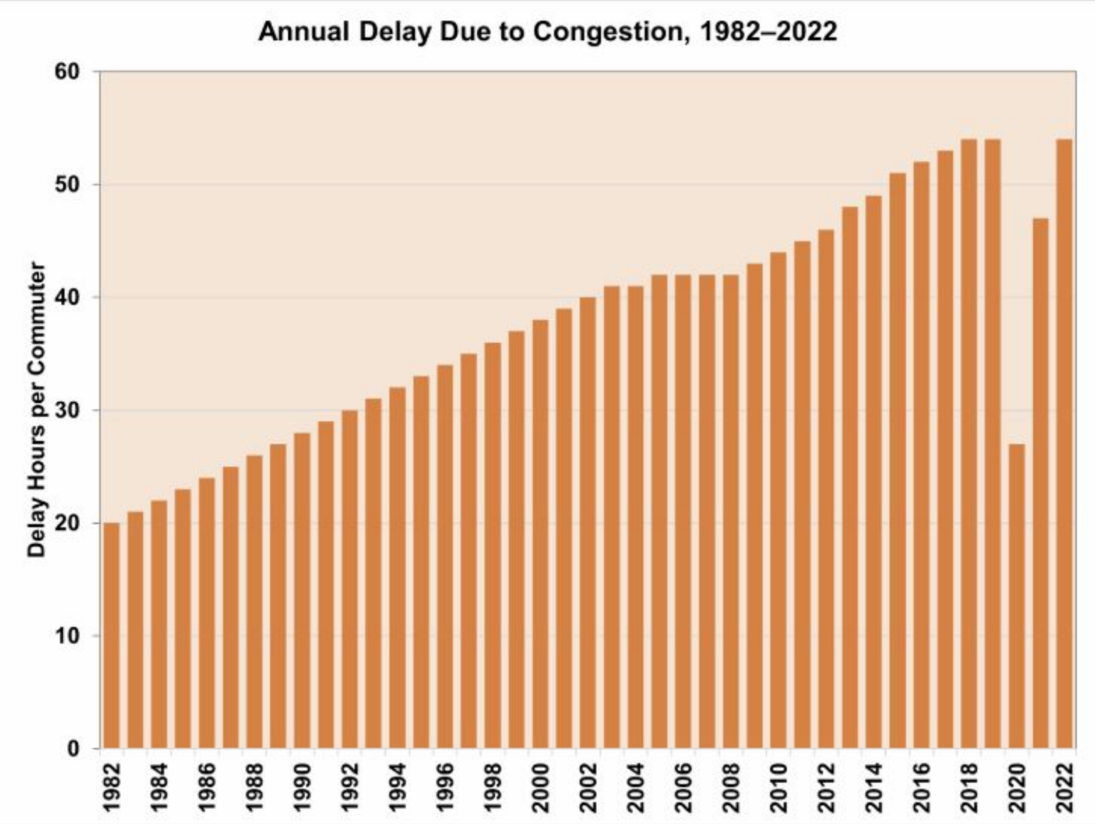
- The physical model is relatively simple to build, making it a practical and scalable solution.
- Advances in AI, IoT, and Digital Twin technology make adaptive traffic control more achievable than ever.

Annual Traffic Delay Due to Congestion (US)

Traffic congestion delays reached **54** hours per commuter in 2022, emphasizing the impact of inefficient traffic signal timings.

Poorly optimized traffic lights lead to:

- Longer wait times at intersections.
- Increased fuel consumption due to idling.
- Higher vehicle maintenance costs from stop-and-go traffic.



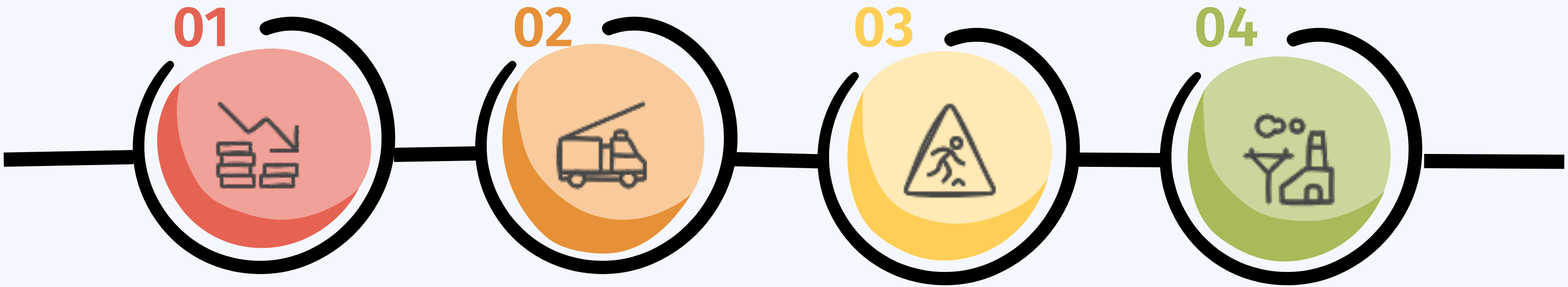
The Need

Economic losses

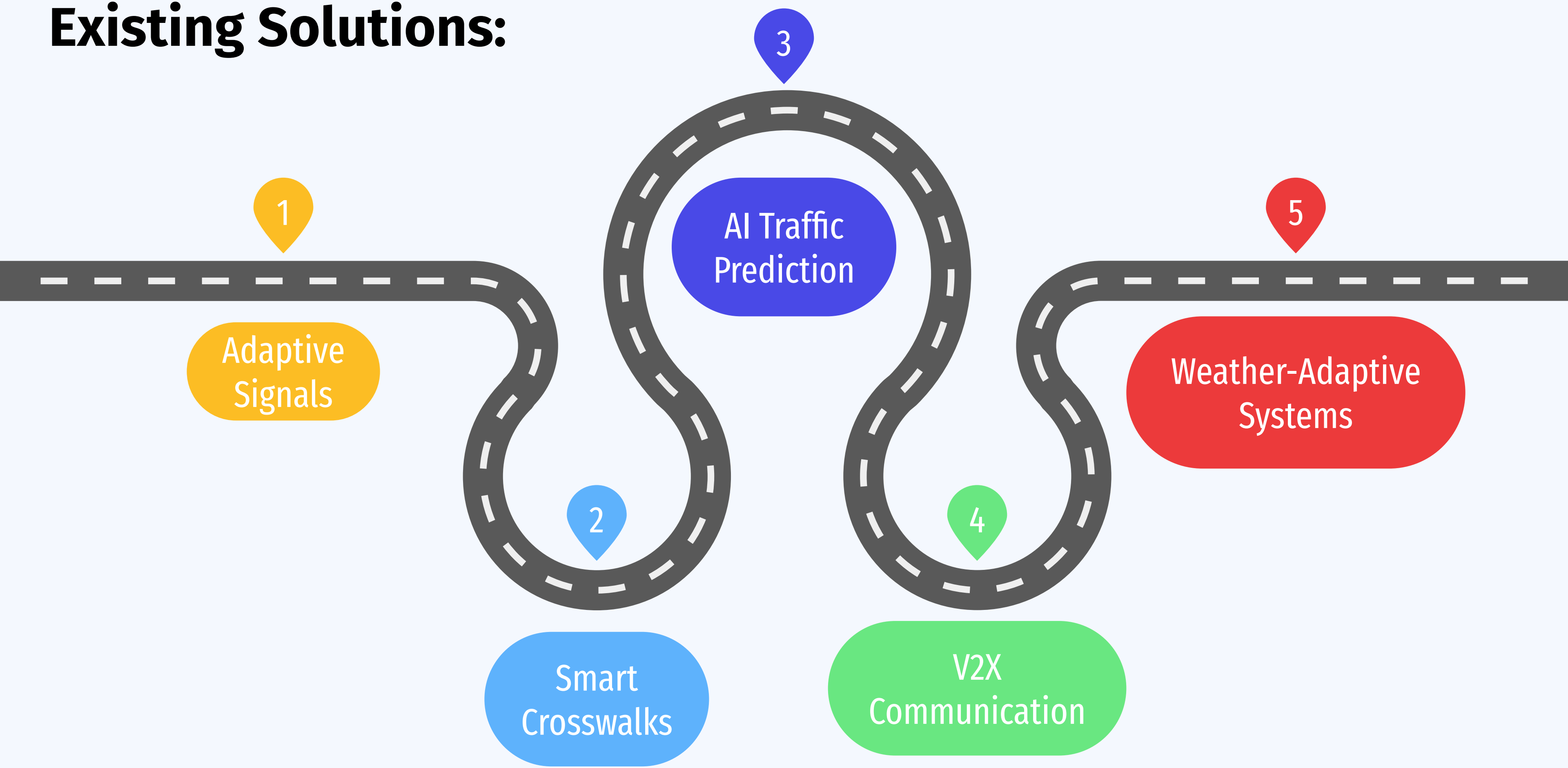
Emergency Response Hindered

Public Safety Concerns

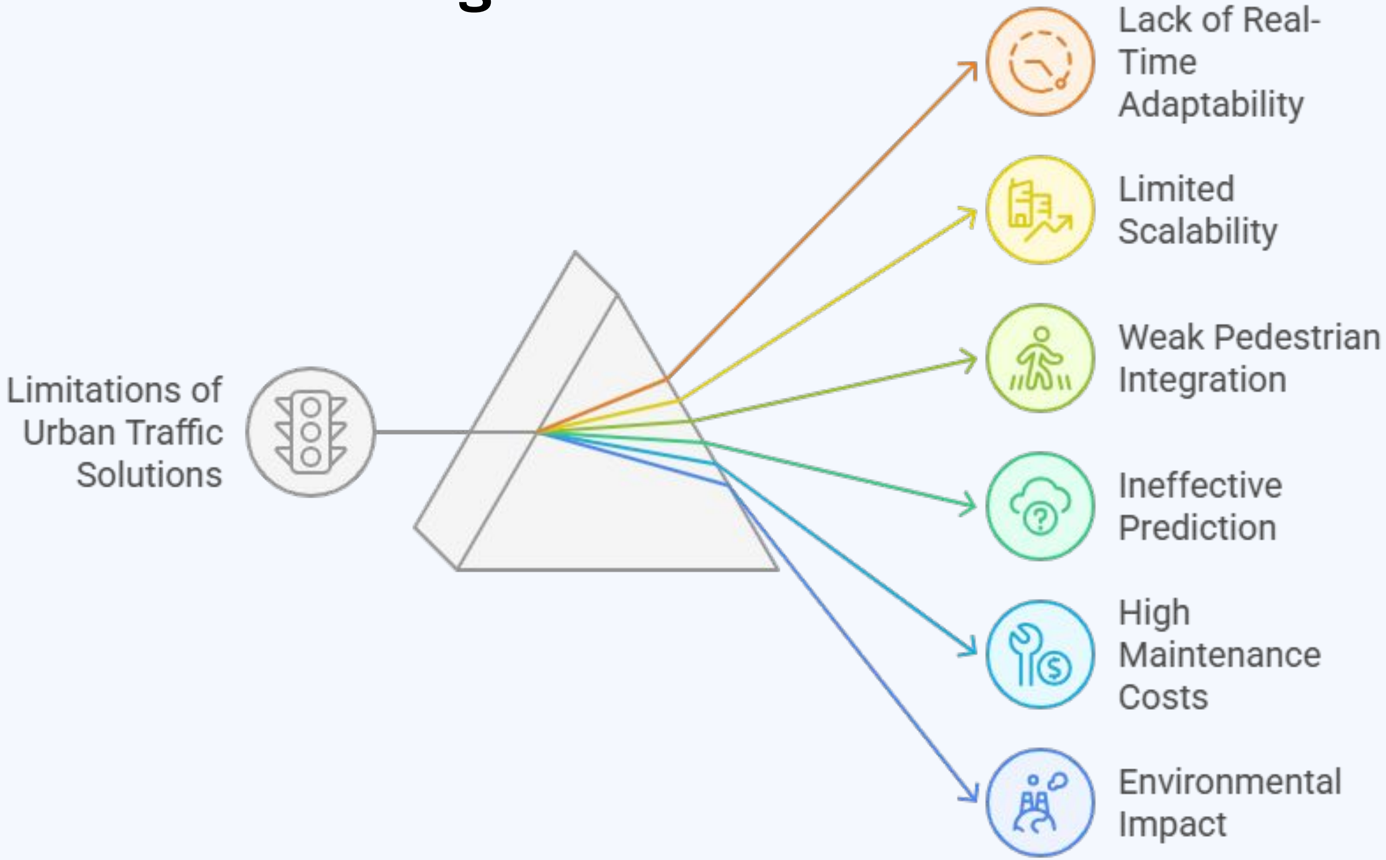
Environmental Harm



Existing Solutions:



Limitations in Existing Solutions



Proposed Solution

🚦 Digital Twin-Based Adaptive Traffic System

🔹 Real-Time Signal Adjustments – Uses AI and IoT to continuously monitor and optimize traffic flow.

🔹 Predictive Simulations – Analyzes data trends to prevent bottlenecks before they happen.

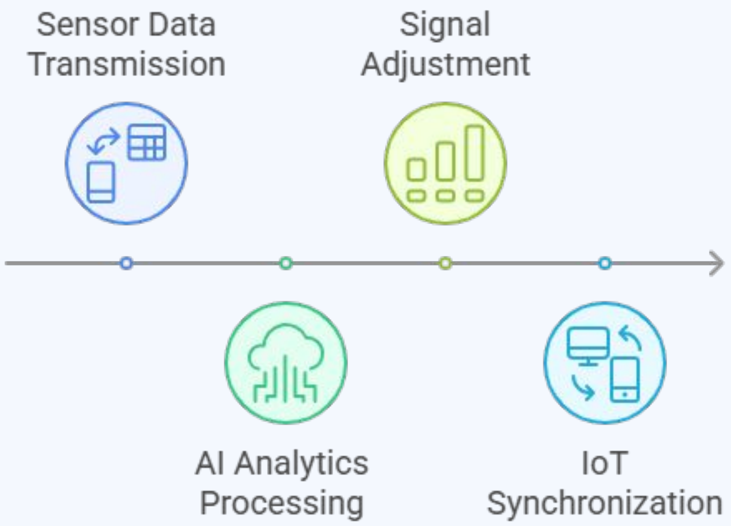
🔹 Pedestrian & Emergency Priority – Smart crosswalks and priority lanes for safety and fast emergency response.

📊 How It Works

📡 Continuous Data Exchange – Sensors send real-time updates to a virtual traffic model.

📉 AI-Powered Analytics – Forecasts congestion and dynamically adjusts signals.

🔗 IoT & Smart Connectivity – Syncs multiple intersections for smoother city-wide flow.



System Architecture and Components

Digital Twin Integration:

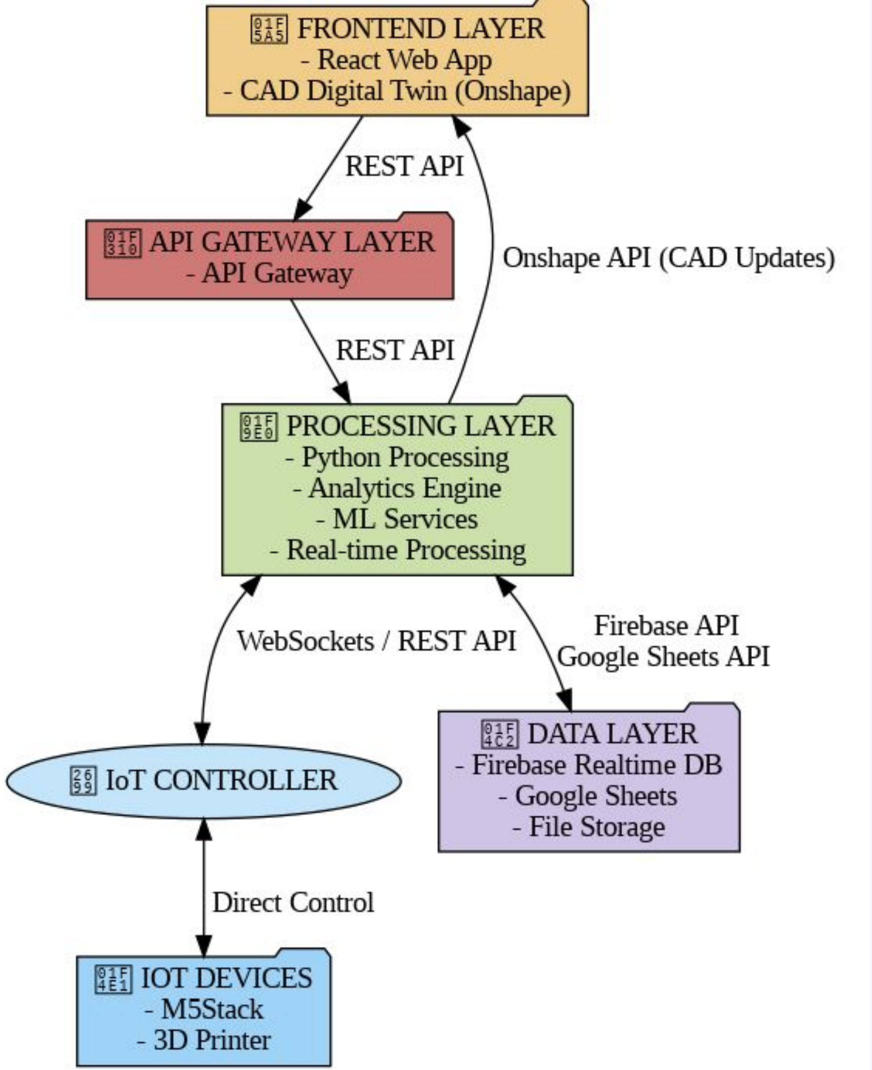
- Data Synchronization via REST APIs
- Digital Twin in Onshape

Web Interface for Monitoring:

- System Data (Traffic, Weather, Alerts)
- Dynamic Web Page Visualization
- User Interaction

Physical Model

- Small-Scale Simulation



What we aim to achieve

🚦 Optimize Traffic Flow – Reduce congestion with real-time adaptive signals.

🚶 Enhance Pedestrian Safety – Implement smart crossings for safer mobility.

🌍 Reduce Environmental Impact – Minimize idling and emissions with AI-driven traffic

Criteria for success

Criterion	Weight (%)	Success Measure
Simulation Accuracy	25%	Ensure at least 90% alignment between real-world data and digital twin predictions.
Real-Time Response	25%	The system updates and adjusts signals within 2 seconds of traffic changes.
Scenario Testing	20%	The system successfully simulates and analyzes at least 5 different traffic changes.
User Experience	15%	90% of users find the system easy to use and understand.
System Responsiveness	15%	Minimize manual interventions by 80%

- Criterion: The key performance areas used to evaluate the system's success.
- Weight (%): The relative importance of each criterion in the overall evaluation. Higher weight means greater significance.
- Success Measure: The specific, measurable target that defines success for each criterion.

Development Challenges And Solutions

Data Integration and Accuracy

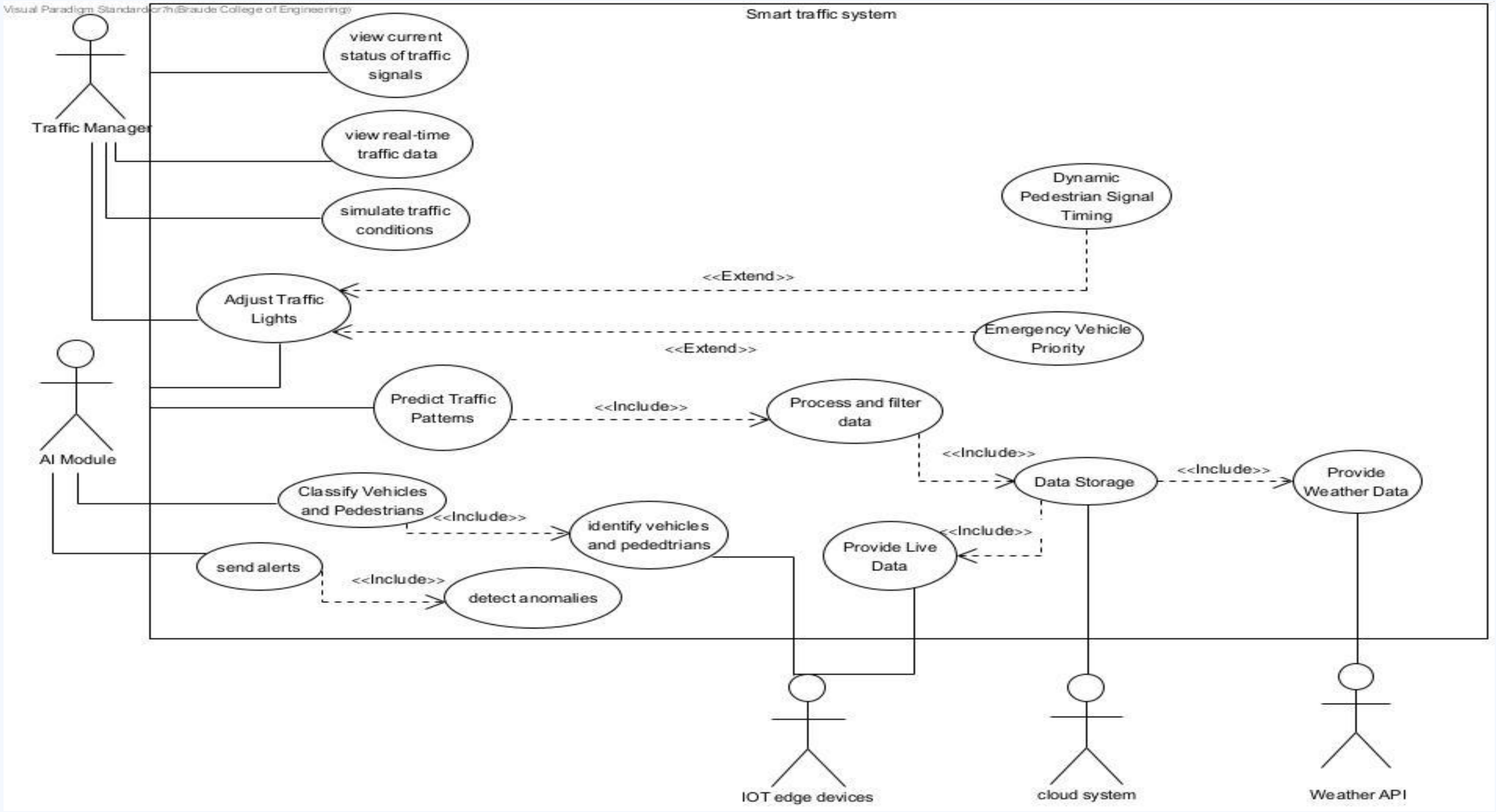
Traffic Flow Simulation Issues

AI Model Adaptation Challenges

Functional and Non-Functional Requirements

Functional Requirement	Non-Functional Requirement
The system allows real-time traffic monitoring and manual signal adjustments.	Performance – Traffic data updates ≤ 500ms, UI response time ≤ 1s.
The system allows AI-based traffic prediction and dynamic signal adaptation.	Reliability – System uptime must be ≥ 99.9%.
The system allows emergency vehicle detection, automatic signal adjustments, and anomaly alerts.	The system supports seamless upgrades with ≤ 5 min downtime.

Use Case Diagram



IoT Devices Used in the Smart Traffic System

Sensors and controllers	Function	Placement	Image
M5Stack Core2 Controller	Acts as the main IoT hub, managing sensors and transmitting data to the cloud.	Installed near the traffic light controller.	
Mini Camera (UnitV K210 AI Camera)	Captures real-time images and detects vehicles and pedestrians	Positioned at the center of the intersection.	
Weight Sensors (Weight I2C Unit)	Identifies vehicle types and monitors road load to optimize traffic light timing.	Embedded in road lanes.	
Ultrasonic Sensors (Ultrasonic Distance Unit I2C)	Measures vehicle gaps and queue lengths for traffic flow analysis.	Placed near intersections.	

AI Modules & Machine Learning for Smart Traffic Lights

Traffic Prediction Models:

- ARIMA & Linear Regression – Predict traffic volumes using historical and real-time data, allowing for timely and adaptive traffic signal adjustments.

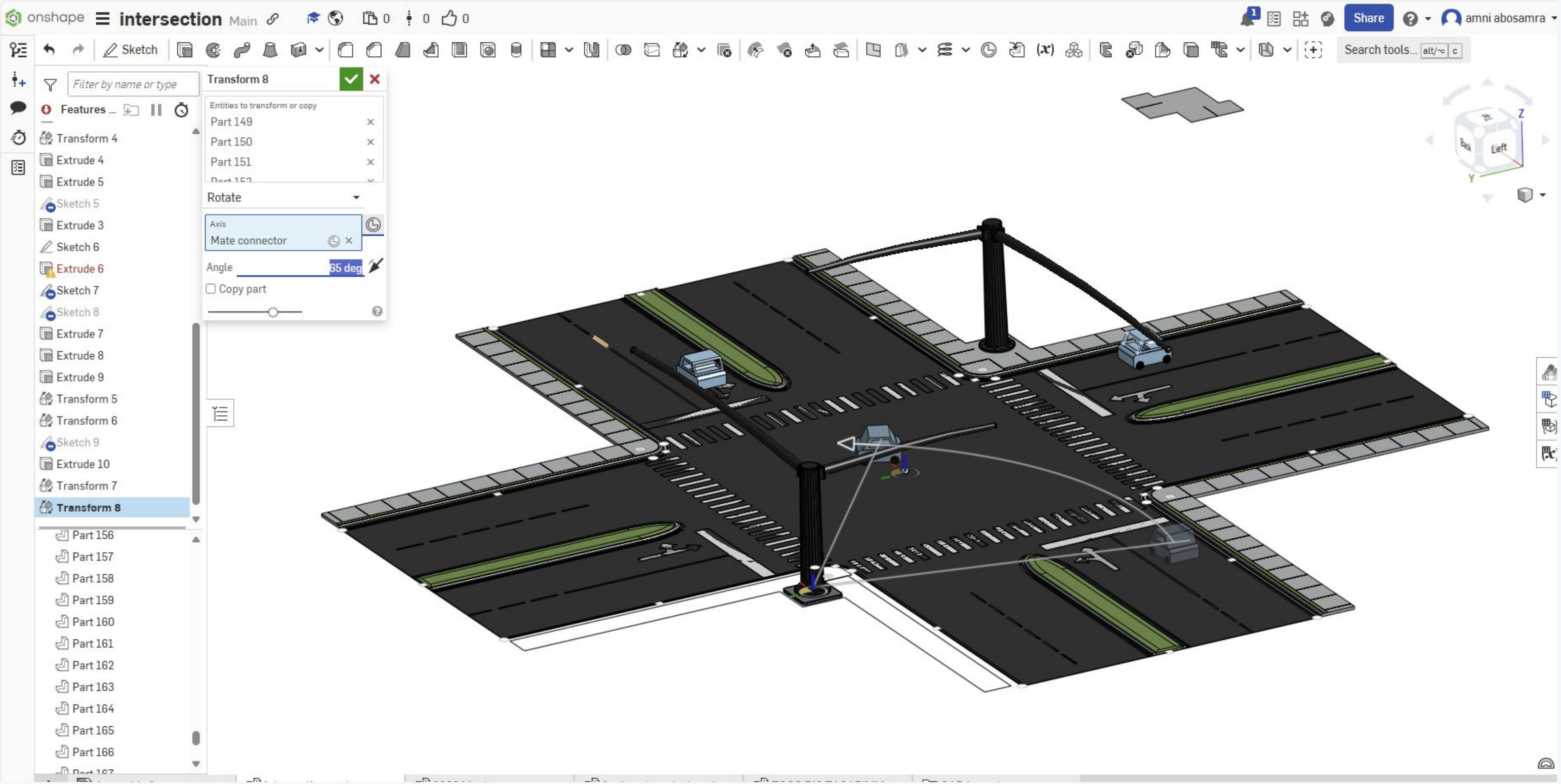
Vehicle & Pedestrian Detection Models:

- Haar Cascades & HOG + SVM – Detect vehicles and pedestrians at intersections, enabling the system to dynamically adjust signal timing based on real-time activity.

Optimization & Anomaly Detection Models:

- Rule-Based Systems & Genetic Algorithms – Evaluate different traffic signal configurations and apply the most efficient timing strategy.
- Z-score & k-Means Clustering – Identify anomalies in traffic patterns by detecting unexpected congestion or sensor malfunctions, ensuring system reliability.

Onshape Simulation

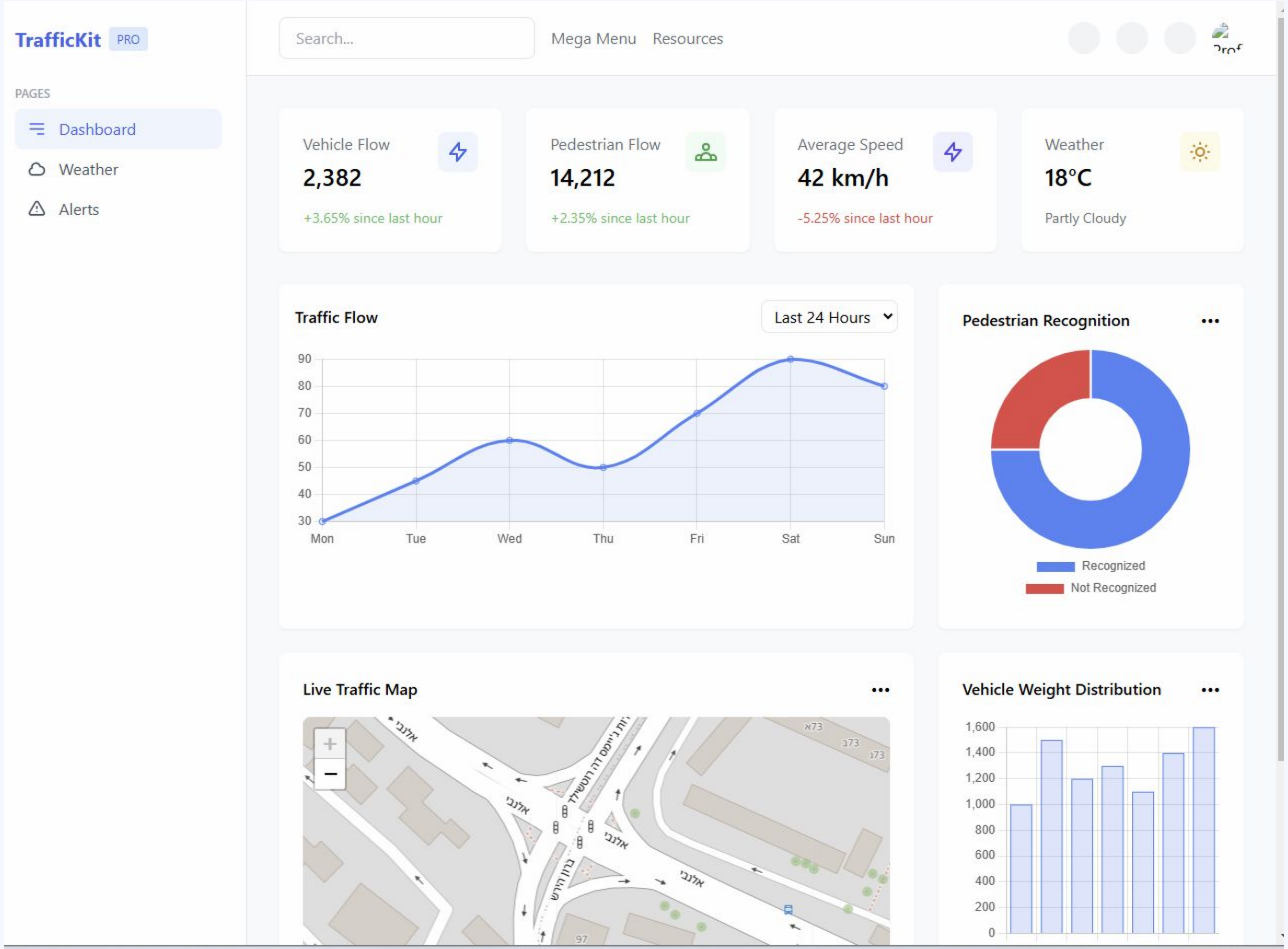


Web Interface

The web interface serves as the central platform for monitoring and managing the smart traffic system. It provides:

- **Real-time traffic data visualization** – Displays live updates on vehicle and pedestrian movement.

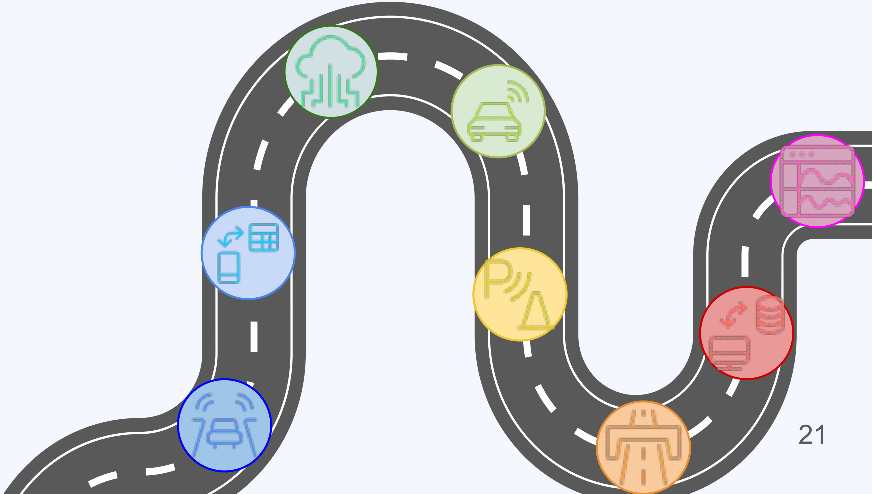
- **System alerts** – Notifies operators of anomalies, congestion, or emergency situations.



Development and Execution Plan 

Workflow:

1. IoT Integration: Collecting real-time traffic and environmental data.
2. AI Model Development: Using reinforcement learning for dynamic signal adjustments.
3. Simulation & Testing: Simulating traffic scenarios in Onshape.
4. Implementation & Optimization: Deploying in real-world intersections.



Testing & Verification

Testing Phases:

- IoT Sensors & Data Collection – Ensuring sensor accuracy.
- AI Traffic Prediction & Optimization – Validating machine learning performance.
- Web Application & Onshape Integration – Ensuring seamless data synchronization.

Test Cases 

Test	Function	Expected Result
Vehicle Detection	IoT Sensors	Accurate vehicle detection (≥95%)
Pedestrian Detection	IoT Sensors	Detect pedestrians in all lighting conditions
Traffic Prediction	AI Model	Predict congestion with >85% accuracy
Real-Time Updates	Web Application	UI updates in <1s

Summary and Conclusion

In conclusion, our project is centered around demonstrating Digital Twin technology in smart traffic management.

- We showcase how real-time digital simulations can mirror and optimize actual traffic conditions.
- By integrating IoT, AI, and Digital Twin, we provide a scalable and future-ready solution for urban mobility.

Thanks!

Do you have any questions?

References :

1. U.S. Department of Energy. (2024, September 2). *Average commuter experienced 54 hours of delay due to traffic congestion in 2022*. https://www.energy.gov/eere/vehicles/articles/fotw-1358-sept-2-2024-average-commuter-experienced-54-hours-delay-due?utm_source=chatgpt.com
2. Traction Technology. (2024, September 2). *Traction Five: How AI is revolutionizing traffic management*. https://www.tractiontechnology.com/blog/traction-five-how-ai-is-revolutionizing-traffic-management?utm_source=chatgpt.com
3. INRIX. (2024). *Scorecard: Download the full report*. https://inrix.com/scorecard/#form-download-the-full-report
4. The Sun. (2024, September 2). *Traffic AI: LYT and the future of smart cities*. https://www.the-sun.com/motors/13134325/traffic-ai-lyt-laramie-bowron/?utm_source=chatgpt.com
5. PubMed. (2012). *Traffic congestion, on average, resulted in a delay of 54 hours per commuter*. https://pubmed.ncbi.nlm.nih.gov/22883716/#:~:text=Traffic%20congestion%2C%20on%20average%2C%20resulted,device%20in%20their%20emergency%20vehicles.
6. Friedman, B. (n.d.). *What is the leading cause of intersection accidents?* Blake Friedman Law. https://blakefriedmanlaw.com/what-is-the-leading-cause-of-intersection-accidents/#:~:text=Types%20of%20Intersection%20Accidents,-Intersections%20come%20in&text=According%20to%20the%20National%20Highway,roads%20cross%20and%20traffic%20converges.
7. Li, C., & Liu, X. (2012). An analysis of traffic congestion and its impact on the environment. *Journal of Transportation Technologies, 2*(3), 248-259. https://doi.org/10.4236/jtts.2012.23027
8. National Public Transport Authority. (n.d.). *External costs of road transport*. Israel Government Portal. Retrieved [Month Day, Year], from https://www.gov.il/en/pages/external_costs_of_road_transport