SustainCity:
The Future of Adaptive Urban Movement
v 1.0.1

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Contents

1   The Project and Its Goals

The following describes the **SustainCity** project and its goals to be achieved, developed as part of the **Software Engineering for HPC** course. We structured this first section into three key parts:

- The **Preface**, introducing the broader environmental and urban challenges motivating this project.

- The **Problem Posed**, describing in detail the technical and society issues to be addressed.

- The **Project Goals**, outlining the core functionalities and expected outcomes.

Preface

Two urgent global concerns are environmental sustainability and climate change; because of air pollution and greenhouse gas emissions, transportation - especially urban commuting - worsens those issues.

The objective of the SustainCity project is to face urban mobility challenges through real-time traffic management, event-driven optimizations, and public transport coordination.

To address these concerns, the project integrates traffic monitoring, event planning, and transport analytics into an adaptive system capable of creating data-driven recommendations for real-time city infrastructure improvements.

Thanks to these system recommendations, urban commuting can be drastically reduced, improving both citizens' well-being and environmental sustainability.

Problem Statement

The **SustainCity** system aims to optimize urban traffic using three key strategies:

- **Real-time Traffic Optimization (Type1 Actions)** The system continuously adapts traffic light timings using real-time congestion data to optimize flow.

- **Long-term Traffic Pattern Analysis (Type2 Actions)** The system analyzes daily congestion patterns to recommend permanent adjustments, such as one-way street configurations, adaptive traffic signal schedules, and public transport optimizations.

- **Event-driven Traffic Management (Type3 Actions)** SustainCity monitors city event feeds (e.g., concerts, fairs, sports games) and adjusts road and transport infrastructure dynamically to reduce congestion during high-footfall gatherings.

Additionally, SustainCity generates **reports for urban planners and citizens**:

- **Daily Reports**: Summarizing average traffic flows and actions taken (Type1).

- **Yearly Reports**: Documenting major infrastructure proposals (Type2, Type3) and their implementation status (accepted/rejected).

To accomplish these goals, we can rely on the following elements:

- A preexisting infrastructure offering sensors that measure the number of seconds cars need to cross each intersection. This infrastructure is developed according to the event-based style. All sensors periodically publish the data they have acquired on a message bus.

- A microservice offering information about public transport schedules. In particular, this microservice offers the following operations:

  - **getScheduleByStreet**: Given the name of a street, it returns the timetable of all stops present on that street.

  - **getScheduleByLine**: Given the number of a specific line, it returns the complete timetable for that line.

- A news channel that transmits information about the events in the city as soon as they are planned.

Project Goals

Our main goal was to develop a software system that creates efficient, sustainable urban transport solutions by providing data-driven recommendations. Therefore, the document aims to meet two objectives:

- Ensuring all functional and technical requirements are met.

- Designing a scalable, efficient, and well-structured urban-mobility solution.

2 Requirement Analysis

2.1 Relevant Human and Non-Human Actors

Let's begin by examining the *human actors* involved in this system first:

- **Traffic Engineers** (Type1): They supervise and verify the correct functioning of the automatic traffic light regulation system. They take action in the event of malfunction, validate traffic management strategies, and analyze logs for future improvements.

- **Urban Area Manager** (Type1, Type2, Type3): They are responsible for overseeing urban infrastructure, long-term policies and constraints related to dynamic traffic light regulation. They also evaluate traffic optimization proposals and approve or reject recommendations related to traffic configurations, transportation scheduling, and road management. Their decisions directly impact the effectiveness of SustainCity's long-term strategies.

- **City Planners and Officials** (Type 1, Type2, Type3): Work alongside **Urban Area Managers** to assess traffic data reports, evaluate permanent infrastructure adaptations, and implement policy changes based on recommendations. They ensure that adjustments are in accordance with environmental and urban regulations. They may also be involved in the approval and monitoring of automated traffic regulation systems.

- **Citizens**(Type1, Type2, Type3): Although not actively involved in the system's technical workings, they are end-users who benefit from improved traffic conditions, congestion reduction, and optimized public transport schedules. They receive notifications through city mobility platforms, public dashboards, transport apps, and digital road signs.

On the other hand, there are also several *non-human actors* needed to ensure the system operates efficiently and delivers accurate data-driven insights:

- **Traffic Management System** (Type1, Type2, Type3): Acts as the core analytical component by collecting, processing, and interpreting data from various sources, such as traffic sensors. This actor continuously monitors daily traffic flows, identifies congestion hot spots, and detects recurring traffic patterns that could benefit from optimization.

- **Public Transport Microservice** (Type2, Type3): Provides comprehensive and real-time public transport schedules. By integrating

this microservice, the system can propose modifications to transport schedules, aligning them with identified traffic patterns to optimize commuter convenience and reduce congestion.

- **Sensors** (Type1, Type2, Type3): Physical devices deployed at intersections and major roadways; these actors gather real-time data about traffic conditions. Accurate and timely sensor data is foundational, enabling the system to analyze traffic patterns and propose meaningful optimizations reliably.

- **Event Monitoring System** (Type3): Detects and transmits event schedules (concerts, sports games, fairs), triggering event-driven traffic adjustments and real-time mobility recommendations. It works closely with the **Traffic Management System** and **Public Transport Microservice** to prevent congestion.

- **Notification System** (Type1, Type3): A critical component for disseminating structured reports and real-time alerts to all relevant actors. It ensures that traffic management decisions — whether real-time, event-driven, or long-term — are properly communicated to all relevant stakeholders.

3   Use Cases

The following use cases describe how the system interacts with traffic data, urban managers, and external events to achieve its objectives. Each use case type corresponds to a specific level of system autonomy and decision-making: Type1 actions are fully automated, Type2 involve semi-automated analysis with human validation, and Type3 relate to exceptional or event-driven scenarios requiring coordinated interventions. The use cases are organized into tables for clarity.

Type1 Use Cases

Use Case	Description
Real-Time Traffic Monitoring	The system continuously receives data from traffic sensors at key intersections, monitoring vehicle wait times and traffic density.
Traffic Flow Evaluation	The system evaluates sensor data to detect significant imbalances between intersecting roads, flagging potential congestion.
Dynamic Light Adjustment Decision	Based on thresholds or patterns, the system autonomously decides to alter green light durations using predefined rules or adaptive algorithms.
Actuation of Traffic Light Changes	Once a decision is made, the system dispatches updated timing configurations to traffic lights for short-term application.
Logging of Actions	All interventions are logged with timestamps, affected roads, and justification for transparency and audit.
Daily Report Generation	The system generates a daily summary of traffic trends and all Type1 interventions for stakeholders and public access.

Table 1: Type1 Use Cases

Type2 Use Cases

Use Case	Description
Traffic Pattern Analysis	The system processes daily traffic data to detect recurring congestion patterns, bottlenecks, or inefficiencies.
Suggest Optimizations	Based on analysis, the system recommends traffic light adjustments, road direction changes, and transit schedule modifications.
Review and Apply Changes	Urban area managers review and approve or reject system-generated suggestions, implementing selected actions.

Table 2: Type2 Use Cases

Type3 Use Cases

Use Case	Description
Event Classification	The system monitors official sources for events, categorizing them by size, location, and expected impact.
Traffic Disruption Forecasting	It predicts congestion using event data, historical trends, and real-time sensor input, enabling preemptive planning.
Dynamic Mobility Adaptation	The system adapts traffic lights, road usage, and public transport routes in response to forecasts.
Approval and Policy Coordination	Proposed actions are submitted to managers and city officials for validation and alignment with policy.
Public Engagement and Notification	Citizens are informed through mobile apps and dashboards about changes, alternate routes, and delays.
Post-Event Traffic Normalization	After events, the system restores standard configurations and analyzes effectiveness to improve future planning.

Table 3: Type3 Use Cases

3.1 Domain Assumptions

The correct operation of the system is based on the following cross-cutting assumptions, organized by thematic area and referencing the relevant use case types (Type1, Type2, Type3).

- *Sensor Infrastructure Reliability* (Type1, Type2, Type3): The system assumes that traffic sensors deployed across the city, especially at intersections and major roads, are consistently operational. These sensors provide essential real-time data for adaptive traffic light control (Type1), daily traffic pattern analysis (Type2), and congestion prediction during large events (Type3).

- *Autonomous Traffic Light Control* (Type1): The system is authorized to autonomously adjust traffic light timings based on real-time sensor data, without prior approval. These adjustments target immediate traffic imbalances and are the foundation for reactive traffic management.

- *Urban Area Manager Oversight* (Type2, Type3): Although the system can autonomously manage traffic lights, larger changes, such as reconfiguring roads or updating public transport schedules, require approval from urban area managers. Their role ensures that data-driven suggestions align with long-term urban planning.

- *Public Transport Data Availability* (Type2, Type3): The system relies on up-to-date access to the public transport microservice, providing accurate timetables and real-time data. This supports both optimization of daily operations (Type2) and event-based rerouting (Type3).

- *Event Data Feeds* (Type3): The system assumes continuous access to official city event schedules, allowing early detection of high-impact gatherings and preparation of mobility strategies accordingly.

- *Inter-System Communication* (Type 1, Type 2, Type 3): Reliable and stable network infrastructure is essential to enable seamless communication among the traffic management system, microservices, event monitoring module, sensors, and urban manager interfaces. Delays or failures in communication could hinder real-time reactions (Type1), the generation of optimization proposals (Type2), and the coordination of event-driven responses (Type3).

- *Logging and Traceability* (Type1, Type2): All system actions, especially autonomous interventions and proposed suggestions, are assumed to be

automatically logged. This ensures accountability, supports auditing by human actors, and enables future analysis.

- *Real-Time Processing Capabilities* (Type1, Type3): The system is assumed to be capable of real-time or near-real-time decision-making, which is essential for reacting to live traffic conditions (Type1) and dynamically adapting to disruptions during events (Type3).

- *Public Awareness and Engagement* (Type3): For event-driven adjustments to be effective, it is assumed that citizens actively consult and respond to the notifications distributed through the system. Informed commuters are critical to mitigating congestion during critical time-frames.

3.2 Requirements

3.2.1 Functional Requirements

Type1

These are mandatory actions the system must fulfill to meet its objectives:

- **Real-Time Traffic Monitoring:** The system must continuously collect data from traffic sensors installed at key intersections to monitor vehicle wait times and traffic density.

- **Traffic Imbalance Detection:** The system must automatically detect significant traffic imbalances between intersecting roads using real-time sensor data.

- **Autonomous Light Timing Adjustment:** The system must autonomously modify traffic light durations in response to detected imbalances, following pre-defined rules or adaptive algorithms.

- **Light Configuration Dispatch:** The system must send updated traffic light timing configurations to the respective controllers without manual intervention.

- **Action Logging:** Every automated change in traffic light behavior must be logged with timestamp, affected intersections, and rationale.

- **Daily Activity Summary:** The system must generate a daily report detailing Type1 interventions and overall traffic conditions for transparency and analysis.

Type2

These are mandatory actions the system must fulfill to meet its objectives:

- **Traffic Data Analysis:** The system must continuously collect and analyze traffic sensor data to detect daily traffic patterns and congestion areas.

- **Optimization Recommendation Generation:** Based on traffic pattern analysis, the system must automatically propose targeted optimization actions. These include adjusting traffic light timing, redefining road directions (such as converting roads to one-way), and modifying public transportation schedules.

- **Suggestion Management:** The system must provide urban area managers with an intuitive interface to view, review, and respond (approve/reject) to proposed optimizations.

- **Reporting:** The system must regularly generate detailed reports documenting both proposed and implemented optimizations, including decisions made by urban area managers.

Type3

The functional requirements are the mandatory actions that the system must carry out to meet its objective and illustrate the interactions between the system and the environment:

- **Event-Driven Traffic Adjustments:** The system must dynamically modify traffic configurations before and during events.

- **Predictive Congestion Forecasting:** AI-driven forecasting enables early identification of mobility bottlenecks.

- **Approval Workflow Management:** Proposed optimizations must undergo a structured review process.

- **Real-Time Public Transport Coordination:** The system must adjust transport availability based on event-driven demand spikes.

- **Public Notification System:** Real-time alerts must inform commuters of route modifications and alternative travel options.

- **Traffic Recovery and Analysis:** The system must ensure post-event normalization and continuous refinement of optimization strategies.

3.2.2   Non-Functional Requirements

Type1

These constraints or conditions influence how the system performs its functions:

- **Real-Time Responsiveness:** The system must analyze sensor input and apply traffic light adjustments with minimal latency to prevent congestion build-up.

- **Fault Tolerance:** The system must handle temporary sensor or controller failures gracefully, continuing operation using fallback logic where needed.

- **Reliability and Availability:** The traffic monitoring and control components must be continuously operational with high uptime to ensure uninterrupted flow management.

- **System Transparency:** All autonomous decisions must be explainable and traceable via logs to support auditing and trust.

- **Data Integrity:** Traffic sensor data and light timing commands must be transmitted securely and stored accurately to prevent corruption or manipulation.

Type2

These constraints or conditions influence how the system performs its functions:

- **Real-Time Responsiveness:** The system must rapidly analyze traffic data and provide optimization suggestions without significant delays, enabling timely decisions by urban managers.

- **Scalability:** It must efficiently handle the large volume of data collected from numerous traffic sensors distributed across an urban area, ensuring consistent performance as city infrastructure grows.

- **High Availability and Reliability:** The system must be operational continuously (with minimal downtime) to support uninterrupted urban traffic management.

- **User-Friendly Interface:** The interface used by urban area managers to review suggestions must be straightforward, intuitive, and accessible, facilitating quick and informed decision-making.

- **Security and Data Integrity:** The system must secure sensitive traffic data and ensure that data used for analyses and recommendations remain accurate, protected from unauthorized access or manipulation.

Type3

The non-functional requirements contain or characterize how the system performs its functions as a whole:

- **Real-Time Responsiveness:** The system must quickly analyze live traffic data and generate optimization suggestions with minimal delay, ensuring timely decision-making for urban managers and preventing congestion before it escalates.

- **Scalability:** The system must handle fluctuations in urban mobility data, adapting to both routine commuting patterns and large-scale disruptions.

- **High Availability and Reliability:** The system must operate continuously with minimal downtime to support uninterrupted urban traffic management.

- **User Accessibility:** Notifications must be structured for easy comprehension by citizens, integrating multiple communication channels.

- **Security and Data Integrity:** Unauthorized alterations must be prevented, ensuring optimization decisions are based on validated event forecasts.

4 System Design

This section outlines the architecture, sequence diagrams, key design decisions, and critical points relevant to event-driven urban mobility adaptations.

4.1 Architectural Overview

Type3

The system follows a modular architecture, ensuring real-time adaptability to traffic disruptions caused by large-scale events.

- **EventCollector** - Continuously monitors and retrieves official event data from external sources.

- **TrafficAnalyzer** - Processes congestion data, predicts affected areas, and identifies high-impact road segments.

- **ConfigurationGenerator** - Computes traffic adaptations, including signal adjustments, lane closures, and reroutes.

- **ApprovalModule** - Validates proposed modifications before execution by urban authorities.

- **NotificationService** - Publishes updates informing citizens about road closures, alternative routes, and adjusted transit schedules.

4.2 Sequence Diagrams

Type3

To ensure efficient operation, the system follows three main interaction sequences:

1. Event Reception

   - Event Collector detects an upcoming event.
   - Event data is retrieved and logged in the system.
   - TrafficAnalyzer prepares preliminary impact forecasts.

2. Traffic Analysis and Configuration Generation

   - TrafficAnalyzer retrieves real-time congestion data.
   - ConfigurationGenerator formulates optimized traffic control measures (e.g., signal adjustments, reroutes).
   - The configurations are prepared for validation.

3. Approval and Public Notification

   - The Urban Manager reviews proposed adjustments and approves the changes.
   - NotificationService informs citizens of road closures, signal modifications, and public transport reroutes.

4.3   Critical points and design decisions

Type3 - design decisions:

- Event-Driven Optimization –¿ Unlike Type 2 actions (which focus on routine traffic improvements), Type 3 actions react dynamically to event-based disruptions.

- Approval Workflow –¿ Ensures human oversight before implementing major transport reconfigurations.

- Public Engagement –¿ Structured communication channels provide real-time notifications to affected commuters.

Type3 - critical aspects:

- Event Data Accuracy –¿ Must ensure data reliability from official event sources.

- Traffic Simulation Limitations –¿ Forecasting congestion trends must balance real-time responsiveness and computational efficiency.

- Citizen Adaptability –¿ The effectiveness of optimizations depends on commuter engagement with system-generated notifications.