Adaptive Traffic Light Controller Project

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1 Introduction

This project involves designing an **adaptive traffic light controller** for a four-way intersection. The system adapts dynamically to real-time traffic conditions to ensure collision-free operation and prioritize heavily congested lanes.

The traffic light controller is modeled as a **Finite State Machine (FSM)** with 16 states corresponding to each lane's traffic light conditions, including **primary green**, **extended green**, and **yellow states**.

2 Problem Statement

The goal is to develop a **traffic control system** with:

1. **Dynamic Timing:** Extend green light duration for congested lanes based on sensor inputs.
2. **Collision Avoidance:** Only one lane can have a green or yellow light at any time.
3. **Timer-Based Yellow and Extended Green:** These states remain active until the timer expires if no next state is defined.
4. **Skipping Idle Lanes:** If no cars are detected in a lane, the FSM skips to the next lane in the sequence.
5. **Efficient Lane Priority:** Ensure a fair balance between lane priorities while dynamically adjusting for congestion.

3 System Requirements

1. **Lanes:** Four main lanes: NS1, NS2, EW1, EW2.
2. **Sensors:**
   - `S1_NS1`, `S5_NS1` for North-South Lane 1.
   - `S1_NS2`, `S5_NS2` for North-South Lane 2.
   - `S1_EW1`, `S5_EW1` for East-West Lane 1.
   - `S1_EW2`, `S5_EW2` for East-West Lane 2.
3. **Traffic Lights:** States: **RED, PRIMARY GREEN, EXTENDED GREEN, YELLOW**.
4. **Timers:**
   - Default green timer: 20 seconds.
   - Yellow timer: 5 seconds.
   - Extended green timer: 30 seconds if congestion (`S5 = 1`) is detected.

4 FSM Overview

4.1 States

The FSM has **16 states**:

1. NS1_RED, NS1_PRIMARY_GREEN, NS1_EXTENDED_GREEN, NS1_YELLOW
2. NS2_RED, NS2_PRIMARY_GREEN, NS2_EXTENDED_GREEN, NS2_YELLOW
3. EW1_RED, EW1_PRIMARY_GREEN, EW1_EXTENDED_GREEN, EW1_YELLOW
4. EW2_RED, EW2_PRIMARY_GREEN, EW2_EXTENDED_GREEN, EW2_YELLOW

4.2 Transitions

Transitions are triggered by:

1. **Sensor Inputs:** Cars detected (S1 = 1) or congestion (S5 = 1).
2. **Timer Expiry:** States transition when their timers expire.
3. **Timer-Based Yellow and Extended Green:** If no next state is triggered, remain in the current state until the timer expires.
4. **Idle Lane Skipping:** If a lane is in RED and no cars are detected (S1 = 0), the FSM skips to the next lane in sequence.

5 FSM Table

Current State	Condition (Inputs)	Next State	**Output**	**Timer Extension Condition**
NS1_RED	S1_NS1 = 1	NS1_PRIMARY_GREEN	NS1: Green; All others: Red	No
NS1_RED	S1_NS1 = 0	NS2_RED	NS1: Red; All others: Red	No
NS1_PRIMARY_GREEN	S5_NS1 = 1	NS1_EXTENDED_GREEN	Extend Green for NS1	Yes
NS1_PRIMARY_GREEN	Timer expires && S5_NS1 = 0	NS1_YELLOW	NS1: Yellow; All others: Red	No
NS1_EXTENDED_GREEN	Timer running	NS1_EXTENDED_GREEN	Extend Green; NS1 active	Yes
NS1_EXTENDED_GREEN	Timer expires	NS1_YELLOW	NS1: Yellow; All others: Red	No
NS1_YELLOW	Timer running	NS1_YELLOW	NS1: Yellow; All others: Red	No

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Current State	Condition (Inputs)	Next State	**Output**	**Timer Extension Condition**
NS1_YELLOW	Timer expires	NS2_RED	NS1: Red; All others: Red	No
NS2_RED	S1_NS2 = 1	NS2_PRIMARY_GREEN	NS2: Green; All others: Red	No
NS2_RED	S1_NS2 = 0	EW1_RED	NS2: Red; All others: Red	No
NS2_PRIMARY_GREEN	S5_NS2 = 1	NS2_EXTENDED_GREEN	Extend Green for NS2	Yes
NS2_PRIMARY_GREEN	Timer expires && S5_NS2 = 0	NS2_YELLOW	NS2: Yellow; All others: Red	No
NS2_EXTENDED_GREEN	Timer running	NS2_EXTENDED_GREEN	Extend Green; NS2 active	Yes
NS2_EXTENDED_GREEN	Timer expires	NS2_YELLOW	NS2: Yellow; All others: Red	No
NS2_YELLOW	Timer running	NS2_YELLOW	NS2: Yellow; All others: Red	No
NS2_YELLOW	Timer expires	EW1_RED	NS2: Red; All others: Red	No
EW1_RED	S1_EW1 = 1	EW1_PRIMARY_GREEN	EW1: Green; All others: Red	No
EW1_RED	S1_EW1 = 0	EW2_RED	EW1: Red; All others: Red	No
EW1_PRIMARY_GREEN	S5_EW1 = 1	EW1_EXTENDED_GREEN	Extend Green for EW1	Yes
EW1_PRIMARY_GREEN	Timer expires && S5_EW1 = 0	EW1_YELLOW	EW1: Yellow; All others: Red	No
EW1_EXTENDED_GREEN	Timer running	EW1_EXTENDED_GREEN	Extend Green; EW1 active	Yes
EW1_EXTENDED_GREEN	Timer expires	EW1_YELLOW	EW1: Yellow; All others: Red	No
EW1_YELLOW	Timer running	EW1_YELLOW	EW1: Yellow; All others: Red	No
EW1_YELLOW	Timer expires	EW2_RED	EW1: Red; All others: Red	No
EW2_RED	S1_EW2 = 1	EW2_PRIMARY_GREEN	EW2: Green; All others: Red	No
EW2_RED	S1_EW2 = 0	NS1_RED	EW2: Red; All others: Red	No
EW2_PRIMARY_GREEN	S5_EW2 = 1	EW2_EXTENDED_GREEN	Extend Green for EW2	Yes

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Current State	Condition (Inputs)	Next State	**Output**	**Timer Extension Condition**
EW2_PRIMARY_GREEN	Timer expires && S5_EW2 = 0	EW2_YELLOW	EW2: Yellow; All others: Red	No
EW2_EXTENDED_GREEN	Timer running	EW2_EXTENDED_GREEN	Extend Green; EW2 active	Yes
EW2_EXTENDED_GREEN	Timer expires	EW2_YELLOW	EW2: Yellow; All others: Red	No
EW2_YELLOW	Timer running	EW2_YELLOW	EW2: Yellow; All others: Red	No
EW2_YELLOW	Timer expires	NS1_RED	EW2: Red; All others: Red	No

6 State and Transition Explanations

6.1 NS1 (North-South Lane 1)

1. NS1_RED:
   - If S1_NS1 = 1, transition to NS1_PRIMARY_GREEN.
   - If S1_NS1 = 0, skip to NS2_RED.
2. NS1_PRIMARY_GREEN:
   - If S5_NS1 = 1, extend green duration by transitioning to NS1_EXTENDED_GREEN.
   - If Timer expires, transition to NS1_YELLOW.
3. NS1_EXTENDED_GREEN:
   - Remain in this state until the timer expires if Timer running.
   - If Timer expires, transition to NS1_YELLOW.
4. NS1_YELLOW:
   - Remain in this state until the timer expires.
   - When the timer expires, transition to NS2_RED.

6.2 NS2 (North-South Lane 2)

1. NS2_RED:
   - If S1_NS2 = 1, transition to NS2_PRIMARY_GREEN.
   - If S1_NS2 = 0, skip to EW1_RED.
2. NS2_PRIMARY_GREEN:

- If S5_NS2 = 1, extend green duration by transitioning to NS2_EXTENDED_GREEN.
- If Timer expires, transition to NS2_YELLOW.

3. NS2_EXTENDED_GREEN:
   - Remain in this state until the timer expires if Timer running.
   - If Timer expires, transition to NS2_YELLOW.
4. NS2_YELLOW:
   - Remain in this state until the timer expires.
   - When the timer expires, transition to EW1_RED.

6.3 EW1 (East-West Lane 1)

1. EW1_RED:
   - If S1_EW1 = 1, transition to EW1_PRIMARY_GREEN.
   - If S1_EW1 = 0, skip to EW2_RED.
2. EW1_PRIMARY_GREEN:
   - If S5_EW1 = 1, extend green duration by transitioning to EW1_EXTENDED_GREEN.
   - If Timer expires, transition to EW1_YELLOW.
3. EW1_EXTENDED_GREEN:
   - Remain in this state until the timer expires if Timer running.
   - If Timer expires, transition to EW1_YELLOW.
4. EW1_YELLOW:
   - Remain in this state until the timer expires.
   - When the timer expires, transition to EW2_RED.

6.4 EW2 (East-West Lane 2)

1. EW2_RED:
   - If S1_EW2 = 1, transition to EW2_PRIMARY_GREEN.
   - If S1_EW2 = 0, skip to NS1_RED.
2. EW2_PRIMARY_GREEN:
   - If S5_EW2 = 1, extend green duration by transitioning to EW2_EXTENDED_GREEN.
   - If Timer expires, transition to EW2_YELLOW.
3. EW2_EXTENDED_GREEN:
   - Remain in this state until the timer expires if Timer running.

- If `Timer expires`, transition to `EW2_YELLOW`.

4. `EW2_YELLOW`:
   - Remain in this state until the timer expires.
   - When the timer expires, transition to `NS1_RED`.