Advanced Traffic Light Control System with Emergency Pre-emption

Project Summary

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1. Project Overview

A comprehensive traffic intersection control system implementing professional-grade PLC programming techniques for intelligent signal timing, emergency vehicle coordination, pedestrian safety, and adaptive scheduling.

Platform: Rockwell Studio 5000 Logix Designer v33
Controller: ControlLogix 5570 (Emulated)
Status: Fully functional and tested

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2. System Capabilities

Multi-Mode Operation

Automatic Mode

- Six-state sequential control with timer-based transitions
- Time-of-day adaptive green times (Normal, Rush Hour NS, Rush Hour EW)
- Emergency vehicle preemption with return-to-state
- Pedestrians walk signal coordination
- Real-time conflict detection and safety interlocks

Manual Mode

- Direct operator control for testing and maintenance
- Independent NS Green, EW Green, and All Red commands
- State timer suspension during manual operation
- All safety interlocks remain active

Night Mode (11 PM - 6 AM)

- NS direction: Flashing yellow (1-second cycle)
- EW direction: Flashing red (1-second cycle)

- Automatic activation based on system clock
- Reduced power operation for low-traffic hours

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3. State Machine Architecture

Normal Traffic Cycle

State	Signal Status	Duration	Purpose
1	NS Green, EW Red	45-60s*	North-South traffic flow
2	NS Yellow, EW Red	4s	NS caution/transition
3	All Red	2s	Intersection clearance
4	NS Red, EW Green	45-60s*	East-West traffic flow
5	NS Red, EW Yellow	4s	EW caution/transition
6	All Red	2s	Intersection clearance

*Duration varies by time-of-day mode

Emergency States

State	Signal Status	Duration	Purpose
7	All Red	2s	Emergency clearance
8	Emergency Green	15s	Priority vehicle passage

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4. Time-of-Day Scheduling

The system automatically adjusts signal timing based on hour of day:

Time Period	Mode	NS Green	EW Green	Use Case
11 PM - 6 AM	Night	Flash Yellow	Flash Red	Low traffic
6 AM - 9 AM	Rush Hour (NS)	**60s**	45s	Morning commute
9 AM - 4 PM	Normal	45s	45s	Standard traffic
4 PM - 7 PM	Rush Hour (EW)	45s	**60s**	Evening commute
7 PM - 11 PM	Normal	45s	45s	Evening traffic

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5. Emergency Vehicle Pre-emption

Operation Sequence

When emergency vehicle detected:

1. Save current state to memory
2. Transition to State 7 (All Red - 2s clearance)
3. Activate State 8 (Emergency Green - 15s)
4. Return to previously saved state
5. Resume normal operation

Safety Features

- Emergency mode overrides all other operations
- Pedestrian signals inhibited during emergency
- Two-second all-red clearance before emergency green
- Seamless return without interrupting traffic flow
- Bi-directional support (North-South and East-West)

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6. Pedestrian Safety System

Walk Signal Sequence

North-South Example:

1. Pedestrian presses button → request registered
2. Request serviced when NS direction has green
3. **WALK:** 7 seconds solid illumination
4. **Flashing DON'T WALK:** 10 seconds (500ms flash, 9 cycles)
5. **Solid DON'T WALK:** Remainder of green time
6. Request automatically cleared after cycle

Timing Coordination

- Walk only activates during appropriate traffic green phase
- Total pedestrian clearance time: 17 seconds
- Late-stage requests denied until next cycle
- Emergency vehicles override pedestrian signals
- Counter-based flash control for precise timing

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7. Safety Systems

Conflict Detection

Monitoring Logic:

IF (Auto_NS_Green AND Auto_EW_Green) THEN

→ Latch Signal_Conflict

→ Activate Safety_Beacon

→ Force system to All Red

→ Halt normal operation

Recovery:

- Manual system reset required (Sys_Reset)
- Safety beacon remains active until cleared
- Operator investigation mandatory before resuming

All-Red Clearance Intervals

- 2-second buffer between opposing green phases (States 3 & 6)
- Allows vehicles to safely clear intersection
- Prevents trapped vehicles
- Meets traffic engineering safety standards

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8. Software Architecture

Routine Organization

Routine	Rungs	Purpose
Main Routine	9	Entry point; orchestrates all subsystem calls
R01_FIRST_SCAN	5	System initialization and startup config
R02_ToD_State	6	Time-of-day mode selection via RTC
R03_Timer_Presets	4	Dynamic timer configuration by mode
R04_Emergency_Mode	14	Emergency detection and pre-emption logic
R05_Process_Logic	23	Core state machine and conflict detection
R06_Night_Mode	3	Flashing signal control
R07_Pedestrian_Handling	24	Walk requests, countdown, flash control
R08_Lights_MappingOutputs	6	Output arbitration (Emergency > Manual > Night > Auto)
R09_Manual_Mode	4	Manual override and timer suspension

Total: 95+ ladder rungs across 10 routines

User-Defined Data Types

Traffic_Light_UDT (12 bytes)

- Red, Yellow, Green status bits
- Vehicle_Detected, Emergency_Active flags
- Green_Time_Preset and Green_Time_Actual tracking

RTC - Real-Time Clock (28 bytes)

- Year, Month, Day, Hour, Minutes, Seconds, Micro_Seconds
- Used for time-of-day scheduling via GSV instruction

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9. Testing & Validation

Test Coverage

Functional Tests (13 cases)

- State machine sequencing (all 6 normal states)
- Timer preset adjustments (Normal, Rush Hour NS, Rush Hour EW)
- Emergency NS preemption with return
- Emergency EW preemption with return
- Pedestrian walk requests (NS and EW)
- Pedestrian flash countdown timing
- Night mode flashing operation
- Manual mode controls (NS Green, EW Green, All Red)

Safety Tests (6 cases)

- Conflict detection activation and latching
- Safety beacon trigger and operation
- Force all-red on conflict

- Prevention of simultaneous green signals
- Emergency override of pedestrian signals
- All-red clearance interval validation

Time-of-Day Tests (4 cases)

- Normal mode timing (9 AM - 4 PM)
- Rush hour NS (6 AM - 9 AM)
- Rush hour EW (4 PM - 7 PM)
- Night mode activation (11 PM - 6 AM)

Validation Method

All testing performed using:

- ControlLogix 5570 Emulator
- Studio 5000 v33
- No physical I/O or hardware required
- Complete functional coverage achieved
- Ready for deployment to actual controllers

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10. Technical Achievements

PLC Programming

- State machine design with timer-based sequencing
- Priority-based output arbitration
- Modular routine organization
- Interlocking and safety logic implementation

Traffic Control Standards

- Signal timing and phasing principles
- Emergency vehicle preemption protocols
- Pedestrian safety integration

- Conflict detection and prevention

Industrial Best Practices

- Safety-critical system design
- Manual override capabilities
- Comprehensive documentation
- Systematic testing methodology
- Ready for real-world deployment

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11. System Statistics

Controller Resources:

- ~80 controller tags
- 13 timers
- 2 counters
- 6 user-defined data types
- 18 I/O points (16 outputs, 2 inputs)
- ~637 bytes total memory

Documentation:

- 10-page project summary
- 23-page ladder logic reference
- 8-page tag listing
- Fully commented code