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Simulated Traffic Lights With Finite State Machine

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Abstract-*Finite State Machines (FSMs) provide a structured, deterministic model for simulating traffic light systems, ensuring safe and sequential control at intersections. This review examines FSM applications in traffic simulation, highlighting theoretical Finite foundations, implementation approaches (hardware and software), performance benefits, limitations, and opportunities in resource-constrained settings like Tanzanian cities. Observations reveal FSMs' reliability for educational prototyping, while gaps exist in adaptive, low-cost simulations tailored to dynamic urban congestion. Recommendations focus on software-based enhancements for future intelligent traffic systems.*

Keywords—Finite State Machine, Traffic Light Simulation, Traffic Signal Control, Moore FSM, State Transition, Verilog, Adaptive Control.

1. INTRODUCTION

Traffic congestion poses a major challenge in urban environments, particularly in developing countries where rapid population growth, increasing vehicle ownership, and inadequate infrastructure exacerbate delays, fuel waste, pollution, and accidents. In Tanzania, cities like Dar es Salaam experience severe congestion, with workers losing significant productive time daily due to fixed-timer traffic lights that fail to adapt to varying conditions.

Simulation offers a cost-effective way to model and test traffic control strategies without real-world risks. Finite State Machines (FSMs) mathematical models with finite states, transitions, and outputs are widely used for this purpose, representing light phases (e.g., RED, YELLOW, GREEN) and timer-driven changes. This review explores FSM-based simulation of traffic lights, covering background, problems addressed, objectives of related studies, literature, key observations, conclusions, and future directions.

1.1 BACKGROUND

Traffic light systems evolved from manual control to automated timers in the early 20th century, with digital implementations emerging in the 1960s[1]. Fixed-timer systems dominate in many regions but perform poorly under fluctusating traffic. Adaptive systems (sensor-based or AI-driven) improve efficiency but increase complexity and cost[2]

FSMs, rooted in automata theory, model sequential logic effectively. A Moore FSM (outputs depend only on state) is preferred for traffic control due to predictable, hazard-free behavior[3]. States represent phase combinations (e.g., North-South Green with East-West Red), transitions occur via timers or inputs, and outputs control signals. Simulations in tools like Verilog (hardware) or Python (software) allow verification of safety (no conflicting greens) and efficiency[4].

In Tanzanian contexts, congestion in Dar es Salaam stems from population growth (>5 million), vehicle surge, poor planning, and limited adaptive infrastructure. Similar issues affect smaller cities like Iringa and Mbeya[5]. FSM simulation provides an accessible prototyping tool for educational and preliminary research in such settings.

1.2 PROBLEM STATEMENT

Conventional fixed-timer traffic lights cause unnecessary delays and congestion, especially during peak/off-peak variations or at multi-direction intersections. In urban Tanzania, this leads to economic losses (e.g., hours lost daily), environmental harm, and safety risks. Hardware-based adaptive solutions are expensive and complex for widespread adoption or testing in resource-limited environments.

Simulation using FSMs addresses this by enabling low-cost modeling of safe, sequential control. However, many existing approaches focus on hardware (FPGA/Verilog) requiring specialized tools, limiting accessibility for education or initial prototyping. There is a need for simple, software-based FSM simulations that demonstrate core principles while highlighting potential for real-world extensions.

1.3 OBJECTIVES

1.3.1Main objective

The primary objective of FSM-based traffic light simulation studies is to model and verify efficient, collision-free traffic control logic. **1.3.2Specific objectives**

i. To review FSM theory and its application in sequential control systems.
ii. To design FSM models (e.g., Moore machines) for multi-way intersections with timer-based transitions.

iii. To implement simulations (hardware in Verilog/FPGA or software in Python) and evaluate safety, timing, and performance.

2.0 RELATED WORKS

Literature on FSM traffic light simulation spans hardware and software domains.

Hardware-focused works use Verilog/VHDL on FPGAs for real-time simulation[2][6]. Examples include Moore FSM designs with 4–6 states for four-way junctions, incorporating timers and optional sensors for density-based transitions[7][8]. Simulations in Vivado or ModelSim verify no conflicts and reduced wait times[1][9]. Discrete logic + FSM hybrids enhance adaptability with minimal hardware[10][5][11].

Software simulations emphasize accessibility[12][13]. Python implementations model cycles with time modules and console/GUI visualization (e.g., Tkinter), demonstrating deterministic behavior[14][15]. Educational tools like Logisim simulate basic FSMs for teaching[16][17].

Empirical studies show FSMs reduce congestion compared to fixed timers, especially with sensors[18]. Tanzanian research highlights Dar es Salaam's issues (e.g., travel time index 2.19, significant productivity loss) but rarely applies FSM simulation locally[5][19].

Gaps include over-reliance on hardware, limited pure software models for education, and few adaptations to African urban dynamics[20][21].

3.0 OBSERVATIONS

3.1Advantages:

FSMs ensure deterministic, verifiable safety (no simultaneous conflicting greens); simplicity aids implementation and debugging; Moore models offer stable outputs; low-cost software simulations enable rapid prototyping and education[22][11].

3.2Limitations:

Fixed-timer FSMs lack real-time adaptability (e.g., to emergencies or variable density); hardware implementations require tools/equipment; pure simulations ignore real-world variables (pedestrians, failures)[9]; scalability issues for multi-intersection networks[23][18].

3.3Performance:

Simulations show reduced average waits and better flow vs. fixed systems; educational value high for CS students learning automata[20][24][23].

3.4Contextual Insights:

In Tanzania, FSM simulation could prototype affordable solutions before costly hardware deployment, but current literature lacks localized applications[25].

4.0 CONCLUSION

FSM-based simulation of traffic lights is a reliable, formal method for modeling safe sequential control, outperforming rigid timers in predictability and educational utility. Hardware approaches excel in performance verification, while software provides accessibility for prototyping. Despite limitations in adaptability, FSMs serve as a strong foundation for traffic management research, particularly in resource-constrained regions facing congestion like Tanzania.

5.0 RECOMMENDATIONS AND FUTURE WORKS

1. To add sensor-based adaptability

Extend the FSM to simulate vehicle density detection (using variables or random inputs in Python) dynamically adjust green phase duration to reduce waiting times (aim for 30–50% improvement over fixed timers).

2. Include pedestrian and emergency priority

Add states for pedestrian crossing (brief all-red + walk phase) and emergency override (e.g., force green or all-red on input) improves realism and safety relevance.

3. Implement graphical visualization (GUI)

Use Tkinter or Pygame to display real-time red/yellow/green lights, timer countdown, and vehicle queues, makes demonstration and results much more engaging than console output.

4. Perform quantitative evaluation & comparison

Measure key metrics (average wait time, throughput, queue length) across scenarios (low/medium/high traffic) and compare your adaptive FSM simulation against a basic fixed-timer baseline, strengthens the project's academic value.

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