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Traffic Signal Optimization Based on Fuzzy Control and Differential Evolution Algorithm

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A B S T R A C T

Urban crossroads are frequently the sites of concentrated urban traffic congestion. An urban road traffic signal management system is required to avoid issues like fuel waste from prolonged idling periods, exhaust pollutants from frequent vehicle starts and stops, and driving delays brought on by traffic congestion on trunk lines. For traffic control studies, maximizing an intersection's traffic capacity and lowering vehicle delay rates have never been easy. Urban traffic signal coordination is thought of as a multi-objective optimization issue. This study examines a mathematical model for metropolitan trunk traffic. To get an optimization, models for average delay, average queue length, total delay calculation for cars at junctions, and vehicle exhaust pollution are developed. model for a new coordinated control system for traffic trunks. Furthermore, the adaptive sequencing mutation multi-objective differential evolution algorithm (FASM-MDEA) and fuzzy control theory are combined in this work. In order to address the issue of traffic signal coordination and control of urban trunk lines, The efficiency of the model optimization approach suggested in this study is shown by the simulation results.

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INTRODUCTION

In a time of fast urbanization and population growth, urban planners and transportation engineers have a critical challenge: managing traffic congestion effectively. In addition to causing financial losses and longer travel times, traffic congestion also degrades the environment and lowers city dwellers' quality of life. In response to this problem, traffic signal optimization has become an important field of study with the goal of improving the sustainability and efficiency of urban transportation networks.

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The primary goal of this research is to create a traffic signal control system that is flexible and dynamic, capable of reacting quickly and intelligently to shifting traffic conditions. In order to address the uncertainty related to traffic dynamics, the study will look into the integration of the Differential Evolution Algorithm for signal timing optimization and fuzzy control for improved traffic flow.

The theoretical underpinnings, practical applications, and advantages of utilizing Differential Evolution Algorithm and Fuzzy Control in traffic signal optimization are covered in detail in this work. Urban transportation networks are expected to benefit from increased traffic flow, less congestion, lower emissions, and eventually, a more sustainable and effective urban environment, by utilizing the synergy between these strategies.

LITERATURE REVIEW

1. "Traffic Signal Timing Optimization: A Review" research paper (2019)

Xinkai Wu, Mohammed Hadi, and Hesham Rakha are the authors.
Published in 2019, this research study provides a thorough analysis of the many approaches and strategies used in traffic signal timing optimization. It emphasizes how crucial timed signals are to increasing traffic efficiency and easing congestion in cities.The work limits its contribution to the development of unique approaches by mostly examining existing methods instead of presenting new optimization algorithms.

2. "Real-Time Traffic Signal Control Using Reinforcement Learning" (2018) research paper
Michael P. Wellman and Alex Z. Wurman are the authors.

This research from 2018 presents a novel method of traffic signal optimization based on artificial intelligence called reinforcement learning. It investigates the possibilities of using machine learning to make decisions about traffic light regulation in real time.Although the paper establishes the theoretical foundation for reinforcement learning in traffic signal control, it might not go into great detail about the difficulties in implementing the system in practice or the issues with scalability.

3.Research Article: "Multi-Objective Traffic Signal Timing Optimization Considering Environmental and Operational Impacts" (2016)
Xuesong Wang, Hai Yang, and Guohui Zhang are the authors.

This research study, which was published in 2016, tackles the difficulty of multi-objective traffic signal optimization by taking operational effectiveness and environmental sustainability into account. It highlights the significance of finding a balance between both objectives.It's possible that the study doesn't cover all of the practical difficulties in applying multi-objective optimization techniques to actual traffic management systems.

4. "Adaptive Traffic Signal Control: A Review" research paper (2020)
Bin Ran and Zhaoyi Xu wrote this.

An extensive analysis of adaptive traffic signal control, a crucial idea in contemporary traffic management, is provided in this 2020 study. It addresses the potential advantages of various adaptive control systems.Although the study offers a5.Research Paper: "Traffic Signal Optimization Considering Mixed Traffic Flows" (2017)
Authors: Hang Yu, Chaoyi Gu, and Hani S. Mahmassani

Published in 2017, this paper addresses the challenge of optimizing traffic signals in scenarios with mixed traffic flows, encompassing both vehicles and pedestrians. It introduces the concept of accommodating diverse road users in signal timing optimization.The paper might not delve deeply into the practical challenges and safety considerations associated with accommodating mixed traffic flows, particularly in complex urban environments. thorough review of adaptive control techniques, it might not go into great detail into individual algorithms and their drawbacks in different real-world traffic situations.

METHODOLOGY

1. Data Collection and Processing: Describe how real-time traffic data is gathered from sensors and other sources, as well as the preparation procedures that are taken to guarantee data consistency and correctness.

2. Fuzzy Control Design: Explain how the fuzzy control system was developed and configured, including how linguistic variables were identified and fuzzy rules were created to simulate traffic situations.

3. Differential Evolution Algorithm Setup: Describe the Differential Evolution Algorithm's setup in detail, taking into account population initialization techniques and parameter tweaking.

4.Defining the Objective Functions: Establish the objective functions that are used to assess the effectiveness of traffic signal timings while accounting for a number of variables, including environmental impact, travel time, and congestion.

5. Optimization Process: Describe the methodical approach to enhancing traffic signal timings, highlighting the cooperative efforts of the Differential Evolution Algorithm and Fuzzy Control in identifying the best possible outcomes.

6.Simulation and Validation: Explain the simulation environment and the validation procedure that were utilized to test the suggested optimization strategy and determine how well it worked to improve traffic flow and lessen congestion.

7. genuine-World Implementation: Talk about how optimal signal timings are really put to use in a genuine traffic management system, together with communication protocols and adjustments for shifting traffic conditions.

8. Performance Comparison: To demonstrate the benefits of the fuzzy control and differential evolution algorithm methodology, compare its results with those of more conventional traffic signal optimization techniques.

9. Sensitivity Analysis: To make sure the system is robust, examine how sensitive the optimization approach is to variations in parameters and traffic circumstances.

A. Principal Fuzzy Controller Parameters

1) Degree of Urgency of Green Light Phase: The number of cars BL in line for the green light phase and the arrival rate BAR of vehicles for the green light phase are what determine the degree of urgency Bu of the green light phase. BL was computed using the subsequent formula:

BL = BL0 + CB (1), where CB is the number of vehicles that arrive during the red light and BL0 is the number of vehicles that are still in the detection zone after the last green light finishes.

2) Level of Urgency in the Red Phase: There are two elements that define the level of urgency in the red phase for Ru: RL, or the quantity of vehicles in line during the red phase, and RAR stands for red phase vehicle arrival rate. The following is the RL calculation formula:

RL is equal to RL0 + CR (2), where CR is the number of cars that arrive during the red light and RL0 is the number of cars that are still in the detection zone after the last green light.

3) Degree of Urgency of Adjacent Intersection Entrance Lane Phase: The number of vehicles NL in line during that phase and the arrival rate of CONTROL RULE TABLE OF GREEN LIGHT PHASE vehicles NAR during the phase, among

which, NL is calculated using the following formula, determine the degree of urgency Nu of the adjacent intersection entrance lane phase.

NL is equal to NL0 + CN (3), where CN is the number of cars that arrive during the red light and NL0 is the number of vehicles that are still in the detection zone after the last green light

B. Module Design

1) Green Light Direction Detection Module at Current Intersection: This module measures the level of urgency with which cars are moving through the intersection in the green light direction. Its input is the unit of piece and the number of BL vehicles in line for the current phase with a change scope of {0, 20}. In the current phase, the cars' arrival rate BAR fluctuates between 0 and 1. With a change scope of (0, 1), its output is the level of urgency Bu of the cars for the green light direction at the present intersection.

a) Fuzzification: Transform {0,1,2,3,...,20}, the fundamental domain of discourse in BL, into {very few, few, medium, many, a huge number}. It is condensed as {VS, S, M, H, VH} for ease of use. In addition, the fundamental domain of discourse of Bu, which is (0, 1), is fuzzified into {very light, light, medium, heavy, very heavy} and simplified as {VS, S, M, H, VH}. Similarly, the basic domain of discourse of BAR, which is (0, 1), is also fuzzified into {very low, low, medium, high, very high}.

b) Selection of membership function: The membership functions frequently used in fuzzy control include the triangle membership function, trapezoid membership function, and Gaussian membership function. The triangle membership function adopted in this study is simple, curved, with a small computing workload, saves spaces and has great sensitivity.

c) Membership function selection: The triangle, trapezoid, and Gaussian membership functions are the membership functions that are commonly employed in fuzzy control. The triangle membership function used in this investigation is highly sensitive, straightforward, curved, and requires little processing power. It also conserves space.

d) Fuzzy inference relationships: There are a total of 25 rules in the control rule table for the green light phase, and each rule represents a fuzzy relationship. The connection matrix Ris for the fuzzy statement "IF A and B then C" is R = (A × B)T1 × C. Ri = (BL j × BARk)T1 × Bul (5) is the corresponding fuzzy relationship for the i th control rule, where i = 1, 2, 3, · · ·, 25 and j, k, 1 = 1, 2, 3, 4, 5; T1 is the column vector's transfer matrix, presenting a 5 × 5 matrix into a 25 × 1 column vector; BARk & Bul are the vectors that correspond to the control rules, respectively. All 25 control rules' combined fuzzy relationships are as follows: R = 25U i=1.

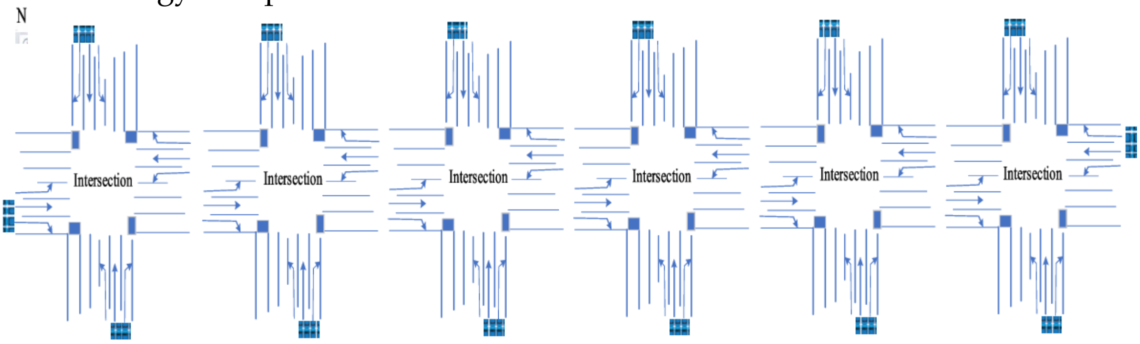
Ri (6) 2) Red Light Phase Detection Module in Current Intersection: The level of vehicle urgency in the traffic flow for the present red light phase is determined by the red-light phase detecting module. It takes in RL as input, with a change scope of (0, 20) and a piece unit. Within the range of (0, 1), RAR varies. Its output, with a change scope of (0, 1), represents the level of urgency of vehicles at the current intersection during the red light phase.

a) Fuzzification: Change {0,1,2,3,…,20}, the fundamental domain of conversation in real language, to {very few, few, medium, many, a great many}. It has been condensed into {VS,S,M,H,VH} for ease of use. Fuzzify the fundamental area of discourse as well. of Ru, or (0,1), into {very light, light, medium, heavy, very heavy} and simplify it as {VS,S,M,H,VH}; of RAR, or (0,1), into {very low, low, medium, high, very high} and simplify it as {VS,S,M,H,VH}.
b) Membership function selection: The triangle membership function and the green light phase are selected in the same way as the red light phase.
c) Creating fuzzy control guidelines: The control rules for the red light phase were obtained by synthesising the expertise of specialists, and they are shown in Table II. The fuzzy statement for this fuzzy control system is "IF A and B then C," which is based on the Mamdani inference process. For instance, the following is an expression of Control Rule No. 1 in Table II: IF RL is VS and RAR is VS, then Ru is VS.
In analogy, there are a total of 25 fuzzy control rules.
3) The detecting module for the entrance lane phase of an adjacent intersection is used to gauge the level of traffic flow urgency during the entry driveway phase of the present nearby intersections. It takes as input NL, which has a unit of piece and fluctuates between 0 and 20. The range of change for NAR is (0, 1). Nu with a change scope of 0 to 1 is its output. The basic domain of discourse in natural language learning, {0,1,2,3,…,20}, should be fuzzified into {very few, few, medium, many, a great many}, which can be simplified to {VS, S, M, H, VH}. Fuzzify the NAR's basic domain of discourse, which is (0,1), similarly, into {very low, low, medium, high, extremely Taking the basic domain of discourse of Nu, which is (0, 1), we simplify it as {very light, light, medium, heavy, very heavy} and simplify it as {VS,S,M,H,VH}.
b) Membership function selection: Both the triangle membership function and the green light phase are selected in the neighboring intersection entrance lane phase.
c) Creating fuzzy control guidelines: As demonstrated in Table III, the control criteria are derived by compiling the expertise of specialists. The Mamdani inference is the basis of this fuzzy control system.
algorithm, or the imprecise assertion "IF A and B then C." For instance, the expression IF NL is VS and NAR is VS then Nu is VS can be used to represent Control Rule No. 1 in Table III.
Comparatively speaking, there are a total of 25 fuzzy control rules [30].

10. Scalability and Generalization: Talk about how the methodology could be expanded to larger and more intricate traffic networks and how it may be used in various urban settings.

11.Ethical and Safety Concerns: Talk about any moral and safety issues surrounding the installation of new traffic signal timings, especially as they pertain to the security of bicyclists and pedestrians.

*12.*Resource Requirements: Describe the hardware and computing resources—including any specialist gear or software—necessary for successfully putting the methodology into practice.



CONCLUSIONS

In order to create common evaluation models of a traffic system, such as the average delay, queue length, and vehicle exhaust emission models, we used the traffic signal control of an urban intersection's main road as the research object and decreased the average vehicle delay as the control target. We used the fuzzy time series to anticipate the traffic flow in each direction of the next cycle by identifying the fleet length in each entrance lane. Based on the traffic flow data, we chose the best phase sequence arrangement and the appropriate timing scheme for the following cycle. To determine each cycle's green light delay, we utilized the real-time detected traffic flow as the adaptive fuzzy controller's input parameter. period of traffic. The fuzzy controller was then optimized using the multi-objective DEA.

The non-optimized fuzzy controller and the optimized fuzzy controller were evaluated in an identical traffic environment through simulations conducted under various traffic circumstances. Furthermore, we examined the traditional Webster and MAXBAND models to enhance the coordinated traffic control system's timing, introduced a novel optimization technique called FASM-MDEA, and resolved the signal timing issue of the recognized traffic trunk line model by employing the best timing approach. Based on the combination of multi-objective DEA and fuzzy control, the simulation results demonstrated that intelligent control technology could successfully cut the average wait time of passing cars at the intersection and adapt to the complex and variable traffic environment. The following is the study's planned future work:

(1) In the context of urban traffic control research, we ought to concentrate on the modeling and management of urban regional traffic flow in addition to further refining the mathematical model of traffic flow and the control algorithm for individual intersections and urban trunk roads.

(2) To address urban traffic issues and boost traffic efficiency, cooperative research between traffic control and guiding systems is required.

(3) It is impractical to test an urban traffic light control technique in a real traffic system using traffic system simulation research.As a result, research on intelligent control of urban road traffic in virtual environments can provide twice the results in half the time.

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