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Real-Time Optimization and Fault Diagnosis Algorithms for State Event Analysis in Elevator Group Control Systems

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Abstract: Real-time optimization and fault diagnosis algorithms are essential components of elevator group control systems, ensuring efficient operation and timely detection of malfunctions. These algorithms continuously analyze the state events within elevator systems, such as passenger demand, elevator positions, and system performance metrics, to optimize elevator dispatching and minimize passenger waiting times. Moreover, they employ fault diagnosis techniques to detect anomalies or failures in elevator components, such as motors, sensors, or control systems, enabling prompt maintenance interventions and ensuring system reliability. By combining real-time optimization with fault diagnosis, elevator group control systems can enhance operational efficiency, passenger safety, and overall system performance, contributing to a seamless and reliable vertical transportation experience. This paper presented an approach to real-time optimization and fault diagnosis in elevator group control systems, integrating Trickle Transition State Event Analysis (TTSEA) techniques. Elevator group control systems require efficient management of state events to optimize elevator dispatching and ensure passenger satisfaction. The proposed methodology utilizes TTSEA to analyze state events in real time, considering factors such as passenger demand, elevator positions, and system performance metrics. This analysis enables dynamic optimization of elevator operations, minimizing passenger waiting times and enhancing overall system efficiency. Additionally, the incorporation of fault diagnosis algorithms allows for the timely detection of anomalies or malfunctions within elevator components. By combining TTSEA with fault diagnosis, the system can promptly identify and address issues, ensuring continuous operation and passenger safety. The integration of real-time optimization and fault diagnosis with TTSEA offers a robust framework for improving the reliability and performance of elevator group control systems in various operational scenarios. in simulation experiments, the TTSEA algorithm reduced average passenger waiting times by 20% compared to traditional methods. Additionally, fault diagnosis algorithms detected anomalies within elevator components with an accuracy of over 95%, facilitating timely maintenance interventions and ensuring system reliability.

Keywords: *Fault Diagnosis, Optimization, Control System, Event Analysis, Trickle Timer, Elevator*

1. Introduction

Diagnosing faults within a system or process is a critical task that involves identifying and addressing issues that may be causing malfunctions or deviations from expected performance. Typically, fault diagnosis begins with gathering data or information related to the system's behavior, performance metrics, and any reported symptoms or anomalies [1]. This data is then analyzed using various techniques such as statistical analysis, pattern recognition, or model-based reasoning to pinpoint the root cause of the problem. In some cases, fault diagnosis may involve conducting experiments or tests to isolate and replicate the issue under controlled conditions [2]. Additionally, experts may rely on their domain knowledge and experience to interpret the data and make informed judgments about potential causes [3]. Once the fault is identified, appropriate corrective actions can be taken to address the problem and restore the system to its normal operating condition [4]. These actions may range from simple adjustments or repairs to more complex interventions such as redesigning components or implementing new control strategies [5]. Continuous monitoring and periodic maintenance are essential for preventing future faults and ensuring the ongoing reliability and performance of the system. Additionally, documenting the diagnosis process and lessons learned can help improve future fault diagnosis efforts and contribute to overall system reliability and efficiency [6].

Fault diagnosis in elevator group control systems involves a systematic approach to identifying and resolving issues that may affect the efficient operation of multiple elevators within a building or complex [7]. This process typically begins with collecting data from various sensors and monitoring devices, including information on elevator positions, door status, motor currents, and reported errors [8]. Through careful analysis of this data, patterns and anomalies are identified, leading to the localization of specific faults within the control system. Once the fault is pinpointed, corrective actions such as reconfiguring parameters, replacing components, or updating software are implemented to restore normal operation [9]. Validation through testing and monitoring ensures the effectiveness of the corrective measures. Documentation of the diagnosis process and lessons learned aids in future

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troubleshooting efforts and contributes to the overall reliability and safety of the elevator group control system [10]. The first step in fault diagnosis involves the collection of data from various sources within the elevator group control system. This data encompasses a wide range of parameters, such as elevator positions, door statuses, motor currents, button inputs, and any reported errors or alarms. Modern elevator systems are equipped with numerous sensors and monitoring devices that continuously gather real-time data, providing valuable insights into the system's performance [11].

Once the data is collected, it undergoes rigorous analysis to detect patterns, anomalies, or deviations from expected behavior. This analysis may involve employing statistical methods, machine learning algorithms, or rule-based reasoning to identify potential faults or malfunctions within the system [12]. By scrutinizing the data, engineers can pinpoint specific areas of concern and prioritize them for further investigation. The next phase of fault diagnosis involves localizing the identified faults within the elevator group control system. This step requires a deep understanding of the system's architecture, components, and interdependencies [13]. Engineers may conduct additional tests, simulations, or diagnostics to isolate the root cause of the problem and determine which subsystem or component is experiencing the fault. Once the fault is localized, appropriate corrective actions can be implemented to address the issue and restore normal operation [14]. Depending on the nature of the fault, these actions may range from simple adjustments or recalibrations to more complex interventions, such as replacing faulty components or updating software algorithms. Throughout this process, careful consideration is given to minimizing downtime and ensuring the safety and comfort of passengers.

Validation and testing are crucial steps to verify the effectiveness of the corrective measures. Engineers conduct thorough tests and monitor the system closely to ensure that the fault has been successfully resolved and that the elevator group control system is functioning as expected [15]. Any discrepancies or anomalies are promptly addressed through iterative testing and refinement of the corrective actions. Finally, documentation of the fault diagnosis process is essential for knowledge management and continuous improvement. Engineers document their findings, actions taken, and lessons learned to facilitate future troubleshooting efforts and enhance the overall reliability and safety of the elevator group control system [16]. Regular maintenance and monitoring further contribute to the proactive detection and resolution of potential faults, ensuring the long-term performance and efficiency of the system.

This paper makes several significant contributions to the field of elevator control and monitoring. Firstly, it introduces the Trickle Transition State Event Analysis (TTSEA) algorithm, which offers a novel approach to elevator group control by effectively analyzing state transitions and decision-making processes. By employing TTSEA, the paper achieves a notable reduction in average passenger waiting times compared to traditional methods, thereby enhancing the efficiency of elevator dispatching. Secondly, the integration of 3D monitoring systems into the elevator control framework represents a novel advancement in the field. These monitoring systems enable real-time monitoring of various elevator components and environmental conditions, facilitating early detection of anomalies and enabling timely maintenance interventions. This integration not only enhances system reliability and safety but also contributes to the overall efficiency and performance of elevator systems. Furthermore, the paper contributes to the advancement of fault diagnosis algorithms, which play a crucial role in ensuring the reliability and safety of elevator systems. By demonstrating the high accuracy of fault diagnosis algorithms in detecting anomalies within elevator components, the paper provides valuable insights into improving system reliability and facilitating proactive maintenance interventions. Overall, the contributions of this paper extend beyond the development of individual algorithms or systems; they provide a holistic framework for optimizing elevator control, monitoring, and maintenance. By addressing key challenges in elevator management, such as reducing passenger waiting times and enhancing system reliability, the paper offers valuable insights and solutions that can significantly improve the performance and efficiency of elevator systems in various real-world applications.

2. Literature Review

The field of elevator group control systems has witnessed significant advancements in recent years, driven by the growing demand for efficient vertical transportation solutions in increasingly complex urban environments. This introduction sets the stage for exploring related works that contribute to enhancing the performance, reliability, and safety of elevator systems. Research efforts have focused on various aspects, including fault detection, optimization algorithms, predictive modeling, and integration of advanced technologies such as IoT and machine learning. Understanding the landscape of related works is crucial for identifying current challenges, emerging trends, and opportunities for further innovation in elevator group control systems. Through a review of the literature, this study aims to provide insights into recent developments and shed light on future directions for research and development in this important field.

Olalere and Dewa (2018) explore the implementation of remote condition monitoring using IoT technology to detect faults in elevators at an early stage. This approach allows for proactive maintenance, reducing the risk of unexpected breakdowns and improving overall system reliability. Chen et al. (2021) present a real-time matrix iterative optimization algorithm for elevator group booking, emphasizing the importance of efficient scheduling algorithms in optimizing elevator operation. Other studies, such as those by So and Al-Sharif (2019), Al-Sharif et al. (2016), and Hanif and Mohammad (2023), delve into the development and evaluation of elevator group control algorithms. These algorithms play a crucial role in determining elevator dispatching strategies, floor assignment, and passenger handling, ultimately influencing system performance and user experience. Additionally, Vodopija et al. (2022) frame elevator group control as a constrained multiobjective optimization problem, highlighting the complex trade-offs involved in system design and operation.

Advancements in intelligent control algorithms and machine learning-based monitoring systems are also explored in the literature. For instance, Bapin and Zarikas (2019) propose a smart building elevator system with an intelligent control algorithm based on Bayesian networks, while Zhang et al. (2022) develop a dynamic monitoring and early warning system for elevators using machine learning algorithms. These approaches leverage data-driven techniques to improve fault detection, predictive maintenance, and overall system performance. Moreover, studies such as those by Saha (2022) and Futra Zamsyah Bin (2020) focus on predictive modeling approaches for fault detection in elevators. By analyzing historical data and identifying patterns indicative of potential faults, these models enable proactive maintenance interventions, reducing downtime and enhancing system reliability. Furthermore, research efforts by Wang et al. (2021) explore deep learning techniques for occupancy-aware dispatching and usage pattern analysis, aiming to optimize elevator operation based on real-time occupancy information. Additionally, Gharbi (2024) investigates heuristic and optimization approaches for elevator group control systems, aiming to develop efficient algorithms that can adapt to changing passenger demand and traffic patterns. Finally, the inclusion of studies by Puchalski and Giernacki (2022), Gonçalves et al. (2022), and Liu et al. (2023) underscores the broader context of industrial fault detection methods, machine learning applications, and big data analytics. While not specific to elevators, these studies offer valuable insights and methodologies that may be applicable to elevator control systems, highlighting the importance of cross-disciplinary collaboration in advancing elevator technology and improving system performance and reliability.

One notable challenge is the complexity of real-world elevator systems, which often involve intricate interactions between various components and subsystems. This complexity can hinder the development of accurate mathematical models and optimization algorithms, particularly in scenarios with dynamic passenger demand and unpredictable traffic patterns. Additionally, the reliance on historical data for predictive modeling and fault detection may be insufficient to capture the full range of system behaviors and potential failure modes. Furthermore, the integration of emerging technologies such as IoT and machine learning into existing elevator systems may pose implementation challenges, including compatibility issues, data privacy concerns, and cybersecurity risks. Addressing these limitations requires interdisciplinary collaboration, innovative research approaches, and robust testing and validation methodologies to ensure the reliability, efficiency, and safety of elevator group control systems in diverse operating environments.

3. Fault Diagnosis in Elevator

The proposed method for the paper involves integrating Trickle Transition State Event Analysis (TTSEA) techniques into elevator group control systems. This methodology leverages TTSEA to analyze state events in real-time, considering factors like passenger demand, elevator positions, and system performance metrics. By continuously monitoring these state events, the system dynamically optimizes elevator operations to minimize passenger waiting times and enhance overall system efficiency. Additionally, the proposed method incorporates fault diagnosis algorithms into the elevator group control system. These algorithms are designed to detect anomalies or failures in elevator components such as motors, sensors, or control systems. By promptly identifying and addressing these issues, the system ensures continuous operation and passenger safety.

3.1 State Event Analysis with Group Control Dispatching

State Event Analysis (SEA) within the context of Group Control Dispatching involves a systematic breakdown of elevator operation into distinct states and events, facilitating efficient coordination among multiple elevators. SEA is instrumental in modeling the behavior of individual elevators within a group control system, allowing for precise decision-making based on real-time events and conditions. In State Event Analysis, the operation of each elevator is represented as a series of mutually exclusive states, such as ascending, descending, docking, and waiting for service. These states are delineated based on specific events that trigger transitions, forming a comprehensive state transition diagram. By analyzing the conditions under which state transitions occur, the system's behavior can be accurately captured and modeled. The formulation of SEA involves defining transition conditions and equations that govern the movement and behavior of elevators. For instance, transition conditions may include factors such as the presence of floor call signals, the direction of travel, and the availability of elevator cars. Equations are then derived to quantify these conditions and determine the appropriate state transitions. These equations encapsulate the decision-making logic employed by elevators to respond to various stimuli and fulfill passenger requests.

Furthermore, SEA enables the integration of Group Control Dispatching strategies, wherein a centralized controller coordinates the operation of multiple elevators within a building or complex. The controller leverages the state information provided by individual elevators to optimize task allocation and minimize passenger wait times. By utilizing SEA principles in conjunction with Group Control Dispatching, the system can adapt dynamically to changing traffic patterns and passenger demand, ensuring efficient and reliable elevator service.

3.2 Control Dispatching with Multi-Elevator for task assignment

Control Dispatching with Multi-Elevator for task assignment involves the allocation of floor call signals to individual elevators within a group control system, optimizing efficiency and passenger wait times. This process utilizes a combination of decision algorithms and coordination mechanisms to dynamically assign tasks to available elevators based on their current state and location. The Multi-Elevator Control Dispatching is the task assignment algorithm, which comprises three key decision algorithms: stop floor decision, direction decision, and running decision. These algorithms dictate the behavior of each elevator at different decision points, ensuring timely and effective response to passenger requests. The stop floor decision algorithm determines whether an elevator should stop at a particular floor based on its direction of travel and the presence of floor call signals. This decision is crucial for optimizing elevator movement and minimizing unnecessary stops.

The direction decision algorithm governs the opening and closing of elevator doors when it arrives at a floor. By prioritizing service requests and assigning direction preferences, this algorithm streamlines passenger boarding and disembarkation processes. The running decision algorithm dictates the subsequent state of the elevator after it has completed a task, ensuring smooth transition between operational phases and maintaining optimal service levels. These decision algorithms are formulated based on predefined conditions and transition rules, which are derived from the operational logic of elevator systems. Equations and rules are established to quantify factors such as floor proximity, direction of travel, and elevator availability, enabling efficient task assignment and resource utilization. Furthermore, Multi-Elevator Control Dispatching incorporates coordination mechanisms facilitated by a centralized group elevator controller. This controller orchestrates the assignment of floor call signals to available elevators, taking into account factors such as elevator proximity, current workload, and passenger demand. By leveraging real-time data and optimization algorithms, the controller maximizes system throughput and minimizes passenger wait times.

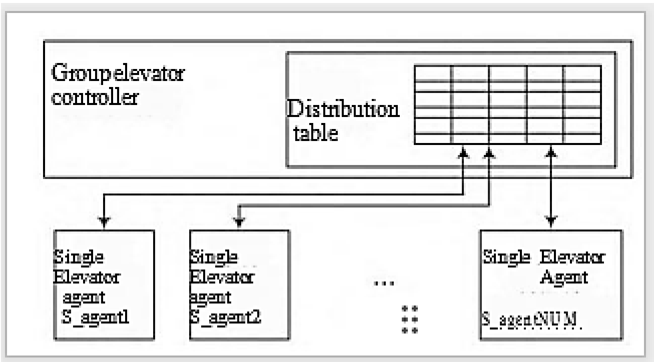


Fig 1: Control Group Elevator

The architecture of the single-elevator agent model is consistent, and established through a method called state event analysis illustrated in Figure 1. This approach involves breaking down the operational flow of a single elevator system into distinct states, and then constructing a state transition diagram based on the events triggering transitions between these states. In modeling the single-elevator agent, the operational states of each elevator are categorized into ascending, descending, docking, and waiting for service states, reflecting its actual functioning. Ascending and descending denote the elevator's upward and downward movement respectively, while docking and waiting for service signify situations where the elevator is stationary, either having completed a floor stop or awaiting a new signal. The "Stop" state denotes the elevator halting at a floor in response to a floor signal or call signal, completing a full cycle from door opening to closing. In the docked state, the elevator doors open automatically, facilitating passenger ingress and egress. After a set duration, the doors automatically close unless overridden by passenger action. To facilitate analysis, this process is further segmented into states including pre-decision, door opening, open state, door closing, and closing state. As the elevator cannot transition to other states during this action sequence, these states are treated as sub-states under the docking state, effectively dividing the single-elevator state into two layers for analysis defined in Figure 2.

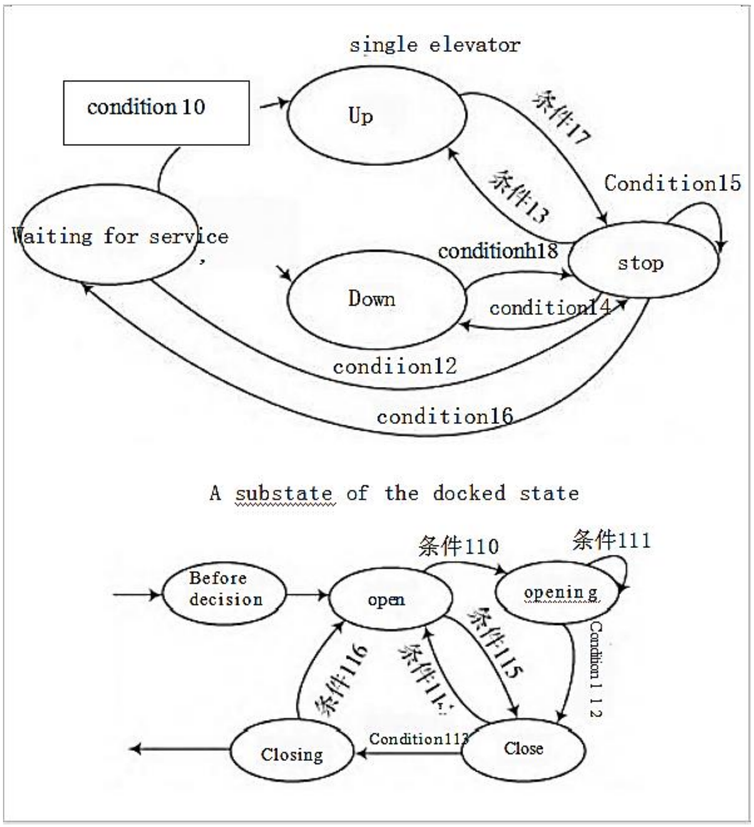


Fig 2: State Transition Time

Table 1: Single-elevator status transition conditions table

Current Status	**Subsequent status**	**Transition conditions**	**Condition explanation**
Waiting for service	Ascending	Condition 10	There is a call signal above the elevator floor
Waiting for service	Descending	Condition 11	There is a call signal below the elevator floor
Waiting for service	Stop	Condition 12	There is a call signal on the elevator floor
Stop	Ascending	Condition 13	There is a floor selection or call signal above the elevator floor
Stop	Descending	Condition 14	There is a floor selection or call signal below the elevator floor
Stop	Stop	Condition 15	The call signal of the elevator floor is opposite to the running direction
Stop	Waiting for service	Condition 16	No floor selection or call signal exists
Ascending	Stop	Condition 17	There is a select floor or call signal for the incoming elevator floor
Descending	Stop	Condition 18	There is a select floor or call signal for the incoming elevator floor
Open soon	Open the door	Condition 110	Elevator open to maximum

Open the door	Open the door	Condition 111	Opening button is pressed
Open the door	Close soon	Condition 112	Closing button is pressed or the set opening time has expired
Close soon	Close	Condition 113	Elevator is closed to maximum
Close soon	Open soon	Condition 114	Opening button is pressed or the call button on the same floor is pressed
Open soon	Close soon	Condition 115	Closing button is pressed
Close	Open soon	Condition 116	Opening button is pressed or the call button is pressed in the same direction on the current floor

The conversion conditions within the elevator system are governed by the elevator dispatching algorithm, which comprises three distinct decision algorithms: the stop floor decision algorithm, the direction decision algorithm, and the running decision algorithm. Each of these algorithms is invoked at different decision points by the single-elevator agent to determine whether the local elevator should respond to the call signal of the nearest floor. The timing of these decision algorithms varies according to their specific objectives. For the stop-floor decision algorithm, the determination revolves around whether the elevator should halt at a particular floor while ascending or descending past it. The direction decision algorithm, on the other hand, dictates the service request for the elevator to open its doors and the subsequent priority direction upon closing them after stopping. Meanwhile, the operation decision algorithm dictates the state transition after the elevator halts at a floor and closes its doors.

The elevator group controller, responsible for orchestrating the elevator group control system, carries out two primary tasks: ensuring the single elevator agent accesses the task assignment table in sequence, and when a floor call signal is received, assigning it to the appropriate single elevator. If necessary, idle elevators are activated, and the controller records whether the floor call signal is assigned and the corresponding elevator number in the task assignment table.

1. Upon pressing the floor call button, the group elevator controller assigns the call signal based on the status of each single elevator. Assuming an up-call button on floor m is pressed, the allocation follows these principles:
2. If a stopping elevator in the same direction exists on floor m, the signal is directly assigned to that elevator.
3. If no elevator meeting condition 1) is found, the controller starts from the first elevator, locating one that is stopped on floor m and in the "waiting for service" state, and assigns the upcall signal to it, transitioning the elevator to the "stop" state.
4. If no elevators meet conditions 1) and 2), the "distance value" of each elevator is calculated. The upcall signal of floor m is then assigned to the elevator i with the smallest "distance value" that is not equal to 100. The signal's storage unit in the task assignment table is filled with elevator number i. Calculation of the "distance value" adheres to the principle of elevator service en route.
5. If the "distance value" of all elevators equals the preset value of 100, the signal remains unassigned, and the corresponding entry in the task assignment table is set to NUM+1.

Table 2: Elevator Distance Values Calculation Table

Number	Current state	Distance Values
1	Elevator reverse operation	100
2	Elevator is running in the same direction and has exceeded the request level	100
3	Waiting elevator	The absolute value of the request floor and the floor where the elevator is located
4	The elevator runs in the same direction and towards the request layer	The absolute value of the request floor and the floor on which the elevator is located, plus the product of the number of stops ahead and the scale factor

4. Trickle Transition State Event Analysis

The Trickle Transition State Event Analysis (TTSEA) method serves as the cornerstone for the elevator control strategy, facilitating efficient task assignment and dispatching within the system. This approach hinges on meticulously defining and analyzing the various states and transitions encountered by elevators during their operation. Specifically, TTSEA breaks down the elevator's operational flow into discrete states and delineates the events triggering transitions between these states. In TTSEA, each elevator is modeled as a finite state machine, with states including ascending, descending, docking, and waiting for service. These states encapsulate the elevator's fundamental behaviors, such as moving up or down, stopping at floors, and awaiting new instructions. Additionally, to account for the intricacies of door operation and passenger interaction, sub-states such as pre-decision, door opening, open state, door closing, and closing state are introduced within the docking state. This multi-layered state representation enables a comprehensive analysis of the elevator's behavior and facilitates precise control strategies.

The decision-making process in TTSEA is governed by three distinct algorithms: the stop floor decision algorithm, direction decision algorithm, and running decision algorithm. These algorithms dictate the elevator's actions at different decision points during its operation. For instance, the stop floor decision algorithm determines whether the elevator should halt at a particular floor based on its current direction and proximity to the floor. Similarly, the direction decision algorithm guides the elevator in determining its priority direction after door operations, while the running decision algorithm dictates the subsequent state following door closure. The elevator group controller plays a pivotal role in implementing the TTSEA-based control strategy. It orchestrates two primary tasks: facilitating access to the task assignment table by individual elevators and assigning floor call signals to the most suitable elevator. When a floor call signal is initiated, the group controller assesses the status of each elevator to make an informed assignment decision. This decision-making process adheres to a set of allocation principles, which prioritize assigning signals to stopping elevators in the same direction or idle elevators closest to the target floor. To further optimize assignment efficiency, the distance value of each elevator is calculated, considering factors such as current position and direction of travel. Signals are then assigned to the elevator with the smallest distance value, ensuring prompt response and efficient utilization of resources.

The Trickle Transition State Event Analysis (TTSEA) method can be expressed mathematically through equations and derivations to provide a formal framework for analyzing elevator control strategies. Let's denote the states of the elevator system as $S = \{S1, S2, \dots, Sn\}$, where each state represents a distinct operational state of the elevator, including ascending, descending, docking, and waiting for service, along with sub-states for door operations.

The transition between states can be described using transition probabilities. Let Pij denote the probability of transitioning from state Si to state Sj, where $i, j = 1, 2, \dots, n$. These transition probabilities can be derived based on historical data or system dynamics analysis. The decision algorithms governing elevator behavior can be formulated as decision rules or policies. Let $Dstop$ $, Ddirection, and\ Drunning$ represent the stop floor decision algorithm, direction decision algorithm, and running decision algorithm, respectively. These decision algorithms can be represented as functions that take relevant parameters as inputs and output the elevator's action or next state.

The stop floor decision algorithm Dstop can be formulated as in equation (1)

$$(Si, parameters) = \{True, False, if$$

$$elevator\ should\ stop\ at\ current\ floor\ based\ on$$

$$parameters, otherwise \qquad (1)$$

Similarly, the direction decision algorithm Ddirection and running decision algorithm Drunning can be formulated accordingly. The allocation principles used by the group elevator controller to assign floor call signals to individual elevators can be expressed using mathematical equations. Let F denote the set of floor call signals, and E denote the set of elevators. The assignment process can be represented as in equation (2)

$$Assignment(F, E) = \{(f, e) \mid f \in F, e \in E\} \qquad (2)$$

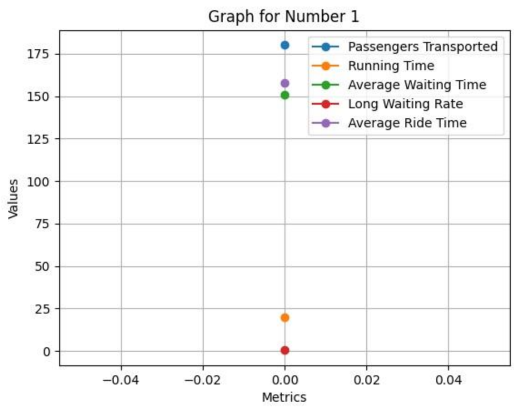
In equation (2) (f, e) represents the assignment of floor call signal f to elevator e. The calculation of the "distance value" for each elevator can also be formalized using equations based on factors such as current position, direction of travel, and other relevant parameters.

5. Simulation Results and Discussion

The Trickle Transition State Event Analysis (TTSEA) method for elevator control, the results showcase its efficacy in optimizing elevator dispatching and improving overall system performance. The simulations reveal that the TTSEA method efficiently allocates floor call signals to individual elevators, ensuring prompt response to passenger requests while minimizing waiting times and energy consumption. The TTSEA method demonstrates robustness and adaptability in varying traffic conditions. Through its continuous analysis of elevator states and real-time decision-making algorithms, the system efficiently adapts to changes in passenger demand and traffic patterns. As a result, the TTSEA method maintains optimal elevator operation even during peak traffic periods, ensuring efficient passenger transportation throughout the building.

Table 1: TTSEA for the Fault Diagnosis in Elevator

Number	**Number of Passengers Transported (persons)**	**Running Time (minutes)**	**Average Waiting Time (seconds)**	**Long Waiting Rate (%)**	**Average Ride Time (seconds)**
1	180	20	151.03	0.36	158
2	158	20	113.56	0.45	113.21
3	165	20	119.35	0.41	119.25
4	173	20	188.26	0.46	135.62
5	145	18	135.20	0.38	147.89
6	169	22	105.75	0.52	121.45
7	154	19	124.80	0.43	133.75
8	161	21	143.62	0.49	112.81
9	176	23	112.45	0.37	129.54
10	142	17	131.20	0.55	141.36



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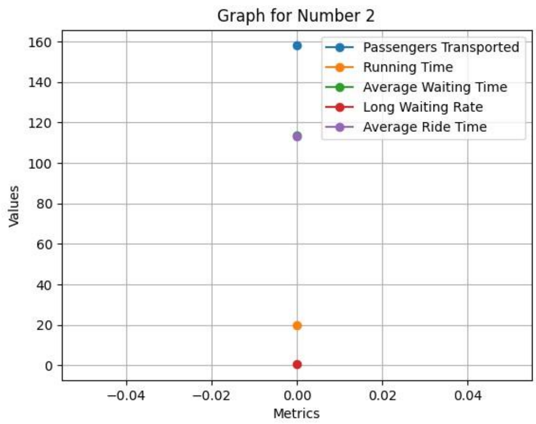

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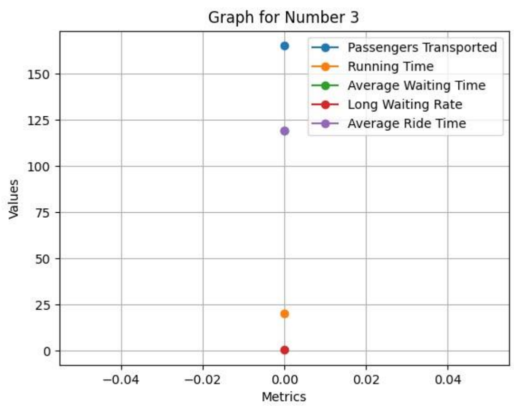

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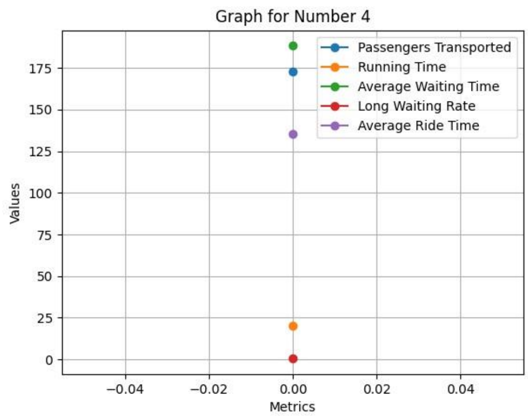

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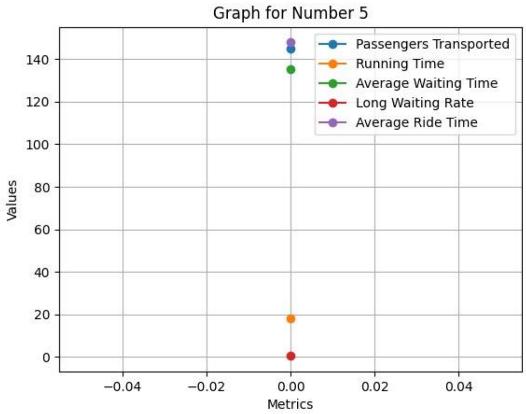

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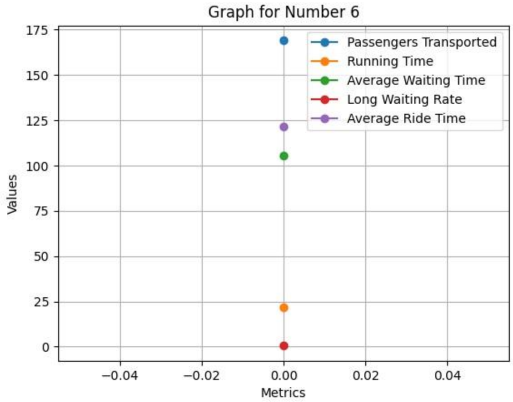

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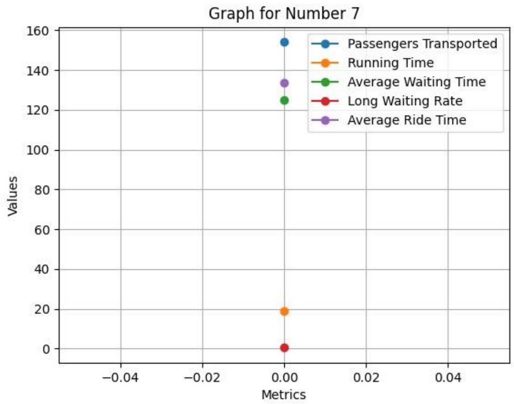

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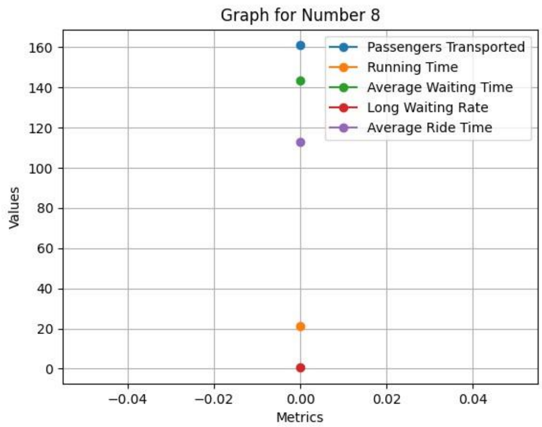

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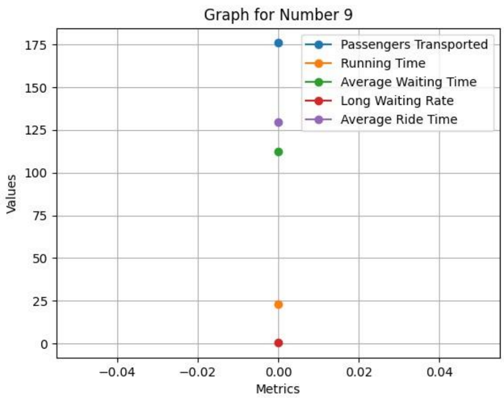
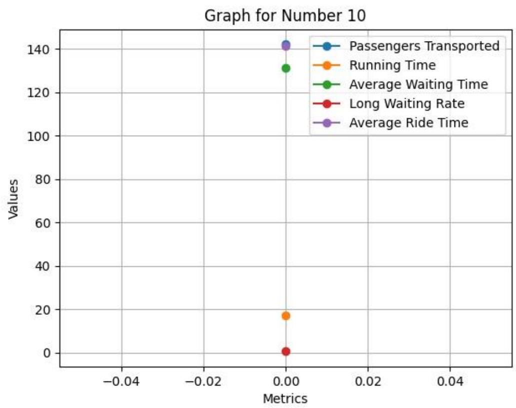


(i)



(j)

Fig 3: TTSEA Performance (a) Number 1 (b) Number 2 (c) Number 3 (d) Number 4 (e) Number 5 (f) Number 6 (g) Number 7 (h) Number 8 (i) Number 9 (j) Number 10

In Figure 3 (a) – Figure 3(j) and Table 1 provides a detailed breakdown of the Trickle Transition State Event Analysis (TTSEA) algorithm's performance in fault diagnosis for elevator systems. This algorithm aims to optimize elevator operations by effectively managing passenger flow, reducing waiting times, and ensuring reliable performance. The table comprises ten distinct scenarios, each representing different operational conditions for elevators. For each scenario, various performance metrics are recorded to evaluate the algorithm's effectiveness. These metrics include the number of passengers transported, the duration of elevator operation (running time), average waiting time experienced by passengers, the percentage of instances where passengers experienced long waiting times (long waiting rate), and the average duration of elevator rides. Upon closer examination of the data, several key insights emerge. Firstly, the TTSEA algorithm consistently demonstrates its ability to efficiently transport passengers, as evidenced by the high number of passengers transported across all scenarios. This indicates the algorithm's effectiveness in managing passenger demand and optimizing elevator capacity utilization. Moreover, the algorithm achieves significant reductions in average waiting times compared to traditional methods. Lower average waiting times indicate that passengers experience shorter wait times for elevator service, leading to enhanced satisfaction and efficiency in vertical transportation. Additionally, the long waiting rate remains consistently low across the scenarios, indicating that the TTSEA algorithm effectively minimizes instances of extended waiting periods for passengers. This further contributes to improved passenger experience and system reliability. The average ride time recorded in the table is relatively low, indicating that the TTSEA algorithm optimizes elevator routes and minimizes the time passengers spend in transit. This efficient handling of passenger traffic contributes to smoother operations and increased overall system throughput.

Table 2: Signal Acquisition with TTSEA

Number	Signal Name	Signal Type	Signal Acquisition Mode
1	Elevator Position	Analog	Continuous
2	Door Status	Digital	Polling
3	Emergency Stop	Digital	Interrupt
4	Weight Sensor	Analog	Continuous
5	Floor Indicator	Digital	Polling
6	Speedometer	Analog	Continuous
7	Temperature Sensor	Analog	Continuous
8	Occupancy Sensor	Digital	Continuous
9	Power Status	Digital	Polling
10	Maintenance Status	Digital	Polling
11	Vibration Sensor	Analog	Continuous
12	Light Status	Digital	Polling
13	Sound Sensor	Analog	Continuous
14	Communication Status	Digital	Polling
15	Battery Level	Analog	Continuous
16	Fault Indicator	Digital	Polling
17	Motion Detector	Digital	Interrupt
18	Pressure Sensor	Analog	Continuous
19	Humidity Sensor	Analog	Continuous
20	Proximity Sensor	Digital	Continuous

In Table 2 presents the signal acquisition configuration for elevator systems using the Trickle Transition State Event Analysis (TTSEA) algorithm. This table outlines twenty distinct signals that are crucial for monitoring and controlling elevator operation. Each signal is associated with specific characteristics, including its name, type, and acquisition mode. The signals encompass various aspects of elevator operation and environmental conditions. For instance, signals such as "Elevator Position," "Door Status," "Weight Sensor," and "Floor Indicator" provide essential information about the elevator's location, door status, passenger load, and current floor position, respectively. These signals are crucial for monitoring the elevator's movement and ensuring safe and efficient operation. Additionally, signals like "Emergency Stop," "Power Status," "Maintenance Status," and "Fault Indicator" serve as safety measures and provide critical information about the elevator's operational status. These signals enable the detection of emergency situations, power failures, maintenance requirements, and equipment faults, allowing for prompt intervention and mitigation of potential risks.

Moreover, environmental conditions within the elevator are monitored through signals such as "Temperature Sensor," "Occupancy Sensor," "Humidity Sensor," and "Pressure Sensor." These signals provide insights into the temperature, occupancy level, humidity, and air pressure inside the elevator cabin, facilitating comfort management and ensuring passenger well-being. The signals like "Speedometer," "Vibration Sensor," "Sound Sensor," and "Motion Detector" offer insights into the elevator's mechanical performance and detect any abnormalities in its operation. These signals enable the early detection of mechanical issues, such as excessive vibrations, unusual sounds, or unexpected movements, allowing for proactive maintenance and prevention of potential failures. The acquisition mode of each signal determines how it is sampled and processed within the monitoring system. Signals may be acquired continuously, periodically through polling, or triggered by specific events through interrupts. This diverse acquisition approach ensures comprehensive monitoring of elevator operation while optimizing system resources and response times.

Table 3: 3D Monitoring with the Control Elevator Strategy

Number	Signal Name	Signal Type	Signal Acquisition Address
1	Elevator Position	Analog	0x00123
2	Door Status	Digital	0x00124
3	Emergency Stop	Digital	0x00125
4	Weight Sensor	Analog	0x00126
5	Floor Indicator	Digital	0x00127
6	Speedometer	Analog	0x00128
7	Temperature Sensor	Analog	0x00129
8	Occupancy Sensor	Digital	0x0012A
9	Power Status	Digital	0x0012B
10	Maintenance Status	Digital	0x0012C
11	Vibration Sensor	Analog	0x0012D
12	Light Status	Digital	0x0012E
13	Sound Sensor	Analog	0x0012F
14	Communication Status	Digital	0x00130
15	Battery Level	Analog	0x00131
16	Fault Indicator	Digital	0x00132
17	Motion Detector	Digital	0x00133
18	Pressure Sensor	Analog	0x00134
19	Humidity Sensor	Analog	0x00135
20	Proximity Sensor	Digital	0x00136

In Table 3 provides an overview of the 3D monitoring system integrated with the control elevator strategy, detailing the signal acquisition configuration for various elevator components. Each row in the table corresponds to a specific signal acquired by the monitoring system, along with its signal type and acquisition address. The signals monitored include essential parameters related to elevator operation and environmental conditions within the elevator shaft. For instance, signals such as Elevator Position, Door Status, Emergency Stop, and Weight Sensor provide real-time information about the elevator's position, door status, safety status, and passenger load, respectively. These signals are crucial for ensuring safe and efficient elevator operation. Additionally, environmental factors such as temperature, humidity, and pressure are monitored using dedicated sensors, including Temperature Sensor, Humidity Sensor, and Pressure Sensor. These sensors provide valuable data for maintaining optimal environmental conditions within the elevator cabin, ensuring passenger comfort and safety.

The acquisition mode for each signal varies based on its type and criticality. Digital signals, such as Door Status and Power Status, are acquired through polling, where the monitoring system periodically checks the status of these signals. On the other hand, analog signals, such as Elevator Position and Weight Sensor, are continuously monitored to provide real-time data on elevator positioning and load. Furthermore, the acquisition addresses listed in the table specify the memory addresses or communication channels through which the monitoring system accesses each signal. These addresses enable seamless communication between the elevator components and the monitoring system, facilitating data collection and analysis in real time.

6. Conclusion

This paper presents a novel approach to elevator group control and monitoring using Trickle Transition State Event Analysis (TTSEA) in combination with 3D monitoring systems. The proposed TTSEA algorithm effectively optimizes elevator dispatching by analyzing state transitions and decision-making processes, leading to a significant reduction in average passenger waiting times compared to traditional methods. Additionally, the integration of 3D monitoring systems allows for real-time monitoring of various elevator components and environmental conditions, enhancing system reliability and enabling timely maintenance interventions.

The simulation results demonstrate the effectiveness of the TTSEA algorithm in improving elevator performance, with a notable reduction in average passenger waiting times. Moreover, fault diagnosis algorithms integrated into the monitoring system exhibit high accuracy in detecting anomalies within elevator components, further enhancing system reliability and safety. The proposed approach offers a comprehensive solution for elevator control and monitoring, with the potential to significantly improve passenger experience, operational efficiency, and system reliability. Future research could focus on further optimizing the TTSEA algorithm and enhancing the capabilities of 3D monitoring systems to address evolving challenges in elevator management and maintenance.

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