Analysis of Fire Lane Obstruction Detection and Resource Dispatch Bottlenecks in High-Density Residential Fire Incidents: A Case Study

Yunwei Wang*
Shenzhen High School of Mathematics and Physics Shenzhen, Guangdong, China
**Corresponding Author*

Abstract: A severe fire broke out in a high-density residential area of Hong Kong in November 2025. The fire spread rapidly from scaffolding on the exterior walls and escalated to a Level 5 fire within a short period [1]. This incident demonstrates that the efficiency of fire rescue operations in high-density residential areas is not only influenced by the scale of the fire but is also closely related to the accessibility of fire lanes, the timeliness of on-site detection, and the rationality of resource dispatch. Taking this fire incident as a case study, this paper constructs a research framework of "incident reconstruction–obstruction identification–access modeling–dispatch analysis" [2][3], drawing on research approaches from the intelligent security field regarding lightweight detection, edge-cloud collaboration, and dynamic dispatch. First, the fire response process is reconstructed in phases to identify key influencing factors in residential rescue operations. Second, an obstruction detection approach focused on fire lanes is proposed to identify obstacles such as illegally parked vehicles, accumulated debris, construction barriers, and gathered crowds. Third, a fire truck travel time model is established, integrating road width, obstruction index, pedestrian density, and on-site transit time into a unified framework. Finally, the resource scheduling bottlenecks in high-density residential fires are summarized and targeted optimization recommendations are proposed. The study concludes that traditional emergency response methods relying on manual patrols and static contingency plans are no longer sufficient to meet the rapid response demands of complex residential fires. Instead, real-time detection, status assessment, and coordinated scheduling should be integrated to form a more proactive smart firefighting support mechanism.

Keywords: High-Density Residential Fire; Fire Lane Obstruction; Object Detection; Edge-Cloud Collaboration; Resource Dispatch

1. Introduction

High-density urban development has altered the conditions for fire response in residential areas. For high-rise or large-scale residential complexes, fire rescue operations do not rely solely on the scale of firefighting resources but are simultaneously influenced by road accessibility, obstacle detection efficiency, and multi-departmental coordination capabilities [2].Existing research on smart security indicates that video detection, anomaly identification, and the integration of edge computing with cloud computing have gradually shifted from a "post-event recording" model to a "real-time sensing-decision support" application model. However, research has primarily focused on general security surveillance scenarios, with insufficient attention paid to issues in fire rescue such as "whether fire trucks can promptly approach the target building" and "how to quantitatively assess passage blockages" [3][4].

On November 26, 2025, a severe fire broke out at Tai Po Wang Fuk Court in Hong Kong. According to public reports, the Fire Services Department received the alert at 14:51, arrived on-site at 14:56, and the fire subsequently escalated, reaching a Level 5 fire at 18:22 [1].To avoid confusion regarding the case name, this article uniformly uses "Tai Po Wang Fuk Court" in Chinese, and the corresponding English name is consistently adopted as "Tai Po Wang Fuk Court" as per public records from the Hong Kong Housing Authority and the Hong Kong Special Administrative Region Government [1][8]. The government subsequently initiated inter-departmental emergency coordination, traffic arrangements, and relocation support, indicating that the incident exceeded the response intensity typically required for a standard residential fire.This incident highlights that in high-density residential areas, the effectiveness of fire rescue operations depends not only on response speed but also on the ability to rapidly establish an effective deployment upon arrival. If roads surrounding the building are obstructed by illegally parked vehicles, temporary debris, construction barriers, or dense crowds of onlookers, the efficiency of fire trucks in approaching the fire site, laying out hoses, deploying aerial rescue equipment, and conducting evacuation and rescue operations will be significantly reduced.

Against this backdrop, this paper uses the Tai Po Wang Fuk Court fire as a case study to attempt to apply concepts from the field of intelligent security-such as lightweight detection, edge-cloud collaboration, and dynamic scheduling-to smart firefighting analysis [2][3][5].The core research questions include: First, how to establish an obstruction detection framework suitable for fire lanes in residential areas; second, how to further convert lane status into a quantitative expression of fire truck travel time; and third, how to analyze resource dispatch bottlenecks in high-density residential fires based on this. The objective of this paper is not to complete an actual system deployment, but rather to propose an interpretable analytical model based on public incidents and existing research, providing insights for subsequent empirical studies.

2. Incident Reconstruction and Problem Definition

According to publicly available information, the Tai Po Wang Fuk Court fire escalated rapidly after it was reported. The spread of the fire was linked to scaffolding and coverings on the exterior walls, necessitating the subsequent deployment of large-scale firefighting, medical, and civil support resources at the scene [1]. From the perspective of emergency response procedures, this incident can be summarized into four phases: initial reporting and arrival of the first responders; assessment of perimeter roads and initial deployment; large-scale reinforcement and search and rescue; and sustained control and post-incident relocation. Although the primary tasks differ across these phases, they all rely on two conditions: first, that on-site access routes allow for rapid approach and vehicle deployment; and second, that the command system can promptly obtain effective information regarding road conditions, obstacles, and pedestrian flow.

Based on this, this paper categorizes the research issues into three levels. The first is the issue of access route availability. High-density residential areas often suffer from insufficient clear road width, limited turning space, and disorderly parking in the vicinity. When combined with a sudden fire emergency, fire trucks may have entered the roads surrounding the residential complex but may not necessarily reach the most critical locations in the shortest time. The second is the issue of obstacle identification. Although traditional manual patrols are intuitive, on-site assessments are prone to delays in environments with smoke, obstructions, low light, or crowd gatherings, making it difficult to provide continuous, structured status information to the command system. The third is the resource dispatch issue. When the scope of an incident expands and multiple buildings or multiple operational fronts require simultaneous support, the absence of risk prioritization and route optimization mechanisms can lead to the indiscriminate deployment of vehicles and personnel, thereby affecting overall efficiency.

Therefore, this paper examines “fire lane obstruction detection” and “fire resource dispatch analysis” within a unified framework, positing that the former provides the foundation for situational awareness while the latter determines response efficiency; together, they constitute key components of smart firefighting decision support.

3. Design of the Fire Lane Occupancy Detection Model

Drawing on existing research on lightweight object detection and edge-cloud collaboration, this paper proposes a "edge-based preliminary detection-cloud fusion" framework for fire lane obstruction detection [2][3][5]. Under this framework, cameras deployed at community entrances, major intersections, or around buildings are responsible for rapid front-end identification, with the edge device outputting simplified results such as obstruction category, location, and lane occupancy ratio;while the cloud aggregates multi-source information and determines the passage status by analyzing time-series changes. Compared to video transmission methods that rely entirely on the cloud, this architecture is better suited for latency-sensitive emergency scenarios and aligns more closely with the “end-to-cloud-to-graph integration” research approach proposed in the previous review.

Regarding detection targets, this paper classifies fire lane obstructions into four categories: illegally parked vehicles, temporary piles of objects, construction barriers, and high-density crowds. The decision to limit obstructions to these four categories is based primarily on three considerations: First, these four categories represent the most common and persistent sources of lane obstruction in high-density residential areas and fire perimeter safety zones;Second, they can be reliably identified by fixed cameras in most scenarios, facilitating rapid output of structured results at the edge; third, they correspond to the three mechanisms that most directly impact fire lane passability-namely, “static width compression,” “persistent spatial encroachment,” and “dynamic passage obstruction”-which align with the regulatory spirit in Hong Kong that emergency vehicle lanes must remain unobstructed and meet basic clear width requirements [9][10].Specifically, illegally parked vehicles and obstructions directly reduce the available width for fire trucks; construction barriers often result in persistent spatial encroachment; and onlookers constitute dynamic obstacles-though mobile, they significantly increase passage obstruction in emergency scenarios. It should be noted that factors such as smoke, low illumination, and road flooding also affect rescue efficiency; however, these are better suited to be incorporated into travel time models as environmental disturbances or correction parameters rather than as primary detection categories in this paper.Given the complex conditions at fire scenes-such as smoke, glare, low light, and obstructions-conventional models are prone to false positives and false negatives when applied across different scenarios. Therefore, research approaches such as unsupervised domain adaptation, image enhancement, and consistency constraints can be adopted to enhance the model’s adaptability to complex environments [4][6][7].

To quantify the condition of the passageway, this paper defines the fire lane obstruction index OI as:

$$OI=\alpha\frac{W_o}{W_r}+\beta\frac{N_b}{N_0}+\gamma\frac{D_p}{D_0} \quad (1)$$

where W_o is the occupied width, W_r is the effective road width, N_β is the number of obstacles, N_0 is the normalized reference for the number of obstacles, D_p is the pedestrian density, D_0 is the normalized reference for pedestrian density, and α, β, and γ are weighting parameters.If $OI < 0.30$, the passage is considered essentially unobstructed; if $0.30 \le OI < 0.60$, passage is restricted; if $OI \ge 0.60$, the passage is deemed severely blocked. Although this expression is simplified, it facilitates the integration of static obstacles and dynamic pedestrian flow into a unified evaluation framework, providing input for subsequent passage modeling and scheduling calculations.

4 Fire Truck Travel Time Model and Dispatch Bottleneck Analysis

Merely identifying road occupancy is insufficient to support scheduling decisions; it is also necessary to convert the identification results into comparable time costs. Based on this, this paper establishes a fire truck travel time model:

$$T=\frac{L}{v_0\cdot f_w\cdot f_o\cdot f_p}+T_i \quad (2)$$

where L represents the effective distance from the fire station to the target area, v_0 represents the ideal average speed, f_w represents the road width correction factor, f_o represents the road occupancy index correction factor, f_p represents the pedestrian flow and intersection congestion correction factor, and T_i represents the time required for on-site deployment and relocation. This model indicates that, when theoretical distances are similar, road narrowing, increased lane occupancy, and increased pedestrian traffic all significantly prolong the time required for fire vehicles to become operational.

Based on the characteristics of the response to the Tai Po Wang Fuk Court fire, this paper identifies three primary types of resource dispatch bottlenecks. First is the spatial bottleneck. High-rise residential complexes are often characterized by dense building clusters, complex road hierarchies, and limited turning space. Once peripheral roads are occupied, fire engines, ladder trucks, ambulances, and command vehicles are prone to interfering with one another.Second is the information bottleneck. If the command system cannot promptly obtain real-time information on the actual accessibility of each access route, it must rely on manual reports for adjustments, making it difficult to optimize routes and execute tasks in parallel. Third is the priority bottleneck. When multiple buildings and multiple operational fronts are affected simultaneously, the absence of a unified risk assessment method makes it difficult to deploy different vehicles and personnel according to the principle of “high-risk first, critical first,” resulting in the scattered use of resources.

To address these issues, this paper proposes three optimization recommendations. First, establish a routine monitoring mechanism for the occupancy of critical fire lanes in residential areas, integrating routine management with emergency deployment.Second, during sudden fires, the system should automatically recommend entry routes based on the OI value and travel time T, rather than relying solely on static maps. Third, introduce a three-dimensional scoring mechanism based on “building risk-access route status-pedestrian density” to implement differentiated deployment of large vehicles, search-and-rescue teams, and evacuation forces. This approach not only continues the research direction of edge-cloud collaboration and dynamic resource scheduling but also better aligns with on-site requirements in complex urban fires.

5. Conclusion

This paper uses the November 2025 fire at Wang Fuk Court, Tai Po, Hong Kong ( ) as a case study to analyze the bottlenecks in fire lane obstruction detection and resource dispatch.The study indicates that in fires within high-density residential areas, the key factors affecting rescue efficiency are not limited to the fire itself; road width, the extent of obstruction, crowd congestion, and the speed of information feedback also play decisive roles. Based on this, this paper proposes a fire lane obstruction index and a fire truck travel time model, and attempts to integrate lightweight detection, edge-cloud collaboration, and dynamic scheduling methods into the smart firefighting research framework.

The primary value of this paper lies in adapting the concepts of real-time detection and collaborative scheduling from intelligent security research to fire rescue scenarios, thereby providing a clear analytical framework for fire lane management and urban emergency response. A limitation is that the current study primarily relies on publicly available data and theoretical modeling, and has not yet been validated using real video samples, road geometric data, or dispatch logs.Therefore, future research could further integrate small-scale data collection, road simulation, and multi-source data fusion to calibrate model parameters and validate their applicability in actual community management.

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