Autonomous Wildfire Response Recommendation System Using Federated Generative Diffusion Models

Msc Artificial Intelligence & Data Science
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1. Motivation

- Wildfires are increasing in frequency and intensity due to climate change (Anastasiou, 2025).
- Effective wildfire management critically depends on rapid and well-coordinated allocation of firefighting resources, yet current response strategies remain largely reactive, slow to adapt, and operationally inefficient (Altamimi, 2022; Zhang, 2025; Yang., 2024).
- There is a critical need for rapid and effective firefighter and resource allocation (Yang, 2024; Zhai, 2025).
- Recent advances in generative AI have enabled faster and more accurate modelling of wildfire behaviour, creating opportutinies to new decision suport solutions (Li, 2024).
- This study explores converting wildfire forecasts into time-critical response recommendations using a decentralised, federated AI framework based on generative diffusion models, where autonomy refers to automated recommendation generation under human oversight.

2. Literature Review

Traditional Wildfire Behaviour Models	**The importance of wildfire forecast models and their limitations** (Li, 2025; Anastasiou et al, 2025)
Resource Allocation & Decision Support	**Tactical allocation and simulation based optimization** (Yang et al, 2024. Zhai et al, 2025)
Generative Models for Wildfire Behavior	**Diffusion models for robust wildfire behaviour prediction under uncertainty** (Xu et al, 2025)
Federated & Decentralized Learning	**Privacy-preserving, multi-region learning** *(Jothiraj, 2024)*

3. Research Questions

RQ 1. How can federated generative diffusion models support real-time tactical decision-making in wildfire response?

RQ 2. How do different environmental data modalities influence the quality of generated recommendations?

RQ 3. How does a federated approach compare with centralised and rule-based strategies in simulated wildfire scenarios?

4. Research Methodology

This study follows a Design Science Research (DSR) methodology, focusing on the design, implementation, and evaluation of an AI-based decision-support artefact for wildfire combat response.

Problem Identification

Fragmented data across agencies, uncertainty in wildfire behaviour prediction, and limited decision-making time during active events

Requirements Definition

Technical and operational requirements were defined for a simulation based wildfire response recomendation system

Artefact Design & Development

A decentralised AI artefact was developed by integrating multi-modal data with locally trained generative diffusion models and federated agregation across nodes

Demonstration & Evaluation

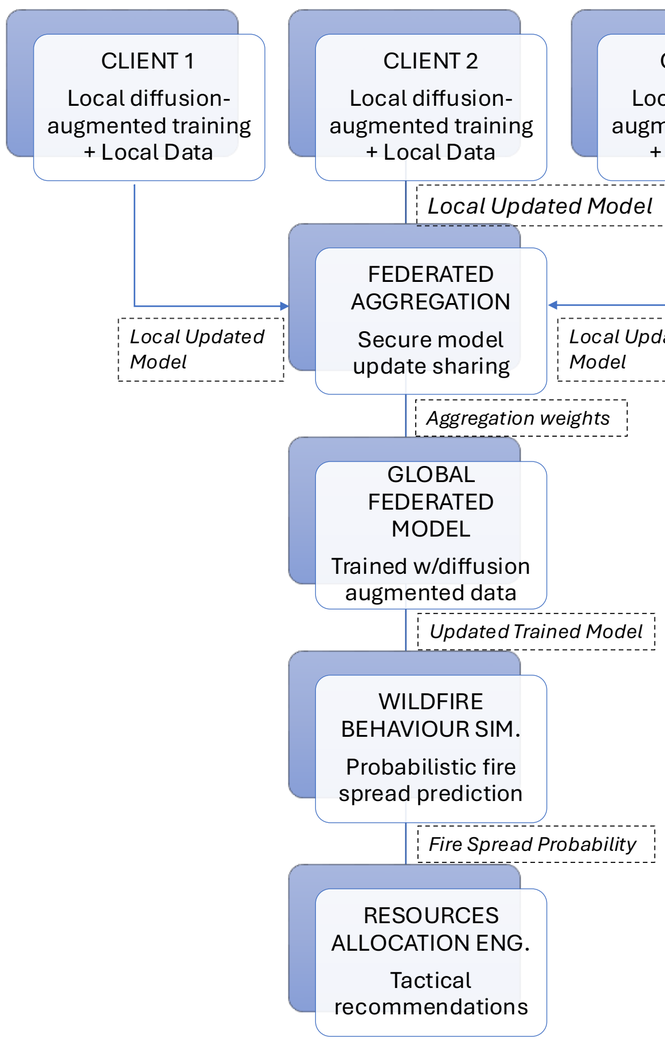
Evaluated through simulation-based experiments comparing federated diffusion based strategies with centralised and rule-based baselines using accuracy, IoU, and latency metrics

Data Inputs

Inputs from multi source environmental data, including weather, topography, vegetattion, fuel conditions, ignition pooints, fire spread Dynamics and satellite images

5. System Architecture

The proposed decentralised architecture enables real-time wildfire behaviour simulation while preserving data privacy by processing satellite imagery, geographic and weather data locally at each client node.



6. Experimental Setup

Simulation-based experimental setup evaluating rule-based, centralised, and federated diffusion-based strategies across decentralised regions.

1. Rule-based baseline

- Heuristic wildfire response using predefined rules and treshholds

2. Centralised learning

- Single model trained on aggregated multi-regional data

3. Federated learning (+ diffusion)

- Decentralised training with diffusion-augmented local data and federated aggregation

7. Key Results

Model/Setup	F1	Accuracy	IoU
Centralized Baseline	0,985	0,973	0,971
Local Client (Avg)	0,973	0,952	0,948
Federated Aggregated	0,975	0,955	0,951

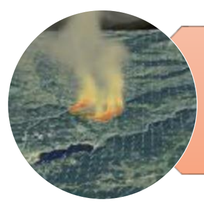
Table 1. Prediction performance comparison across strategies.

8. Conclusions

The results demonstrate that federated generative architectures can robustly support real-time wildfire response recommendations for operational decision-making at scale.

(RQ 1) 1. Federated learning achieved performance comparable to a centralised model while enabling real-time local decision support.

(RQ 2) 2. Using multiple environmental data sources with diffusion improved model robustness where regional data were limited.



(RQ 3) 3. Federated aggregation reduced performance diferences and outperformed local only models.

9. Future Work

- Quantitative evaluation of the resource allocation module using operational decision metrics (e.g. containment time, cost).
- Controlled ablation studies to assess the contribution od individual environmental data modalities to prediction and simulation quality.
- Extension of the framework to larger-scale real-world wildfire datasets beyond the Sim2Real-Fire subset used in this study to assess scalability and deployment readiness.

References:

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