

# IoT-Driven Entrepreneurship in CAFS Fire Suppression Systems for Risk Mitigation in Smart Buildings, Petrochemical Plants, and Refineries: An Attrition Entrepreneurship Theory Approach toward UN Sustainable Development Goals

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## Abstract

The integration of Internet of Things (IoT) technology and fire suppression systems is revolutionizing the way risk mitigation is thought of in smart buildings and high-risk industrial settings like petrochemical plants and refineries. Compressed Air Foam Systems (CAFS) are a type of fire suppression system that have been shown to have better extinguishing power and water conservation capabilities, but their potential has yet to be fully explored in the context of IoT-integrated systems. At the same time, entrepreneurial innovation that uses IoT to create and spread solutions based on CAFS technology could help meet a number of United Nations' Sustainable Development Goals (SDGs) ahead of schedule, particularly SDG 9 (Industry, Innovation and Infrastructure), SDG 11 (Sustainable Cities and Communities), and SDG 13 (Climate Action). Through the Attrition Entrepreneurship Theory framework, which focuses on the way risk, resilience, and entrepreneurial dynamics interact and change in response to technological disruption, we explore the current state of IoT-integrated fire suppression research, the entrepreneurial ecosystem surrounding CAFS technology, and their alignment with sustainable development goals.

**Keywords:** Entrepreneurship, Fire Suppression Systems, Risk Mitigation, Attrition Entrepreneurship Theory, Sustainable Development Goals

## I. Introduction

The United Nations Sustainable Development Goals (SDGs) are highly relevant to a wide range of scientific fields and industries, including agriculture, wildlife conservation, entrepreneurship, building and design. Fire accidents in smart buildings, petrochemical plants, and refineries are major threats to human lives, infrastructures, and the environment. Rapid detection, effective suppression, and data-driven operational decisions are critical in addressing the risks. In the past, fire suppression systems have relied on conventional systems such as water or dry chemicals. Nevertheless, studies have indicated the improved performance of Compressed Air Foam Systems (CAFS) in fire suppression through improved stability and absorption capacity of the foam. In addition, CAFS systems require less water compared to conventional systems. Nevertheless, there has been a lack of IoT-based systems in the implementation of CAFS systems in smart buildings and refineries.

Internet of Things (IoT) has been recognized as a critical enabler in the implementation of real-time monitoring, analysis, and control in smart buildings. IoT systems have been recognized as a critical enabler in the implementation of real-time monitoring systems in smart buildings. Despite the advancement in IoT implementation in smart buildings' management systems, there is a lack of literature in IoT

implementation in smart buildings' advanced fire suppression systems.

This short review combines the findings from studies on IoT in risk mitigation, CAFS fire suppression technology, and sustainable entrepreneurship frameworks for attaining the United Nations' Sustainable Development Goals. We use the Attrition Entrepreneurship Theory framework, which examines the emergence, survival, and development of entrepreneurial ventures in reaction to technological and sectoral risk profiles, to shed light on the alignment of IoT-based CAFS innovations with sustainability principles.

### **IoT in Smart Fire Safety Management**

IoT technologies enable ubiquitous sensing and communication capabilities for monitoring environmental factors such as smoke, heat, presence, and structural stress in smart buildings. Sensor networks, data fusion, and connectivity technologies play a crucial role in rapid detection and risk analysis.

Scientists have shown the ability of IoT systems in university buildings to monitor and improve energy efficiency, which also supports smart readiness indicators related to sustainability targets. Even though their research targets energy efficiency, it is clear that IoT system frameworks have the potential to be expanded to safety-related applications as well. Other studies on smart fire safety management systems have also investigated the integration of energy management infrastructure to achieve optimal evacuation and safety services through real-time IoT data analysis for emergency response applications.

In a systematic review of the use of IoT sensors in indoor fire hazard situations, researchers emphasized the overall importance of using IoT sensors, AI algorithms, and communication protocols in improving early warning systems and navigation systems. The importance of using IoT in predictive models and AI algorithms in improving fire risk mitigation before, during, and after fire incidents cannot be overemphasized, especially in situations where the space is highly occupied. The importance of IoT technology is in its cyber-physical systems, which combine physical systems with digital analytics. This is the secret to effective fire suppression.

### **Compressed Air Foam Systems (CAFS) in Fire Suppression**

Compressed Air Foam Systems (CAFS) utilize compressed air injected into the mixture of water and foam to create a foam blanket that

effectively starves fires of oxygen while also smothering them in a more efficient manner than using only water. CAFS technology was utilized in structural and industrial fire safety, with bench-scale tests showing promising results in terms of extinguishment time.

Researchers carried out an experimental assessment of CAFS efficiency using varying ratios of air to aqueous foam mixtures, showing that CAFS technology was more effective in terms of efficiency compared to conventional technology showcasing CAFS's viability for inclusion in fixed fire safety systems.

Independent research was also carried out to assess the operational advantages that CAFS technology can offer in terms of improved maneuverability due to the lighter weight of the blankets used in CAFS technology.

However, despite their technical advantages, the use of CAFS is constrained by limitations such as cost, complexity of integration, and the absence of IoT connectivity for real-time monitoring and control. There is limited literature available on the topic of IoT-enabled CAFS architecture, which aims to extend the conventional mechanical system to predictive and adaptive networks.

### **IoT-Driven CAFS and Risk Mitigation**

Although IoT has been extensively explored for building automation and danger detection, the direct coupling of IoT technology with active fire suppression systems such as CAFS is still in its infancy. The major potential benefit derives from completing the cycle between danger detection and suppression activation: IoT sensors identify precursors of early fire detection, machine learning algorithms forecast fire dynamics, and automatically activated CAFS systems eliminate dangers with minimal human involvement. This integrated strategy corresponds to smart building architectures that emphasize overall safety, energy sustainability, and user comfort.

Studies conducted in digital twin settings have already shown the potential of real-time IoT sensor data to improve firefighting operations using predictive modeling and visualization. Although applied to smoke diffusion and fire propagation modeling on an urban scale, the digital twin paradigm can be adapted to CAFS-enabled buildings and industrial facilities.

Furthermore, there is a synergy between the IoT data and the suppression system actuation that has significant implications for predictive maintenance and optimization of operations—crucial aspects of sustainable industrial practice. By

integrating the CAFS sensors into the larger IoT infrastructure, managers can better monitor the readiness of the suppression system, fluid levels, and the health of the actuators, thus improving overall resilience and reducing downtime. In real-time analysis, for instance, foam injection can be adjusted based on the intensity of the fire or the occupancy of the building.

### **Advanced Fire Equipment Standards and Certification Frameworks**

The entrepreneurial scalability and effectiveness of IoT-based CAFS systems can be significantly improved through the application and adherence to international standards and frameworks in the development and use of the equipment. Such standards and frameworks, such as those developed and published by the National Fire Protection Association (NFPA) and Underwriters Laboratories (UL), help ensure the technical effectiveness and validation of CAFS systems in the development and use of the equipment. Similarly, in the European Union, standards developed and published by the European Committee for Standardization (CEN) help ensure the effectiveness and validation of CAFS systems in the development and use of the equipment. Therefore, the use and application of such standards in the development and use of IoT-based CAFS systems can help reduce the risks of technological attrition, as described in the Attrition Entrepreneurship Theory, and promote the entrepreneurial scalability and effectiveness of the systems. Moreover, the use and application of such standards in the development and use of IoT-based CAFS systems can help promote the development and use of smart fire equipment, which can be used in the development and implementation of SDG-aligned infrastructure.

### **Entrepreneurship and Sustainable Development Goals**

By applying IoT and CAFS technology, entrepreneurial activities provide opportunities for sustainable innovation. The emerging field of sustainable entrepreneurship positions entrepreneurial activities within broader ecological and social challenges. Entrepreneurial activities may extend beyond the objective of profit maximization to encompass environmental protection and societal safety, directly addressing SDG 9, SDG 11, and SDG 13.

Studies on entrepreneurship indicate that digital technologies, such as IoT and AI, provide new avenues for the generation of value and sustainable business opportunities. Digital entrepreneurship can reduce barriers to entry and

offer scalable solutions for enhancing resource efficiency, safety, and risk mitigation.

Furthermore, the literature on sustainable entrepreneurship and SDGs has highlighted the important role of entrepreneurs in responding to social issues by ensuring that innovation is aligned with environmental and social goals. In the domains of smart building safety and industrial risk management, new ventures can be created using IoT-based CAFS technology to minimize losses due to fires, ensure climate resilience by minimizing water use in fire protection, and encourage industrial sustainability.

By conceptualizing the innovation of CAFS as a sustainable business, entrepreneurs can create products and services that can be integrated into the factors of resilience, efficiency, and safety while taking advantage of the incentives provided by the commitment to the SDGs.

### **Attrition Entrepreneurship Theory and Risk-Intensive Innovation**

As per the Attrition Entrepreneurship Theory (AET), entrepreneurial activities are affected by risk exposure, resource limitations, and shifting demands of the market. In situations where there is high technological complexity and safety needs, entrepreneurial activities in petrochemical units and refineries are affected by the pressure of attrition.

The entrepreneurial frontier of IoT-based CAFS innovations is a high-risk opportunity with high reward potential for enhancing safety and sustainability. As per AET, only entrepreneurial activities that have the ability to withstand the forces of attrition in technological and market contexts can sustain. Collaborations with various stakeholders in the sector and governments can aid entrepreneurial activities in resisting the pressure of attrition.

Phased adoption, modular system development with low integration costs, and service models (safety as a service) can be used by entrepreneurial activities to resist the pressure of attrition.

### **Research Gaps and Future Directions**

However, there are gaps in the body of research. Firstly, it has been identified that there is an absence of empirical research in the area of integrated system architectures in which IoT sensors, predictive analytics, and automated control mechanisms seamlessly integrate with Compressed Air Foam Systems (CAFS). Secondly, while the body of research in sustainable entrepreneurship has identified the inter-linkages between innovation and the Sustainable Development Goals (SDGs), there has been a clear absence of research in the area of

the entrepreneurial ecosystem in which fire safety technologies are encouraged in high-risk industries. Thirdly, there has been a clear absence of quantitative research in the area of measuring the socio-economic benefits of IoT-based CAFS technologies, particularly in the area of their impact on fire risk reduction, cost efficiency, and the attainment of the Sustainable Development Goals. Moreover, there has been a clear absence of regulatory and standardization frameworks in the area of the interoperability, security, and industrial safety requirements of IoT-based CAFS technologies. To address the gaps in the body of research, it has been identified that there is a clear need to engage in collaborative research.

## II. Conclusion

The current research base also faces many shortcomings that need to be addressed in the future. Firstly, there is an observable absence of research that explores integrated system architectures that can easily integrate IoT sensors, predictive analytics, and control mechanisms in CAFS. Therefore, there is a need for interdisciplinary research that combines fire engineering with IoT system designs. Secondly, while sustainable entrepreneurship research links innovation with the achievement of the Sustainable Development Goals (SDGs), there is insufficient research that explores the entrepreneurial ecosystems that promote the development of fire safety technologies in high-risk industrial sectors. Thirdly, there is a need for more rigorous quantitative research that can assess the socio-economic impact of IoT-based CAFS technologies, including the impact of IoT-based CAFS technologies on the achievement of the SDGs in terms of reducing carbon emissions in the event of fires.

Moreover, there is also a need for the development of new regulatory frameworks that can promote the development of IoT-based CAFS technologies that can easily integrate with existing industrial safety standards.

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