Opportunities for Application of Disruptive Technology in a Disaster Management System to Address Gaps in Australian Bushfire Response

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Abstract:
Australia has recently experienced increasing instances of natural disasters, including floods, drought, and bushfires. The Bushfires in 2019-20, also known as Black Summer, were particularly impactful. This led to an in-depth governmental investigation of its management via Royal Commission and Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO). Key recommendations for an improved disaster management system included removing silos, improve data accuracy and sharing, and using a systems design approach. In response to these reports, this paper explores how disruptive technology- blockchain, intelligent systems, and Intelligent Internet of Things (IIOT)- can be used to improve disaster response, particularly as it applies to bushfires in Australia. The method used to explore this was, first, a review of government reports on the 2019-20 bushfires to identify disaster management gaps and recommendations. Subsequently, a review of available literature was conducted to find how disruptive technology was being applied to disaster management systems. Finally, this paper explores implications of disruptive technology and presents potential next steps in research toward the future creation of a prototype.

Keywords:
blockchain, disaster management system, intelligent internet of things, intelligent systems

1 Introduction and Justification

Disaster management (DM) is defined as the coordination of prevention, mitigation, and response to disaster to support the public (Qadir et al., 2021). It involves carrying out actions such as monitoring, preparedness, planning, prevention, relief, and recovery (Kaur et al., 2022). A disaster management system is a set of interconnected tools, techniques and processes required to manage disasters. Effective disaster management in Australia, and globally, is crucial to preventing loss of life and other disaster impacts. This paper narrows the focus to disaster management system for disaster response (DMSR), the coordination of effort during a disaster to respond to emergencies, understanding risks, and allocating resources to perform impact mitigating actions.

1.1 Black Summer – The 2019-20 Australian Bushfires

This research was inspired by the Australian natural disaster that was the 2019-20 Bushfires, also known as Black Summer. A bushfire, or wildfire, is an uncontrolled fire fuelled by vegetation. Australia is prone to bushfires due to its hot and dry climate (Mark Binskin, 2020).

The unprecedented scale of the fire required advanced and urgent cooperation, as multiple fires raged across Australian States. Multiple government jurisdictions needed to work together to respond.

An Australian Royal Commission is a government-independent body which performs an inquiry into matters deemed of high national importance, often where significant failings are found in responsibility to the public. The CSIRO is Australia's national science agency. Both these bodies were engaged to review gaps in the Black Summer bushfires and make recommendations for improvements. This paper addresses gaps and recommendations for Australian DMSR as identified by the Royal Commission 2020 (RC) (Mark Binskin, 2020) and CSIRO (CSIRO, 2020b) . We then review and analyse recent disruptive technologies which may contribute to close gaps identified.

1.2 Australia's Disaster Management - Current State

The current Australian bushfire management approach is mainly qualitative, relying on expert insights to make judgements, and using experienced coordinators to make complex judgements in real time (Zarghami and Dumrak, 2021). Recent research has veered toward the need for a quantitative approach to supplement this (Zarghami and Dumrak, 2021), where accuracy can be increased with real time complex decisions supported by big data and data analysis. Zarghami and Dumrak (2021) argue traditional qualitative approaches to bushfire management will no longer suffice given the scale and increasing complexity of recent disasters. This is reiterated by the Royal Commission, which highlights the lack of accurate information being passed between parties (Mark Binskin, 2020). Recently, this recognition has sparked research interest in supplementing technology, in particular, intelligent systems, to support complex human decision making (Zarghami and Dumrak, 2021).

Australia's current disaster management bodies are many and siloed (Mark Binskin, 2020, CSIRO, 2020b). Australia's bushfire coordination effort is performed largely by impacted government (usually at state and local government level) jurisdictions, supported by several specialist bodies, including National Council for Fire and Emergency Services (AFAC), Emergency Management Australia (EMA), Australian Institute of Disaster Resilience (AIDR), and the BNHCRC (Bushfire and Natural Hazards Cooperative Research Centre) (CSIRO, 2020a). Additionally, the CSIRO reports that technology platforms used for disaster management vary between states and territories and perform different functions (CSIRO, 2020b).

1.3 Royal Commission and CSIRO – Gaps and Recommendations

On 28th October, 2020, after the devastating national impact of the 2019-20 Bushfires, the Royal Commission published its comprehensive recommendations for improving effectiveness of natural disaster management in Australia (Mark Binskin, 2020). Importantly, the Royal Commission acknowledged the likelihood of increased natural disaster occurring due to climate change, in particular due to rising sea levels and rising temperature (Mark Binskin, 2020). Further, future disasters will be more complex and more difficult to manage(Mark Binskin, 2020).They conclude that a more comprehensive disaster management approach is needed (Mark Binskin, 2020).

The Royal Commission report provides evidence-based gaps which form a starting point to improve the Australian bushfire response (Mark Binskin, 2020). The recommendations, though touching a wide variety of technology, are general, and do not provide a unified view of a potential response system. These identified gaps, and subsequent key recommendations, together with those of the CSIRO's, will be used as a basis for the remainder of this paper.

Recommendations by the CSIRO (CSIRO, 2020b), Australia's national science agency focus more on technology and systems. New and emerging technology can be incorporated to potentially improve effectiveness of disaster management systems. This is echoed by the CSIRO report into the future of emergency management in Australia (CSIRO, 2020a, CSIRO, 2020b). A summary of recommendations is presented in the Results section. This paper proposes three disruptive technology areas that addresses the recommendations from CSIRO and Royal Commission, based on review of recent related literature: Intelligent systems, blockchain, and IIoT.

2 Research Methodology

The methodology for this paper centres around finding peer reviewed research and Australian Government official documents. The intent is to perform gap review in the current Australian Bushfire DMSR, given government documents, and investigate how related recent disruptive technology innovations may address them. Figure 1, below, summarises the methodology used to perform the literature review.

Scopus and Google Scholar search databases were selected, as they offered a broad selection of relevant research with full text links. Research paper searches were limited to peer reviewed articles and book chapters published since 2015. However, Scopus and Google Scholar searches did not contain official Government reports, so the search was widened to include official Australian Government departments and agencies websites.

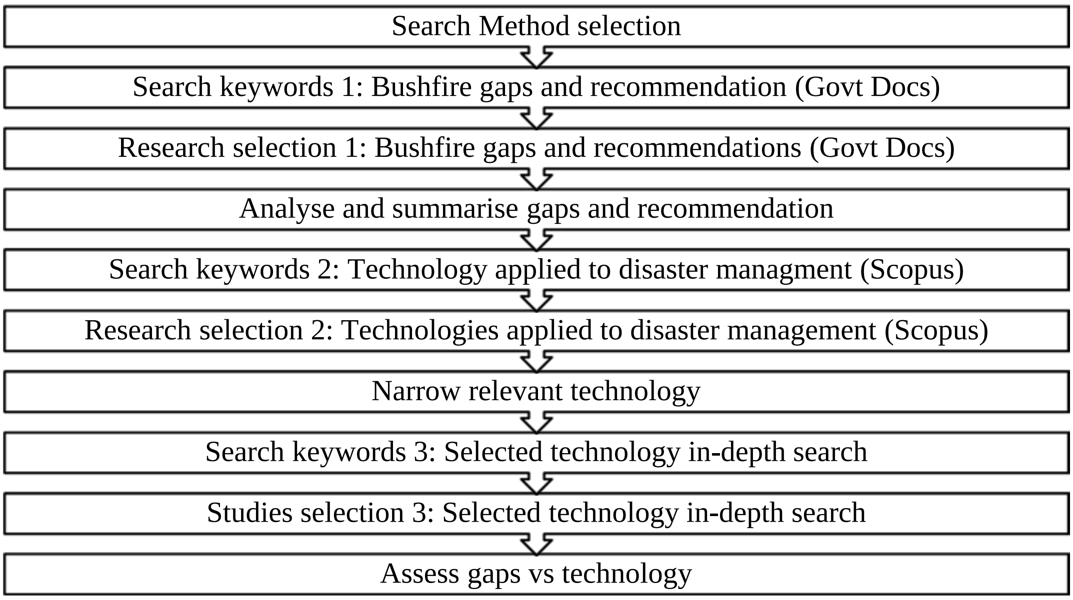

Figure 1. Research Methodology

Once the databases were selected, a comprehensive review was performed of available documentation around the 2019-20 Australian Bushfire disaster response gaps and recommendations. The purpose of the review was to identify and codify both gaps (what was done poorly, what was missed), and proposed recommendations for resolution in an updated DMSR. Two Government requested reports formed the basis for gap and recommendations analysis, the Royal Commission and CSIRO reports in response to 2019-20 Black Summer (CSIRO, 2020b, Mark Binskin, 2020).

Next, a search was done via Scopus and Google Scholar to review what recent technology was applied to bushfire DMSR or global natural disasters in general. A filter removed all non-peer reviewed papers, and any papers prior to 2019. The search was also limited to journals and conference proceedings. The initial search term used was “disaster management system”. The resulting 6196 documents provided an overview of common recent technology used around the world and locally. Titles were reviewed for themes. It allowed for narrowing the disruptive topics to three commonly and recently researched areas: blockchain, intelligent systems, and IIoT. Once all relevant target papers were identified and reviewed, analysis were performed, with attention to addressing earlier identified gaps and recommendations. The results present below highlight, first, the recommendations found in the first round of searches into Australian Government reports, then how each technology area can address them.

3 Findings and Discussion

3.1 DMSR Gaps and Recommendations from Royal Commission Report

Three important gaps, were identified by the Royal Commission report (Mark Binskin, 2020). The first area identified as an issue is the siloed systems, processes, and resources. This makes it difficult to get approval between borders and to share resources (Mark Binskin, 2020). The second is incorrect or incomplete data provided during response communication. This delays response or results in incorrect actions, putting lives in danger (Mark Binskin, 2020). The third gap is the ineffective use of resources (Mark Binskin, 2020). This gap identification is also supported by the report from the National Bushfire and Climate Summit of 2020 which states that the Australian Defense resources were under-utilised in Black Summer disaster (Ltd., 2020). The suggestion is that the capabilities of resources be assessed and coordination improved where resource engagement is concerned (Ltd., 2020) .

In response to these gaps, the RC and CSIRO made key recommendations post Black Summer 2020, as summarised in Table 2 (Mark Binskin, 2020, CSIRO, 2020b). First, both reports emphasise the need for a national approach to disaster management, with closer collaboration between jurisdiction and coordinating bodies, facilitating more effective sharing of resources and collaboration (Mark Binskin, 2020, CSIRO, 2020b). This addresses gap 1, the need to improve collaboration and reduce siloes, by providing a unified platform for communication, policy definition, and information sharing. This recommendation also addresses the second gap, incorrect or incomplete data sharing, because it provides a central data platform which is consistent to all stakeholders. The recommendation addresses the third gap, ineffective use of resources, by providing a central pool that can be prioritised across jurisdictions. The second recommendation is to improve data quality, minimising misinformation and preventing errors due to incorrect or incomplete data (CSIRO, 2020b, Mark Binskin, 2020). The last recommendation, to incorporate a systems approach to improve DMSR risk analysis and analytics, is solely reported by the CSIRO (CSIRO, 2020b). By improving relevancy of data, it implies the removal of siloed data sharing, thus addressing gap 1. The second gap is directly addressed by this recommendation. Resolution of the third gap is implied, since accuracy of underlying data promotes better resource allocation decisions.

Finally, CSIRO proposed that systems thinking is required. Systems thinking, using a multi-disciplinary and risk-based analysis approach would address all three gaps. The systems thinking approach views a system as an ecosystem of interconnecting components, that all work together and impact one another, rather than individual (siloed) parts. It requires multi-disciplinary knowledge sharing to improve decision making throughout the system. It would also entail a risk-based approach to prioritise critical decisions.

Table 2. Royal Commission and CSIRO Recommendations (Source: Royal Commission, 2020;CSIRO, 2020)

Id	**RC** (Mark Binskin, 2020).	**CSIRO** [5].
1	A nation-wide approach to disaster management is needed, with improved coordination and cooperation between government bodies and regions. (Pp 23).	A harmonised and collaborative national approach is required to achieve global best practice. (Pp 8)
2	Data needs to be comprehensive, accurate, consistent, timely, shared and nationally consistent. (Pp 103)	Data Availability is a key disaster management enabler. (Pp 8)
3		Systems thinking to deal with complexity. This includes for multi-disciplinary approach and a risk-based analysis. (Pp 8)

In the next section of the results, we review each technology area – blockchain, IIoT and intelligent systems – to investigate how these recommendations can be addressed.

4 Disruptive Technology Addressing Gaps and Recommendations Identified by the Royal Commission Report

4.1 Blockchain

Blockchain is a distributed, decentralised, and immutable public ledger, with a peer-to-peer network topology (Chowdhury et al., 2022). Data blocks, stored in a distributed manner, are linked in a chronological data chain (Huang et al., 2020). Although blockchain was originally created for financial transactions and digital currency, since the introduction of smart contracts, it has been adapted to serve other areas such as supply chain management, and now, potentially disaster management (Hunt and Zhuang, 2022, Chowdhury et al., 2022).

Blockchain has the potential to address all three recommendations from the Royal Commission and CSIRO. Firstly, the peer-to-peer communication, together with smart contracts technology, provides a platform for national collaboration in a DMSR. Abunadi and Kumar (2021) proposed a blockchain disaster management system for streamlining covid-19 responses and highlighted the secure, consistent, and transparent information as an important benefit.

Collaboration between coordinating parties and the public is another innovation offered by blockchain research, addressing the first recommendation. One innovative study proposed a way of enhancing resource management during a disaster by enabling a sharing economy via blockchain (L'Hermitte and Nair, 2021). In their model, the traditional resources available to coordinators in a disaster is extended to include community resources, which may include emergencies supplies and tools, to people assistance in an impacted region (L'Hermitte and Nair, 2021). An obvious advantage resulting from this would be additional resources closer to the source of impact. Another recent study proposed a blockchain system that targeted resolution of inter-organisational barriers in humanitarian supply chain (Ali Ihsan Ozdemir, 2021). It concluded that the key area that blockchain could contribute to was building trust between siloed parties.

Blockchain also improves data accuracy, availability, and reliability in accordance with the second CSIRO recommendation (CSIRO, 2020b, Mark Binskin, 2020). System and data resilience is one key advantage provided by blockchain (Chowdhury et al., 2022). The distributed nature of the blockchain network supports stability and security, meaning that it is difficult to overtake or interfere with the network and the information it holds. An immutable, distributed transaction ledger further supports secure real time transactions, as modifications are not possible. Generally, the blockchain can support the distribution of information in near real time without sacrificing control (Talley, 2019).

With the distributed nature of the blockchain, data and processing are carried out on multiple redundant nodes rather than on a central server, so the system itself can recover if a node is inoperative. Blockchain could form the foundation for inter-jurisdiction communication, providing a stable platform for critical information exchange (L'Hermitte and Nair, 2021).

Blockchains (particularly via immutability and distributed storage) also provide data traceability and data integrity (Huang et al., 2020) which is a crucial foundation for a DMS. Effectively, this makes the data passed around the system tamper-proof. In terms of addressing gaps, data being tamper-proof and transparent enhances data integrity and accuracy overall. By default, the blockchain was built to have full visibility of all data communication, which again, enhances data integrity.
Lastly, as evidenced by the recent research examples, by applying systems thinking to disaster management, blockchain can provide a holistic system for DMSR, and therefore address the third recommendation (CSIRO, 2020b). Blockchain facilitates the third recommendation by the CSIRO, having a systems approach with foresight and risk management. At its core a systems approach provides a quantitative, logical interconnected structure solution to problems. Because blockchains carry tokenised value, it is possible to quantify risk in a DMSR. For example, several fires may be developing in various areas, and limited resources would need to be allocated. The blockchain DMSR could provide a value to risks calculated in the background, to prioritise an area for resource allocation. These values could be passed through the blockchain and updated continuously.

4.2 Intelligent Systems

An intelligent system responds to real world events, recommending next steps and continuously adjusting parameters automatically in real time for optimal outcomes. Prior generations of software relied on business rules which were translated into a strict set of logical pathways to a conclusive action. Meanwhile, intelligent systems incorporate big data, AI and machine learning in order to analyse, interact with other systems and self-learn to make recommendations (Avvenuti et al., 2018, Bukhari et al., 2022). Machine learning looks through data to find patterns to optimise an outcome. Artificial intelligence learns by mimicking the neural pathways of human. It generally provides higher accuracy than machine learning. Human intervention by humans may be required as AI training of the system may not cover all scenarios, and to enhance the “senses” of the system (Avvenuti et al., 2018). An intelligent DMSR has the potential to address the second recommendation for improved accuracy of information made by the CSIRO (CSIRO, 2020b) by relying on objective learnings to quantify risks and optimise recommended responses to those risk scenarios. An intelligent system often uses real time input such as sensors and real time data extraction (for instance, live weather reports). In the bushfire DSMR scenario an intelligent system would take information about various risk scenarios from existing data sources, human input, sensors, and other provided information to make recommendations for response.

In addressing the third CSIRO recommendation, a systems thinking approach to risk and forecasting (CSIRO, 2020b), there are multiple examples of applying intelligent systems to disaster scenarios risk assessment and response. We identified three overarching interacting areas: risk assessment, response action selection, and resource allocation as shown in figure 2.

Risk scenario assessment involves, in existing bushfire areas, determining the relative risk bushfire to population (including human life, wildlife and natural flora and fauna, business).

The risk assessment manages two things: firstly, the movement of bushfire and extent of impact that will entail, and secondly, the current impact of bushfire under way in terms of damage being done to the region. Recent disaster management risk assessment research has moved to artificial intelligence and machine learning to improve accuracy of risk evaluation and prediction. Looking at risk assessment, Zhang et al. (2018) (Zhang et al., 2018) simulated an improved neural network algorithm for predicting flood levels forecasting and flood damage. Importantly, the model showed improved accuracy over older comparison models. Other recent research is centred around finding optimal bushfire prediction. Research found that by combining weather, satellite data and weather sensors, bushfire risk could be predicted (Ma et al., 2020).

The second interactive aspect of the intelligent decision support for DMSR is response scenario selection. There are multiple options for response, such as warning, evacuation, calling on various resources to fight the fire. Difference in risk and availability of resources could result is a difference in response scenario selection. An intelligent system prototype used stochastic game network to evaluate optimal decision in an emergency in order to minimise industrial loss (Kaur and Bhatia, 2021). Other research concentrated on using AI to uncover optimal decisions in managing crowds according to risk scenario (Alawad et al., 2020).

The third interactive aspect of DMSR is resource allocation. This manages resource depending on risk analysis, resource availability and response scenario selection. One study proposed combining intelligent systems with crowd sourcing in a emergency management scenario (Avvenuti et al., 2018), which, while adding complexity of information, vastly increases the scope of available information. With big data and analytics, this data can be more easily sorted and used in a DMSR. A bushfire DSS would require assessing fire risk in real time across targeted risk areas (which can be most of the country, but especially areas with heavy foliage). The feeds would need to include geospatial information systems (GIS), real time weather information (temperature, wind direction, humidity), IIoT devices (including heat sensing drones and other sensor devices) and human reports.

4.3 Intelligent Systems and Intelligent Internet of Things (IIoT)

IoT refers to connected devices that can communicate with systems. Examples that can be applied to a DMSR are sensors, aerial devices, robots and satellites. Unmanned Aerial surveillance (UAV) can be used to retrieve real time images of fire for analysis, the locations often being too dangerous or cumbersome for human access (Nosouhi et al., 2022). Wireless sensor networks (WSN) are a recent innovation in sensor technology being lightweight, low-cost, easy to deploy, and scalable (Dixit and Jindal, 2022).

One study uses machine learning to find an optimal network route to decrease delay in communication from the WSN and improve energy efficiency (Dixit and Jindal, 2022). Though prone to latency, Satellite information provides infrared radiation (analysis of hotspots) across a broad expanse of land in one view (Nosouhi et al., 2022). Where human life would be endangered by response action, a robot may be utilised. Unmanned ground vehicles (UGV) (Alamouri and Gerke, 2019) and robots are deployed in disaster scenarios, providing up to date information at the scene. Some examples include progressing through impacted areas and providing visual and other feedback, performing robotic firefighting, and performing rescue operations. The range of public smart devices is broad, and can include smart phones for emergency alerting, which is widely used already in Australian bushfires. It can also include special in-vehicle GPS and radio devices independent of smart phones to track and manage traffic during a disaster (Liu and Wang, 2019).

IIoT incorporates machine learning and AI into IoT. It is the amalgamation of AI, machine learning and big data with connected devices (Qiu et al., 2022). Various machine learning approaches have been applied recently to bushfire susceptibility mapping, including random forest, support vector machine and logistic regression (Hosseini and Lim, 2021).

There is an overlap between intelligent systems and IIoT in that they both include AI as a central component. where IIoT focuses specifically on how devices can interact with AI to provide analysis, intelligent systems encompass a greater scope of end-to-end management, with AI-powered decision support. However, IIoT is crucial for an intelligent bushfire DMSR, since IoT based risk analysis would be a starting point for many decisions such as resource allocation to priority risk scenarios. IIoT addresses the second Royal Commission and CSIRO recommendation to provide more comprehensive data availability by producing better quality data analytics (Chowdhury et al., 2022, Mark Binskin, 2020, CSIRO, 2020b), especially around risk and impact analysis, including predictive analytics. The following review aspects of IIoT which contribute to this.

IIoT has powerful predictive capabilities. Another bushfire prediction method using NASA's Earth Science dataset (ESDIS), identified forest fires using ANN-MLP (multilayer perception) AI algorithm to provide high detection accuracy of up to 99.67% (Kumar and Kumar, 2020). This was significantly higher than the KNN machine learning algorithm used for comparison (Kumar and Kumar, 2020). Yet another recent study proof of concept was developed using a robust IIoT (UAV and satellite information) in early risk detection for bushfires used machine learning anomaly detection (Nosouhi et al., 2022), though some cost constraints must be overcome in order to implement this nation-wide (Nosouhi et al., 2022).

Rather than relying on historical data, a recent study used deep learning time series analysis, using multi-model data with deep learning, fusing image and weather data, in order to detect bushfire using near real time with a 93.4% accuracy rate (Phan et al., 2020). The data captured was spatial, temporal and spectral in addition to weather data to provide a more complete picture of near real time risks (Phan et al., 2020). As expected, when temperatures rise over a short period in a weather sensor, and if the weather is already hot and dry, this provides the highest risk of fire (Phan et al., 2020). This is a significant step toward having a DMSR risk assessment in real time (Phan et al., 2020).

Potential impact needs to be measured continuously in real time. This would measure to what extent an area would be impacted by loss of property, loss of wildlife and loss of human life, and that includes population, population density in impacted (Sanka and Cheung, 2021) areas, amount of foliage and changing weather conditions that may move the fire to a denser location. This would enhance the risk scenario assessment in real time for decision support.

An innovative development in technology research combines IoT driven by blockchain (BIoT). In this approach, the blockchain provides a platform for inter-device communication and distributed data storage (Kaur et al., 2022). A 2022 publication proposed applying blockchain based IoT to disaster management (Kaur et al., 2022). The idea is to build resilience into a network of IoT devices such as sensors and allow them to share information in real time (Kaur et al., 2022). There are three layers in the disaster response BIoT model which includes data gathering with installation of sensors, connectivity of smart IoT devices, data processing, analysis and storage (Kaur et al., 2022).

From a DMSR improvement perspective, a national standard and protocol for the use of IIoT would need to be created in order to address the first recommendation by RC and CSIRO (Mark Binskin, 2020, CSIRO, 2020b), that is, the creation of a single national platform for disaster management. IIoT easily addresses the second recommendation of improving data accessibility and quality provided by RC and CSIRO (Mark Binskin, 2020, CSIRO, 2020b). IIoT provides advanced data analysis that can be applied to risk predictions, as the presented research highlights. The outcome of combining IIoT into a DMSR would make more accurate information more readily available to decision makers, disaster responders, government agencies, and other participating parties (Kaur et al., 2022).

5 Conclusion and Further Research

This paper presented an exploration of disruptive technology that may be applied DSMR, addressing gaps and subsequent recommendations identified by the Royal Commission and CSIRO after the 2019-20 Black Summer bushfires. From the results, the potential for technology around intelligent systems, IIoT and blockchain to improve DMSR is encouraging. Our research found that each identified disruptive technology area potentially contributes to these recommendations.

As discussed in the results section, Intelligent systems and IIoT has the potential to address all three recommendations by centring decision making around increasingly accurate data. In that way not only can decisions be made in real time, but predictive analytics can be used to forecast risk. This leads to an enhanced risk-based decision approach, looking at complex systems through systems thinking lens, as per CSIRO recommendation 3. This technology requires accurate data for training of the system to support decisions, which addresses recommendation 2. Data-based decisions cannot operate in siloes, addressing recommendation 1.

Blockchain is flexible enough to facilitate jurisdiction governance authority where required, whilst also making public access to critical system access readily available. This serves to address the first recommendation in that it provides a national, unified disaster management system. System democratisation supports multi-disciplinary involvement, increasing the quality of decision making as outlined in recommendation 3.

There are, of course, other necessary factors that determine successful bushfire management not covered in this paper. The importance of building natural-disaster proof housing and infrastructure is highlighted by the Sendai framework (Nations, 2015). CSIRO stresses the importance of addressing climate change (CSIRO, 2020b). Using preventative measures prior to the requirement for response is also crucial. This includes public education, education of coordinators and public agencies, and research (CSIRO, 2020b, Mark Binskin, 2020).

While presenting a potentially viable option for advancing natural disaster management in Australia and beyond, there are further steps that must be taken to achieve deployment of such an enhanced system. The first step for future research is to create a full model for review. While this report presents an overview of available options for the deployment a DMSR using intelligent systems, IoT, and blockchain, the next level of analysis would analyse the best of each technology and find innovative ways to meld those into one system. Opportunity for future research into Intelligent DMSR would include reproducing some of the results found overseas in Australia, adapting and amalgamating technology found here, and looking at the latest research or address implementation challenges, to create a unified DMSR model. The second future step is a functional prototype in collaboration with Australian disaster coordinating agencies that can be tested and reviewed by experienced experts. Beyond this, the same principles explored in this paper can potentially be applied to other areas of disaster management.

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