THE SUDEM APPROACH: ADVANCED AIR MOBILITY EMERGENCY OPERATIONS BASED ON FUTURE ADVANCED COMMUNICATION SYSTEMS – AS CRUCIAL ELEMENTS OF A SYSTEM OF SYSTEMS FOR EFFECTIVE DISASTER MANAGEMENT

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Abstract: *During the last 150 years the average temperature of the Earth's atmosphere has increased by 1,3 °C, leading to a significant increase in extreme environmental events and disasters in our densely populated areas. In addition, anthropogenic disasters from large-scale accidents or warfare are on an unfortunate rise.*

The ERASMUS+ project SUDEM (2023-1-BG01-KA220-HED-000159479) is establishing and validating a novel interdisciplinary higher education knowledge transfer model and curriculum, with focus on the digitalisation of the overall disaster and emergency handling lifecycle. The international team embeds principles of practice and education from all relevant domains, incl. risk and disaster monitoring and management, decision-making support, AI, IoT, Data Science, remote sensing (satellites and drones) and data fusion, data management.

The project unites a consortium of leading European Higher Education and Research organisations, leveraging international collaboration to align academic programs with the demands of the optimal disaster management, incl. the decision-making support. SUDEM emphasises creating adaptable and accessible educational modules that can be implemented across diverse Higher Education and Life-Long Learning organisations.

This paper represents the results of the SUDEM Foresight study – a core project methodology element, enabling the elaboration and delivery of an efficient response to the identified demands and challenges, potential solutions, a relevant system architecture, and an optimal future development scenario incl. education, process management, policy, and finally a unique knowledge and training package as a core project result.

ПОДХОДЪТ SUDEM: АВАРИЙНИ ОПЕРАЦИИ С МОДЕРНА ВЪЗДУШНА МОБИЛНОСТ, БАЗИРАНИ НА БЪДЕЩИ МОДЕРНИ КОМУНИКАЦИОННИ СИСТЕМИ – КАТО КЛЮЧОВИ ЕЛЕМЕНТИ НА СИСТЕМА ОТ СИСТЕМИ ЗА ЕФЕКТИВНО УПРАВЛЕНИЕ НА БЕДСТВИЯ

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Ключови думи: *Управление на бедствия и аварии, дигитализация, форсайт, Модерна Въздушна Мобилност, Система от системи, Модерни Комуникационни Ссистеми, заинтересовани страни, Безпилотни летателни системи, образователни модели*

Абстракт: *През последните 150 години средната температура на земната атмосфера се е повишила с 1,3 °C, водещо до значително увеличение на екстремните природни явления и бедствия в нашите гъсто населени райони. Освен това, антропогенните бедствия, причинени от мащабни инциденти или войни, за съжаление са в нарастване.*

Проектът ERASMUS+ SUDEM (2023-1-BG01-KA220-HED-000159479) създава и валидира новаторски интердисциплинарен модел за трансфер на знания и учебна програма за висше образование, с фокус върху дигитализацията на целия цикъл на управление на бедствия и извънредни ситуации. Международният екип включва принципи на практика и образование от всички съответни области, включително мониторинг и управление на рискове и бедствия, подкрепа при вземането на решения, изкуствен интелект, интернет на нещата, наука за данните, дистанционно наблюдение (сателити и дронове) и обединяване на данни и тяхното управление.

Проектът обединява консорциум от водещи европейски организации за висше образование и научни изследвания, като използва международното сътрудничество за съгласуване на академичните програми с изискванията за оптимално управление на бедствия, включително подкрепа при вземането на решения. SUDEM поставя акцент върху създаването на адаптивни и достъпни образователни модули, които могат да бъдат внедрени в различни организации за висше образование и организации за учене през целия живот.

Настоящият документ представя резултатите от форсайт изследването на проекта SUDEM - основен елемент от методологията на проекта, който позволява изработването и предоставянето на ефективен отговор на идентифицираните нужди и предизвикателства, потенциални решения, подходяща системна архитектура и оптимален сценарий за бъдещо развитие, включително образование, управление на процеси, политика и накрая уникален пакет от знания и обучение като основен резултат от проекта.

Introduction and background

Introduction

With climate change the global average temperature has measurably increased which in turn has created a constantly higher relative humidity. With this, the number of extreme environmental events has significantly risen, affecting populated and often remote areas. Additionally, anthropogenic or human-caused disasters such as large-scale accidents and warfare consequences have also been contributing to catastrophic loss of life and infrastructure. Dealing with these is the domain of Disaster Management (DM) which is responsible for the preparation, response, and recovery from disasters [1]. The involved entities include emergency response services, operators and vehicles, hospitals, communication and coordination systems, monitoring systems, weather forecasting, policy and decision making entities, DM response control centres, and more. However, novel technologies and methods are on the way to improve many aspects of this critical domain. Advanced Air Mobility (AAM) is to unlock easy access to the third dimension, and digitalisation and Advanced Communication Systems (ACS) are to enable the optimal timely AAM operations and enhance the DM's capabilities.

The SUDEM project – ERASMUS+ KA220

In this regard, the SUDEM project is a 2-years EU-project, coordinated by SRTI-BAS, for the Sustainable Disaster and Emergency Management Processes Digitalisation. Its idea is to establish and validate a novel interdisciplinary higher education and LLL knowledge transfer model and curriculum. The project is aimed at Higher Education and Life-Long Learning organisations, and is focused on the digitalisation of the overall disaster and emergency lifecycle planning, handling, and management processes. The final goal is to create a pool of highly-capable DM experts with an adequately intensive focus on digital tools incl. Unmanned Aerial Systems (UAS), and thus to contribute to significant long-term decrease in disaster-caused life and infrastructure losses.

What is Foresight and why do we apply it?

The SUDEM project is to also deliver a Foresight document on DM, the integration of advanced digitalisation – including ACS, and AAM. But, what is Foresight? For context, the DM System of Systems (SoS) is a complex and interdisciplinary field, and integrating new technologies and methods needs to be planned with strong consideration and long-term perspective of social, economic, and environmental factors. Thus, strategic foresight allows for: the identification of thematic challenges and opportunities for solutions, the exploration of development scenarios, and for the provision of policy making support [2]. It is a highly flexible format which enables interdisciplinary solution creation and development - invaluable precisely for DM, the integration of adequate digital technologies and methods, and the widespread adoption and operation of AAM in this context.

Our relevant public funded projects

Other relevant public funded projects where the SUDEM team participated and gathered experience and knowledge from are the following:

- REGUAS (German Federal Ministry for Digital and Transport, 2022–2024): where it was investigated how the supply of rural areas with high added value (and urgent) goods could be optimally energy efficient in a regional context using multirotor UASs.
- AiRMOUR (Horizon 2020, 2021–2023): where the major outcome was a foresight on the current status of the interdisciplinary field of air mobility, identifying the challenges and exploring the possible solutions.
- 5G!Drones (Horizon 2020, 2019–2022): where the goal was the trialling of several UAV use-cases for the covering of various 5G services.
- ETHER: which addresses the issue of vertical handovers between Terrestrial Networks (TN) and Non-Terrestrial Networks (NTN) (satellites, low altitude platforms) to guarantee Quality of Service (QoS) and service availability.

Disaster management (DM)

To further expand on DM, there are various disasters impacting Europe and the world - natural/environmental and human-caused. The former includes floods, earthquakes, storms, strong winds, volcanic eruptions, wildfires, and more, while the latter includes pollution, industrial accidents, warfare, transportation accidents, etc [3]. There are multiple stakeholders and systems involved in the preparation and response to such events which requires efficient and effective coordination for the successful execution and completion of operations. The relevant challenges for achieving more resource efficient DM include the following:

- Insufficient utilisation of the aerial domain (3rd dimension) in critical situations, which is potentially a vast advantage in disaster situations (remote access and better perspective/view point).
- Lack of or underutilisation of digital technologies for the further enhancement of DM capabilities.
- Lack of or insufficient communication and coordination systems in critical locations.
- Insufficient situational awareness in highly dynamic situations.
- More efficient and effective structure for collaboration between stakeholders.

Moreover, 2/3 of the world's population lives in Metropolitan areas and in many cases these can be classified as mega cities with populations between 20 and 40 million inhabitants. Each citizen in the world corresponds to 115 t building mass, and for a citizen in Germany – 490 t building mass. This means that each citizen contributes with thousands of EUR towards various infrastructure, thus protecting it is imperative, as well as optimising the resource efficiency of DM operations. Ultimately, preparedness, mitigation, sensing, and prediction and forecasting should be just as important if not more than simply the adequate reaction to disasters.

Towards resource efficient Disaster Management

SoS approach and why?

To achieve an optimal DM structure and integration of novel technologies and methods a System of Systems approach is needed. A definition of SoS is: "A collection of independent systems, integrated into a larger system that delivers unique capabilities. The independent constituent systems collaborate to produce global behaviour that they cannot produce alone" [4]. In this context the relevant DM systems include emergency services, sensing stations, hospitals, air traffic control, relevant agencies, military units, volunteers, logistics, transport hubs, etc. And with the digital and AAM domains this also includes operators, Unmanned Vehicles (UV), relevant operational and maintenance logistical hubs, data centres, communication services, etc. Thus, SoS is needed for the clear and better communication and coordination pathways between the relevant stakeholders, clear operational and responsibility structure, improved process efficiency, and adequate, effective, and timely resource allocation and tasks execution.

AAM

AAM can be defined as aerial systems that provide services in novel ways through the usage of aircraft in domains that can benefit significantly from them. UAS are already in use for DM, however, their full potential is yet to be realised. Moreover, UASs' added value is increased in the context of extreme emergency conditions - for example disasters, meaning that environmental sustainability becomes secondary in this case. Also, collapsed buildings, landslides, damaged infrastructure, harsh geography, and more can all block DM efforts in which case public service is the priority, thus the need for aerial utilisation via UAS. Drones can perform tasks such as critical goods delivery, situational monitoring, search and rescue, communications transfer, etc. However, for this AAM potential to be utilised, ready, resilient, and redundant ACSs and/or smart on-board systems must be available to ensure the operational sustainability, flexibility, and safety of the aerial systems.

Our relevant projects: insights

Work during the REGUAS project assessed the operational feasibility of rural UAS logistics for high added value goods, with emphasis on using multirotor UAS. The assessment was conducted through simple flight simulation, via an energy estimation model for multirotor drones in MATLAB, and then with the execution of practical validation tests. The reference flight path was a 16 kilometres round trip between two settlements and with a 2 kg payload. The results from the energy estimation model include the range and the optimal energy efficient velocity of the studied multirotor UAV (as shown on Figures 1 and 2). The conclusion was that medium-sized multirotor UAVs can perform reasonably well at medium ranges and in remote areas with the added benefit of being able to carry payloads of useful sizes and weights. The conducted optimal velocity estimation allows for the planning of useful cargo amount and range.

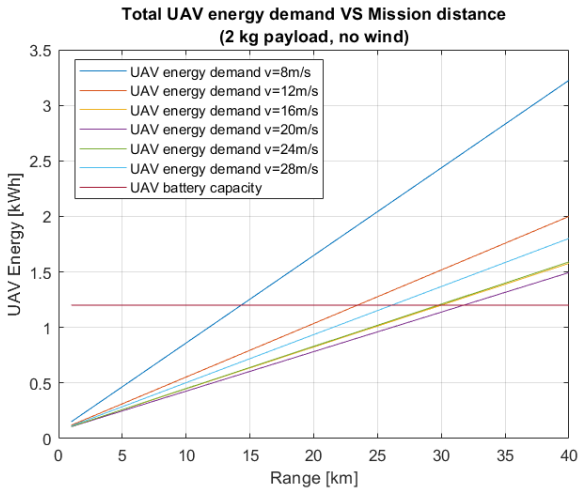

Fig. 1. Relation between total energy demand and mission distance for various airspeeds and a 2 kg payload, the horizontal line represents the energy capacity of the REGUAS UAV's battery

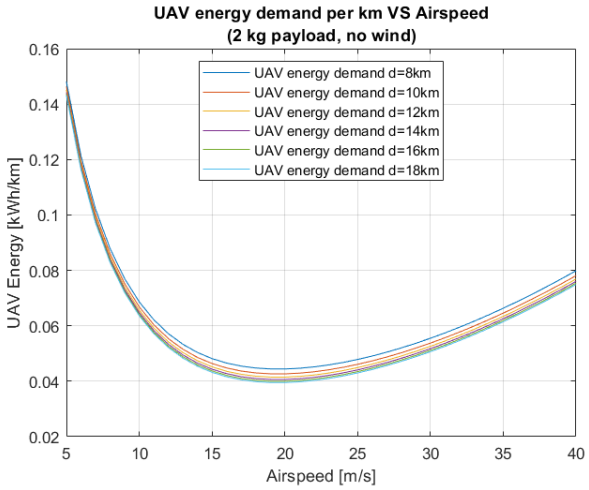

Fig. 2. Relation between energy demand per unit distance and airspeed for various ranges and a 2 kg payload

The work at the 5G!Drones project included the further development and commercialisation of 5G cellular drones teleoperated at a distance of up to 100 km or performing autonomous logistics tasks. Furthermore, tethered drones were acting as occasional 5G base stations or broadcasting/jamming nodes.

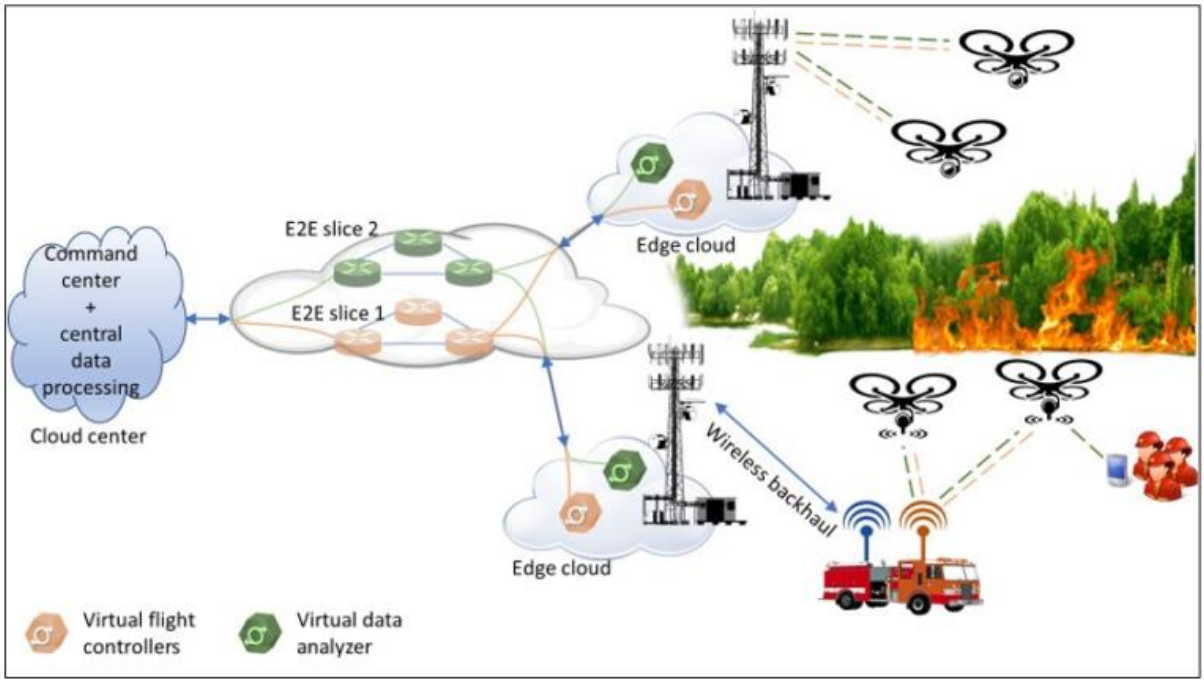

Fig. 3. Public safety/saving lives use case

Digital tech incl. ACS - key AAM enablers and DM enhancers

To achieve operationally sustainable, resource efficient, and safe AAM, as well as to enhance DM capabilities – digital technologies and methods, including ACSs, are needed. The way advanced digital technologies, incl. ACS, will enable this is through the following:

- Monitoring of air traffic for safe DM AAM operations.
- Provision of navigational and communication capabilities in remote regions and extreme situations.
- Defence against unauthorised system access/denial, and its misuse.
- Efficient and effective coordination by the involved stakeholders.

The key digital and ACS technologies and methods to be utilised include the following:

- Tethered drones acting as mobile communication hubs.
- Standardisation protocols – for international airspace management.
- Cybersecurity protocols which will be a key enabler of safe operations – especially important for DM.
- Utilisation of IoT and remote sensing, edge computing, image processing, and Machine Learning (ML), which is to allow for better and autonomous decision making and forecasting of environmental events.
- Unmanned aerial vehicles Traffic Management (UTM) for safe and efficient AAM operations.

Novel education models – long-term operational sustainability

To ensure sustainability and operability of novel systems in the DM domain, long-term educational pathways for new and experienced professionals must be established in higher education, and lifelong learning and train-the-trainers methods. The main identified educational domains for the DM domain of the future are:

- DM fundamentals: Workflow and risk mitigation, Disaster monitoring, Multi-Agent Decision making processes, System resilience, Nuclear safety, and DM.
- Digitalisation: Data-driven decision making support, IoT, ML, Edge Computing, cybersecurity, communication protocols, etc.
- Train-the-Trainers: long-term sustainable increase of the pool of highly capable experts and trainers in the DM domain – to educate the people who will educate the next generations.

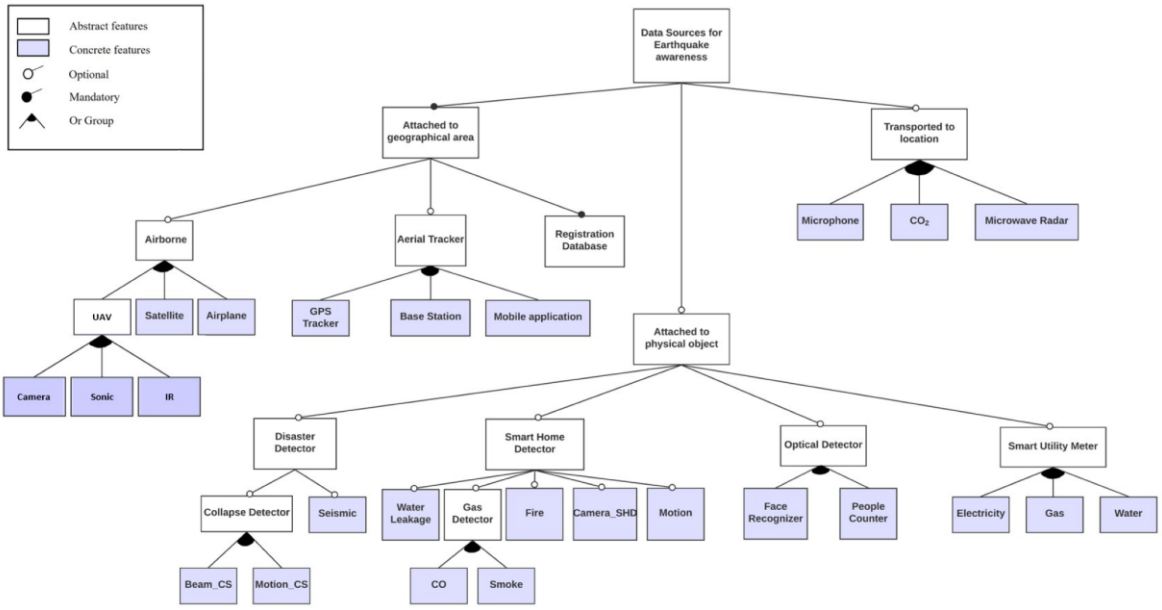

Fig. 4. An example data sources domain architecture of the envisioned SUDEM SoS

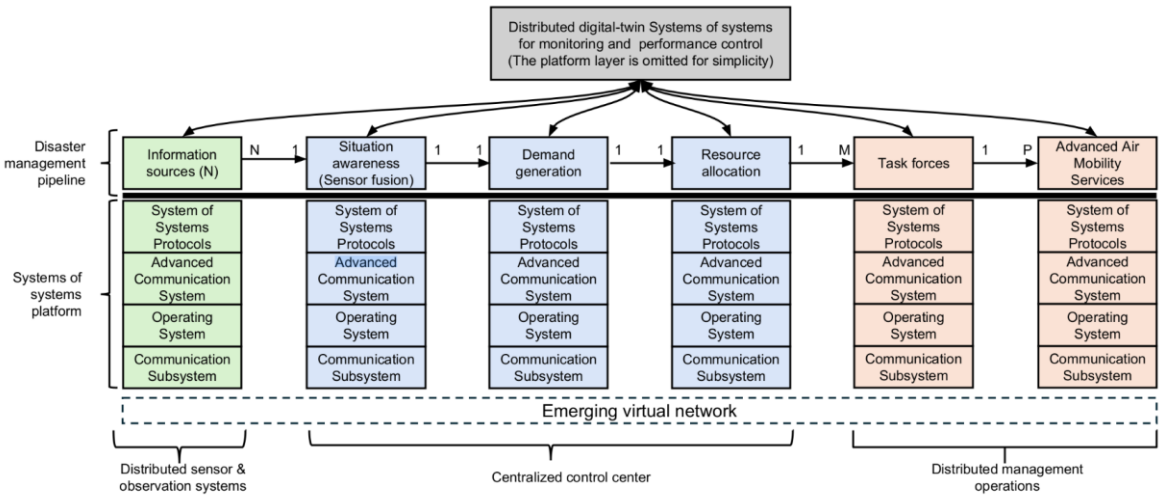

Fig. 5. An example AAM-supported SoS architecture for DM

Conclusion

The main conclusions of the SUDEM work so far include the following points:

- An SoS approach is needed to allow for efficient and effective communication and coordination of DM stakeholders, their systems, and for the allocation of critical resources.
- AAM is a critical resource for utilising the vertical domain and allowing for better and novel DM operations, however, its potential is yet to be fully utilised.
- Digital technologies, including ACS, will be the key enabler of operationally sustainable AAM operations, including their safety and efficiency.
- Long-term educational models, in HED & LLL, on novel relevant technologies and methods are crucial for better DM outcomes in the future.

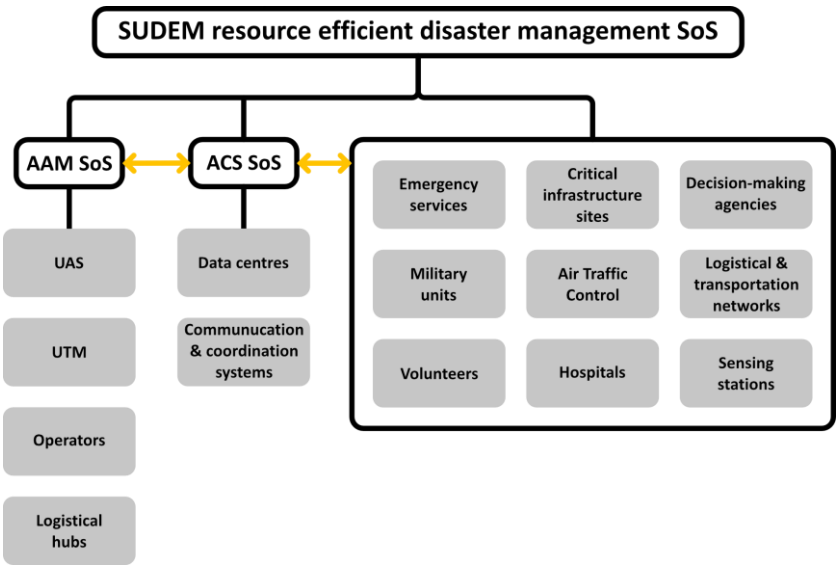

Fig. 6. An example of the SUDEM overall SoS approach

FORESIGHT results

What are the main findings?

- A System of Systems (SoS) approach is needed for the Disaster Management (DM) domain together with Advanced Air Mobility (AAM) and Advanced Communication Systems (ACS), in order to improve processes efficiency and decision-making support. AAM through Unmanned Aerial Systems (UAS), equipped with imaging technology and sensors, can play a crucial role in situational assessment, especially in disaster zones that are inaccessible by traditional means, and ACS will be achieved by combining data from various sensors to plan adequate and effective resource allocation for optimal response and prevention of tragic outcomes. Sustainable and efficient AAM will be achieved through ready, resilient, and redundant ACSs.

- The future identified development directions, addressing the digitalisation challenges, are focused on the need for standardised protocols, enhanced cybersecurity measures, and advanced predictive capabilities. The optimal future, envisioned in this report, involves a fully integrated DM framework where real-time data sharing, predictive analytics, and autonomous decision-making systems operate seamlessly across borders.

What are the implications of the main findings?

- The DM SoS approach, through sustainable and efficient AAM which will be achieved together with ready, resilient, and redundant ACSs, would enable a cohesive and rapid response to a wide range of disaster types, including floods, earthquakes, wildfires, and industrial accidents, leveraging technologies to automate and enhance resilience in disaster response.

- Based on the findings of the authors from several relevant EU projects and the findings of the current foresight study, the main SoS development and educational domains which should be the focus of future DM developments are: DM fundamentals & SoSs (Workflow and risk mitigation, Disaster monitoring, Multi-Agent Decision making processes, System resilience, Nuclear safety, and DM), Digitalisation (Data-driven decision making support, Internet of Things (IoT), Artificial Intelligence (AI), Edge Computing), ACSs, and Train-the-Trainers (towards long-term sustainable increase of the pool of highly capable experts and trainers in the DM domain).

- Currently defined standardised AAS capabilities and long-term vision of their development generally include wide range of current and future needs of AAS including their application to DM; however, implementation (by vendors) and deployment (by mobile network operators) of features crucial for AAS and DM may need systemic support from authorities/regulators and joint, cross-industry sustainable roadmap planning.

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