Automating and Decentralising Satellite-based Emergency Mapping

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***Abstract*—The quantity and diversity of stakeholders in space is increasing and centralised management of their assets is becoming more complex. New technologies in Web3 such as Decentralised Autonomous Organisations (DAOs) can bridge the communication gap with neutral and automated systems, and distribute currently centralised processes that are inherently decentralised by nature. One of these processes is Satellite-based Emergency Mapping (SEM) for Disaster Response Management (DRM). With automated decision strategies and transparent ledgers, a fairer and more accessible system can be built to handle the increase in stakeholders as well as the increasing number of natural disasters occurring. A DAO also address' the key issue with the current SEM process, such as decreasing the current three days wait, required to produce the necessary processed and analysed data for end users, after the disaster occurs. Moreover, with fleets of satellites belonging to different governmental and private organisations, a specific central authority cannot be identified to manage the process in an efficient and equitable way. The paper discusses the need for a more decentralised and automated system for DRM by presenting evidence of current bottlenecks and lays the foundations of the first DAO for on-orbit assets management and demonstrates which Web3 technologies could further improve SEM in this first phase of charter activation.**

***Index Terms*—Satellite-based Emergency Mapping, SEM, DRM, DAO, Blockchain, Insights from Space, Decentralised Technologies**

I. Introduction

As the number of satellites in space as well as diversity of their operators grows, control and communication complexity is increasing. Protocols for Disaster Response Management (DRM) are becoming more complex as new stakeholders join, the number of natural disaster occurring due to global warming is increasing and new satellite payload capabilities. Projects such as International Charter Space and Major Disasters (ICSMD), Copernicus and Sentinel-Asia operate with many space agencies from around the world. These emergency mechanisms integrate members from government positions, satellite operators, data processors, and on ground response teams, using Satellite-based Emergency Mapping (SEM) services to provide critical information for coordination and response after disasters occur. Disasters such as Earthquakes, Tropical Cyclones, Droughts, etc, cause damage to infrastructure and lives over massive areas, often in remote locations, and satellite Earth Observation (EO) data can provide a overview of the disaster and help the best course of action to determine the response necessary using SEM. However, time sinks in the SEM process currently exist due to geopolitics, centralisation and lack of automation, which delay response and coordination after disasters hit.

With the growth of Web3 and Distributed Technologies, new systems can be built to manage protocols such as SEM to reduce the time taken for SEM data to be delivered as well as reducing bias and improving adoption of new stakeholders. This study looks at space assets management, the existing DRM and SEM mechanism, and how all these current processes could be automated and decentralised with the integration of Web3 technologies, specifically a Decentralised Autonomous Organisation (DAO). How this addition will help navigate the pitfalls of the current processes is discussed in section III, and a new architecture for SEM using Web3 technologies is set out in section IV.

II. The Current DRM and SEM Process

The current SEM protocol follows the path shown in figure 1. At the top of figure 1, the disaster occurs or is forecasted and the decision for requirement of SEM is made. The Authorised User (AU) of the SEM protocol then must call the SEM manager who assigns a focal point (the organiser of that specific SEM activation) if the disaster is verified. The focal point communicates with the AU to determine what images are required, goes on to decide who should take satellite images, and organises the EO data processing after the image is taken. The images are then distributed directly to the AU as well as most data being publicly released. The current method of SEM for natural disaster relief, where contact between entities is mainly manual, and the whole process is fragmented and heavily centralised, causes delays in response. This inefficiency is ultimately affecting the end user, where the quicker the satellite data is received, the more effective it is for coordinating a response. The two major SEM activation services are Copernicus and ICSMD [1]. Other protocols such as Sentinel-Asia and National Disaster Reduction Center of China also exist however lack public information and operate on a much smaller scale than Copernicus and ICSMD.

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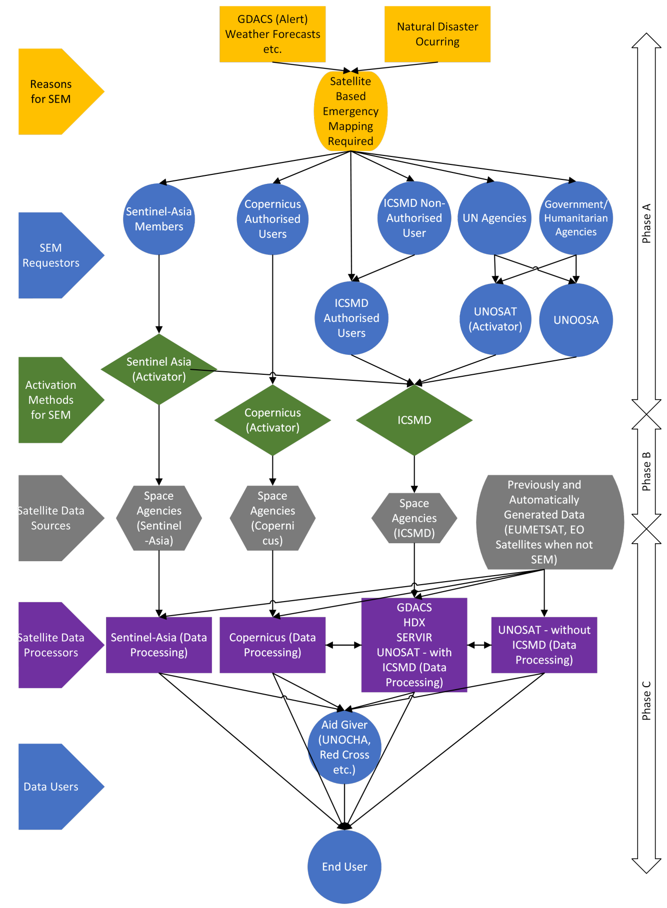


Fig. 1: Current flow of Requests, Information and Aid when activating SEM [1]–[11]

A. Process Breakdown

The SEM process can in general be divided in three subsequent phases:

- **Phase A (Activation Phase)** - The time between the event occurring and the activation of ICSMD and/or Copernicus. This includes someone requesting activation, verification of the request, and activation of SEM.
- **Phase B (Data Collection Phase)** - The time between Activation of either ICSMD or Copernicus and the first data collected by a satellite of the affected region post-event.
- **Phase C (Data Processing Phase)** - The time between the first satellite data collection and the first publication of the data for the end user.

B. Data availability for analysis

The data used to analyse the SEM process has been collected from ICSMD's 815 activations [2] and Copernicus' 656 activations [5]. To study the centralisation in SEM, ICSMD's activation are used, due to the higher number of activations where, activators, satellite operators and focal points/managers are defined than that of Copernicus. ICSMD is also a global protocol compared to Europe based Copernicus, showing a more global picture of who is using SEM. Vice versa, Copernicus is used to analyse the time lapsed across each phase, due to its more complete data about dates and times. (Data for both ICSMD and Copernicus is up to date as of April 2023).

TABLE I: First 30 and Last 30 usable data points averaged from Copernicus SEM for Phase durations and their improvement

Phase	First Avg (hrs)	Last Avg (hrs)	Percentage Improvement
A	210.0	44.1	79%
B	233.8	12.2	95%
C	37.4	24.9	33%
Total	481.3	81.2	83%

C. Duration Requirements

As stated previously the phases duration analysis is undertaken only on Copernicus data. In figure 2 following the black line, it can be seen that the overall time for each activation has dropped over the years. It is now approximately 80 hours on average over the past year. Looking at the number of activations active at any one time it is interesting to see that high number of active SEMs often aligns with sharp changes in the overall protocol time. The increases at these points could be due to the system becoming overloaded and each process lasting longer. When the overall time drastically decreases, this could be due to the implementation of a new technology/protocol or the system needing to work faster to adapt to the increased number of activations. These sharp variations in time show the need for a more scalable system which should also help lower the overall duration of SEM.

As the overall time has decreased, the contribution of each phase has changed. Taking the first thirty and last thirty usable data points from the Copernicus SEM data, the time for each Phase is given in table I. The first thirty data points are between 2015 and 2019 while the last thirty are from 2022 to present. It can be seen that between these time periods improvement has occurred over all phases. Looking at both table I and figure 2 phase B now makes up the minimum amount of time in the overall process and phase A makes up the largest portion. Phase A and B are points where human interaction, verification and approval are significant time components and are places where the technology discussed in this study could bring the greatest improvements. For phase C, the data processing segment could be impacted by the proposed approach of data processing and oraclisation mechanisms discussed in section IV-C. Data dissemination techniques can be integrated into this technology, but has not been considered at this stage.

D. Centralisation

Phase A's large portion of time can be caused by having only specific AUs being able to activate SEM and only specific approvers being able to approve it. Therefore the centralised nature of this phase may be contributing to its prolonged time. Relying on a manual, human centered activation procedure, while ensuring trust and control on the process, it can be prone

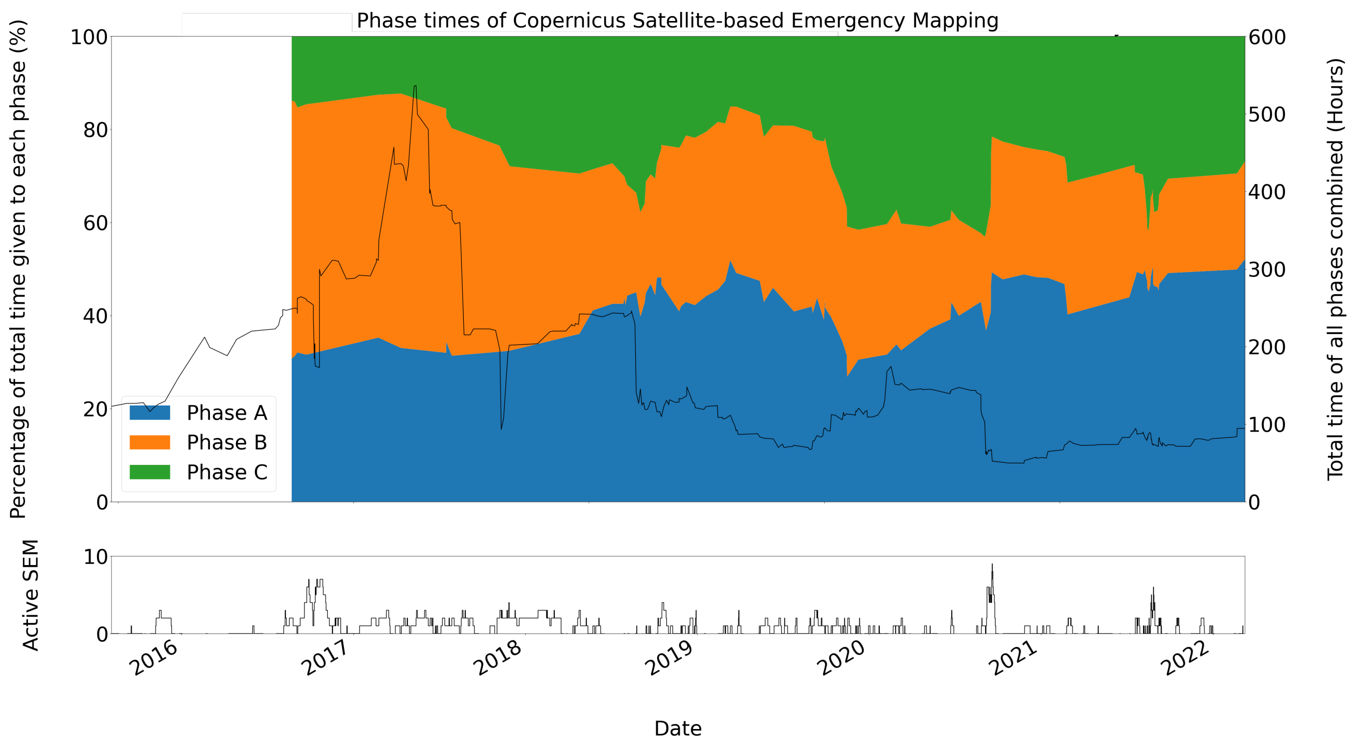


Fig. 2: Top: Time requirements of each phase given as a percentage of whole and time of whole, for Copernicus SEM from 2015 to present. Bottom: Number of SEM activations at a given time for Copernicus SEM from 2015 to present. (51% of all Copernicus activation's give usable data)

to human errors and delays. Moreover, satellite data tends to be provided by few developed countries compared to those who activate and manage SEM, therefore AUs may also not want to rely on these more developed countries even when SEM would prove beneficial. This can be seen in figure 3 where the satellite operators and SEM manager's nation is more likely to have a higher human development index than the data user's [2]. The time it takes for information to spread from the affected region to the AUs may also be detrimental to the activation time. Factors such as remoteness of the affected region, infrastructure between the affected region and the AUs, and time of the disaster (i.e. if its at night) can all increase activation time. As only one organisation is chosen for each SEM activation as the manager, or focal point, a single point of failure or delay also exists.

III. DAO for SEM

This project focuses on automated decision and activation of SEM in the context of a DAO for space asset management. A DAO is a Web3 development which is used to replace or automate interactions between individuals similar to how any organisation works nowadays [13]. Although DAOs are highly scalable, the cost to deploy such a system on current first generation blockchains is high. However, many new scalability solutions are occurring with systems such as third generation blockchain networks and layer 2 roll-ups becoming more prominent, solving such issues with cost.

All users of the DAO can view and utilise the automated smart contracts as part of the automation of decision strategies

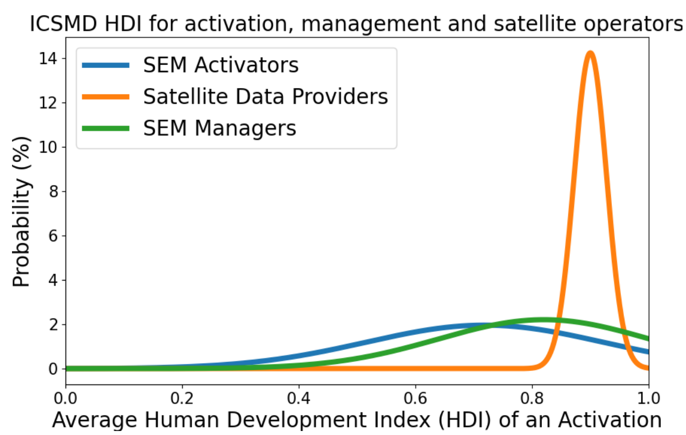


Fig. 3: Probability distribution of ICSMD Data Providers vs Data Users Human Development Index (Human Development Index from [12] 2021, 25% of all ICSMD gives usable data)

for the DAO. This will increase the transfer speed of information between different users while allowing for all users to put trust in the smart contract logic. Rather than specific agencies and people being in control of communicating and deciding a plan for each natural disaster, standardised, transparent and unbiased strategies can be followed to complete the SEM request. Users that were new to the system or do not understand the process of SEM can still use and provide information to the network, allowing for a larger data pool and more access.

A DAO on a blockchain network brings neutrality through decentralisation of ownership of the DAO. This translates into a circular governance, developing a marketplace for SEM data, EO data in general, funding of new projects and upgrading the current SEM protocols, which lowers the requirements for nations or local authorities to access the SEM system. This contributes in reducing political frictions and offers low bias upon any entity needing such a support system. If the DAO stakeholders decide that the logic needs to be improved, voting can be used to allow users who understand the problem to make these fair and useful changes.

IV. Web3 SEM Process Architecture

The basic architecture, seen in figure 4, shows a possible simplification of the current SEM process and how simple blockchain smart contract logic could be used to provide automation of the SEM process.

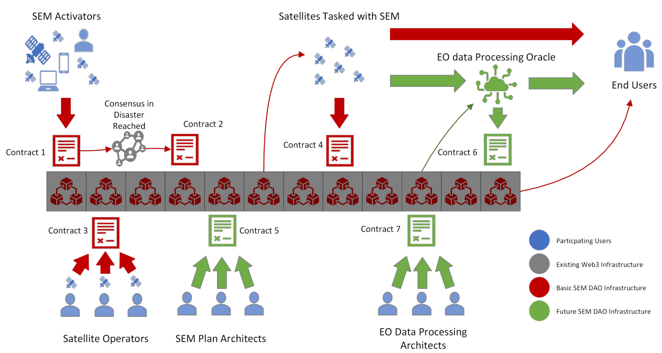


Fig. 4: Current SEM process automated with a DAO and other decentralised technologies (Grey objects are existing web3 infrastructure, blue objects are users involved, red objects are basic SEM DAO infrastructure, and green is optional future infrastructure to increase capabilities)

A. Social Activation (Contract 1 and 2)

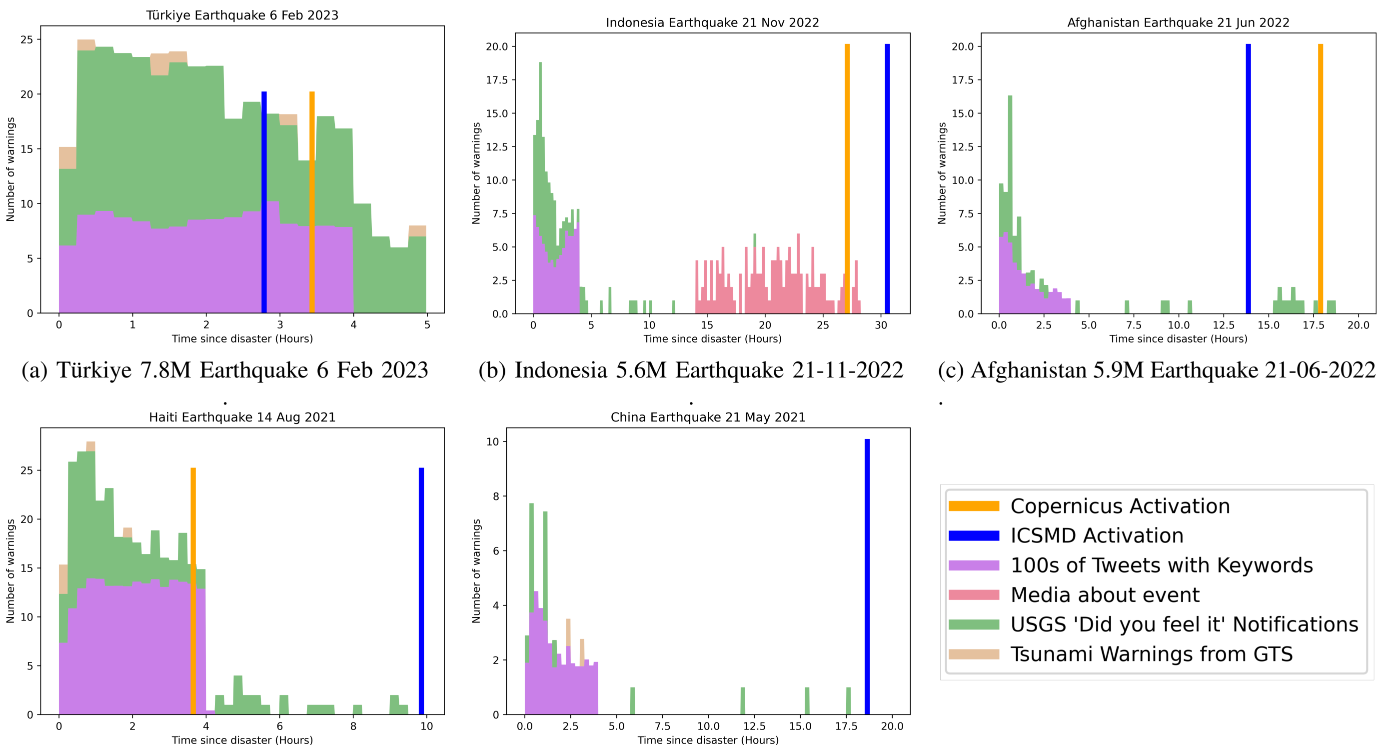
Almost immediately after a disaster occurs, many people, automated systems and potentially satellites, can detect the natural disaster. Many of these ”detectors” can post information on the internet or to certain systems. A good example of this can be seen in figure 5 where immediately after these 5 earthquakes, that later activated SEM, thousands of people started tweeting keywords such as ”Earthquake”, ”Terremoto”, ”Tsunami” and the name of the country of the affected areas. The Global Telecommunications Service (GTS) [16] is a system that brings together information from different meteorological stations acting as an early warning system for tropical storms, but also transmits alerts on nearly all earthquakes including predictions on possible tsunamis. The United States Geological Survey (USGS) [15] gathers information from around the world from anyone with a seismograph and builds a model of the earthquake to help those affected. These are three examples of distributed knowledge on 3 centralised systems, where many more also exist for both earthquakes and all other types of natural disasters. Fusion of this distributed knowledge could be used to activate SEM and also determine the targets for specific imaging, such as location and satellite sensor requirements. As well as integrating post-event detectors into what we call Social Activation mechanism. Forecasting and predictions could be used to further accelerate the time required to activate SEM.

Replacing the existing AUs with Social Activation would allow SEM to ignore geopolitical bias from the AUs and government of the AUs. It would be active at all times of day, even when people in the affected regions are asleep. This would mean time is not wasted by AUs trying to determine the target regions for SEM from potentially massive amounts of data they would normally gather from the members of their country. When magnitude and depth of earthquakes are used as triggers for SEM activation, lower magnitude but still high damage often causes delay, as can be seen in figures 5b, 5c and 5e compared to much faster activation in the high magnitude earthquakes in figures 5a and 5d. With social activation, the actual damage of the earthquake can be determined faster from the people experiencing it, to further accelerate SEM activation. This is common in many types of natural disaster, where the measure of the strength of the disaster is only a factor in the determination of the overall damage of the disaster.

B. Satellite Bidding and Tasking (Contract 3 and 4)

To increase the speed of selecting which satellite provides which data, a list of possible satellites to be used is made available and sorted by most suited, for the disaster. If operators and owners of satellites bid their satellites before with some sort of staked currency it would incentivise them to complete the task if they are chosen, or risk financial loss. Bidding could be done per disaster, however this may require time and therefore slow down the overall time to response. Alternatively, the satellites could be put “on call” and the satellites that have suitable sensors and orbits for the specific disaster are automatically placed into the bidding pool. Sorting of the satellites bid would then have to be based on a list of suitability requirements set in contracts 1 and 2, determined from the the warnings provided by Social Activation, and the satellite sensors and equipment available onboard the given satellite.

From the satellites in the bidding pool, selection could be done by humans or possibly further rule based automation could be undertaken. If the proposed network can run on-board satellites, direct action could be taken, by the satellite noticing at the top of the list. Approval could also be sent through encrypted channels on-chain from the operator to satellites for immediate tasking. In the future if satellite to satellite communications becomes public, a communications infrastructure such as [17] could be built on top of a gossip protocol [18]. However, this network would effectively be a large adversarial satellite network between a wide range of stakeholders where geopolitics could influence satellites’ desire to spread correct information. To solve this, distributed ledgers could be used to secure such a network and make the communications immutable. Although a blockchain network would not work as they tend to be time synchronous, something satellite communications would not be, other distributed



(a) Türkiye 7.8M Earthquake 6 Feb 2023 (b) Indonesia 5.6M Earthquake 21-11-2022 (c) Afghanistan 5.9M Earthquake 21-06-2022 (d) Haiti 7.2M Earthquake 14-08-2021 (e) China 6.1M Earthquake 21-05-2021 (f) Legend

Fig. 5: Timelines directly after earthquakes. Specific earthquakes chosen from last 5 GDACS red alert earthquakes where Copernicus or ICSMD were activated. Data taken from [6], [14], [15], [5], [2] . (Note that Tweets with keywords is measured in 100s of tweets, and Copernicus and ICSMD Activation are only marked for time, not number of warnings.)

ledger technologies such as Hashgraph [19] are asynchronous and would therefore work on such a satellite network.

C. System Architects, Data Oraclisation and Data Processing Architects (Contract 5, 6 and 7)

Two major concerns of distributed systems, are computation costs and data storage costs, when they have grown to a size where 51% attacks [20] are economically unfeasible and the network has generally become reliable (Vulnerabilities still exist [21]). These are two elements that EO data heavily relies upon with data processing requiring large computational power due to the large size of the data to be used, and data storage because of the size of the data itself. Data processing costs can be mitigated through the use of validation that a process has been completed or in the future zero-knowledge proofs [22] to prove the task has been completed, with minimal distributed system costs. Data storage costs are harder to minimise but new systems in Web3 are beginning to solve this problem. Inter Planetary File System (IPFS) [23] and Filecoin [24] are two new methods that could potentially allow for EO data storage. Such methods of data storage and data processing are still economically expensive, therefore, until such methods are fully developed, a hybrid system could be built, between distributed and centralised, which could be used with EO data being held on the data providers server and the distributed network acting as a marketplace as discussed in section III.

When multiple satellites provide data with different sensors for monitoring the same disaster, the data will inevitably have discrepancies due to uncertainties, sensor characteristics and potentially be affected by biases. A single source of truth in the data can be hard to find, for the end user, when they shouldn't have to spend time sorting through data. Therefore, an oracle can be made to fuse the data, provided for the same disaster, together, which would improve accuracy as well as identify and remove bias from data itself. Building an automated oracle can also provide the vehicle to integrate new methods for data processing and fusion. This can allow for anyone to propose methods for data processing further increasing the marketplace and opening up the system for easy onboarding of any new stakeholders.

System architects can put forward new improved logic as mentioned in III and stakeholders can vote within the smart contracts. However, some sort of metric, discussed in section IV-D, must be created to incentivise positive behaviour on the network as well as thwarting a multitude of different attacks such as sybil attacks [25].

D. Trust Management

To avoid the capitalistic tendencies of using staked money as the stakeholder voting power, which would discourage new users from using the system, a way of measuring trust should be created. Measuring the trustworthiness of actors on a network is complex and can use many different models as can be seen in [26]. This trust metric can be broken down into social trust [27] where the trust is based on the trust given to the actor providing the data and a "network trust" which is determined from how the actor supports the network through actions such as communicating data through the network. Methods of calculating network trust have been considered in [28], [29] and [30]. Putting both together on the transparent backbone of a DAO can dissuade malicious intent on the network and if necessary reduces the impact of these malicious parties on the network and the services it provides. When a entity provides misleading or incorrect data, their trust will be reduced. Vice versa, if an entity provides useful, unbiased data to the network their trust rating can increase, contributing more to data produced and potentially increasing compensation for their service. This could be implemented through measurements of the oracle and how accurate a users data is to others, through measuring how correctly a satellite operator collects the EO data compared to a plan, or through measuring how early a user creates a warning of a disaster occurring in Social Activation. The use of such transparent metrics can incentivise new users and stakeholders to join as they could gather social credit in the network no matter how much data or methods they wish or are capable to provide. Although network trust has previously been investigated, further work can be explored in the specific domain, while social trust will need specific algorithms for the domain.

V. Conclusions

A solution to the management and communication complexity problem of the increasing diversity and quantity of stakeholders in space could be the implementation of a DAO. With a world that is becoming more divided and all reaching towards space, a shared neutral system that is owned and operated by all stakeholders and users can be the most equitable and efficient way to reduce SEM waiting times and helping combat climate struggles. Fusing Web3 technologies with SEM will bring many improvements including scalability, security, and neutrality however is a large paradigm shift from the current systems space infrastructure. Unbiased transparent logic for automation of decision strategies and Web3 security can provide trust for all entities involved. Implementation of a social activation system can bring the large quantity of disaster notifications, warnings and forecasts together to build a faster, more resilient and fairer system for those affected. This system can also provide the communications infrastructure required to develop more advanced on board capabilities such as on board processing and autonomous decision making, and oracle development for large scale data processing and reduce bias map production.

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