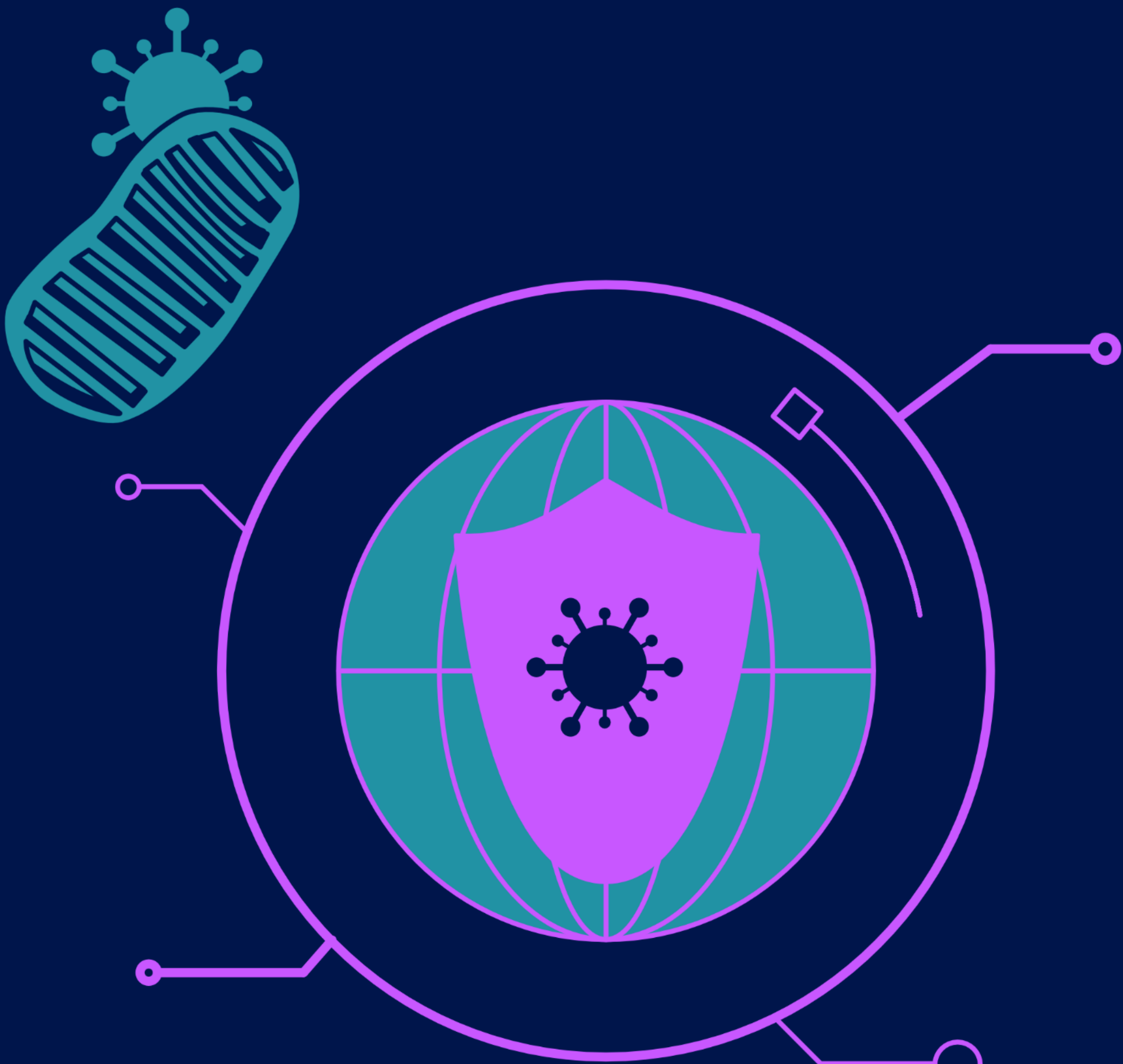
Report

# Future Pandemics: Leveraging Space for Prevention and Preparedness



INTERNATIONAL SPACE UNIVERSITY

ONLINE

ISP2020

# Future Pandemics:

# Leveraging Space for Prevention and Preparedness

## Final Report

International Space University Intensive Space Program 2020

The 2020 Interactive Space Program was held by the International Space University (ISU).

Electronic copies of the Executive Summary and Team Mission Report may be found on the ISU website (https://isulibrary.isunet.edu/).

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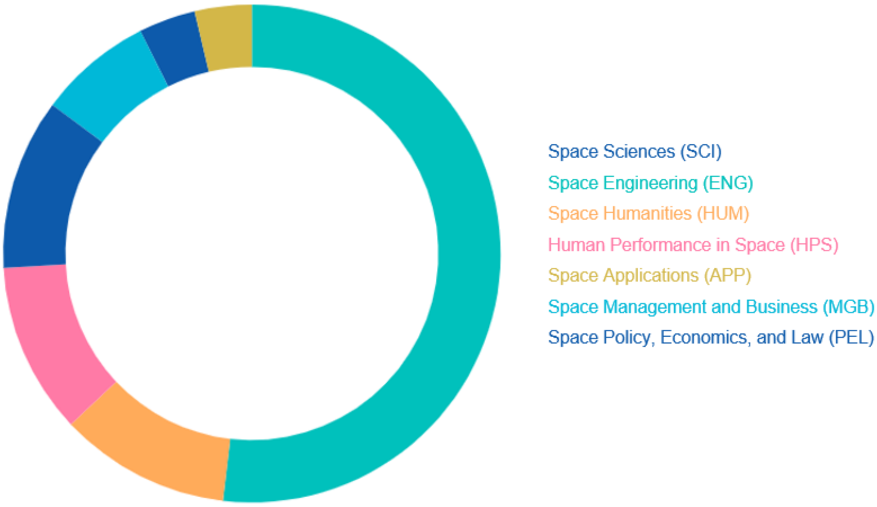
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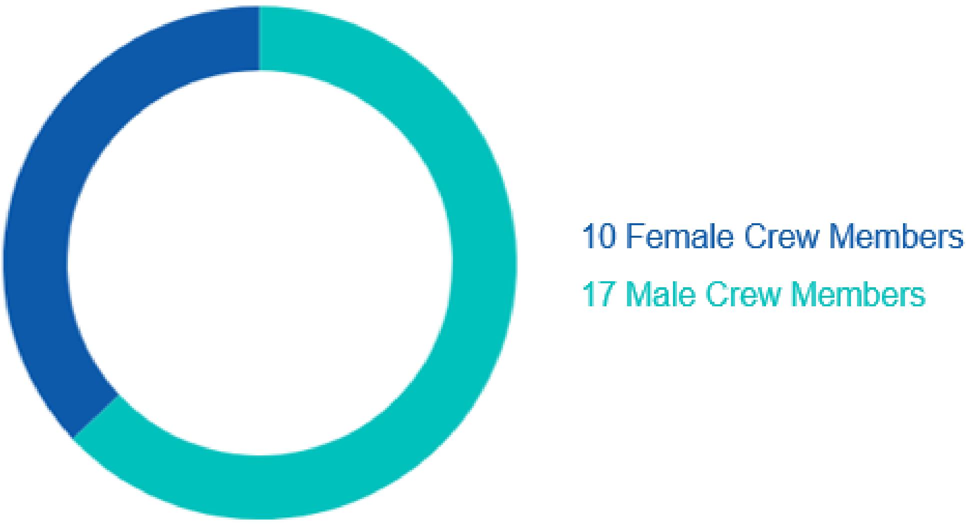
10 Female Crew Members
17 Male Crew Members

# Abstract

From the very beginning of humanity's activities in space, the population of the Earth has benefited from space applications and exploration. Space assets have helped society in the fields of communications, Earth observation, disaster mitigation, telemedicine, public health services, and pandemics management.

The objective of the mission is to study the existing policies, mechanisms, and practices in pandemic prevention and preparedness around the world, to understand existing gaps, to bring out innovative suggestions using space applications and technology to prevent the next pandemic from happening and to be better prepared to limit its impact if it does happen.

Having performed a thorough analysis of reports and findings from previous pandemics, we determined that using a combination of the following space-based technologies and applications would help us to improve efforts in preventing and preparing for future pandemics. These applications and technologies include and are not limited to satellite internet, small satellite constellations, Artificial Intelligence (AI) tools for creating disease risk maps, Global Navigation Satellite System (GNSS), Earth Observation (EO) data, and Unmanned Aerial Vehicles (UAVs).

We also investigated a list of relevant use cases where space technologies and spin-off inventions can help, such as in areas of tele-maintenance, disaster relief, and tele-agriculture. We recommend setting up a rapid response task force, an international charter for pandemics, and a global medical situation awareness system for effective outreach, fast communication, and coordinated actions among the governments, relief organizations and task forces. We have also made suggestions for national governments, international institutions, and businesses to further their efforts and support for advanced space and epidemiology research to develop vaccines and therapeutic medicines that can help prevent and better prepare us for future pandemics.

# Faculty Preface

In July and August of 2020, an international, interdisciplinary, and intercultural group of professionals came together virtually online to address the issues made important by the COVID-19 pandemic crisis affecting the world. We were part of an innovative new program called the Interactive Space Program 2020 (ISP20).

The first ISP cohort was divided into three habitats: Orbit, Moon, and Mars to collectively develop a Team Mission report on, 'How Space Contributes to the Monitoring, Mitigation, Prevention, and Preparedness of Pandemics'. Our Moon Habitat team was assigned the important duty of developing recommendations on how the world can prepare for and hopefully someday prevent future pandemics by using space technology. Twenty-seven remarkable individuals from fifteen countries worked together as a team on the mission project for five weeks to develop recommendations to guide health crisis planning in the years to come.

The Moon Habitat participants did not meet face-to-face during the entire project, yet they were able to organize and successfully conduct this complex space research project remotely. Their work reflects the remarkable ability of what passionate people can accomplish even when faced with unfamiliar tools and strange working conditions. They discussed and debated online until a series of well-thought-out recommendations emerged. This experiment demonstrated an entirely new way to harvest the intelligence and insights from a group of dispersed individuals with different academic backgrounds and cultural approaches who were united by their interests in pursuing careers working in the space industry.

It has been an amazing experience for us to work with this talented group of professionals focused on such a significant topic to the world in the area of health management and future space activities. We invite the reader to use this document as a guide for approaches to prepare and prevent future pandemics.

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| Gary Martin | Commander, Moon Habitat |
| Camilo Andrés Reyes | Officer |
| Dr Paul Iliffe | Officer |

# Crew Preface

The Coronavirus pandemic that began in 2020 reminded humankind of the fragility of the human body, independent of race, social status, and age. With this came the realization that humankind needs to cooperate closely in the future to monitor, prevent, mitigate, and prepare for future pandemics. It is with the Interactive Space Program (ISP) hosted by the International Space University (ISU) that we have begun to address these issues.

Team Moon consists of twenty-seven individuals from fifteen nations with diverse professional backgrounds and experiences who solely convened online and in a collective effort investigated the processes of using space applications & technology to aid in preparedness and prevention of future pandemics.

This report contains contributions from all twenty-seven crew members, approaching the topics from our different backgrounds and merging them into a series of feasible proposals addressing future emerging pandemics, trying to integrate an international, intercultural, and interdisciplinary attitude.

During our project, we have realized once again how privileged we are to be able to live in areas with accessible medical institutions, and we sincerely hope to expand this access to all humankind with the aid of space-related technology and networks. This opportunity to work with individuals from diverse backgrounds online has also taught us valuable lessons that will guide us in our personal and professional futures.

We wish to express our sincere gratitude to all the faculty, staff, lecturers, mentors, and alumni, especially Gary Martin, Paul Iliffe, and Camilo Andrés Reyes, for their constant support and generous guidance.

We hope our proposals will be implemented in the near future not only when tackling an emerging pandemic, but also to improve current medical care for those living in underprivileged conditions.

Team Moon

ISP 20, worldwide

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# List of Acronyms

| | |
|---|---|
| AI | Artificial Intelligence |
| AIDS | Acquired Immune Deficiency Syndrome |
| ASEAN-WEN | Association of Southeast Asian Nations Wildlife Enforcement Network |
| BMJ | British Medical Journal |
| BSI | British Standards Institution |
| CDC | Centers for Disease Control and Prevention |
| CITES | Convention on International Trade in Endangered Species of Wild Fauna and Flora |
| CMG | Control Moment Gyroscope |
| COVID-19 | Coronavirus Disease 2019 |
| EO | Earth Observation |
| EOS | Earth Observing System |
| ESA | European Space Agency |
| ESCF | European Sample Curation Facility |
| EU | European Union |
| FPV | First-Person View |
| GDP | Gross Domestic Product |
| GDPR | General Data Protection Regulation |
| GHSI | Global Health Security Index |
| GIS | Geographic Information System |
| GP | General Practice |
| GPS | Global Positioning System |
| GVP | Global Virome Project |
| H1N1 | Influenza A Virus Subtype H1N1 |
| HIV | Human Immunodeficiency Viruses |
| HTS | High Throughput Satellites |
| ICARUS | International Cooperation for Animal Research Using Space |
| ICT | Information and Communication Technology |
| IHR | International Health Regulations |
| ISP | Interactive Space Program |
| IoT | Internet of Things |
| ISS | International Space Station |
| ISU | International Space University |
| JAXA | Japan Aerospace Exploration Agency |
| JAMA | Journal of the American Medical Association |
| LiDAR | Light Detection and Ranging |

| | |
|---|---|
| MRSA | Methicillin-resistant Staphylococcus Aureus |
| MSA | Medical Situational Awareness |
| MSRRF | Mars Sample-Return Receiving Facility |
| NGO | Non-Governmental Organization |
| NASA | National Aeronautics and Space Administration |
| PHEIC | Public Health Emergency International Concern |
| PPE | Personal Protective Equipment |
| SaMoLoSa | Satellite Monitoring for Logistics Safety |
| SARS | Severe Acute Respiratory Syndrome |
| SatCom | Satellite Communication |
| SatEO | Satellite Earth Observation |
| SatNAV | Satellite Navigation |
| SCS | Smart Coop Solutions |
| SMS | Short Messaging Service |
| TB | Tuberculosis |
| UAV | Unmanned Aerial Vehicles |
| UK | United Kingdom |
| UN SPIDER | United Nations Platform for Space-based Information for Disaster Management and Emergency Response |
| UN | United Nations |
| UNOOSA | United Nations Office for Outer Space Affairs |
| US | United States |
| UV | Ultra-Violet |
| VTOL | Vertical Take-Off and Landing |
| WHO | World Health Organization |

# Introduction

## Aims and Objectives

As humanity continues to grow and endeavors to become a multi-planetary species, the consequences of being unprepared for a global pandemic on Earth have become more evident. This report will present a set of recommendations to the international community for improving preparedness for and prevention of future pandemics. To do so, an interdisciplinary, international, and intercultural outlook is needed when investigating space technology applications and the use of extraterrestrial resources. This report focuses on the themes of prevention and preparedness for future pandemics utilizing space-based applications. The key areas addressed are preventing outbreaks of infectious diseases, finding key parameters to predict outbreaks, monitoring of hotspots, data analytics, and developing protocols for international cooperation. This report aims to provide recommendations for a prepared infrastructure system, and detailed rapid response plans to prevent and prepare for future pandemics.

## Methodology

To accomplish our goals, our team began by using resources such as the subject guide on Space Technologies and Pandemics from the International Space University (ISU)'s Library Knowledge Portal (ISU, 2020), the NASA Spinoff Database (NASA, 2020), and the industry portal from ESA Space Solutions (2019). The team also conducted a thorough literature review by using multidisciplinary research databases such as Web of Science and ProQuest, as well as clinical databases such as the Cochrane Database of Systematic Reviews to find the most recent research material on pandemic prevention and preparation. We also used these to investigate national and international response efforts during past disease outbreaks.

The team also collected and analyzed scholarly articles from periodicals, namely the American Journal of Epidemiology, the Journal of the American Medical Association (JAMA), the New England Journal of Medicine, The Lancet, and the British Medical Journal (BMJ). In addition, the team consulted official documents from international organizations in the UN system. During the Interactive Space Program (ISP), the Team interacted with many experts in the field of Earth Observation, communication, and telemedicine. We formed several sub-teams and had extensive discussion and brainstorming sessions to identify disparities and potential improvements.

## Report Structure

Chapter 1 discusses the need to create a world Medical Situation Awareness (MSA) system to prevent future pandemics. Chapter 2 discusses how to leverage satellite internet and satellite constellations to improve communication and outreach efforts in public health education in areas with little or no terrestrial communication and the establishment of National Pandemic Response Taskforces that use Unmanned Autonomous Vehicles (UAVs) to enable future efforts to respond to a disease outbreak quickly. Chapter 3 calls for the establishment of a new Charter for Space and Pandemics, or the extension of the Charter for Space and Major Disasters to facilitate better governance and international collaboration to safeguard the wellbeing of the world's populations. Chapter 4 then presents use cases based on space spin-off inventions and discusses how to leverage them to be better prepared for future pandemics. The importance of using space as an experimental field to develop vaccines and new medications is also highlighted.

## Definitions

According to The Dictionary of Epidemiology (2001), a *pandemic* is defined as "an epidemic occurring worldwide, or over a very wide area, crossing international boundaries and usually affecting a large number of people'' (p. 131).

In this report, *Early Prevention* is defined as the measures, tools, methods, policies, and procedures to prevent a potential community outbreak, and *Late Prevention* measures as the tools, methods, policies, and procedures to prevent a disease outbreak from progressing to a pandemic. *Preparedness* is defined as the tools, policies, resources, and techniques available to minimize the negative impact of a pandemic on individuals, societies, and economies. *Space Assets* is defined as all equipment and technologies designed to support space activities that employ existing space-related applications and systems as well as related spin-off innovations.

# Chapter 1 Building a Worldwide Medical Situation Awareness (MSA) System

## 1.1 Introduction

This chapter discusses the need for a worldwide Medical Situation Awareness (MSA) system to enhance countries' abilities to prevent future pandemics. An MSA system will make use of Earth Observation (EO) data and case reporting to allow for better preparation plans and localized prevention measures.

## 1.2 Medical Situational Awareness (MSA) System

Medical Situational Awareness is needed to ''provide useful and actionable information for preparing and employing medical assets (DeFraites & Chambers, 2007, p. 1071)'' to aid in the prevention of and preparation for public health threats and future pandemics.

An MSA system serves as an accurate early warning system for diseases based on environmental data and data on past disease outbreaks that have been identified and validated. It can be used to examine disease risk maps for potential outbreaks and allow for the monitoring of specific areas, as well as to help the planning and execution of actions during an outbreak, such as medication delivery, enforcing lockdowns, identifying populations and areas at risk for future testing, and enhancing social distancing measures.

Data concerning medical assets and resources, such as infrastructure and personnel, can be gathered and analyzed to improve health logistics, especially during critical pandemic situations. As many infectious diseases share the same environmental and social conditions favoring their spread, an international effort is required to closely monitor these indicators with Satellite Earth Observation (SatEO) applications to identify specific regions of concern and to develop a global infectious disease risk map. This map would be updated continuously and alert relevant authorities of any changes in conditions that might indicate an outbreak.

There are many resource management databases, but very few are integrated. An MSA system aims to bring together data from disparate systems and allow different users to view data at different levels, giving each user the data, they need to make the best decisions possible. Several types of data can be incorporated into the MSA system, such as geographical data and SatEO data to obtain a better understanding of how infectious diseases spread. Detailed MSA tools not only help to evaluate disease transmission pathways and confirmed case distribution, but also provide useful insights in an epidemiological context, including questions on who was infected, and when and where were they infected. This system builds on to existing systems such as the Alabama Incident Management System which monitors supply levels, staffing, resources, and utilities (Institute of Medicine (US) Forum on Medical and Public Health Preparedness for Catastrophic Events, 2010). In early prevention stages, a worldwide MSA/EO system can also be used to:

- Identify and produce zonal maps of healthcare providers, such as hospitals, general practitioners, rural health practitioners, and a complete map of undertakers, cremation services, and burial grounds
- Ensure adequate stocks of medical supplies and Personal Protective Equipment (PPE) are stored safely at identified risk areas, and monitor stock and conditions closely using

Satellite Communication (SatCom) technologies.

- Help to prevent medical theft - a study by the British Standards Institute (BSI) (2020) of 203 countries estimates global annual pharmaceutical and medical cargo theft at $1 billion with the UK, the US, Mexico, Italy, and India suffering the most; to prevent future medical theft, Satellite Earth Observation (SatEO) applications can be employed to monitor traffic volume and patterns at key storage locations
- Devise a strategic network plan to optimize the routing of emergency response vehicles and a decision support system for local and national governments, as well as public health authorities to implement policy-based measures and monitor real-time disease risk maps. Such maps can be used to delineate containment zones and distribute vaccines and medical supplies.

Continued communication channels need to be ensured when traditional communication links fail to function. Therefore, the creation of an MSA web-platform and mobile application is also needed to prevent such failures from happening. A worldwide MSA/EO system that uses satellite information, together with an upgraded global communication infrastructure, could provide us with valuable information to aid in the prevention and preparation for future pandemics. Figure 1 below shows a sample screen of an MSA interface used in the simulation of an influenza outbreak in Thailand by DeFraites and Chambers (2007), the bottom graph shows expected and actual seven-day interval count of infections and the table on the left presents the region's alertness level.

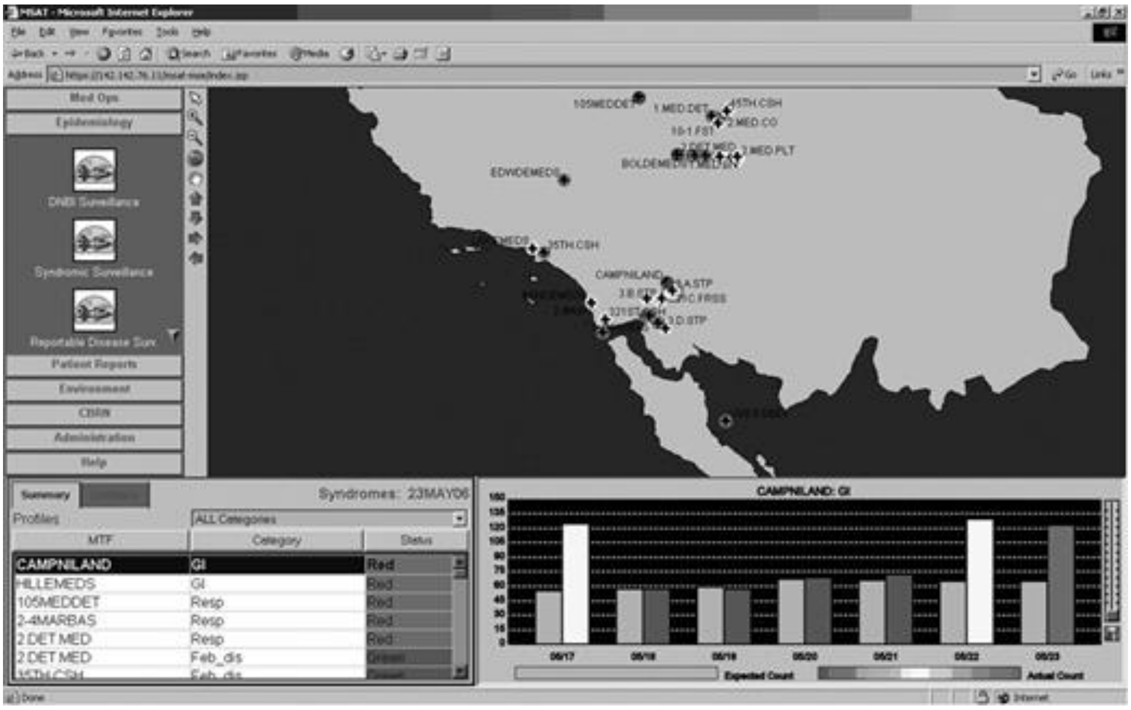


*Figure 1 Sample screen display of an MSA system (DeFraites & Chambers, 2007)*

## 1.3 Earth Observation for MSA

Now, researchers can detect environmental data with relatively low-cost methods such as using satellites equipped with electro-optical sensors. With new technologies and research, future efforts can also make use of better environmental sensors as discussed in Appendix I. For example, to increase spatial and temporal resolution as well as the spectral acquisition of SatEO data, one can increase satellite count, integrate more sensors, and use spectrometers to improve imaging technologies. In 2019, Planet Labs was able to double the spectral bands acquired, thus improving imaging technologies by a higher degree (Planet Labs, 2019). This would mean that, by replacing satellites at end of their lifespan or increasing the number of satellites, with a relatively small expense, it is possible to obtain enough data for making accurate SatEO mapping.

This would provide us with more detailed and accurate spatial information for the proposed MSA system. It is possible to incorporate more accurate SatEO data into the MSA system by combining data collected at higher spectral, spatial, and temporal resolutions. Several space agencies have launched different Earth Observation missions with various payloads that provide better data. It is recommended that researchers link these data with an advanced real-time, web-based and mobile application platform in the MSA system to obtain a real-time mapping of key locations and information regarding disease transmission.

## 1.4 Using MSA System to Prevent Zoonotic Spillovers

While it is not possible to use remote sensing satellites to directly detect disease outbreaks, it is possible to leverage them to monitor the environmental factors that are often indicators for disease outbreaks, for example, groundwater intensity, vegetation, temperature, and flooding conditions. As diseases have different transmission mechanisms and pathways, environmental data can be used in combination with geospatial information such as population density to identify areas for potential outbreaks (Space Foundation, 2019).

This section discusses how to use satellite data to prevent potential zoonotic outbreaks. A ‘zoonosis’ is ‘‘any disease or infection that is naturally transmissible from vertebrate animals to humans’’ (WHO, 2020). Humanity faces an increasing risk of zoonotic outbreaks due to changing climatic conditions that increase the frequency of human-animal contact and effects from commercial animal farming practices, and other socio-economic factors.

The Centers for Disease Control and Prevention (CDC) (2017) has estimated that 3 out of 4 new or emerging infectious human diseases are transmitted by animals. For the last hundred years, two new viruses have transferred to humans from their natural hosts per year (Woolhouse, et al., 2012). As human activities, such as poaching, continue to threaten the natural ecosystem, humans are at an unprecedented level of risk of ‘zoonotic spillovers’, namely, the possibility of animal-to-human pathogen transmission. Humans also have a higher chance of encountering wildlife as a result of practices like commercial logging, which results in large-scale deforestations – animals’ habitat change is a primary driver for zoonotic spillover (Jordan & Howard, 2020).

Space assets can help to minimize human contact with wild animals. For example, remote sensing applications, AI tools, and SatEO data can be used to detect areas of deforestation and estimate possibilities of potential zoonotic spillovers. It is possible to use these tools to identify and combat illegal poaching activities, together with drone systems and communication satellites for wildlife tracking to enforce and enhance international efforts such as the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES, 2020) and the Association of Southeast Asian Nations Wildlife Enforcement Network (ASEAN-WEN, 2020).

Remote sensing, supported by telecommunication satellites, radar tracking, and drone systems (Hodgson, et al., 2018) can also contribute to the Global Virome Project (GVP, 2020) to prevent zoonotic transmission (Carlson, et al., 2020). The GVP is an international effort to identify, within a decade, ninety-nine per cent of all zoonotic viruses with epidemic and pandemic potentials to better predict, prevent, and respond to future viral pandemic threats. This project aims to strengthen global and local capabilities to monitor, prevent and respond to an outbreak or pandemic caused by future zoonotic spillovers, knowing that the potential causative organisms are already evolving/present in animal populations.

## 1.5 AI for MSA System

AI uses computers to imitate human cognitive abilities and is a widely recognized technology that allows researchers to leverage satellite data more effectively and accurately. Machine Learning is a branch of AI with algorithms having the ability to ‘learn’ from data by themselves and make predictions based on provided data. Several companies in the space sector, as well as public sector agencies, have utilized AI tools and applications to predict vector-borne diseases such as Zika, Chagas, dengue fever, and malaria with environmental indicators such as surface temperature (Khormi & Kumar, 2015).

Other than SatEO and weather data, researchers and public health experts can use AI, SatEO applications, and Big Data to identify regions at risk for potential outbreaks. Big Data refers to extensive datasets that need to be analyzed computationally to produce insights. These tools can help to track and monitor social media data to recognize signs for early outbreaks. Tweets and Facebook posts on crowded hospitals can be combined with location data that alert and warn about potential disease outbreaks.

By creating an algorithm that searches social media platforms, it is also possible to better understand changes in the public's behavior. Bento, et al. (2020) studied how people searched COVID-19 related information following the first public case announcement in fifty US states using search intensity data from Google Health Trends API. This study found that initial attention was often short-lived, suggesting more efforts in communication and outreach in public health education is needed to prevent outbreaks escalating and spreading. Chapter 3 discusses in more detail the need for a new space charter on pandemic prevention to facilitate collaboration between industrial partners, businesses, public health authorities to develop and actualize such AI modelling systems.

## 1.6 Geographic Information Systems (GIS) for MSA

Geographic Information Systems (GIS) can utilize SatEO data from satellites and communication networks to enhance the medical situation awareness before, during, and after any outbreaks or pandemics.

Remote sensing satellites and GIS systems can be used to assess demographic and socio-economic factors that favor disease transmissions such as age-gender distribution, inequality, poor sanitary conditions, overcrowded housing, and specific land-use factors, e.g. the location of meat-processing factories to better assist in the preventing and preparing for future pandemics. GIS technologies enable government authorities, public health experts, and epidemiologists to understand and determine the geographic distribution and spread of infectious disease, and allow for surveillance, control, and decision on intervention strategies (Dogru, et al., 2007). GIS can be utilized to plan for containment zones to control spread and ensure essential supplies. Local governments can also use GIS systems in combination with other applications such as drones to scan and monitor public places for social gatherings, Chapter 2 discusses the use of (UAVs) in more detail.

Other types of data, such as individual health records, can be aggregated and anonymized to inform researchers of how a disease spreads in a region, the ethical and legal implications of these practices will be discussed in Chapter 4. Further research is needed to study other data types that could be incorporated into the MSA system.

This chapter has outlined several space-based applications that can be leveraged to monitor and track Earth's resources, animal, and human populations. A worldwide MSA system that incorporates these applications and various data can be created to help prevent and prepare for future pandemics.

## 1.7 Recommendations

Based on the above discussions, we have 3 main recommendations, as described in Table 1 overleaf.

*Table 1 Chapter 1 Recommendations*

| Number | Recommendation |
|---|---|
| **1.1** | Use GIS to enhance efforts to monitor deforestation, track wildlife, study climate change using space-based technologies and applications to prevent zoonotic spillovers. |
| **1.2** | Establish a worldwide MSA system using AI tools to enhance countries' abilities to prevent future pandemics. The MSA system will make use of SatEO data and case reporting to allow for better preparation plans and localized prevention measures. |
| **1.3** | Use satellite technologies such as space radar tracking and SatEO Data for biodiversity surveys to identify and analyze zoonic viruses and diseases. A dedicated space mission could be designed. |

# Chapter 2 Communication, Outreach, and Quick Response

## 2.1 Introduction

This chapter focuses on efforts to enhance communication and outreach for public health education. This chapter also focuses on the establishment of national pandemic response taskforces to better understand the ways to prevent outbreaks from escalating into pandemics. A lack of adequate, immediate communication during an outbreak could increase disease transmission. At the same time, carefully constructed and well-executed rapid response plans with detailed guidelines and recommendations are crucial to containing a potential outbreak.

## 2.2 Communication and Outreach

Public health education is key to communication during outbreaks and pandemics. A lack of widespread public health awareness may lead to populations taking unnecessary and risky actions that could either cause an initial infection or exacerbate an outbreak (Fishhoff, 2017). Dobson, et al., (2020) has found that insufficient outreach for pandemic prevention information is a common problem in low-income countries while Walsh (2018) highlighted how providing education to health care professionals can prevent infectious disease outbreaks. The World Health Organization (WHO, 2011) has also identified the lack of national ground communication infrastructure as a significant barrier for the effective distribution of health-related data and information in Africa. A study by the UN High-level Advisory Board on Economic and Social Affairs (2020) finds that active state intervention is required to promote public health development and knowledge distribution. Additionally, public investment in infrastructure and education are essential in achieving this goal.

Previous pandemics have highlighted that local response capacities do not always meet expectations and requirements, especially in less economically developed areas. It is important to educate at-risk populations on topics such as risk factors, hygienic routines, possible symptoms with infectious diseases, and treatment measures. There have been a number of successful initiatives implemented in the past to improve public awareness and health outreach, such as the implementation of a toll-free hotline to compliment family planning teachings by the Democratic Republic of Congo Population Services International. A number of African regions have set up emergency toll-free phone numbers for a variety of specific health concerns including HIV/AIDS, cholera, H1N1 and TB (WHO, 2011).

However, such use of mobile and wireless technologies and applications require an existing communication infrastructure and thus have a reduced presence in low-and-middle-income countries that are likely to be at higher risks of outbreaks. Other barriers to disease treatment and access to health information include affordability, availability, restricted access for women who often have low levels of digital literacy, and the lack of an integrated public system that provides information on both digital and traditional media channels. Effective policy implementation is also essential in ensuring citizens' data security and privacy for telemedicine and tele-education purposes (WHO, 2011).

As discussed above, a significant barrier to effective public health communication efforts is the lack of existing communication infrastructure, where space-related technologies and applications can offer solutions. SatEO technologies can be used to identify and plan for areas that need terrestrial communication infrastructure or upgrades and assist in the planning of communication infrastructure to ensure ground stations are not destroyed by flooding or landslide. The section below presents two additional space-enabled solutions to improve public health communication efforts.

## 2.3 Satellite Internet

Space assets can help significantly during pandemic responses to quickly and securely distribute information and to deliver telemedicine services. However, such practices are only possible in areas with satellite, submarine, or terrestrial access to the Internet. According to the International Telecommunications Union, in 2019, only 53.6 per cent of the world population are Internet users. Further initiatives are needed for expanding digital inclusion.

A satellite internet system aims to provide global internet coverage with no reliance on national infrastructure. The use of reliable satellite internet, combined with dedicated local health services and internet stations, could provide highly effective internet coverage in rural, remote, and low-income regions with little or no terrestrial telecommunications. A cost-effective satellite internet program will revolutionize efforts in communicating information to these regions and allow for more telemedicine and tele-education practices with video calls and access to WHO endorsed health education materials made possible on a large scale. New developments in the satellite internet market, with new providers such as SpaceX’s Starlink, would help to cut costs and increase connection speeds as well as have lower latency problems using Low Earth Orbit. Starlink has envisioned a near-global coverage beginning in 2021 (Cooke, 2020).

## 2.4 Reflective Satellite Constellations

Outreach from space using passive sunlight reflection is known as obtrusive space advertising, and has been demonstrated by the recently launched Humanity Star by Rocket Lab. Orbital reflector technologies have also been proposed to illuminate specific areas, as demonstrated by the Znamya satellites (Potter & Davis, 2009), and to beam light during night time to solar power stations (Rosemary, et al., 1991). These concepts can be utilized to build satellite constellations with reflective components to produce visual messages for public health outreach and education, such as broadcasting important information to affected areas to prevent pandemics from occurring and for better preparedness.

Space advertising raises concerns within the space community as a potential source of space debris and light pollution, which led to the ban of certain practices under US law, but not in UN treaties. Nevertheless, it should be highlighted that these would be not for profit purposes, but for education and outreach in the benefit of public health. Furthermore, to mitigate light pollution concerns, reflectivity could be reduced outside target areas, and early deorbiting conditions could be imposed once outbreaks or spillover risks are over.

## 2.5 National Pandemic Response Taskforces

National pandemic response taskforces are centralized coordinated response teams that use space assets and tools described in this report to help local and national governments to take proactive measures in outbreak prevention. Authors for this section have studied the shortcomings of several national and international agencies’ responses during the COVID-19 crisis.

These taskforces constitute a government entity that is funded by respective national governments to serve as a consistent source of information on pandemics to prevent the spread of pseudo-scientific claims of viruses, diseases, and vaccines (Dredze, et al., 2016). One way of funding them is through the use of respective state-issued bonds and specific tax relief plans. They would receive minimum control from political parties and must remain impartial for the sake of public health. If an outbreak happens, the taskforces will consolidate all relevant research regarding that disease and produce appropriate public health communication and education content. They would also decide on the best communication channels and strategies and deliver public health warnings to even the most remote communities. As there are many agencies whose responsibilities align with one or more roles of the taskforces, the taskforces must work with these national research and health departments to ensure a coordinated response through all levels of government. These taskforces would also collaborate with the WHO to prevent outbreaks and pandemics, and they can leverage the space applications outlined previously, such as the MSA system as well as satellite internet to ensure a coordinated effort.

During previous disease outbreaks, there were situations where antiscientific beliefs have spread in low-income communities as well as in educated echelons, partly caused by the politicization of scientific facts and anti-corporation sentiment (Linden, et al., 2018). These taskforces would serve as a trusted source of scientific information and would have nodal offices in every administrative region, such as every province to disseminate public health information. These taskforces will also conduct periodic training with citizens on emergency responses as well as to conduct mock drills with selected businesses to ensure biosafety.

When an outbreak occurs, these taskforces will utilize the space applications discussed previously, as well as drone systems to deliver rapid response and prevention measures.

## 2.6 Drones and Unmanned Aerial Vehicles

The use of space-based aircraft technology can guarantee a rapid response in the event of future pandemics. UVAs capable of vertical take-off and landing (VTOL) that use Satellite Navigation (SatNAV) applications can be used in life-saving missions such as guiding ambulances to find the shortest route to a patient's home. Moreover, UAVs can perform safe disinfection operations. For example, scientists in Galway and Limerick in Ireland have developed a drone with an ultra-violet light emitting payload that can sterilize public surface to help to reduce the transmission of viruses (Mannion, 2020). The drone has a pre-programmed route to fly over and emit this sterilizing UV light when humans are out of the area, leaving the public space sanitized.

UAVs can ensure rapid transport of crucial medical supplies, blood, and tissue samples between healthcare facilities and support emergency services (Raidió Teilifís Éireann, 2020). They can also deliver vaccines to communities that are hard to reach with poor transportation infrastructure. In areas with a high number of infections, UAVs can significantly reduce contact between patients and frontline healthcare workers when medical staff use the temperature sensor on UAVs to scan patients' body temperatures (Kamel Boulos & Geraghty, 2020). When immediate telemedicine responses are needed, UAVs can be used in line with visual data communication through a First-Person View camera for medical staff to make a detailed inquiry with a patient.

When used in combination with other telemedicine tools such as mobile applications, UAVs can ensure a stable and quick channel for exchanging information between patients and doctors. UAVs that use GIS systems and mapping could also help researchers and the national pandemic response taskforces to understand the distribution of confirmed cases over a geographical region. There are several UAVs that could operate autonomously at low-cost with high efficiency and prevision. They are a crucial tool for continuous prevention and rapid response measures while more in-depth analyses are needed to study the use of sensitive data in the tracking of a certain transmission chain.

## 2.7 Recommendations

This chapter discussed how to leverage satellite internet and satellite constellations to improve communication and outreach efforts in public health education and the establishment of National Pandemic Response Taskforces that use UAVs to enable future efforts to respond to a disease outbreak quickly. Based on the above discussions, 3 main recommendations are made and presented in Table 2.

*Table 2 Chapter 2 Recommendations*

| Number | Recommendation |
|---|---|
| **2.1** | Enhance communication and outreach efforts on public health education through satellite internet and reflective satellites |
| **2.2** | Set up National Pandemic Response Taskforce that uses MSA system and all the other space applications discussed in this report |
| **2.3** | Leverage drones and unmanned aerial vehicles for rapid response purposes |

# Chapter 3 A New Charter for Space and Pandemics Prevention

## 3.1 Introduction

This chapter discusses the benefits for international institutions, national governments, and industrial partners to use data gathered from space applications collaboratively for pandemic prevention and calls for a new global initiative between space agencies, WHO, and UNOOSA (United Nations Office for Outer Space Affairs) to establish a new or modified charter within UN-SPIDER (United Nations Platform for Space-based Information for Disaster Management and Emergency Response) network.

## 3.2 International Public Health Governance and the Benefits of Space Collaboration

The space industry has been successful in tracking the impacts of pandemics during the COVID-19 crisis and in previous Zika virus and Ebola outbreaks. Chapter 1 discussed how GIS data from Earth observation satellites could be used in the MSA system to analyze the spread of an outbreak and develop predictive models to learn which regions and individuals are at risk of infection. These applications can aid epidemiological research using synchronized and coordinated databases with various and dynamic sources (National Academies of Sciences, Engineering, and Medicine, 2016). Data gathered from space-based applications could be publicly shared within a network of space agencies, national governments, and major industrial partners under a transparent framework. As discussed in Chapter 2, countries can also collaborate and establish a tightly woven net of staffed Satellite Communication (SatCom) ground stations to identify and report possible outbreaks, particularly benefitting remote areas and regions.

To prevent future pandemics, close collaboration between international stakeholders is needed - the WHO has the role of leadership in coordinating the global response to diseases and pandemics. However there are concerns on the organization responsiveness against global health crisis and pandemics (Kamradt-Scott, 2016), which could be mitigated through larger technical weight and situational awareness that space collaboration can provide. UNESCO could also be another stakeholder, as communication and outreach is a key aspect for pandemic prevention. On the other hand, the UN SPIDER network includes the United Nations Office for Outer Space Affairs, which is an example of international collaboration between space agencies and countries across the Globe. The institution provides mechanism for cooperation to major disasters through the International Charter on Space and Major Disasters (2020), and also contributes to Early Warning Systems as the International Asteroid Warning Network, and for hurricane and droughts applications.  Additionally, some Non-Governmental Organizations (NGOs) involved in the space and public health fields can benefit from cross-collaboration with other institutions.

## 3.3 Recommendations

This chapter discussed the need for the establishment of a new space charter to facilitate better governance and collaboration in international public health to safeguard the wellbeing of the world's populations and the benefits that data sharing and tool development.

Therefore, the workgroup proposes to *either* extend the International Charter on Space and Major Disasters, *or* the creation of an analogous charter on Space and Pandemics within the UN-SPIDER network. This would enhance the collaboration between space agencies, industry, NGO's, UNOOSA, UNESCO, and WHO while including new applications focused on prevention and preparedness for pandemics. It would also benefit from UNOOSA and Agencies' space capabilities and WHOs medical knowledge, and UNESCO's influence on education and outreach. While the charter may also be used for mitigation and monitoring during a pandemic, two key aspects can contribute to prevention and preparedness:

1) Data-sharing between space agencies and companies for pandemic prevention and preparedness
2) Development of MSA tools for outbreaks and epidemic predictions and its indirect impacts, and to develop risk maps of possible zoonic diseases spillovers and emergence by tracking emergence factors

Furthermore, the charter would be activated when considered necessary by any member to prevent major outbreaks from resulting in a pandemic, and, if possible, a mechanism would be implemented for a Pandemic Warning Network tracking emergence factors for primary prevention.

Data sharing within the charter raises concerns on intellectual property breaching, especially for private companies, and on sharing data from countries which might be considered to have a detriment in national defense. It is, therefore, necessary to account for these issues and highlight to the specific actors that the data should be used only for pandemic prevention and preparedness purposes, which might be done through binding international agreements or by relying on the ethical standards from all stakeholders

These recommendations are summarized in Table 3.

*Table 3 Chapter 3 Recommendations*

| Number | Recommendation |
|---|---|
| **3.1** | Extend the International Charter on Space and Major Disasters or to create a new charter on Space and Pandemics Prevention within the UN-SPIDER network. This would enhance the collaboration between space agencies, industrial partners, UNOOSA, UNESCO, and the WHO to use space-based applications on preventing and preparing for future pandemics |
| **3.2** | Facilitate data sharing between space agencies, international institutions, industrial partners, and other businesses |
| **3.3** | Collaborate in the development of MSA systems and creation of global disease risk maps |

# Chapter 4 Enhancing Preparedness for Future Pandemics

## 4.1 Introduction

This chapter will outline 3 indicators used to assess the current status of preparedness for pandemics, then present 5 use cases from telemedicine, tele-maintenance, disability support, emergency relief, and tele-agriculture to illustrate how to integrate space and non-space assets to ensure an adequate level of preparedness. The importance of using space as an experimental field to develop vaccines and new medications is also highlighted.

## 4.2 Assessing Preparedness with Existing Indicators

To assess a country's preparedness for future pandemics, there must be quantifiable indicators that one can be validated with scientific evidence. Three indicators that accomplish this goal have been identified. The Global Health Security Index is a joint-collaboration between the Nuclear Security Initiative, the John Hopkins Center for Health Security, and the Economist Intelligence Unit Project Teams (GHSI, 2019). The GHSI hosts a panel of experts from thirteen countries to create a framework that measures a country's preparedness for epidemics and pandemics and investigates one hundred and ninety-five countries across 6 categories: Prevention; Detection and Reporting; Rapid Response; Health System; Compliance with International Norms; and Risk Environment. Results of these investigations have found that:

- 81 per cent of countries studied have scored very low for biosecurity
- 85 per cent of countries studied showed no evidence of completing a biological threat assessment in line with the WHO's International Health Regulations (IHR)
- 89 per cent of countries studied could not demonstrate a provision for providing medical countermeasures when a public health emergency occurs

The WHO evaluates a country's preparedness for a public health emergency through an annual questionnaire for member states with elements such as maps for key resources for priority risks, distribution plans for national stockpile reserves, and a directory of health experts in the country (WHO, 2015). As discussed in previous chapters, SatEO applications can be used to monitor storage sites and use SatCom applications to aid communications in times of emergencies.

It is also important to assess international institutions and national governments' financial preparedness for future pandemics. As the UN's agency responsible for international public health, the WHO is fighting at the front line of preparedness and prevention of future pandemics. Hence, sufficient funding is essential for the WHO and member states to plan for effective measures. With a total planned budget for 2020-2021 of US$ 5.84 billion, the current WHO budget has increased by thirty-two per cent compared to that of 2018-2019 (WHO, 2019). New funding initiatives have also been introduced to increase financial preparedness. The WHO has re-introduced an Emergency Operations and Appeals budget with an estimated funding of US$ 1 billion to ensure the required capacity to respond to unforeseen events like the COVID-19 pandemic outbreak (WHO, 2019). Also, the WHO Foundation, launched in May 2020, is a legally independent entity that facilitates financial contributions from individual donors and corporate partners to support the global health ecosystem in emergency preparedness. It endeavors to fund and advance initiatives and strategies on effective and rapid responses (WHO Foundation, 2020).

## 4.3 Space Applications for Epidemiology and Vaccine Development

The microgravity environment in space provides an advanced testing ground for rapid growth of microbial systems related to infectious disease, specifically pathogenic virulence, which can be beneficial for vaccine and treatment development. Bacteria are always interacting with fluids, and it has been observed that common areas of infection in the human body are areas with low fluid shears. Microgravity is the ultimate low-shear environment, providing a very interesting platform to study bacteria. Bacteria seems to sense shear levels and reprograms itself to adapt to the microgravity environment. The unique microgravity environment of space allows for deeper studies of these effects. It is believed that fluid shear could be an explanation for the increase antibiotic resistance in space cultures (Love, 2016). Using space as an experiment field can contribute to better understanding of pathogenic evolution (Weish, et al., 2020). In addition, space research can contribute to improved medicine delivery systems by using crystallization techniques, as demonstrated by the Japan Aerospace Exploration Agency

(JAXA) "space crystals" lab on ISS. This lab applies rapid crystallization, a process of purification to improve the quality of macromolecular crystals that is finding applications to put chemical compounds into pills to enhance drug discovery (McPherson & DeLucas, 2015) (Zhang , et al., 2019). The space environment was also seen to have an impact on the immunology of astronauts, and by studying this effect it would be possible to better understand the human immunological system and develop vaccines. The space environment can also provide an excellent bio-contained environment to conduct advanced epidemiological research with hazardous pathogens and demonstrate new techniques such as gain-of-function research. Gain-of-function research involves experimentation that aims or is expected to increase the transmissibility and/or virulence of pathogens (Selgelid, 2016).

More detailed information on how the space environment can contribute to epidemiology and vaccine development is detailed in Appendix III.

<u>Establish Baseline Parameters for Scientific Research</u> - The baseline parameters for scientific research include the development of better baseline studies on pathogenic evolution research in microgravity environments conducted at the International Space Station (ISS) or other platforms to generate high-quality data, specifically, related to global pandemics. Making available the data e.g. through a global common database from these studies funded by state agencies, commercial agencies, and other to the public in an open data initiative, is important to increase international cooperation and transparency. The legal and ethical implications of such research and open data initiative are discussed in Section 4.5.

<u>Streamline Research Process for Faster Outcomes</u> - Improved strategies and streamlined processes (e.g. application process) are needed for better and faster access to the ISS, particularly for agencies and commercial companies researching pathogens and developing vaccines while maintaining codified safety measures. It is recommended to provide incentives to commercial agencies, such as pharmaceutical or biomedical companies, since commercial companies are the future in space flight and can take greater risks compared to government space agencies. Providing this incentive to increase research development of therapeutics and vaccines that allow for proprietary rights, while simultaneously allowing for released baseline data that will greatly assist in the prevention of pandemics. In addition, it is recommended increasing incentives for NGOs and philanthropic actors like the Gates Foundation, might be a pathway to acquire grants to study infectious disease in microgravity. Improved government participation in space research and development is recommended to alleviate the potential fallout of their economies from global pandemics.

<u>Improving advanced pathogenic research while tackling biosafety issues</u> - New research techniques, such as gain-of-function research as mentioned above, can significantly advance our understanding of pathogenic evolutions and virulence, but can present important biosafety and biosecurity concerns (Selgelid, 2016). These require an increase of public awareness and knowledge together with greater transparency and improved regulations and guidelines e.g. using planetary protection standards and protocols for prevention of forward and backward contamination. Some of these concerns can be addressed with bio-contained experimentation conducted onboard orbiting space laboratories with human astronauts, or remotely operated using robotic systems, while exploiting the unique space environment. Performing advanced pathogen research in space can prevent and prepare us for pandemics through advancing our knowledge on microorganisms and immunology.

## 4.4 Assuring Preparedness by Utilizing Space Assets

This section presents 5 use cases to illustrate how to utilize space assets to assure preparedness for the next pandemic. For additional use cases, please refer to Appendix IV.

<u>Use Case 1 – Telemedicine</u> - During the COVID-19 pandemic, not only were hospitals operating overcapacity, but difficulties also arose when patients with non-communicable diseases were required to stay at home or were afraid of visiting hospitals (Garg & Wray, 2020). How to leverage space assets to ensure the continuous delivery of healthcare services?

Scottish Islands Connected Health may provide useful learnings. This is a low-cost service that reduces the need for patients on remote islands to travel for specialist consultations (Catapult, 2018). First, health workers at rural General Practices (GP) conduct a colonoscopy using a swallow-able camera known as a ‘PillCam.’ Image data is then transmitted to specialists using High Throughput Satellites (HTS), and they can assess the patient without the need to travel or direct contact. Such initiatives could ensure uninterrupted healthcare service delivery in rural and remote areas and can serve as emergency responses for urban patients who are unable to leave their homes.

In addition to existing practices, we have conceived of a new product that uses space assets to deliver healthcare services while overcoming geographical and time constraints. This is an Internet of Things (IoT) device with a continuous, direct connection to medical staff. It hosts a user-friendly interface that encompasses speech output, easy-to-read buttons, a camera, and a microphone to enable tele-medical staff to provide a 'personal touch', as well as a handlebar with sensors transmitting various vital signs. Once connected, the connection automatically routes to the nearest coordination center where a coordinator decides on the best course of action. The device can also work with space spin-off innovations like vMetrics, a system that helps patients with chronic cardiovascular diseases to better monitor anti-coagulation (NASA, 2013). This device is also helpful for inhabitants of remote areas where access to clinical medicine is restricted. Once preliminary examination and diagnosis are complete, drones could deliver essential medications while SatCom applications could be used to ensure secure transmission of data where terrestrial communication is limited. In normal times this would reduce the risk of infection greatly for the above-mentioned risk population and would hopefully lower the threshold to contact medical personnel when in need of medical advice.

During the COVID-19 pandemic, the world has witnessed a mismatch between the demand for and supply of medical personnel across geographic areas. The MSA system discussed in Chapter 1 can help us to prepare ourselves for the next pandemic better for countries to coordinate and reduce the time and efforts needed for qualified doctors and nurses to travel from one country to another and help. The new space charter described in Chapter 3 can help to minimize the bureaucratic hurdles involved in dispatching medical personnel across its member states. Satellite-enabled communication allows effective communications between foreign medical personnel and local patients with real-time translation services to avoid misunderstandings and enable an efficient workflow. With SatCom and SatEO applications, international institutions and domestic public health authorities can coordinate volunteers who are matched with medical staff in need of their translation services; this would be most helpful for patients who use rare languages in remote regions such as the Amazon basin. A graphic illustration of this use case can be found in Appendix V.

<u>Use Case 2 – Tele-maintenance</u> - A pandemic poses additional challenges other than stressed health systems when economic production and international trade halt. While energy, food, and water systems are indispensable in our everyday lives, during a pandemic, their effective operations may be threatened with inadequate personnel and disrupted supply chains, and even stopped when situated in inaccessible locations for human operators. To prepare for these situations, it is important to seek aid from space startups like Cosmic Srl that provide new methods of tele-maintenance using space spin-off technologies with a ‘low-cost device that is easy to install on any vehicle to measure the water content of the ground around pipelines and identify leaks’ (Business with ESA, 2020). In addition, the Satellite Monitoring for Logistics Safety (SaMoLoSa) system monitors ‘‘critical parameters during transports carrying hazardous goods in unpowered transport assets such as rail tank cars and intermodal tank containers’’ (Business with ESA, 2016). These applications could help to prevent production incidents and safeguard people’s lives during a pandemic.

<u>Use Case 3 – Disability Support</u> - For preparing for future pandemics, additional considerations must be made for people with disabilities who may have greater risks of contracting the disease, as they may experience difficulties when implementing basic hygienic routines (WHO, 2020). It is possible to leverage innovative devices like Theia, a portable, autonomous handheld

device that employs Light Detection and Ranging (LiDAR) to allow visually impaired individuals to orientate in outdoor environments and indoor spaces to enable them to locate and access sanitary facilities. Theia also uses a ‘‘control moment gyroscope (CMG), a technology found in space vehicles at the International Space Station (ISS), that requires very little user input and can actually ‘move users’ hands in open spaces (Loughborough University, 2020)’’, making handwashing a more viable option for people with disabilities.

Use Case 4 – Disaster Assistance and Emergency Relief - The current COVID-19 pandemic has called for better emergency relief measures when areas and regions suffer from both natural hazards and public health emergencies. For example, Bihar and Assam, two states in India, struggled against monsoon flooding and increasing COVID-19 cases concurrently (Mishra & Singh, 2020). How might emergency relief agencies learn from these experiences and leverage space assets to improve disaster assistance and emergency relief practices? e-Drift is a virtual platform developed by ESA that provides national and local governments access to Earth observation datasets from the Sentinel constellation (ESA, 2019). Such systems help municipalities to swiftly estimate the number of people affected by a natural disaster, as well as quantify the amount of required donors’ assistance in monetary terms.

Use Case 5 – Tele-agriculture - The COVID-19 pandemic has called for revised practices in farming, particularly in commercial farms where animal concentration is high and human-animal contact is frequent. Many national governments took precautions to contain the virus; for example, in the Netherlands and Spain, authorities have eliminated more than one million minks in fear of animal to human transmission (Theisen, 2020). These operations were not without ethical and environmental implications while also causing direct economic losses for business owners. How might commercial farms leverage space assets to monitor and manage livestock effectively while avoiding unnecessary extermination? SatEO and SatCom applications can be combined to provide farmers with a way to monitor herds distantly and reduce direct human-animal contact. Smart Coop Solutions (SCS) is an IoT based sensing service that is particularly useful in areas with poor or no terrestrial communication (Business with ESA, 2019). If an anomaly occurs, farm owners can alert the relevant authorities swiftly for further actions.

## 4.5 Ethical and Legal Implications

It is important to consider the solutions detailed and discussed above, as with any new technology, from an ethical standpoint. AI and data analytics can help greatly in pandemic prevention; however, where computational decision making is concerned, there is a potential for bias. Algorithms may treat specific geographic regions favorably when human designers unintentionally pass on their own biases or even try to manipulate these programs. While some efforts have been made to reduce such occurrences (Yeung & Lodge, 2019), such as the Montreal Declaration on the Responsible Use of AI (Université de Montréal, 2017), researchers and experts need to be aware of the possibility of an AI becoming an unethical one (Vanderelst & Winfield, 2018). Perhaps the most well-known approach to ethics in AI comes from Asimov's (1942) ‘three laws of robotics’, which seek to ensure human safety above all else.

In addition to discussions of ethics in AI, the accumulation of private data for surveillance and monitoring purposes during public health emergencies requires attention. Space technologies help us to harness the power of data, such as health-related data, location and tracking data, and identifiable personal data. Ethical issues may arise relating to data collection, analysis, and dissemination of personal data and information. As national governments have seen during the COVID-19 pandemic, and as with the contact tracing apps, some resistance exists in its usage in certain countries and regions, resulting in varying degrees of success in implementation. There is no global consensus on the conditions of the legality of the use of personal data. While some regions, such as the EU and its General Data Protection Regulation (GDPR) directive, have taken a proactive approach with strict standards to protect and govern the collection, use, dissemination, and storage of personal data, other regions and countries have less stringent regulation.

There is a consensus that rampant, illegitimate, and unproportioned collection of personal data poses threats to good governance and democratic practices. International institutions and national governments have also recognized, to some degree, that in situations such as public health emergencies, public safety outweighs personal freedom concerns. In the context of the COVID-19 pandemic, the UN has recommended that ethical considerations must be made for surveillance and tracking technologies, as well as their analysis and communication (UNICEF, 2015). The UN also recommends that countries implement any tool or technology for surveillance and tracking purposes in a non-intrusive manner and abiding by stringent protection and international human rights standards. More importantly, even if a data collection tool has followed legitimate purposes, i.e. used for public health concerns, any resulting data processing should safeguard against potential violations of data privacy. Further research is needed to ensure data privacy and protection are in line with prevention and preparedness measures for future pandemics.

The UN has highlighted the following risks of data and privacy violation with the use of digital technologies:

(i) risk of misuse of collected data by both authorized users and illegal hacking access to it; and

(ii) risk of infringement of rights as a result of the data collection such as loss of privacy, discrimination, and harassment.

Based on this information, during a pandemic, the UN recommends that only data collected and processed for legitimate purposes can be used and must be used in the principle of proportionality, where "[o]nly the level of identification necessary to achieve the intended public health outcomes should be used in technologies (UNICEF, 2015)." Data collection should refrain from going beyond necessary identification to achieve the intended public health outcomes. And when possible, technologies should use aggregated, de-identified, or anonymized data.

To achieve an ideal level of preparedness for future pandemics, certain thresholds on the speed, scale, and invasiveness of data collection need to be discussed. This will be a process that encompasses a diverse range of actors such as local and national governments, regional and international institutions, and corporate partners. To have better governance in utilizing space technologies and applications, and hopefully, with the establishment of a new space charter, it provides a venue where members can engage with multidisciplinary partners.

## 4.6 Recommendations

This chapter discussed 3 indicators to assess current level of preparedness and presented use cases based on space spin-off inventions. The importance of using space as an experimental field to develop vaccines and new medications is also highlighted. Based on the above discussions, 4 recommendations are made in Table 4.

*Table 4 Chapter 4 Recommendations*

| Number | Recommendation |
|---|---|
| **4.1** | Identify and quantify current indicators for pandemic preparedness by using factors of the Global Health Security Index, citizen internet access statistics, and funding figures. Later, National Pandemic Response Taskforces can use these indicators to verify for any quantifiable increase in pandemic preparedness. |
| **4.2** | Further advanced space and epidemiology research efforts by:<br>• Establishing baseline parameters for scientific research<br>• Streamlining research process for faster outcomes<br>• Improving advanced pathogenic research while tackling biosafety issues within space research and planetary protection lessons learned |

| | |
|---|---|
| **4.3** | Implement a 'space in all' approach by incorporating space assets with non-space assets in areas such as telemedicine, tele-maintenance, disability support, emergency relief, and tele-agriculture to ensure an adequate level of preparedness. |

# Conclusion and Future Work

## Conclusions

This report discussed in Chapter 3 how the existing UN-SPIDER network could contribute to better prevention and preparedness measures for future pandemics with the creation of a new Charter for Space and Pandemics or the extension of the Charter for Space and Major Disasters focused on data sharing and in the development of MSA and other systems discussed in Chapter 1. In Chapter 2, it also highlighted the importance and benefits of space applications, such as satellite internet and reflective satellites in communication efforts to enhance the public's awareness and knowledge about public health education. In addition, it presented how the use of UAVs could help countries and public health agencies to rapidly respond to disease outbreaks and prevent potential outbreaks escalating into a future pandemic. Chapter 4 discussed how to leverage space as an experiment environment that facilitates the development of new vaccines and medicines that would aid epidemiological research. The sections also outlined the technologies, applications, and space spin-offs in areas such as telemedicine, tele-maintenance, disaster response and emergency relief, disability support, and tele-agriculture that can help individuals, business, and economies to prepare for the potential dangers and obstacles posed by future pandemics.

Throughout this report, it has been emphasized that to better prevent and prepare for future pandemics; the world needs to harness the potential of space assets in line with further international cooperation and global collaboration. With these recommendations, international institutions, national governments, and corporate partners can leverage space assets, the space sector, and outer space to continue to safeguard and improve the general wellbeing of the world's populations.

## Future Work

This report has given few considerations to the difficulties relating to the funding of complex and extensive recommendations discussed above. However, several possible solutions can help to resolve this issue, and further work is needed to develop more sound financing plans. For example, states can devise specific bonds to support funding for the national pandemic response taskforce. Governments can also create specific tax relief program and pre-tax donation systems dedicated to research projects, such as the creation of an MSA system, that are related to pandemics prevention.

Further study is also needed to evaluate the existing systems to aid the creation of a global MSA system.

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# Appendix I Situational Awareness

Situational awareness is "the perception of elements in the environment along with a comprehension of their meaning along with a projection of their status in the near future" (Endsley, 2000).

## Earth Observation

Earth Observation satellites can have a wide range of electro-optical sensors, and these divide into active and passive sensors. Electro-optical sensors are used in all satellites, from multi-ton satellites to CubeSats, and can be used in any orbit.

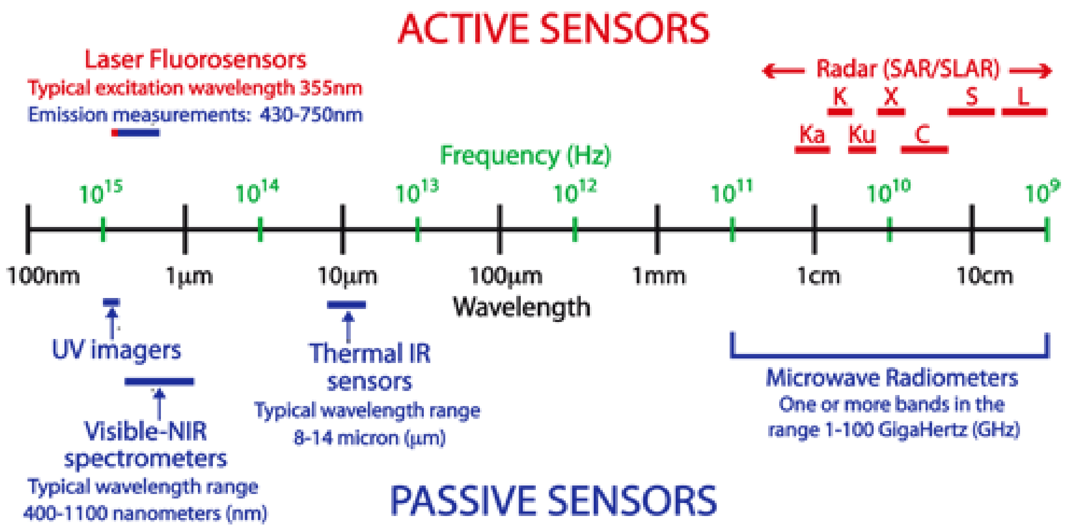


*Figure 2 Active and passive sensors for remote sensing (SEOS, 2019)*

Moreover, these sensors are characterized by the wavelength they are able to collect: different wavelengths give different information on the subject investigated.

Electro-optical instruments can have different capabilities:

- Multi-spectral or Hyperspectral imaging– related to the amount of different wavelength acquired (Schowengerdt, 2006).
- Medium to high spatial resolution imaging – related to the smallest resolvable dimension (varies from cm to km)
- Medium to high temporal resolution imaging – related to the time between acquisitions

The three phases (solid, gas and liquid) each reflect, emit, or absorb different wavelengths in different ways. This allows the satellites to detect several different parameters – including ground temperature, moisture, and air quality index.

The technical characteristics listed above limit or improve the efficiency of these systems. Having more wavelength collected gives different information, having higher spatial accuracy allows for a more accurate evaluation of the system under analysis, and having higher temporal resolution grants faster response time to prevent disastrous phenomena such as disease outbreaks.

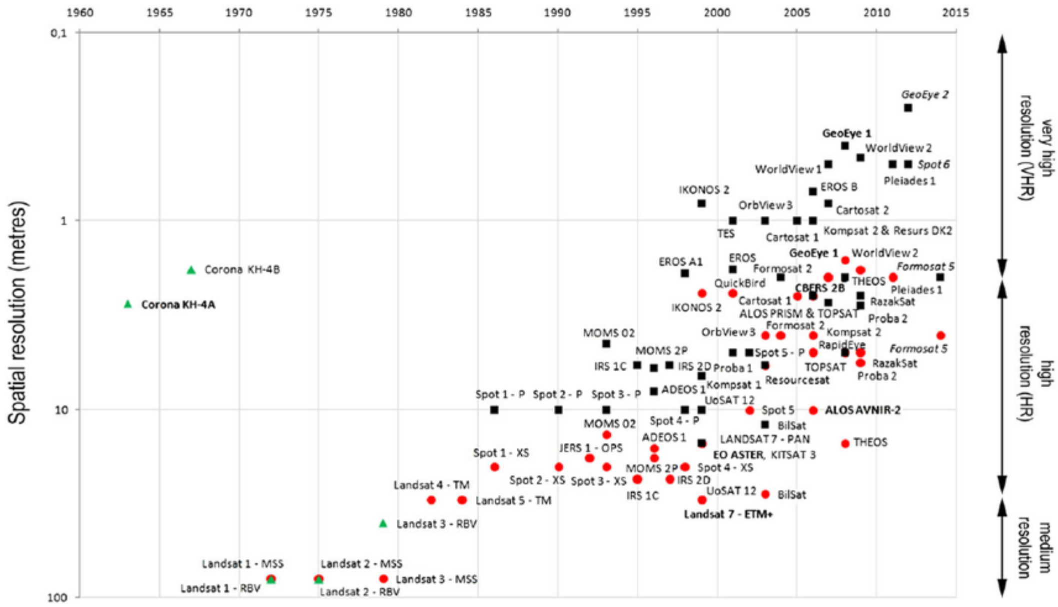


*Figure 3 Satellites with medium to high spatial resolutions (Deroin, et al., 2012)*

Figure 3 above shows the spatial resolution launched in relation to the time frame and from this, it can be inferred that the satellites that have been launched recently have very high-resolution capacities to give more accurate data and observations.

## Environmental Data

Environmental data associated with the spread of mostly zoonotic diseases include sea level, water quality, water flow velocity, rainfall, air and water temperature, humidity, cattle density, atmospheric pressure, wind speeds, wind direction, and vegetation pattern. The direct melting of permafrost also increases the risk of disease outbreaks. Most of these environmental data is directly related to climate change and can be obtained through remote sensing with SatEO satellites.

The past has shown that many communicable diseases are caused by changes in environmental conditions. Zoonoses are mainly transmitted by accidental human encounters with animals, which will increase due to climate change and the destruction of natural animal habitats (Dincer, et al., 2010). An example of this is fruit bats (Genus Antibeus) who feed near human settlements if their habitats have been disturbed (often by logging). These contributed to viral emergences in Malaysia, West Africa, and Australia, and are the probable carrier for the virus behind COVID-19, SARS, and Ebola.

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# Appendix II SatEO, SatNAV, and SatCom Applications

Satellite Earth Observation (SatEO) applications are commonly used for resource and environmental monitoring as well as for geological and meteorological research. They can also be employed in agriculture, aquaculture, and forestry management and nautical navigation.

Satellite Navigation (SatNAV) applications allow us to obtain positioning data from the Global Navigation Satellite Systems (GNSS). They are commonly used to track vehicles and the Satellite Automatic Identification System (SAT-AIS) aides maritime and logistics practices.

Satellite Communication (SatCom) applications support the transmission of audio, video, and text-based data and provide secure data transmission channels. They provide connectivity for remote areas and regions lacking terrestrial communication and support applications that require a large bandwidth. Increasingly, SatCom technologies are used in combination with the Internet of Things (IoT) applications to provide Beyond Line of Sight (BLOS) communication with autonomous ships and drones.

# Appendix III Advanced Space and Epidemiology Research

The UN's 17 sustainable development goals have one common underlying theme: improving global health (UN, 2020). On the other hand, the COVID-19 crises showed that pandemics are a serious threat. Dr Farhan Asrar poses the question "if every pandemic will simply have 'known unknowns' and 'unknown unknowns'" (Asrar, 2020, p. 26). The human race could be facing a virus so virulent that we cannot contain and treat it, resulting in the extinction of humanity.

The microgravity environment in space provides an advanced testing ground for the rapid growth of microbial systems related to infectious disease, in particular the growth of the virulence of pathogens, which can be beneficial for vaccine and treatment development. It has been shown that certain bacteria can increase its population growth rate, virulence response, and resistance as a consequence of the higher selective pressure and mutation rates. This can contribute to faster development of vaccines or therapeutic agents by identifying basic functions of specific traits, as for the Salmonella bacteria (Wilson & et al, 2008) (Zhang , et al., 2019), and can help to understand specific pathogens with high mutation rates which complicate vaccine development, as for the flu and HIV. Besides pandemic prevention, the space environment can also provide breakthroughs in the field of tissue engineering (Wehland & Grimm, 2017).

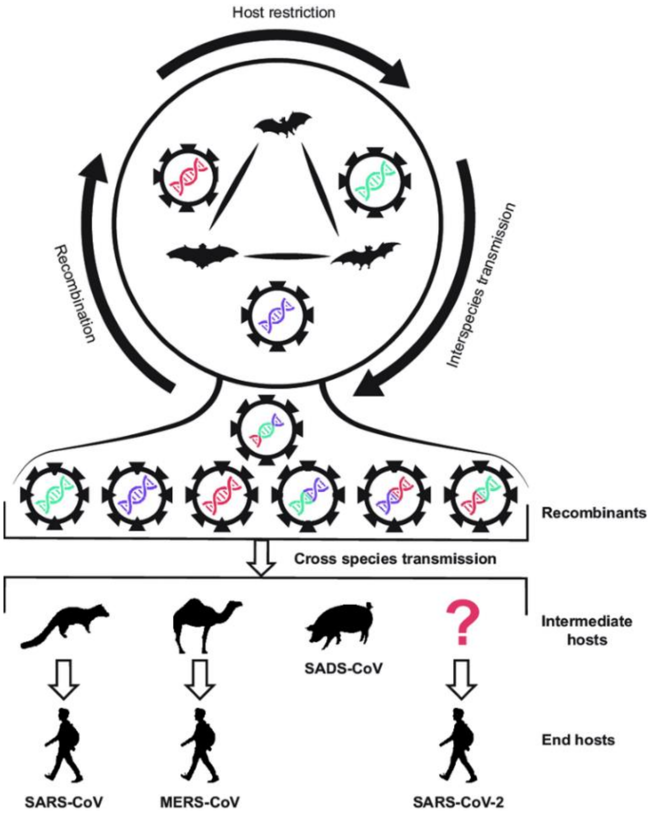



*Figure 4 Pathogenic Cycle of zoonotic viruses and transmission to humans (Wei, et al., 2020)*

**Bacterial Systems** – Extensive research on bacterial systems including Salmonella, MRSA (Staphylococcus aureus), and Streptococcus pneumonia bacteria have been conducted in space. Advances in phage research could also be achieved, as there is an increasing trend to larger antibiotic resistance (Taylor, 2015). Bacteria are always interacting with fluids, and it was observed that common areas of infection in the human body are areas with low fluid shears. Microgravity is very interesting to study bacteria, as it is the ultimate low-shear environment and this is believed to be the reason why an increased antibiotic resistance in bacteria space cultures can be observed (Love, 2016) (Clemens, 2020).

a) **Viral Systems** – Rapid growth of viral systems in microgravity can produce faster mutations and increased virulence, advancing our understanding of its pathogenic evolution and increasing the knowledge and capacity to respond to viral spread, outbreaks, and treatments. In particular RNA viruses such as SARS-CoV-2 or COVID-19, with a possible bat origin, have a high degree of mutation, as they are under strong selective pressure, although lower than influenza, HIV, and other viruses. (Welsh, et al., 2020). Regarding the development of an effective vaccine, a stable genome is required, and by studying its evolution, it can be possible to identify key vaccine approaches. (Taishin Akiyama, 2020) (Rooney, et al., 2019).

b) **Crystallization** – Space can provide a unique crystallization approach which can lead to faster pharmaceuticals compounding for improved medicines delivery systems. The Japan Aerospace Exploration Agency (JAXA) has a “space crystals” lab on ISS for rapid crystallization, a process of purification to improve the quality of macromolecular crystals that is finding applications to put chemical compounds into pills and to enhance drug discovery (McPherson & DeLucas, 2015) (Zheng, et al., 2014).

c) **Space Medicine – Immunology** Research in space can push the boundaries of discovery in immunotherapy and vaccine development. It has shown that the immune system is reduced due to the extreme environment, together with lack of sleep and isolation, which results in unique induced stressors on the immune system (Welsh, et al., 2020). Viruses that are suppressed in a healthy human on Earth such as herpes can get reactivated as a result of the dysfunction of the immune system during and after spaceflight. This condition is very interesting to understand how the immune system works and test boosters for the immune system as well as vaccines. Experiments can be conducted to understand the impact of microgravity on production and secretion of monoclonal antibodies from a cell line, ultimately aiming to improve the rate at which quality immunotherapies can be manufactured here on Earth. (Peta Bradbury, 2020)

d) **Advanced research of infectious diseases: Gain-of-function** - Advanced infectious disease research using gain-of-function techniques may accelerate vaccine research and development for pandemic strains of influenza, coronaviruses (CoV), and others (Institute of Medicine and National Research Council, 2015) by artificial alteration of the gene sequence and analysis. This does present significant ethical and biosafety issues (Selgelid, 2016), and accidents can lead to hazardous release and outbreaks, as has historically occurred in research facilities. Some researchers have recommended the use of higher safety measures and facilities as those in biosafety level 4 laboratories (Swazo, 2013), analogous to the European Sample Curation Facility (ESCF) and Mars Sample-Return Receiving facility (MSRRF) considered for Mars sample return missions (Hutzler, et al., 2017). This can also be performed in space, as for some ISS experiments (Amselem, 2019) and as considered for Mars Sample Return Missions to prevent back contamination. These risks can be larger when considering global efforts to identify major zoonic viruses (as the Global Virome Project), which are at risks of spillovers and causing infectious diseases, for subsequent analysis and study to prevent pandemics.

e) **Planetary protection and pursuit of long-term Human settlement off of planet Earth**. This humanity preservation plan is to ensure the continuity of our species. Those exploration missions will force humanity to develop new technologies and human life support systems that will have direct benefits and applications on Earth. Exploration missions can help to find new life elements that would allow us to find new treatments to resolve future pandemics on Earth. As researchers collect life samples from other planets or plan for future exploration operations, space resource usages will grow. It is necessary to regulate space sample returns to avoid Earth contamination by new unknown pathogens.

# Appendix IV Relevant Use Cases

*Table 5 Relevant use cases*

| Use Case | Usage | Description |
|---|---|---|
| **Broadband Access for Rural Regeneration (BARRD)** (ESA, 2018) | Telecommunication | An easy-to-install, low cost broadband system for rural communities |
| **Biological Light Fieldable Laboratoy and for Emergencies (B-LiFE)** (Business with ESA, 2017) | Disaster Assistance and Emergency Relief | An easy-to-set-up diagnostic facility with a mobile tent and specialized equipment for testing biological samples |
| **Coldsun** (D3TN, 2020) | Telecommunication | A ready-to-use and low-cost buoy relay system for deep-sea communication |
| **Cosmic Srl** (Business with ESA, 2020) | Tele-Maintenance | a low-cost device that can be installed on any vehicle to detect and identify leaks around water pipelines |
| **e-Drift** (ESA, 2019) | Disaster Assistance and Emergency Relief | Platform service to help municipalities to estimate the impact of natural disasters swiftly |
| **Hipersfera** (2020) | Multipurpose | Unmanned airship technology with an industrial-grade payload capability |
| **IoTrees** (2020) | Forestry | Remote forest management and monitoring |
| **MOWGLI** (i-EM, 2020) | Energy | A management system for micro and renewable grids in rural regions |
| **Orbital EOS** (Business with ESA, 2020) | Tele-Maintenance | A platform service that uses AI and SatEO applications to detect oil spills |
| **Project Impactor** (Business with ESA, 2020) | Insurance and Microfinance | Location-based service supporting financial inclusion by providing farmers with meteorological information about their lands |
| **Satellite Monitoring for Logistics Safety (SaMoLoSa)** (Business with ESA, 2016) | Logistics | For tracking, monitoring, and managing the conditions of hazardous goods in unmanned transport assets |
| **Scottish Islands Connected Health** (Catapult, 2018) | Telemedicine | Low-cost service that reduces patients on remote islands the need to travel for specialist consultations |
| **SCS** (Business with ESA, 2019) | Tele-agriculture | An IoT based sensing service that helps farmers to monitor chicken coops as well as livestock remotely, particularly useful in areas with poor or no terrestrial communication |
| **Theia** (Loughborough University, 2020) | Disability Support | A portable, handheld device that helps visually impaired individuals to orientate in outdoor environments and indoor spaces |
| **Ultra Rapid Deployable Antenna (URDA)** (ESA, 2018) | Telecommunication | Swiftly deployable Antenna for emergency conditions and areas in stress |
| **Virtual Stage** (ESA, 2008) | Entertainment | Real-time art production delivered by satellites |
| Continued Overleaf | | |

| Use Case | Required Space Assets | Target Users |
|---|---|---|
| **Broadband Access for Rural Regeneration (BARRD)** | SatCom applications and satellite uplink stations | National and local governments |
| **Biological Light Fieldable Laboratory for Emergencies (B-LiFE)** | An inflatable satellite antenna equipped with SatCom applications | National and local governments |
| **Coldsun** | Satellite networks | Maritime research; offshore operators; fishing companies |
| **Cosmic Srl** | Access to the GNSS and SatNAV applications | Corporate utility clients and local municipalities |
| **e-Drift** | SatEO applications with data from the Sentinel constellation | National and local governments; emergency relief agencies |
| **Hipersfera** | SatCom and SatEO applications | National and local governments; commercial clients; offshore operators |
| **IoTrees** | SatCom applications | National and local governments; commercial clients |
| **MOWGLI** | EO satellites; telecommunication satellites; navigation satellites | Microgrid owners, operators, designers, and developers |
| **Orbital EOS** | Earth Observation applications and optical satellite data | Oil companies, national, and local governments |
| **Project Impactor** | Remote sensing technologies and SatEO applications | NGOs and poverty alleviation programs |
| **Satellite Monitoring for Logistics Safety (SaMoLoSa)** | Access to the GNSS and SatCom applications | National and corporate clients in fleet management |
| **Scottish Islands Connected Health** | High Throughput Satellites | Rural and remote medical clinics; urban patients unable to leave home |
| **SCS** | Access to GNSS, SatCom, SatEO applications | Individual and commercial farmers |
| **Theia** | LiDAR and Control Moment Gyroscope Technologies | Visually impaired people who are unable to host guide dogs |
| **Ultra Rapid Deployable Antenna (URDA)** | High-bandwidth SatCom applications | Emergency relief, military, broadcasting |
| **Virtual Stage** | Satellite-based Network Cinema System | Education & Art Outreach Agencies and NGOs |

# Appendix V Telemedicine Use Case Illustration

Figure 5 shows a graphic of an Internet of Things device with a direct connection to medical staff. The image is provided courtesy of Maria Grulich and Julia Neuhof.

It hosts sensors transmitting various vital signs (skin conductivity, heart rate, pulse and O2 saturation) to a coordination center. From there, a connection can be made to, for example, an after-hours physician.

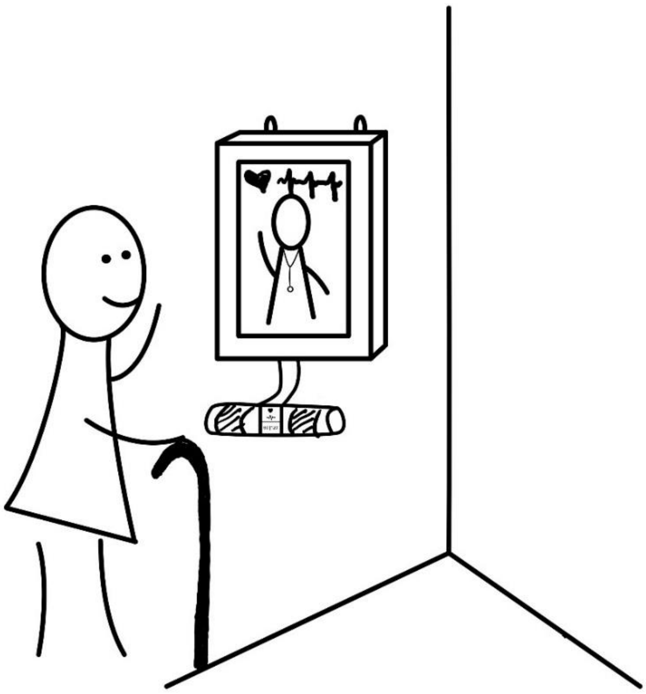
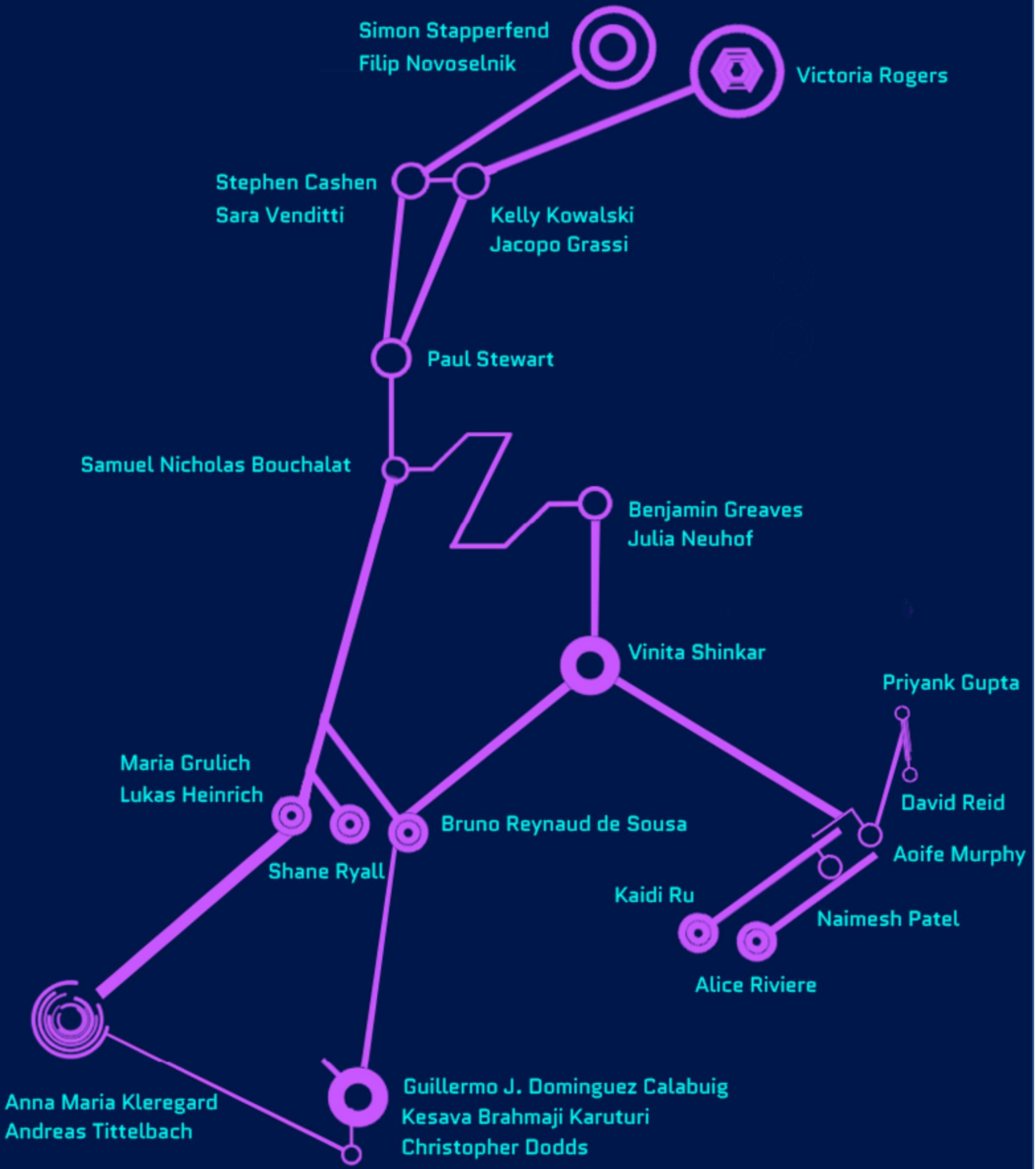


*Figure 5 Using IoT Telemedicine Device at Home*

*Figure 6 SatCom and SatEO allow effective communications with real-time translation services.*

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