The Premonition System for Monitoring Biological Threats: Societal and Policy Dimensions

Preliminary draft

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1. Introduction

The Premonition Biological Weather Station is based on unique sensor devices that can identify a wide range of insects and other arthropods. The current configuration of the Biological Weather Station has been optimized for lure, identification, and capture of mosquitoes, but it can also be configured to capture other flying arthropods. For example, Premonition and our collaborators in the Netherlands and Tanzania are using the weather stations to measure changes in arthropod biodiversity due to land use and climatic changes. As currently used in Harris County, Texas, the Biological Weather Station selectively traps targeted mosquito types and processes collected mosquitoes back at a lab to identify diseases such as malaria, West Nile virus, dengue fever, and Zika virus. The analysis screens all molecular material of a mosquito sample including pathogens within a mosquito, host DNA of a bloodmeal if the mosquito recently fed, the pathogens within the host blood of the mosquito bloodmeal, and the overall microbiome of a mosquito.

The DNA and/or RNA associated with the pathogens is analyzed using a combination of research fields that include public health, computer science, and biology. The first main benefit is to develop a technology for disease monitoring that is similar to what we currently have for real-time weather monitoring. In other words, the system will provide an early warning system for emerging disease threats. The second main benefit of the project is that the integration of the data from the sensor networks with analysis based on multiple research fields also provides opportunities for new scientific research that can contribute to the fields of biology, ecology, and public health.

As with any new technology, there is a need to evaluate its societal implications and to develop guidance for best practices of implementing and using the technology. Because we are still at an early stage and cannot anticipate all implications, the analysis that follows is necessarily preliminary. We draw on an approach to technology assessment known as "responsible research and innovation," which has gained widespread acceptance in policy circles across diverse countries (e.g., Stilgoe and Guston 2017). We follow an approach to responsible innovation that breaks down the issue of societal and policy dimensions into broad areas that have received the most attention in many countries, based on our background research on other emerging technologies and cyberphysical systems (Hess et al. 2021). For this project, these dimensions include economic efficiency, environmental sustainability, equity, governance, privacy, safety, and security. The discussion below is divided into seven subsections that correspond to these seven basic areas.

The goal is not to mandate a strict set of ethical principles or guidelines; rather, it is to provide an empirically grounded approach to societal and policy issues (Hess et al. 2021). It is difficult to anticipate all societal dimensions and implications for best practices and policies, and such analysis will need to be modified as more information becomes available. We also clarify that the term “policy” is not understood in the limited sense of government rules and mandates. Although some policies of this type may become necessary as the Premonition system becomes more widely used, at this initial stage we also include guidelines and best practices for governmental organizations (mostly public health organizations), NGOs, and businesses that may use the technology.

2. Societal and Policy Dimensions and Recommendations

2.1 Economic efficiency

From the economic perspective, a central question is, “Is it worth it?” The Premonition system offers important societal benefits, and some of these benefits can be calculated as economic benefits. Costs and benefits are both direct and indirect.

For direct benefits, early detection of mosquito-based threats can allow for more precise targeting of chemical sprays to areas at greatest risk, which in turn reduces no-targeted use of insecticidal sprays and the labor and equipment necessary to execute wide-scale spray operations. Also, public goodwill is increased with provision of better, more accurate estimates of risk as well as reduced release of chemical sprays in close proximity to residents.

Conversely, the implementation of the program will also entail direct costs of monitoring, data analysis, communication of results, and data management. There may be changes in staffing or the need for additional staff with expertise that can enable efficient use of the new forms of data. Agencies will need to monitor costs and benefits to ensure that the programs are producing savings and to identify areas where changes may be appropriate to enhance the economic advantages of the program.

We do not yet have data on the direct cost-benefit ratio. At present, the system is only in its initial testing stages, and costs are likely to decline as it becomes more widely available. If costs outweigh benefits, it is likely that the systems will require subsidies similar to those provided by the government for weather monitoring systems.

There is a second area of indirect benefits and costs, and this area involves different government actors and calculations. Indirect economic benefits include the reduction of health-care costs for the treatment of humans, pets, and farm animals, and there are benefits from reduced absences for both workers and employers. The system could also provide early-warning benefits for potential pandemic outbreaks. The calculation of these benefits could be part of the analysis used justify support from local, state, and/or federal governments. It is likely that the analysis of indirect benefits for public health and economic productivity would provide a strong case for subsidies.

2.2 Equity

Mosquito-based disease monitoring and intervention programs often include attention to equitable access to the programs across the different neighborhoods of a city or county. In some cases, lower-income neighborhoods may have greater exposure to mosquito-borne diseases if they are located in areas with poor drainage or other exposure risks. However, wealthier neighborhoods located near water may also have elevated risk. Thus, equity considerations based on the sociodemographic characteristics of neighborhoods are important to ensure that monitoring and intervention programs are fair to all residents. These considerations must also be balanced by the geographical and infrastructural characteristics of neighborhoods that may affect different levels of potential risk.

The advantage of the Premonition system over existing monitoring and intervention programs is that it will provide much more specific and rapid information about potential risks. The information from the program can improve already existing practices that identify neighborhoods most in need of intervention. The term "intervention" is understood here to include targeted spraying, introduction of genetically modified mosquitoes where such programs exist, recommendations for draining accumulated water near residences, and public health recommendations. The information from the system can help to target scarce public resources to neighborhoods most in need, and in this sense, it can improve equitable access by having access based on higher quality data about risk and exposure.

A second type of equity issue involves the communication of the program to the public. There are diverse potential beneficiaries or consumers of the information. A communication strategy will need to include what kind of information should be reported to other government agencies, the media, the health care system, and community and neighborhood organizations. Equity considerations that inform the communication strategy would include ensuring that the information reaches diverse neighborhoods and is presented via media that are accessible to residents. On this point, there is a literature on communication strategies for pest management programs that can provide some guidance. (For a review, see Dyck et al. 2021.)

2.3 Environmental Sustainability

The most obvious environmental benefit of the Premonition system emerges from its capacity to track real-time data in a region. The resulting information is precise, and it will enable more targeted spraying and less overall use of chemical control. Furthermore, in areas of the world where mosquito control involves the release of genetically modified mosquitos ("gene drives") and other approaches such as introducing Wolbachia pathogens into mosquitoes (which do not harm humans), the technology could help to monitor the effectiveness of the programs and any negative side effects that have been a concern of some civil society organizations (Boëte 2018, De Campos et al. 2017, Kuzma et al. 2018). In turn, these direct benefits can trigger indirect benefits such as the improved health of an ecosystem due to lower exposure to insecticides and improved health of wildlife from more effective mosquito control. Because of the complexity of ecosystems, it is difficult to estimate the environmental sustainability benefits until pre- and post-studies are conducted.

Another area of environmental benefit is that the genomic data sets collected from the samples are very large, and they provide opportunities for new scientific research. Researchers will have access to significant new information about the microbiome of regions that can enable improvements in generalizable scientific knowledge about changing ecosystems. This research can contribute to existing fields such as studies of relationships between changing patterns of pathogens and changing conditions of weather, climate, and ecosystem structures (Caminade et al. 2019, Kulkarni et al. 2022).

The increase of knowledge about the environmental benefits of more targeted intervention, coupled with emerging scientific research based on the data sets, will potentially draw the interest of environmental agencies, farmers, recreational groups, and other organizations that are interested in new knowledge about changing ecological conditions. Thus, as the system becomes more widely available, the communication strategy will need to become diversified from a public health focus to include broader questions related to the interests of these other actors.

2.4 Governance and Participation

We envision that the monitoring system will be used primarily by public health agencies at the local and subnational level. Utilizing existing communication strategies, these agencies will then share information with other local government agencies, businesses, and civil society organizations, and the local public health agencies will share alerts with state and federal (or even international organizations). Reporting on the program and its accountability ultimately involve elected public officials. In this sense, the issues of governance are largely continuous with existing practices.

Many existing programs of mosquito control go beyond governance in the sense of accountability and communication to elected political officials. Some of the existing programs also engage community members and groups in both design and implementation decisions (Schairer et al. 2019, Schwartz 2017). In a workshop held at the University of Oxford, researchers noted, "The most immediate conclusion from our discussion was the need to have an expansive notion of 'engagement.' Community participation in vector control is not simply a matter of obtaining individual or collective consent for a particular intervention but of integrating a diverse range of knowledge, experiences, and interests into the intervention itself" (Bartumeus 2019; see also Institute for Science, Innovation and Society, University of Oxford, and the Department of Global Health and Social Medicine, King's College London, 2018). In short, public health agencies will also need to examine existing public participation and consultation programs for changes that may be needed in response to real-time monitoring and increased data about disease risks.

One question that the research team has already identified is how to define warnings, the point at which warnings are communicated to the public, and the recommendations that accompany warnings. Using the early warning system of weather as a model, it may be beneficial to identify levels of biothreat and to indicate which stakeholders should receive communications based on the level of threat detection. By having a standard protocol for defining threats and communication practices based on the level or type of threat, public health agencies could be protected from later allegations that they failed to properly communicate important public health information regarding risk. One goal of the system design is to have publicly available applications similar to real-time, radar-based weather monitoring systems. These systems are usually also accompanied by an interpretive scheme that helps to identify the severity of the weather threat.

As the sensor networks become more widely available and used by actors other than government agencies, another governance issue could emerge. To the extent that private-sector organizations become involved in monitoring, data analysis, and communication, the governance model of government agencies (ultimately responsible to elected officials and to the public through participation programs) may need to be modified. Instead, a more policy-driven model may be needed to provide the positive and negative incentives to for-profit entities to ensure that they are also following best practices for all areas of societal implications and policy.

The team has also noted that the governance and participation dimension should also include sensitivity to the different cultural conditions of the region where Premonition Biological Weather Stations are being used. Some areas or communities within an area may have low trust of government agencies, and they may be concerned with the type of information that can be collected, partly when DNA and blood are mentioned. These concerns overlap with privacy, safety, and other issues and may be addressed through those lenses. However, there is also a broader need to recognize that communication and participation strategies need to be cognizant of cultural differences across communities.

2.5 Privacy

A primary objective goal of the Premonition system is to collect data through metagenomic analysis on arthropod vectors of disease and the new and emerging pathogens that they transmit. Because mosquitos carry the blood of wild animals, pets, farm animals, and humans, it is likely that the DNA of humans and animals owned by humans will be sampled. The discussion here will focus on privacy issues for human DNA.

There are already well-established privacy practices and policies for other technological systems that store and manage sensitive human information. These systems include medical and educational records as well as broader consumer information gathered through purchases. At a global level, countries with developed privacy policies tend to follow either the Fair Information Practice Principles (used in U.S. policy) or the General Data Privacy Protection Act (used in European Union policy), which have similar underlying principles (Dahn 2014; European Commission 2016). Analysis of other technological systems that are gathering significant private information, such as automated metering infrastructure for electricity, can provide guidance on best practices for managing sensitive private information (Lee and Hess 2021). Among the best practices, already in place in some countries, that have been identified for privacy for cyberphysical systems are the following: an independent data storage organization, rules for sharing data (who can receive data, for how long, and for what purposes), and a separate monitoring and enforcement authority so that there are resources and expertise to ensure that privacy guidelines and policies are implemented (ibid.).

As the systems become more widely available, there will be a need for policies to define the limits of how human DNA information is stored, analyzed, or made available. The more straightforward solution may be to remove from the databases any information that could identify individual humans and potentially also animals that they own (which could indirectly identify humans). In other words, datasets could be cleaned to have information only on pathogens, or information on pathogen-host relationships could be made anonymous so that it is not available at the individual level. If a decision is made to include this information in the databases, then a second level of policy would need to address who has access to the information. For example, could law enforcement access the information to identify missing persons? Could it also access the information to identify wanted persons? In countries with high levels of surveillance of domestic populations and low constitutional protections, the capture of human DNA could be used as part of surveillance operations (Miller and Smith 2022). In the U.S., this issue also intersects with equity considerations because of the history of concern with DNA dragnets and racialized profiling (Blindebach et al. 2021).

Privacy concerns may not be restricted to individual humans. Some neighborhoods or households may want to ensure that any information collected from their site is used in a way that the connection with the location is masked. As apps become available that specify neighborhoods at risk, the information could affect housing values or rental markets when a neighborhood is identified as at risk. To the extent that exposure maps change rapidly in ways similar to weather maps, it seems unlikely that housing values would be affected in longer time horizons. However, chronic exposure could have some effect on housing values.

2.6 Safety

Premonition Biological Weather Stations are located in areas where pets and humans, including children, are unlikely to be, and the devices can be protected with a screen fence. (See the photo image below.) The devices can be powered by electricity from batteries or a connection to an electrical system. The current beta version of the project has devices that weigh about 70 pounds. Doors on the devices only open for mosquitoes, and they are made of light plastic that would not injure human fingers. The infrared lights are not harmful to humans at a standard distance. More information is available in a field guide that the team has prepared (Harris County Public Health 2023).

Source: Harris County Public Health 2023.

The procedures and monitoring devices are still in a testing stage, and they may change with new information and as the design of the devices develops. Safety guidelines are likely to be at the organizational level, and governmental policy directives should be configured as recommending or requiring adherence to best practices, which are likely to change. Having explicit safety guidelines can protect public health agencies and manufacturers from liability, or reduce it, should an unforeseen event emerge.

In general, safety is less salient for this type of technological system in comparison with other emerging technologies. For example, safety is a substantial area of societal concern and policy development for connected and automated vehicles, where safety discussions are embedded in a long history of government regulation of vehicular and road safety (Lee and Hess 2020). In contrast, the Premonition devices are not mobile, and they can be fenced in and located in areas away from children.

2.7 Security

As an early warning system for exposure to new arthropod--borne diseases, the Premonition system provides clear biosecurity benefits. The likely source of the diseases is from migration of wildlife, changes in ecosystem flora and composition, human travel, and transportation networks such as overseas shipping. However, it is also possible that threats can emerge from other actors, such as hostile groups, rival countries, or laboratory leaks. In this sense, the Premonition system is not just an early warning system for diseases; it is a general early warning system for biothreats.

At this point, the primary policy implication from a security perspective involves guidance on communication, that is, what information is communicated and to whom. Local public health authorities are likely to be the first to become aware of new disease vectors and pathogens. As noted above, these agencies have established pathways of communication to other public health units in local, state, and federal governments. However, there will be a need to develop a clear communication strategy about which other agencies receive what kinds of information, at what level of warning, and from whom. For example, should local public health organizations communicate information only to state agencies and the Centers for Disease Control, which in turn are responsible for communicating information to federal agencies, or should they engage in direct communication of threat to national security agencies?

A second security challenge is cybersecurity. As the system is developed and used in multiple locations, there will be a need to assess the cybersecurity challenges of the databases and information systems networks and to develop guidelines for best practices for the management of the databases that emerge from the project (Vogel et al. 2017). The challenges mainly involve protection from hostile foreign governments that may find advantages from hacking into the databases and stealing the information. Here, the concern may intersect with the human DNA privacy discussion above.

Researchers on the team have noted that one potential cybersecurity risk is that hackers could attack the AI algorithms onboard the device. For example, it may be possible for a hacked device to not trap the species that are informative about disease spread and instead trap only mostly benign species in order to evade the ongoing bio-attacks by an adversary. Another example to target the device’s AI to spread higher level warnings in a particular area in order to divert resources there, while at the same time or sometime later bio-attacking other areas. This kind of diversionary tactic could incur more damage before mitigation can be put in place (like honeypots in other examples of cybersecurity).

A third type of security issue is theft of the devices, pirating of the technology, and intellectual property theft of the artificial intelligence and computational technology that enables the system to work.

3.0 Conclusion

In summary, this review has examined seven societal dimensions and potential policy implications for the Premonition Biological Weather Stations. The weather stations offer many potential benefits to governments, businesses, residents, animals, and ecosystems, and there is potential for existing warning systems for emerging diseases and biological threats to undergo enormous improvement with this approach. There is a wide range of possible uses, including for research and biodiversity analysis, and the focus here has been on detection of diseases through the analysis of collected arthropods. Although it is difficult to anticipate all possible uses, benefits, and costs, this analysis provides a preliminary peek at some of the societal dimensions, policy issues, and guidelines for best practices.

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