Vida Decision Support System: An International, Collaborative Project for COVID-19 Management with Integrated Modeling

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The Vida Decision Support System (Vida) is an application of the Environment-Vulnerability-Decision-Technology (EVDT) integrated modeling framework specifically aimed at COVID-19 impact and response analysis. The development of Vida has been an international collaboration involving multidisciplinary teams of academics, government officials (including public health, economics, environmental, and demographic data collection officials), and others from six states: Angola, Brazil, Chile, Indonesia, Mexico, and the United States. These collaborators have been involved with the identification of decision support needs, the surfacing and creation of relevant data products, and the evaluation of prototypes, with the vision of creating an openly available online platform that integrates earth observation instruments (Landsat, VIIRs, Planet Lab's PlanetScope, NASA's Socioeconomic Data and Applications Center, etc.) with in-situ data sources (COVID-19 case data, local demographic data, policy histories, mobile device-based mobility indices, etc.). Vida both visualizes historical data of relevance to decision-makers and simulates possible future scenarios. The modeling techniques used include system dynamics for public health, EO-based change detection and machine learning for environmental analysis, and discrete-event simulation of policy changes and impacts. In addition to the direct object of this collaboration (the development of Vida), collaborators have also benefited from sharing individual COVID-19-related insights with the network and from considering COVID-19 response in a more integrated fashion. This work outlines the Vida Decision Support System concept and the EVDT framework on which it is based. The international team is using Vida to evaluate the outcomes in several large cities regarding COVID cases, environmental changes, economic changes and policy decisions. It provides an overview of the overlapping and diverging needs and data sources of each of the collaborating teams, as well as how each of those teams have contributed to the development of Vida. The current state of the Vida prototypes and plans for future development will be presented. Additionally, this work will discuss the lessons learned from this development process and their relevance to other integrated applications.

Keywords: COVID-19, pandemic, earth observation, model-based systems engineering, decision support

1. Introduction

The past few decades have seen a significant increase in the number of earth observation system (EOS), both governmental and privately operated, and a similar diversification of the kinds of data that they generate [1–3]. With the increasing availability of earth observation (EO) data has come a commensurate rise in EO applications, particularly those outside of the traditional military, science, and meteorology domains. We have seen near real-time monitoring of wildfires [4], agricultural monitoring [5, 6], and maritime safety [7], to name just a few. This trend was recently acknowledged in the Decadal Survey for Earth Science and Applications from Space [8]. This survey highlighted the increasing importance of linking earth science and application, including in the second element of its suggested strategic framework: “Embrace innovative methodologies for integrated science/applications.” Such “innovative methodologies” include ways of processing EO data but also the design of EOSs.

The onset of the COVID-19 pandemic brought yet another potent demonstration of both the potential utility of EO data and the pressing need to bring it into application. EOSs have observed (temporary) dimming of urban nightlights [9], improved air quality [10], and cleaner water [11], all as a result of the coronavirus pandemic. Such investigations tend to stop at the identification and quantification of such phenomena. They do not extend into integrating these observations into policymaking. In order to accomplish this, EO data must be both *available* and *accessible*. By availability, we mean that the data exists and can be transmitted to interested decision-makers. This requires that EOSs exist, that they have been designed in such a way as to provide useful data for these applications, and that the data is available in a timely fashion for a reasonable cost to decision-makers. Availability is addressed in the NASA Earth Science Division’s Directive on Project Applications Program, which lays out a plan to consider earth science applications in the early phase of mission design [12]. Furthermore, availability is more relevant on longer time scales, as little can be done in response to a sudden pandemic to alter the design of acpeos or even significantly speed up the data pipeline.

Accessibility, on the other hand, refers to whether decision-makers are aware and interested in the data, that is has been processed in such a way as to be relevant to them, and it can be integrated into existing or new decision-making processes. It is to this end that decision support systems (DSSs) can prove useful. This paper is aimed at demonstrating one approach to the creation of such a DSS, specifically one aimed at coronavirus response. The subsequent sections of this paper will layout of the Environment-Vulnerability-Decision-Technology (EVDT) Modeling Framework, which underlies this work, before discussing the stakeholder network, methods used for the underlying components, and some useful insights generated by the tool and its development process. We will then conclude with a discussion of future work on this tool and the relevance to other such endeavors.

2. Framework, study area, and methods

2.1. EVDT Framework

The EVDT Modeling Framework is an application of model-based systems engineering (MBSE) that leverages emerging technologies in several fields. Like all MBSE modeling frameworks, the tool presented here combines information from multiple disciplinary models, but this project is unique because it combines modeling capability drawn from earth science, social science, complex systems modeling of human behavior, and systems engineering models of technology designs. These disciplinary models are arranged in a customizable feedback loop, the default arrangement of which is shown in Figure 1A, though the specific arrangement depends on the application (remote observation system design, policy design, scenario planning, etc.). This particular arrangement of EVDT is structured so as to address four interrelated questions:

1) The Environment Model asks, “What is happening in the natural environment?”
2) The Vulnerability Model asks, “How will humans be impacted by what is happening in the natural environment?”
3) The Decision Model asks, “What decisions are humans making in response to environmental factors and why?”
4) The Technology Model asks, “What technology system can be designed or acquired to provide high quality information that supports human decision making?”

Previous applications of EVDT have focused on sustainable development. Two examples are studying the impact of mangrove conservation on local fishing communities in Rio de Janeiro, Brazil (using a time step of multiple years) [13, 14] and informing management of the invasive water hyacinth in southern Benin (using a time step of one month). Other, in progress applications include mangrove conservation in Indonesia and water and fire management in the Yurok Nation of California, USA (See "Accessible Decision Support Systems Utilizing the Environment-Vulnerability-Decision-Technology modeling framework” by Seamus Lomabrdo, et al. in Session B1.5 of this conference).

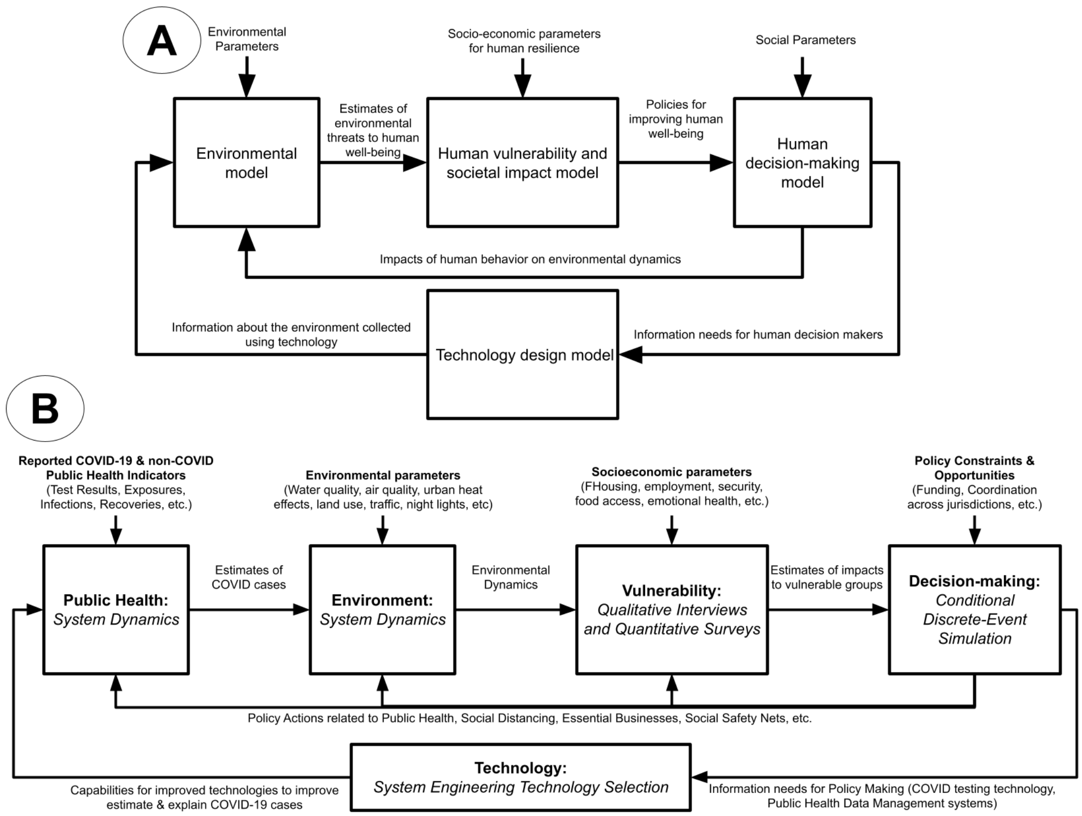

Fig. 1 Top: The default arrangement of the EVDT Modeling Framework, with examples of component models. B: The Vida Decision Support System, an extension and application of EVDT designed to support decision making by governments during COVID-19.

2.2. Vida Decision Support System

The Vida DSS represents an application of the EVDT Modeling Framework to the ongoing COVID-19 pandemic. Its creation had two primary motivations. The first was interest from previous and ongoing collaborators on EVDT sustainable development projects to build similar tools for responding to the pandemic. The second was a recognition that the impacts of and responses to the pandemic can be characterized as a complex system, thus warrenting the kind of multidisciplinary, model-based approach of which EVDT is an example [15]. To this end, multi-disciplinary and international team of experts was assembled [16]. In order to properly center and prioritize the public health aspects of the pandemic, a dedicated Public Health Model was added to the default EVDT arrangement, as shown in Figure 1B. This application of the EVDT Modeling Framework to inform decision making by governments during a global pandemic is called the Vida DSS.

2.3. Study Area: Six Municipal Areas

The Vida International Network currently spans six countries and four continents, focusing work on specific major metropolitan areas. These are:

1) Luanda, Angola
2) Rio de Janeiro, Brazil
3) Región Metropolitana de Santiago, Chile
4) Java & Sulawesi, Indonesia
5) Querétaro de Arteaga, Mexico
6) Boston, USA

The Network is constituted by a mix of academic researchers, government officials, and private consultants, chosen for both their field-specific expertise and their familiarity with one or more of these locations of interest. The government officials themselves span several different offices, including public health departments, data management authorities, science ministries, and space agencies. Participation in the Network is directed at two ends: (1) development of the Vida DSS, and (2) sharing information and resources for responding to the pandemic. The first is accomplished through an iterative process in which the local stakeholder representatives are engaged at every step. Specifically, the local stakeholders help to identify site-specific needs and thereby inform the DSS architecture (shown in Figure 2); surface, provide, and integrate relevant data products, particularly those generated in-situ by government authorities; participate in the design and implementation of the DSS prototypes; and evaluate the prototypes. These activities are conducted through weekly or biweekly meetings between the Boston-based research team and individual site representatives and through online collaboration via the local collaborators own online data repositories (e.g. Rio de Janeiro's Data.Rio [17] or Chile's Datos-COVID19 [18]), the Vida project's own code repository [19], and through interaction with the browser-based version of the Vida DSS prototype [20].

Involving these stakeholders is the definition of the system architecture is key, as it is the framework by which we "analyze, interpret, design, and manage complex systems across their micro- and emergent macro-properties" [21]. Here the term "architecture" is intended in its systems engineering meaning, namely the "abstract description of the entities of a system and the relationship between those entities... The premise [of system architecting] is that our systems are more likely to be successful if we are careful about identifying and making the decisions that establish the architecture of a system" [22]. Success means not only that the DSS is functional and accurate, but that it actively serves the needs of the identified stakeholders. Both the form and the function of the DSS must be in service to this end, not to the idle preferences of the authors. This means that the DSS must be able to handle the datasets of interests to the stakeholders, that it must be intelligible and useful to them (such as being available in their own native language), and that it must be able to be interrogated by them. This last requirement is why, wherever possible, Vida is built using open source tools and, where this is not feasible, that is uses tools already commonly in use by the stakeholders (such as ArcGIS Online).

The second objective of the Network is primarily accomplished through monthly, full Network meetings, at which participants present and discuss useful lessons and tactics for addressing coronavirus response, including topics not directly related to Vida. Examples of such topics are how to implement wastewater viral testing and how to integrate the data generated into decision-making, how to approach health surveillance in elderly care facilities, and how to identify high vulnerability neighborhoods. These discussions promote innovation and enable cross-location learning that may not otherwise occur.

2.4. Public Health Model

The most notable variation that Vida has compared to previous EVDT applications is the addition of a dedicated Public Health Model. While the specific data collection definitions, coverage, and update cycles vary, each of the participant locations have been collecting and publishing coronavirus-related epidemiological data on a regular basis, including newly identified infections, deaths, hospitalizations, etc. Vida ingests this data and uses it both to display historical trends alongside the other components and to conduct simulations of potential future behavior, with an emphasis on future trajectories of infections and hospitalizations. The Public Health component is based on a Susceptible-Infected-Recovered (SIR) system dynamics model. SIR is a compartmental epidemiological model and one of the most commonly used variants, due to its relative simplicity and flexibility. System dynamics is a modeling approach commonly used in both 'pure' epidemiological contexts [23] and in broader public health policy contexts [24]. Figure 3 shows a diagram depicting the layout of the Vida Public Health Model. In addition to the three traditional SIR components, it has two other health compartments: Hospitalizations and Deaths. These reflect some of the primary decision points and metrics of performance that policymakers are using. In most of our application contexts, population counts for each of these compartments is readily available on a daily or weekly basis.

In the top left and bottom left of the diagram, the initial inclusions of Environment and Vulnerability components are shown. These are obviously cursory and highly assumptive. As we have continued active development with out collaborators (which involves weekly or biweekly meetings) and have collected empirical data, we have begun expanding on these elements. Air pollutants, for example, are not merely a function of closure policy. In most locations that we have examined, and in research conducted by others [10], initial coronavirus-related closures resulted in a sudden drop of emissions (further discussion on this in the Results section). Furthermore, there is some evidence that weather and air pollution have a modest impact on COVID-19 transmission [25], leading to the inclusion of such an element in the top left of the diagram.

This model is non-spatial, though in some locations of interest with distinct geographies (such as the Indonesian islands of Java and Sulawesi), multiple independent instances of the model are generated.

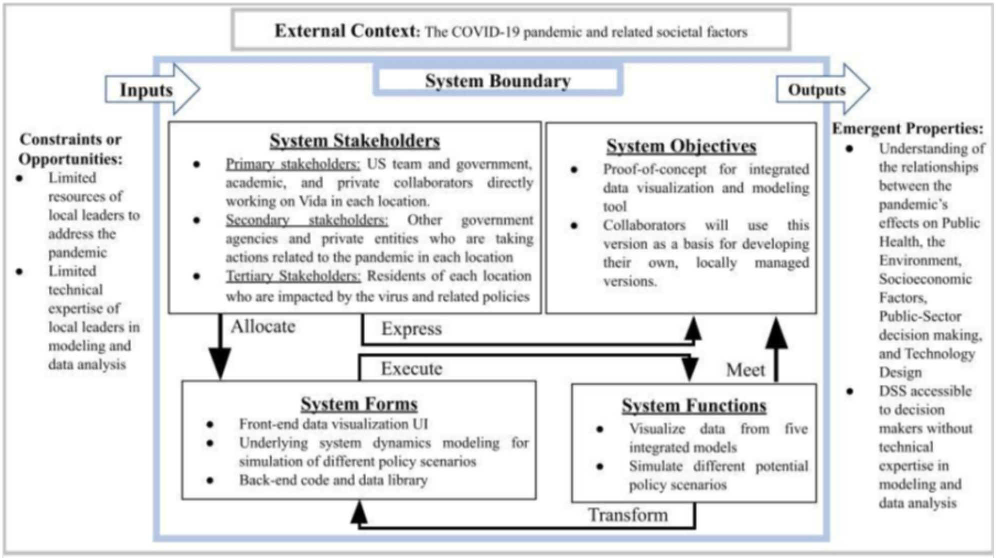

Fig. 2 The high-level functional systems architecture of the Vida DSS.

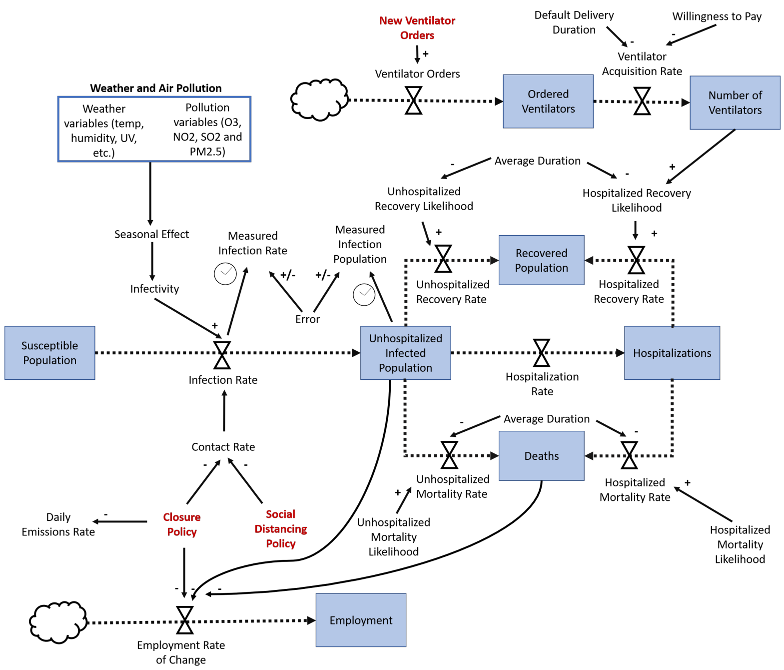

Fig. 3 Current version of the SIR system dynamics model used by the Vida project.

2.5. Environment Model

There are numerous environmental phenomena generated or influenced by the coronavirus pandemic. Urban nighttime lighting patterns changed and (generally) dimmed [9]. Air quality noticeable improved as traffic patterns changed and work-related emissions declined [10]. In many places, water quality noticeable improved and noise diminished [11]. Our team has pursued these using both remote sensing data (Landsat and Sentinel for air and water quality estimations, VIIRS for nighttime lighting, Planet and Sentinel SAR for traffic pattern changes) and in-situ sensors (such as the Rio de Janeiro MonitorAr program's air quality sensors).

For nightlights, the VIIRS VNP46A2 dataset was used [26]. This dataset contains daily panchromatic (visible and NIR) imagery at at a resolution of 15 arc-seconds (approximately 450m for the locations of interest) that has been corrected for atmospheric interference and moonlight variation. It is thus well suited for examining artificial lights, such as those generated by cities. We process it by masking out clouds and water (thereby eliminating transient lights from ships) using supplied quality flag, then taking weekly median values to reduce intraweek variation, before calculating the relative anomaly compared to the 2019 median value for each pixel, thereby standardizing comparisons across time and space. We can then compare specific pre-and-post pandemic time periods to identify changes. Further normalization can be performed by identifying any long term trend from Jan 1st, 2019 to March 1st, 2020 (the approximate start of the pandemic) and subtracting this extrapolated trend from the post-pandemic data.

For air quality, data from Rio de Janeiro MonitorAr air monitoring stations was used. In-situ sensors take hourly measurements to monitor a range of air quality parameters (e.g O3, CO, SO2, PM10, etc.) in 8 different barrios, or neighborhoods, of Rio de Jeneiro. The dataset is provided publicly and freely through Rio de Janeiro's Data.Rio website [17]. For the purposes of this study, we focused on changes in the measured PM10 pre-and-post pandemic. We process the data for each barrio by first calculating weekly averages to reduce intraweek variation, as we would expect there to be a difference in air emissions throughout the week (for instance, weekends versus weekdays). Then the data was fit using a least-squares estimate to a sinusoidal wave with an annual period. This sinusoidal curve is the average seasonal variation in PM10 for that barrio, and it is subsequently subtracted out from the data. A best-fit line is then calculated for this seasonally-corrected data. The best-fit line is long-term (multi-year) trend in PM10 measurements, and it is also subtracted out. At this point, the data is corrected for intraweek, seasonal, and annual trends, and we can then construct normalized histograms and compare the pre-and-post pandemic distributions to identify changes and trends. Similar analyses have been conducted using Chile's Sistema de Información Nacional de Calidad del Aire [18] for the Santiago area.

2.6. Vulnerability Model

Traditional, government-collected socioeconomic impact data largely does not exist at the fine temporal resolution required for coronavirus-related assessment, so we had to develop the Invisible Variables Initiative (not discussed at length in this paper) to work with our collaborators to develop surveys and interview procedures to elicit needed information. This initiative is led by Dr. Katlyn Turner and funded by the Natural Hazards Center at the University of Colorado, Boulder. As the pandemic has developed, however, some more traditional metrics, such as unemployment data, that show responses to the crisis are beginning to be released.

Another aspect of societal impact and vulnerability that Vida monitors is mobility. This includes movement as demonstrated by telecommunications activity, automobile traffic, air traffic, and ship activity. Telecommunications activity is being made in numerous jurisdictions either directly by private companies [27] or via government data repositories [18] and integrated into Vida. Data on air traffic is commonly collected and published by local government authorities. Data on ship activity can be generated through the use of Sentinel radar imagery by masking out land and permanent structures, then looking for transient bright spots on navigable bodies of water, particularly around major ports. This process can be seen in Figure 4. The period of 2018 through the start of the pandemic was used to establish a baseline of ship presence. This was then compared with activity after the onset of the pandemic to identify changes.

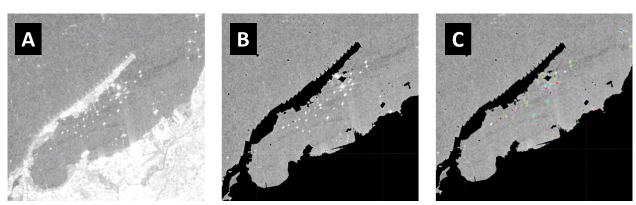

Fig. 4 Ships identification process. A: Sentinel-1 SAR imagery of the Luanda area. B: Masking out land and permanent structures. C: Identifying individual ships.

2.7. Human Behavior and Decision-Making Model

Obviously the primary decision axis is containing the spread of coronavirus and properly treating those who are infected. In practice this tends to express itself as various forms of public area and business closures and restrictions, individual social distancing requirements (such as mask wearing), and medical equipment acquisition and allocation. In Rio de Janeiro, for example, many of these policies have been grouped together into a six phase Resumption

Plan that has clear indicator-based conditions for when to advance to the next phase [28], which facilitates visualization and simulation in Vida. Most of the locations of interest have similar qualitative, ordinal policy categories, with varying numbers of steps or details.

We are also actively refining a consistent process for transforming such policies from qualitative ordinal categories into quantitative scores, building upon such projects as the CoronaNet Research Project [29]. This is done both to enable consistent visualizations where various quantitative metrics (active coronavirus cases, air quality, mobility indices, etc.) can be directly compared to policy actions over time (e.g. in Fig 8). It also enables some level of comparison across locations of interest in order to help draw causal relationships and identify the impacts, both positive and negative, of certain policies. Our approach to this is to break policies into different categories (e.g. social distancing / masking requirements, business closures or capacity limitations, travel restrictions, etc.) and defining specific ranks within such category (e.g. no outdoor events with greater than 15 people vs no outdoor events with greater than 50 people). The local teams for each location of interest are involved in both the definition of these ranks and the categorization of local policies into them. This system is still in progress, as it is important to avoid oversimplifying or categorizing policies.

2.8. Technology Model

Various forms of sensing technology are relevant during a viral epidemic. While our team has remained primarily focused on satellite-based earth observation technology and in-situ environmental sensors, another key form of relevant sensing technology is coronavirus testing (both the technology of the individual tests and the social technology that is the regional testing regime). Rates of testing can be integrated into the public health model through its influence on the difference (or lack thereof) and delay between the estimated number of active infections and the measured infections.

3. Results

The focal point of this collaboration is the creation of the Vida DSS, the current state of which is described below. The development process brought several ancillary benefits however. One of these was the aforementioned sharing of information and collaboration across the locations of interest. Another was a set of correlations and causal links identified between the Vida components through visual comparison and data analysis. Some of these findings were able to be generalized across locations while some were more specific. A selection of such findings are presented below.

3.1. Decision Support Tool and User Interface

At the time of writing, two distinct versions of the Vida DSS exist, both of which are undergoing active development and should not be viewed as final products. The first, shown in Figure 5, is an open-source, desktop-based version written in Python (the code is available online [19]), that can be run on various operating systems (recent versions of Windows, MacOS, and various Linux distros have been tested).

The user interface can be easily switched between languages (English, Spanish, and Portuguese are currently available, with easy functionality for adding additional languages) and between the locations of interest.

This version can present temporal data, spatial data, and spatiotemporal data. The first of these is done through plots (visible on the left of Figure 5, but the placement of the plots can be reconfigured by the user), with the data visible in the plots controllable through dropdown menus. The other two kinds of data are presented in the kinds of maps shown on the right, which is currently displaying visual imagery of the Rio de Janeiro area overlaid with the most recent PM10 measurements from in-situ monitoring stations. Should either the raster imagery or the vector geographic data be available at multiple points in time, additional slides appear at the bottom of the image to allow the user to select specific dates. Non-spatial data are saved in CSVs, vector spatial data in shapefiles, and raster spatial data in GeoTIFF format.

In addition to presenting historical data, the desktop version of the DSS can also conduct public health simulations, using the system dynamics SIR model presented earlier. This simulations can either be run manually, with the user selecting specific policies at each week using the controls in the bottom left, or automatically for specified time periods, according to certain pre-coded decision rules (listed in the bottom right) based on the official policies of the location of interest.

This model is currently being calibrated using historical data, expanded as new dynamics become evident, and examined by public health experts. Various potential improvements are evident, including combining the SIR system dynamics model with an agent-based model to help address some of the deficiencies of the system dynamics approach [30], such as the lack of a spatial component. The goal is not for the authors to continue development of this model indefinitely ourselves, but rather to hand over the model and its associated user interface to local collaborators in each of the application areas, so that they can continue to adjust it to their local circumstances. Other future improvements include more automated ingestion of data from online data repositories, streamlined exporting of visualizations, and making this version accessible online.

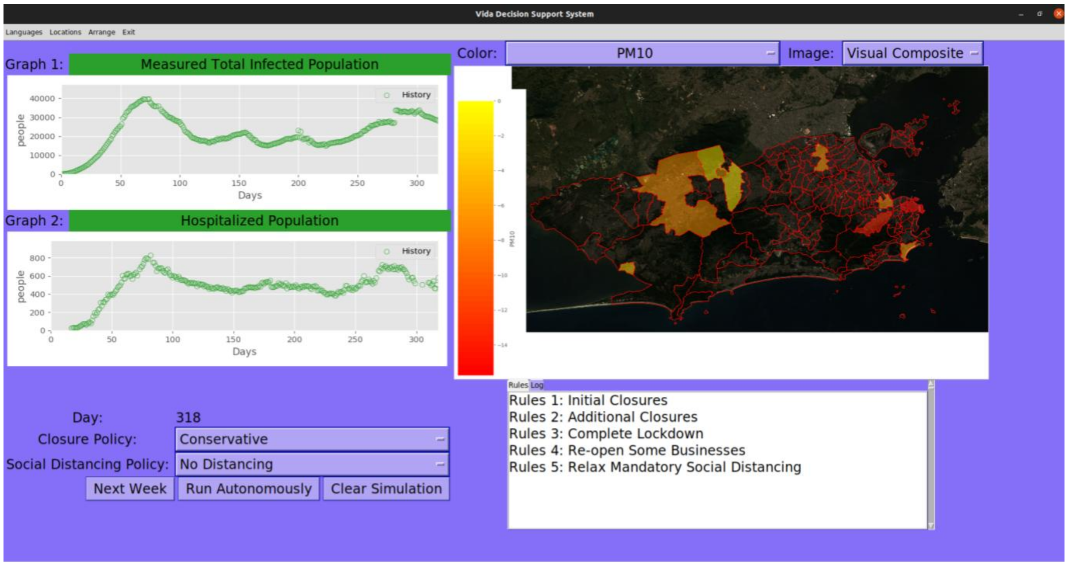

Fig. 5 Prototype of the desktop version of the Vida user interface for Rio de Janeiro.

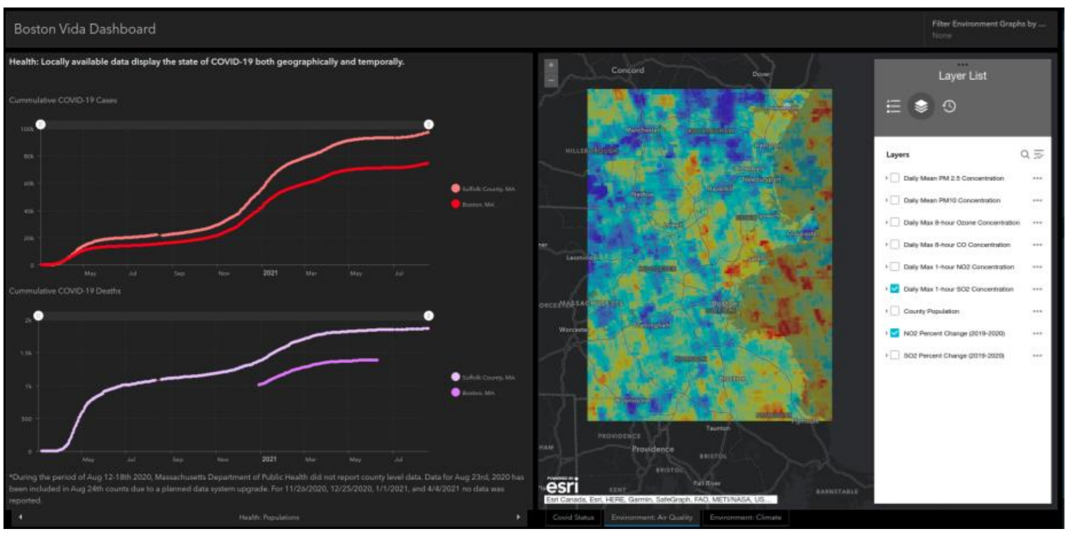

Fig. 6 Prototype of the online version of the Vida user interface for Boston.

The second version of the Vida is online, created in collaboration with Blue Raster and hosted by Esri's ArcGIS Online [20], and has somewhat different functionality. This version, shown in Figure 6 (using the Boston areas as an example), focuses on the presentation of historical data and thus lacks simulation capability. It does however have the capability of showing more graphs at the same time, including allowing the user to merge multiple graphs into one for easy comparison, and an overall more streamlined interface.

The remaining portions of the Results section will focus on several specific insights and analysis that have arisen out of the Vida development and use processes.

3.2. Nightlights

Similarly to other researchers, we detected significant changes in nightlights due to the onset of COVID-19 and later policy changes [9, 31]. In particular, areas associated with air travel and tourism experienced significant decreases in nightlights and associated human activity (areas in purple along the eastern and southern edges of Rio de Janeiro in Figure 7). Downtown and commercial areas experienced a similar, though less dramatic decrease. Primarily residential areas (the yellow, east-west arc across the middle of Figure 7), meanwhile, significantly brightened. These trends are apparent both for relative percentage change across these areas and when the changes are normalized for long term trends. Graphs showing such changes for airports and specific tourist-centric areas in Rio de

Janeiro, Brazil and Bali, Indonesia can be seen in Figure 11 of the Appendix. The results of basic statistical analysis, particularly t-tests to determine if pre-pandemic and post-pandemic brightness are actually different, for various bairros and areas of Rio de Janeiro can be seen in Figure 12.

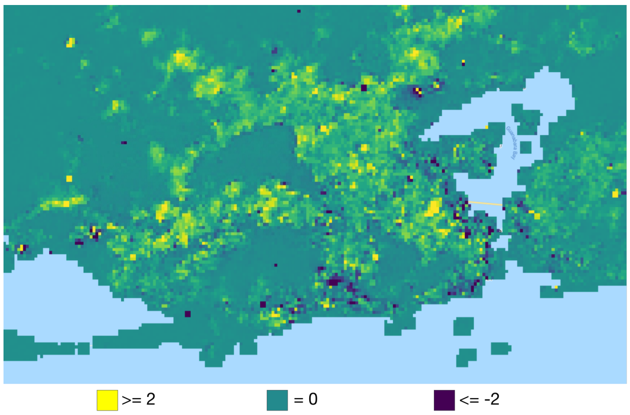

Fig. 7 Theil-Sen trend estimator for normalized changes in nightlights in Rio de Janeiro during the initial phases of the pandemic (March 1st to August 30th, 2020).

3.3. Mobility

Telecommunications-based measurements of Vida have also provided insightful for decision-makers. Figure 8 compares mobility with active coronavirus cases and policy status in Santiago, Chile and Rio de Janeiro, Brazil. Some variations are unsurprising: a upward spike during Chile's constitutional referendum, downward spikes for the winter holidays. Others are more relevant for policy-making. Specifically, once the number of active cases declines, mobility increases even if policies remain restrictive.

We are actively working to conduct more systematic analysis in this domain as well as examining the possibility of linking telecommunications-based mobility with nightlight measurements and thereby make spatial extrapolations.

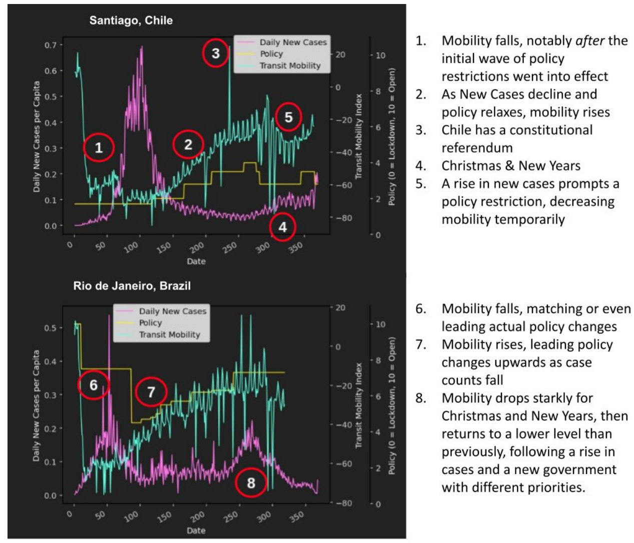

Fig. 8 Comparisons of coronavirus cases, policy changes, and mobility for Santiago and Rio de Janeiro. Day 0 is set at the first confirmed COVID-19 case in that location (04/Mar/20 for Santiago, 07/Mar/20 for Rio de Janeiro).

3.4. Shipping and Transit

Initial results regarding ship tracking in the harbor of Luanda, Angola suggest that there may be a visible change in ship number and location related to the pandemic. Compared to the preceding two years, the monthly average number of ships within the Bay increased slightly after the onset of the pandemic and continued to remain higher throughout the year. In the offshore area outside of the bay, the average monthly number of ships was lower than in the two years preceding the pandemic. As the number of COVID-19 cases in the country climbed, the number of ships within the bay further increased, while the number of ships in the offshore area decreased (as shown in Figure 9). The extended docking within the harbor could reflect a reduction in ships conducting trade or delays in the process of loading and unloading ships due to COVID-19. Further investigation is needed into the accuracy and statistical significance of these results in order to draw conclusions. However, at this early stage of analysis it appears that detecting changes in economic proxies such as ship movement using satellite imagery is possible and we plan to extend our analysis to other regions for comparison.

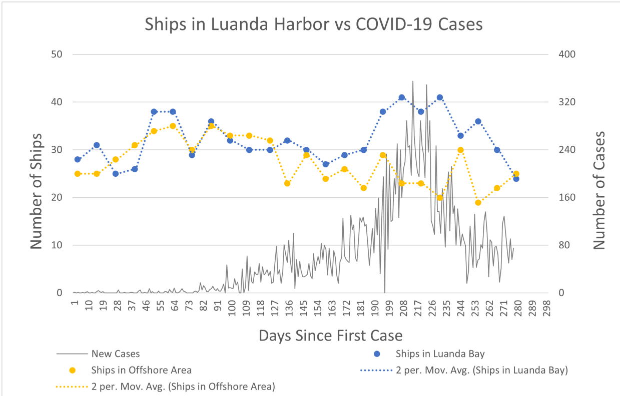

Fig. 9 Ship presence over time for the Luanda area.

3.5. *Air Quality*

We ran two-samples t-tests and Anderson Darling tests on the normalized histograms of the pre-and-post pandemic variation-corrected PM10 data, assuming that the pre-pandemic distribution was approximately normally distributed. These tests determine if the pre-pandemic and post-pandemic PM10 measurements are actually different. In particular, as seen in Figure 10, we found that tourist areas had a significant decrease in measured PM10 post-pandemic, while some rural or residential areas had slight decreases. We found a significant increase in PM10 measurements post-pandemic in the downtown/business district, with some smaller increases in mixed use/residential and recreational areas.

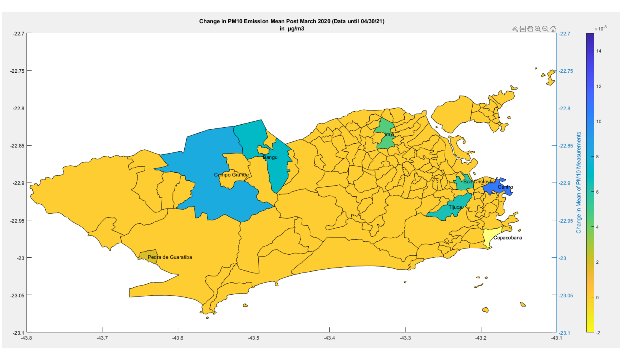

Fig. 10 Changes in PM10 levels in several bairros of Rio de Janeiro during the first two months of the pandemic, normalized for intraweek, seasonal, and annual trends.

4. Discussion and Future Work

Moving forward, work is ongoing to improve the Vida DSS in several regards. This includes:

1) Automating data updates and ingestion
2) Standardizing architecture and implementation to facilitate reuse of model components
3) Add simulation capabilities to the online version
4) Improving visualizations
5) Adding a spatial component to the epidemiological model
6) Continue air quality, nightlight, and mobility analysis with the potential for integrating these into the simulation capability

Furthermore, the Vida development process has had numerous ancillary benefits beyond the actual DSS. As mentioned earlier, the Vida International Network has facilitated international collaboration, allowing participants to share innovations and insights from their COVID-19 efforts. It has also encouraged intra-country collaboration but providing a motivation for outreach between government officials, academic researchers, and community leaders in order to fill data gaps and answer pressing questions. This process has also raised awareness of the utility of space-based EO data, potentially preparing participants for future pandemic and non-pandemic applications.

Acknowledgements

We would like to acknowledge the input and support of the broader Vida team and other collaborators. Teams from several countries voluntarily spent time with the authors to advance a prototype version of the Vida Decision Support System for their region. For each team, multiple volunteers participated from universities and government agencies. Here we list the team leads while appreciating all the contributions. Mr. Felipe Mandarino of the Pereira Passos Municipal Institute of Urbanism (IPP) for Rio de Janeiro, Brazil. Prof Joga Setiawan (Diponegoro University) and Dr. Hanifa Denny (Diponegoro University) lead coordination for the Indonesia Vida work. Prof Joaquin Salas (Centro de Investigación en Ciencia Aplicada y Tecnología Avanzada, Universidad Querétaro) and Mr. Alejandro Monsivais (Mexican Space Agency) led coordination for the Mexico Vida work. Jose Guiridi (Ministerio de Ciencia, Tecnología, Conocimiento e Innovación) led coordination for the Chile Vida effort; and Zolana Joao, Gilson Santos, Eduina Teodoro, and Joana Caetano (Management Office of the National Space Program) led coordination for the Angola Vida work. Finally, we would like to thank the Soffen Memorial Fund for supporting registration and travel to IAC.

Appendix

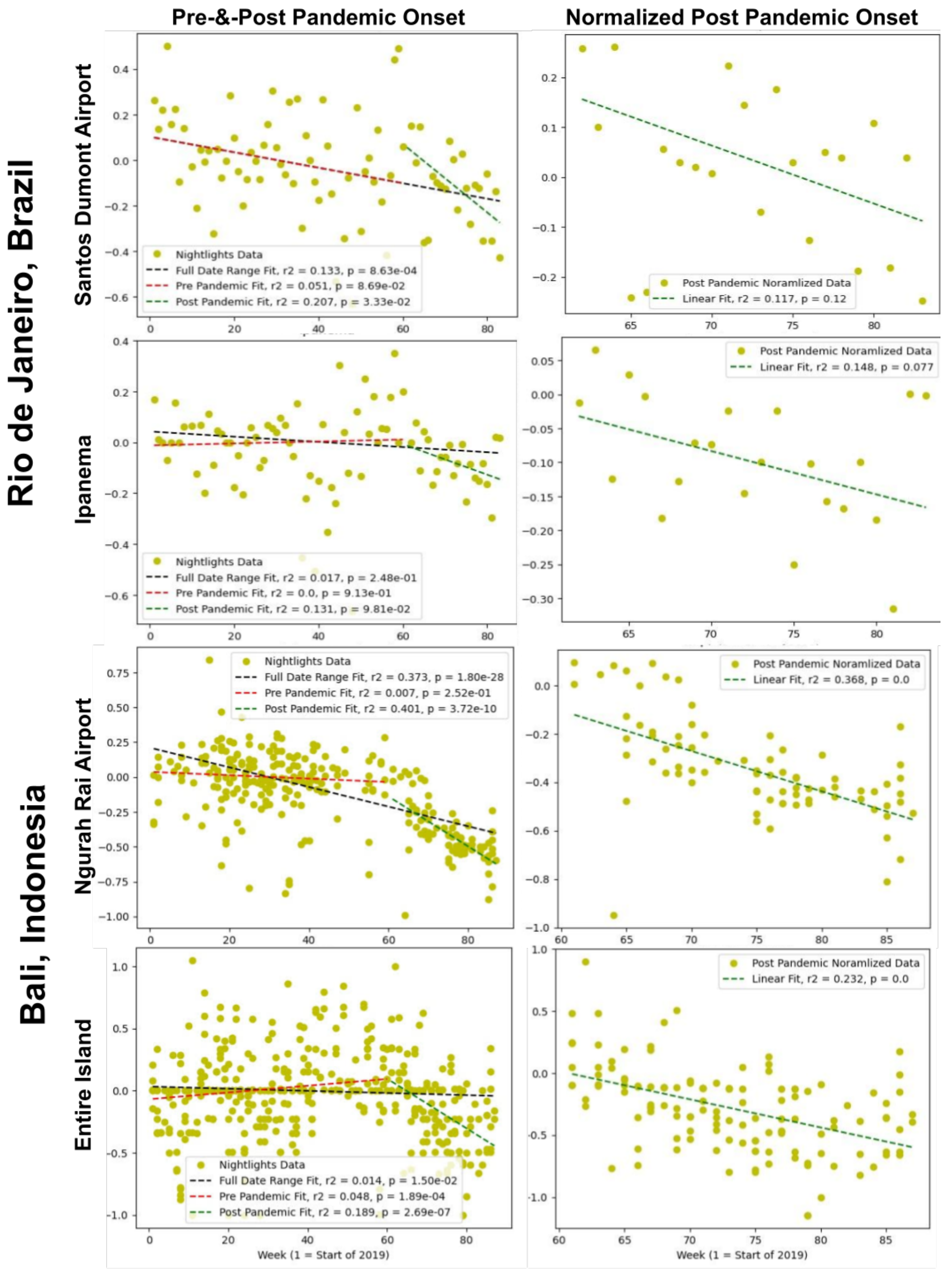

Fig. 11 Pre-and-post pandemic nightlight trends for Rio de Janeiro and Bali, showing both airports and tourist-centric areas.

Area	Type	Pre vs Post T-Test P-Value	Normalized Data Linear Fit P-Value	Pre Pandemic Trend (*1000)	Post Pandemic Trend (*1000)
Barra da Tijuca	Tourist	0.000	0.11	-0.64	-3.73
Campo Grande	Suburb	0.503	0.93	0.25	0.62
Centro	Downtown	0.115	0.97	-0.67	0.40
Cidade de Deus	Mixed Use / Residential	0.433	0.01	-0.50	6.92
Cidade Nova	Downtown	0.604	0.88	-3.76	-3.27
City	Entire City	0.347	0.45	0.58	4.78
Copacabana	Tourist	0.769	0.90	-1.44	-0.71
Galeao Airport	Airport	0.000	0.24	-2.57	-7.22
Industrial Area	Heavy Industry	0.395	0.04	0.41	-7.00
Ipanema	Tourist	0.063	0.08	0.38	-6.00
Pedra de Guaratiba	Rural / Residential	0.052	0.70	-0.76	-2.40
Santos Dumont Airport	Airport	0.005	0.12	-3.38	-15.00

Fig. 12 Statistics for nightlight trends in several bairros (neighborhoods) and areas of Rio de Janeiro. Greens indicate stronger statistical significance, red less. Yellows indicate negative trends, blue positive.

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