Developing a Socio-Economic Resilience Index (SERI) Model and an Integrated Urban Services Resilience Index (IUSRI) Model using a System Dynamics Approach

Katrina A. Abenojar

Jean Meir P. Jardeleza

Charlotte Kendra Gotangco Gonzales

Jairus Carmela C. Josol

Joseph Emanuel C. Litam

Joaquin Ignacio D. Campos

TECHNICAL REPORT #2

Submitted by the Systems Team

to the Coastal Cities at Risk in the Philippines (CCaRPH) project

January 2021

ACKNOWLEDGEMENTS

This transdisciplinary action research was carried out under the Coastal Cities at Risk in the Philippines: Investing in Climate and Resilience Project, with the aid of a grant from the International Development Research Centre (IDRC), Canada, and implemented by the Ateneo de Manila University (ADMU), in collaboration with the Manila Observatory (MO), Ateneo Innovation Center (AIC), and the National Resilience Council (NRC). The views expressed herein do not necessarily represent those of IDRC or its Board of Governors. The funding source encourages the submission of the research for publication but had no role in the study design, data collection, data analysis and interpretation, and writing of the paper.

Aside from the CCaRPH researchers and faculty, we would also like to thank the local governments of Pasig City and Valenzuela City who took time from their very busy schedule to accommodate us. The same could be said for the national government agencies such as Maynilad, Manila Water, PAG-ASA, and DPWH.

Additional support was provided through the Ateneo de Manila University Research Council and the Ateneo Institute of Sustainability.

ABSTRACT

This study developed the Integrated Urban Services Resilience Index (IUSRI) using a system dynamics approach to serve as a holistic, quantifiable, and dynamic resilience assessment tool for cities. The IUSRI is the integration of the Socio-Economic Resilience Index (SERI) and the Urban Ecosystem Resilience Index (UERI). The SERI and UERI scores are considered jointly for the IUSRI score, which reflects the city's overall resilience rating. The development of the SERI and its integration with the UERI was the focus of this study. The SERI supplements the UERI's ecosystem services with socio-economic services, i.e. health, education, and protection services, as well as housing and employment. The services approach quantified resilience by comparing the city's service capacity with the ideal, based on the city's specific needs and targets. For the SERI, this capacity changes over time according to the target capacities and growth rates for the chosen socio-economic service indicators.

Three scenarios were tested for each city: Business-As-Usual (BAU), Priorities, and COVID-19 Scenarios. Under the BAU Scenario, the SERI model projects the resilience scores over time with the assumption that the city continues to develop without changing their targets or growth rates. Under the Priorities Scenario, parameters are changed according to the city's priorities: (a) Pasig City with in-city housing projects and higher targets for health and education and (b) Valenzuela City with outside-city housing projects and a focus on developing agricultural production. Under the COVID-19 Scenario, the impact of the coronavirus pandemic on the city's socio-economic services was tested. For the IUSRI runs, SERI BAU and Priority Scenarios were combined with the UERI BAU and Priority Scenarios to determine the city's overall IUSRI resilience scores. Different scenarios can further be tested with the aid of the Graphical User Interfaces (GUI) developed for customizing the model parameters.

The SERI model showed that both cities begin with sub-optimal resilience scores, but these improved slightly with the Priority Scenarios. The COVID-19 scenario showed the sharp, temporary decline in resilience score especially for health and employment. Education service resilience scores were highest in Valenzuela City, while Health service resilience scores were highest in Pasig City. Only the Pasig City resilience score eventually becomes optimal at the end of each scenario. With the integrated IUSRI runs, Priority Scenarios had better results, but still sub-optimal with the SERI score being higher than the UERI scores in each run for both cities.

The SERI and IUSRI models developed in this study can be used as tools not only to assess resilience outcomes of different policies over time, but also to benchmark resilience performance of cities. For the IUSRI, the multi-dimensional nature of resilience is considered as it covers both ecosystem and socio-economic services, and the cities using this can be better informed and approach their policy assessment and benchmarking in a more holistic way.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF EQUATIONS

1. Introduction

Recent evidence shows that economic and human losses have been increasing in the past 20 years. Economic losses due to extreme weather events rose by 151% between 1978-1997 and 1998-2017 (UNISDR, 2018). Climate change, along with population growth, economic development, and rapid urbanization, among others, make disasters more catastrophic in high-risk areas such as coastlines, flood plains, and earthquake zones (UNISDR, 2018). The damages from the impacts of climate change necessitates frameworks and tools that can help planners and decision makers enhance resilience especially in high-risk areas.

The concept of resilience has been used in various fields such as ecology, engineering, economics, and psychology, and is now being used increasingly in disaster risk management (DRM). The United Nations Office for Disaster Risk Reduction (UNDRR), formerly UNISDR (UNISDR, 2015) define resilience as "the ability of a system, community or society exposed to hazards to resist, absorb, accommodate to and recover from the effects of a hazard in a timely and efficient manner, including through the preservation and restoration of its essential basic structures and functions".

Resilience in DRM is commonly defined as city, community or a system's capacity, and in some cases ability (The National Academies, 2012), to resist, absorb, tolerate, and recover from disasters. Aside from the above definition by UNDRR, resilience in DRM has also been defined as the capacity of a system to adapt and survive shocks by changing and rebuilding itself (Manyena, 2006), to resist and recover from shocks independently and improve by learning (Zhou *et al*., 2010), and to manage changes in the system with a long-term view (DFID, 2011). Because of the multidimensional nature of resilience and the dynamisms of disaster management, one of the biggest challenges for scholars and practitioners alike rests on how to operationalize resilience so as to appropriately inform decisions and actions on the ground.

1.1 Resilience Dimensions

Scholars have moved towards operationalizing resilience definitions with the objective of assessing or enhancing resilience in a specified spatial extent. Operationalizing resilience often involves indicators categorized into social, economic, institutional, physical, and natural domains (Ostadtaghizadeh *et al.*, 2015). Domains in some operationalization tools are more specific, using indicators concerning buildings that other scholars would consider under the physical domain, and community competence indicators which can be placed under the social domain. Resilience of a system in a particular domain is linked to resilience in other scales or domain (Cutter *et al*, 2008 and de Brujin *et al*., 2017). For example, the resilience of a community is linked to the resilience of the physical environment (Cutter *et al*., 2008). The resilience of different system components (i.e. dimensions) also differ depending on the context. Therefore, resilience assessment tools must be context-specific, especially at local scales, to facilitate effective allocation of resources and management of hazards and adaptation strategies (Frazier *et al*., 2013).

Resilience assessment tools and resilience characteristics have also been categorized according to capacities. Meerow and Stults (2016) carried out a review of definitions of a climate resilient city, which they found to be broad in the sense that the definitions describe the general capacity of cities in dealing with the impacts and disturbances of climate change. Some critical features of resilient system are absorptive capacity, adaptive capacity, and transformative capacity (Béné *et al*., 2014). Parsons *et al*. (2016) define coping capacity as the "resources and abilities of a system to prepare for, absorb, and recover from disaster/natural hazard event," and adaptive capacity as the "processes that enable adjustment through learning, adaptation, and transformation". These different capacities can be related to the two dominant perspectives of resilience: engineering and socio-ecological (Rus *et al*., 2018).

1.2 Assessing Resilience

Ostadtaghizadeh *et al*., 2015 note that most of the current indicators are qualitative, hence majority of the tools and approaches available are qualitative. There are very few resilience methods that explicitly suggest how to quantify resilience and how to compare resilience across communities (Bruneau *et al*., 2003 and Cutter *et al*., 2010 as cited by Gotangco *et al*., 2014). Among the attempts to quantify resilience is to index and assign weights to indicators based on their relative importance. Indices, however, tend to be static and fail to assess resilience over time (Gotangco *et al*., 2016). There are many frameworks and tools that are multidimensional but are static or provide only a snapshot of the resilience in time. Assessing resilience over time is essential to understand its indicators and track progress resulting from initiatives to maintain and enhance resilience (Klein *et al*., 2003 and Cutter *et al*, 2008 as cited by Gotangco *et al*., 2016). Simonovic and Peck (2013 a,b), Gotangco *et al*., (2016), and Feofilovs *et al.* (2020) used system dynamics models in developing resilience tools that are able to provide assessments over time.

System dynamics (SD) models are designed to understand patterns of growth, decay, and oscillations in a system and involves the analysis of inter-relationships among system components (Ford, 2010 and Gotangco *et al*., 2016). Simonovic and Peck (2013b) incorporates the various dimensions of resilience in a space-time dynamic resilience measure using system dynamics simulations. Gotangco *et al.* (2016) also used system dynamics to quantify resilience with the same approach as Simonovic and Peck (2013b), focusing on damage profile in calculating resilience by simulating the change in system performance based on adverse impacts of a disturbance and the adaptive capacity to help the system cope and recover from disturbance.

In Simonovic and Peck (2013b), the resilience of a system (e.g. a coastal city) starts at 1, which denotes no degradation in the system performance. If a disturbance such as flood occurs, which causes sufficient damage to infrastructure, the performance quality is immediately reduced. With such approach, they are able to simulate how a system recovers in time until the resilience score is back to 1 or possibly greater than 1. However, the approach of setting the baseline at 1 assumes that the quality of system performance is not degraded to begin with - which is not always the case especially in the context of less developed countries where status quo conditions are already sub-optimal. This approach, like other resilience assessment models using system dynamics (e.g. Feofilovs *et al*, 2020), are not ideal for inter-city comparisons. The approach also lacks the feature of allowing for comparison against a standard or goal that can enhance resilience (e.g. increasing green spaces in an urban system to reduce flooding risks).

Assessing resilience requires an approach that is (1) holistic or multidimensional, (2) measurable or quantifiable, (3) dynamic, and (4) useful for benchmarking with targets, standards, or comparing with other system context. To address the need for a resilience tool that meets the four criteria, we developed an Integrated Urban Services Resilience Index (IUSRI) Model using system dynamics. The IUSRI Model takes the Urban Ecosystem Resilience Index (UERI) Model (Campos, Litam *et al*, 2020), which covers ecosystem services, and supplements it with socio-economic subsystems for a holistic, quantifiable, and dynamic resilience tool. The IUSRI uses the same approach as UERI in assessing urban resilience over time through an index that combines the resilience scores of different subsystems. The index is designed such that the final index would have a value of 1 if the performance or conditions are equal to the set standards or goals, less than 1 for sub-optimal conditions, and greater than 1 for better system performance that exceeds standards or goals. This approach ensures that the IUSRI Model is also useful for benchmarking, goal-setting or inter-city comparison.

2. Review of Related Literature

2.1 Existing tools for assessing and operationalizing resilience, their objectives, and considerations

A good number of tools that assess resilience exist, each with different objectives and different analysis components. Among the tools, Helfgott (2018) provides a strength-based operational framework for resilience, which involves defining 'resilience of what, to what, for whom, over what time frame'. She presented points in operationalizing resilience built upon the works of Ulrich (1987) and Midgley (2000), particularly in defining boundaries of the system of interest, what disturbances must be included, features of the system must be preserved, at what analysis time frame, and whose views are considered in the decision process. She applied the framework to characterize and manage resilience of a farming community in Nepal against climate change. The application involved asset mapping, back-casting of plans, and farming exchanges to explore different perspectives and scenarios in building community resilience.

Frameworks or methods in assessing resilience also tend to focus on a specific aspect of a system. Mostafavi (2017), for example, proposes to assess specifically the resilience of transportation infrastructure to natural disasters using a Systems-of-Systems approach. The approach involved analyzing resilience at different levels (infrastructure sectors, assets, performance condition, and natural hazards), considering different players and factors in decision-making (resources, stakeholders, operations, and policies), and different components of system (asset, network, sub-national, and national levels).

Literature on operationalizing and assessing resilience vary in complexity (Ostadtaghizadeh *et al*., 2016), not just in terms of scope or level of analysis but also in terms of indicators used and level of interactions among different systems (social and ecological) and dimensions (space and time). The indicators also vary depending on the goal. Kotzee and Reyers (2016) used 24 indicators to measure and map flood resilience across different landscapes; while Hegger *et al*. (2016) used three indicators to assess flood resilience in terms of capacities.

Numerous review papers provide a list of tools and frameworks to assess and operationalize resilience. Bhamra *et al*. (2011) reviewed 74 resilience literature for the application of concepts and methods to small and medium enterprises (SMEs). While the application of the review is aimed at SMEs, the authors carried out the review at a wider context, categorizing resilience literature into three elements: perspectives, topics/concepts, and methodologies. Perspectives considered were ecological, individual, community, organizational, and supply demand. Topics/concepts are classified into behavior and dynamics, capabilities, strategy and performance. Methodologies included case studies and models/frameworks. Focusing on literature classified by Bhamra *et al*. (2011) as 'methodologies', 51 are on theory building, 21 are case studies, 6 are surveys, and 16 are models/frameworks. Rus *et al*. (2018) also carried out a review of literature targeted towards a specific application: seismic events. Although there's a particular application, the review was also comprehensive and categorized resilience assessment tools according to spatial extent (building, infrastructure, city, and open space), temporal phase (before, during after the event; short-, medium-, and long-term; etc.), resilience in engineering, ecological resilience, socio-ecological resilience, and assessment approaches used (qualitative or quantitative).

Focusing on community disaster resilience, Ostadtaghizadeh *et al*. (2015) reviewed 17 studies and analyzed these in terms of the domains, indicators, and indices. Their review found that interdependencies exist among the domains, indicators, and hazards considered by the tools, and hence suggest that indicators be grouped into five categories of domains to make resilience operationalization more systematic: social, economic, institutional, physical, and natural. The sub-categories under these indicators suggested by Ostadtaghizadeh *et al*. (2015) are presented in Table 1.

Table 1. Categories of community disaster resilience indicators and their synonyms or sub-categories (Ostadtaghizadeh et al., 2015).

Domain	Synonyms or sub-categories
Social	Human Capital, Lifestyle and Community Competence, Society and Economy, Community Capital, Social and Cultural Capital, Population and Demographics, Environmental Risk Knowledge
Economic	Economic Development, Society and Economy
Institutional	Governance, Organized Governmental Services, Coastal Resource Management, Warning and Evacuation, Emergency Response, Disaster Recovery
Physical	Physical Infrastructure, Infrastructural, Land Use and Structural Design
Natural	Ecosystem

Balsells *et al*. (2015) reviewed literature on operationalizing urban resilience particularly to floods, mapping these out according to their focus (resilience of a particular system to floods or urban resilience as a whole), urban dimensions (physical, social, and economic), and urban spatial levels (territory, city, neighborhood, and building).

Sharifi (2016) also carried out a review for community resilience, focusing on actual tools that have been designed for Community Resilience Assessment (CRA). The tools were analyzed in terms of whether these were able to incorporate multiple dimensions of community resilience, assess cross-scale relationships, whether these are able, capture system changes in time, address uncertainties and employ participatory approaches. The characteristics of these tools are divided into scale (community, city, infrastructure, etc.), format (index, toolkit, scorecard), whether the tool is quantitative or qualitative, and whether the assessment is formative (ex-ante) or summative (ex-post).

Resilience assessment tools and resilience characteristics have also been categorized according to capacities. Meerow and Stults (2016) carried out a review of definitions of a climate resilient city, which they found to be broad in the sense that the definitions describe the general capacity of cities in dealing with the impacts and disturbances of climate change. Some critical features of resilient system are absorptive capacity, adaptive capacity, and transformative capacity (Béné *et al*., 2014). Parsons *et al*. (2016) define coping capacity as the "resources and abilities of a system to prepare for, absorb, and recover from disaster/natural hazard event," and adaptive capacity as the "processes that enable adjustment through learning, adaptation, and transformation". These different capacities can be related to the two dominant perspectives of resilience: engineering and socio-ecological (Rus *et al*., 2018).

2.2 Mapping out resilience tools according to capacities and dimensions

We attempted to map out resilience tools according to four capacities (prepare, absorb, recover, and transform) and community level resilience dimensions (socio-economic, institutional, infrastructure, and natural/environmental). While it is not the intention of this paper to provide a comprehensive review of resilience tools nor to cover all resilience tools, we deem it important to mapped out the tools to serve as a guide and a reference for future application.

Building on the categorization of resilience framings and tools in literature, below is a suite of resilience tools that are mapped according to dimension and temporal resilience scales linked with capacities. The mapping scheme is similar to that of Balsells *et al*. (2015). Dimensions included are socio-economic, institutional, and infrastructure, and natural/environmental, along with a cross-cutting dimension category. With regards to temporal scale, we map tools that involve assessing a system's ability to prepare for, absorb, and recover from a disaster under short-term resilience, while tools under long-term resilience are those that assess the ability of a system to transform (Table 2). The categorizations of capacities in this paper is primarily based on Sharifi and Yamagata (2016) and the resilience definition used by Parsons *et al*. (2016). Fox-Lent *et al*. (2015) refer to these capacities as stages of disaster management.

Table 2. Description of temporal-capacity domains.

Domain	Description
Prepare	Tools that contribute to a system's ability to "predict and prepare for disruptions" and minimize potential adverse impacts (Sharifi and Yamagata, 2018). Tools that assess "preparedness activities aimed not at resisting change but preparing to live with it; this could be by building in redundancy within systems when partial failure does not lead to the system collapsing or by incorporating failure scenarios in" (Bahadur *et al*., 2010 as cited by Béné *et al*., 2014)
Absorb	Tools that assess whether a system can "minimize the overall impacts of a disruption" by accommodating "initial shocks from the disruptive event [...] without a significant deterioration in a system's performance" and avoid "cascading impacts" of disruptions (Sharifi and Yamagata, 2016) Tools that assess how a system is able to absorb shocks "while maintaining its functions and structures" (Meerow and Stults, 2016).

Recover	Tools that assess how a system is able to bounce back or return to its original state. Tools that assess how a system responds to disruptions and reinstate al operations and services to "pre-event capacities and efficiency" (Sharifi and Yamagata, 2016).
Transform	Tools that assess activities that enhance a system, possibly by incorporating learning or forecasting (de Brujin *et al*., 2017) and the "capacity of the system to create fundamentally new system" following a disaster (Walker *et al*., 2004 as cited by de Brujin *et al*., 2017)

A total of 15 studies are mapped in a matrix of dimension and capacities. Eight tools were mapped as having indicators categorized across more than two dimensions, while six tools were mapped to assess capacities cutting across prepare, absorb, recover, and transform (Figure 1).

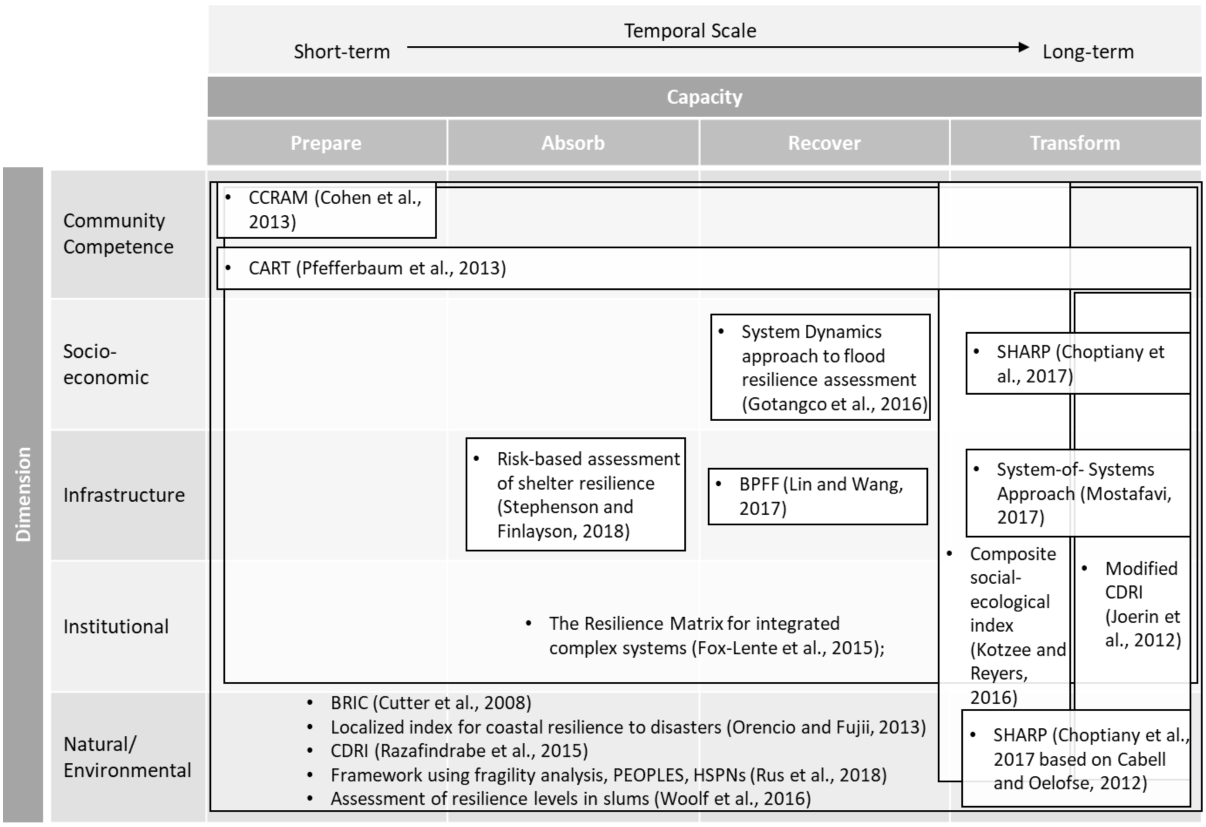


Figure 1. Map of assessment tools for disaster resilience in a matrix of dimensions and capacities.

Tools from two studies were identified under the socio-economic dimension: Gotangco *et al*. (2016) and Choptiany *et al*. (2017). We identify the model of Gotangco *et al*. (2016) under a system's capacity to recover because it looks at how well the system recovers financially after flooding. The tool by Choptiany *et al*. (2017) is considered under the transform dimension due to the participatory nature of the tool, incorporating learning to influence possible system change as response to climate shocks.

Three studies were identified with tools that assess infrastructure resilience. Stephenson and Finlayson (2018) is under the absorb phase because it assesses the vulnerability of resettlement buildings on how well these can protect individuals from hazards. Lin and Wang (2017) employs probabilistic damage evaluation, hence, we categorize this tools that assess a system's ability to recover (e.g. metrics concerning the extent to which buildings can provide immediate shelter following a disaster). The information that can be obtained from the proposed approach of Mostafavi (2017) was used to design strategies to enhance resilience in transportation sector, hence it is mapped under the transformation category.

Two studies were identified to assess resilience in terms of community competence. The tool by Cohen *et al*. (2013) can serve as a good predictor for community resilience during an emergency and has the potential to aid decision-makers in foreseeing and planning for emergency situations, hence it is mapped under the prepare phase. The CART toolkit in Pfefferbaum *et al*. (2013) is flexible and can be adaptable for assessment of all capacity phases.

Tools from eight studies were identified to have cross-cutting dimension. One tool is by Cutter *et al*. (2010) which we identify under tools for assessment of a systems ability plan for, absorb, and recover from disaster because indicators relating to these phases are included in the tool (e.g. quantifying percent population covered by a hazard mitigation plan under the plan phase, quantifying percent housing units not built before 1970 and 1994 under the absorb phase). Baseline indicators may also illustrate a system's capacity to respond and recover from a disaster event (Frasier *et al*., 2013). Their tool also has an indicator explicitly relating to recovery. The tool by Razafindrabe *et al*. (2015) is mapped under the prepare phase as it provides an assessment the resilience to help plan for onslaught of future climate hazards, although it may also be applied for case studies that assess resilience across other temporal-capacity phases. The overall approach proposed by Rus *et al*. (2018) encompasses all temporal-capacity phases of resilience, although the preparedness phase was commonly observed for the main methodologies they used. The tool presented by Kotzee and Reyers (2016) is mapped under transform phase because their approach was guided by principles of resilience (Biggs *et al*., 2012) that included maintaining diversity and redundancy, managing, connectivity, managing slow variables and feedbacks, fostering of complex adaptive systems thinking, encouraging learning and broadening participation. The tool proposed by Woolf *et al*. (2016) is deemed applicable across the different capacities as these are all evident in the indicators (e.g. assessing preparation by identifying high-risk areas, assessing ability to absorb shocks by defining how robust housing communities evaluating diversity of skills and jobs, assessing ability of system to recover from stress, and assess ability to for long-term adaptation). The tool by Joerin *et al*. (2012) is concerned primarily with assessing the community's adaptive capacity following a disaster, hence we place this tool under transform (not under recover because the tool is not concerned with patterns of recovery).

The tools that have been mapped out are further discussed below in terms of being able to provide multidimension, quantitative, and dynamic assessment, as well as usefulness in benchmarking and comparison to standards or other resilience measures.

2.2.1 Tools that provide holistic assessment of resilience

Indicators and variables in operationalizing resilience of human systems tend to be grouped according to different geospatial and social dimensions (Table 3). These dimensions somehow reflect the disciplines that have used resilience as a concept - disciplines such as ecology (Holling, 1973; van der Leeuw and Aschan-Leygonie, 2005 as cited by Helfgott, 2018), engineering (Holling, 1996), mechanics (Rankine, 1867 and Hoffmann, 1948 as cited by Alexander, 2013), materials science (Siambabala *et al*., 2011), psychology (Bloch *et al*., 1956 as cited by Alexander, 2013), and economics (Audretsh & Lehmann, 2016, and Di Caro, 2017 as cited by Morkunas *et al*., 2018).

Table 3. Categories of resilience indicators from literature.

Cutter *et al*. (2008)	Balsells *et al*. (2015)	Balsells *et al*. (2015)	Ostadtaghizadeh *et al*. (2015)	Rus *et al*. (2018)
Ecological Social Economic Institutional Infrastructure Community Competence	Territory City Neighborhood Building	Physical Social Economic	Social Economic Institutional Physical Natural	Building Infrastructure City Open space

Common among these indicator dimensions are socio-economic (e.g. demographics and monetary assets), institutional (e.g. policies and organizational indicators), human community competence (e.g. awareness and learning), physical infrastructure (e.g. buildings and utilities or lifelines), and natural/environmental (e.g. resilience of wetlands, biodiversity) categories. It is reasonable to group indicators according to these dimensions since resilience is context specific.

Resilience of a system in a particular domain or geospatial scale is linked to resilience in other scales (Cutter *et al*, 2008 and de Brujin *et al*., 2017). For example, resilience of a community is linked to the resilience of the physical environment (Cutter *et al*., 2008). Therefore, resilience tools should be able to offer assessment that is holistic and multidimensional.

There are resilience tools that target a specific dimension, such as the Communities Advancing Resilience Toolkit (CART) by Pfefferbaum *et al*. (2013), while most frameworks and tools cover various dimensions such as System-of-Systems Approach for Integrated Resilience Assessment in Highway Transportation

Infrastructure Investment by Mostafavi (2017) and qualitative generic framework tool of Woolf *et al*. (2016) .

The CART (Pfefferbaum *et al*., 2013) is a participatory toolkit consisting of assessment and analytical instruments to enhance a community's resilience, specifically in terms of community competence. The toolkit is premised on the interrelation of four domains: connection and caring, resources, transformative potential, and disaster management. CART tools include: assessment survey (field test questionnaire to assess resilience), key informant interviews, data collection framework (to identify data sources and availability), community conversations, neighborhood infrastructure maps (map of physical infrastructure), community ecological maps (to describe communication and interaction among social groups and organizations), stakeholder analysis, SWOT analysis, and capacity and vulnerability assessment.

Mostafavi's (2017) proposed System-of-Systems approach assesses resilience of transportation infrastructure in United States of America. The objective of the proposed approach is to investigates the status quo, drivers and barriers for enhancing resilience of transportation infrastructure. The approach has three dimensions: (1) classifications in terms of sectors (e.g. transportation and power), assets, phases (e.g. preparedness, recovery), and natural disasters; (2) components comprising of resources, stakeholders, operations and policies; (3) and levels of analysis at the asset, network, sub-national, and national levels. The tool was applied in two case studies related to Hurricane Sandy in 2012 and the Colorado Floods in 2013. In-depth interviews to answer the assessment objectives were carried out among stakeholders who were involved in the planning, mitigation, response, and recovery phases in the case study (e.g. transportation managers, urban planners, city managers). The information was then used to design strategies to enhance resilience in transportation sector.

The proposed tool of Woolf *et al*. (2016) assesses resilience-building projects in slums, particularly infrastructural projects based on four main categories: external resources, assets, capacities, and qualities. Each category has sub-headings or qualifiers, and each qualifier has indicators. Qualifiers under external resources are connections and information, services, and natural resources; under assets are physical, economic, environmental, human, and social assets; capacities are resourcefulness, adaptive and flexible, and learn; and system qualities are strong/robust, well located, diverse, redundant, and equitable. Each indicator of the qualities is gauged according to best-case and worst-case scenarios and are assigned a score on the ordinal scale to denoting areas of strength, concern, and weakness for each of the scenario. The scores are averaged per indicator and represented graphically using a radar graph. The tool was applied in Soweto East community in Nairobi, which was a beneficiary of the UN Habitat's Kenya Slum Upgrading Program (KENSUP). The tool was used to assess community resilience before and after the KENSUP completion.

The tools discussed in the succeeding sections are further examples of multidimensional assessment of resilience.

2.2.2 Tools that quantify resilience

Ostadtaghizadeh *et al.*, 2015 note that most of the current indicators are qualitative, hence majority of the tools and approaches available are qualitative. However, it is necessary to quantitatively characterize multidimensional resilience to compare relative effectiveness of different resilience strategies (Zobel and Baghersad, 2020). Moreover, the use of indices and/or metrics can aid in monitoring changes and prioritizing strategies to enhance resilience through space and time (Parsons *et al.*, 2016).

Tools that quantify resilience use indicators, indices and matrices. One example is the tool proposed by Stephenson and Finlayson (2018) to assess resilience of reconstruction shelter buildings provided in the wake of disaster which have become permanent homes in three settlements in Leyte (Badiangay, Plaridel, and Calabnian). The method involves measuring physical vulnerability using a normalized scale and assessing flood and wind hazard levels using a risk matrix. The vulnerability assessment involved visually observing the buildings and used simple mechanical indicators for increased likelihood of damage to the structure by flood water or wind pressure translated into a numeric vulnerability factor on a normalized scale from 0 to 1. The hazard assessment involved physically going to the sites and assessing damages caused by a typhoon (in this case Haiyan). Satellite imageries were also used to analyze geomorphological context. Indicators for flooding resilience were the presence of second story, raising of ground floor, and presence of concrete slab. Indicators for wind resilience were roof shape, overhang and roof vents.

There are other tools that also quantify resilience of urban systems, focusing on infrastructure such as buildings and transportation. Lin and Wang (2017) developed a tool to assess community-level vulnerability of buildings to geological hazards using functionality metrics, which are immediate occupancy ratio ("percentage of a building portfolio that can provide a safe occupancy immediately following a disaster"), household dislocation ratio ("percentage of households in a community that are displaced due to loss of household habitability and short-term shelter needs"), and direct loss ratio ("ratio of total direct loss to total assessed value of a building portfolio"). The performance of individual buildings is aggregated to calculate the community-level portfolio functionality. The building portfolio fragility function they used can show the probability for example that a certain area can provide immediate occupancy following an earthquake.

Rus *et al*. (2018) proposed a framework to measure resilience of different components of an urban system: resilience of individual physical element (infrastructure) using probabilistic fragility analysis, community disaster resilience using composite index methodology, and resilience of the urban system as a whole using complex network approach (graph theory). The authors built upon existing literature on resilience measurement methods and conceptualized these for application to seismic events. They propose to assess resilience of a building stock using fragility functions and GIS tool to obtain data and map out the results, citing programs such as Hazus (Kircher *et al*., 2006) that use probabilistic fragility analysis. Rus *et al*. (2018) focused on the transportation sector in the assessment of infrastructure, identifying road networks as the basis for other technical infrastructure. At the community level, they cite the PEOPLES Resilience Framework (Cimellaro, 2016 and LESAM, 2016), in which each dimension (population and demographics, environmental/ ecosystem services), physical infrastructure, lifestyle and community competence, economic development, and social-cultural capital) has a performance metric which is combined with the metric of other dimensions through multilayered approach. In assessing the urban system as a whole, they cite the Hybrid Social-Physical Networks (HSPNs) (Cavallaro *et al*., 2014) which combined engineering and ecosystem approaches.

Resilience tools that use a combination of qualitative and quantitative approaches are also available, as well as tools that can provide metrics based on data gathered through surveys. Below are some examples of these tools and frameworks.

Fox-Lent *et al*. (2015) build on The Resilience Matrix (RM) described by Linkov *et al*. (2013) in assessing the performance of an integrated complex system. The RM, which has been applied in assessing resilience performance of individual system components (e.g. ecological, energy, and engineering), consists of a 16-cell matrix of four rows and four columns. The rows describe the "general management domains of a complex system (physical, information, cognitive, social)", while the columns describe the "four stages of disaster management (plan/prepare, absorb/withstand, recover, adapt)". Accomplishing the assessment using RM entails defining system boundary and disaster scenarios, identifying critical system functions that have to be maintained, selecting indicators for each function, generating score for each cell, and aggregating the matrices to arrive at the overall performance rating. The framework was applied in a case study in assessing the coastal community resilience at Rockaway Peninsula, Queens, New York. In this case study, both quantitative and qualitative metrics were used in the matrix cells.

Choptiany *et al*. (2017) developed an assessment tool called "Self-evaluation and Holistic Assessment of climate change Resilience of farmers and Pastoralists (SHARP)". SHARP is participatory survey-based assessment tool to increase adaptive capacity of the farming community to address climate change-related shocks (both general and context-specific). The tool focuses on the major areas of agricultural livelihood through "environmental, social, governance, and economic aspects of climate resilience”. It includes 54 questions related to the 13 indicators of agroecosystem resilience developed by Cabelle and Oelofse (2012). A relative resilience score is calculated by aggregating the ratings of respondents on certain questions about indicators (e.g. how many water sources, self-assessed adequacy of water sources, and self-assessed importance of the question). The responses are normalized through a scale rating from 0 to 10 and. The resulting aggregate score is the relative resilience ranking in which a high score denotes that the indicator is more resilient and less important, and a low score means low resilience, adequacy, and high importance. The tool was developed for small-holder farmers and pastoralists in sub-Saharan Africa, although it may be adopted for application in a global context.

Cohen *et al*. (2013) used the Conjoint Community Resiliency Assessment Measure (CCRAM) tool (Aharson-Daniel *et al*.) to estimate a community's disaster resilience based on people's perceptions through six factors: leadership, collective efficacy, preparedness, place attachment, social trust, and social relationship. The tool has two phases: a survey with community respondents covering the six factors and collection of information regarding infrastructure and services essential in routine and emergency situations from local authorities. The survey involves Likert-scale answers to questions on resilience perceptions and also covers demographic details and information on respondents' personal experiences relevant to disaster. The survey gathers information about the respondents' perceptions about their individual and the community's resilience. Among the applications of the tool is by Cohen *et al*. (2013) in a small to medium size town in Israel. The authors carried out statistical analysis to confirm the quality of the tool in assessing perceived community resilience, and conclude that the tool served as a good predictor for community resilience during an emergency and has the potential to aid decision-makers in foreseeing and planning for emergency situations.

Orencio and Fujii (2013) used a localized index to assess disaster resilience of a coastal community in Baler, Aurora, Philippines. The case study was carried out at local level, in which local decision-makers were asked to identify criteria and elements that may indicate the community's resilience. Analytical Hierarchy Process (AHP) was used to determine the relative importance of the criteria and elements. The categories of criteria were based on Twigg (2007), and included Environmental and Natural Resource Management, Human Health and Wellbeing, Sustainable Livelihoods, Social Protection, Financial Instruments, Physical Protection and Structural and Technical Measures, and Planning Regimes. The scores of the criteria were finalized using the Delphi Technique.

Joerin *et al*. (2012) build upon the Climate Disaster Resilience Index (CDRI) (source) to quantitatively assess community resilience based on a combination of coping and adaptive capacities, including how previous experience of disaster contribute to enhancing coping capacity. Dimensions in the tool are physical (electricity, water, sanitation and solid waste), social (health, education and awareness, social capital and preparedness), and economic (income and employment, household assets, finance and saving). Data gathering involved household surveys and interviews with local community leaders though focus group discussion. The assessment involved understanding patterns of damage in community households in relation the services and aspects concerning the dimensions (e.g. under physical dimension, quantifying percentage of houses damaged during a disaster without piped water supply; under social dimension, quantifying percentage of houses damaged in which household members were knowledgeable about climate change impacts).

Some of the tools discussed above are able meet the criteria of providing measurable and multidimensional assessments but are static and fail to assess resilience over time.

2.2.3 Tools that measure resilience over time

There are two dominant perspectives in resilience: socio-ecological and engineering. Engineering perspective presents a more static and result-oriented approach as it looks at how a system resists change and bounces back to the "stable" condition after an adverse event. Socio-ecological perspective is a more dynamic concept, is processes-oriented, and looks at interactions among different physical and social components of a system in preparing for and adapting to new conditions following an adverse event. Other "synonyms" of engineering/static/result-oriented resilience are "bouncing back", "elastic" and "homeostatic", while other terms used for socio-ecological/dynamic/ process-oriented concept of resilience are "bouncing forward", "ductile" and "autopoietic" resilience (Rus *et al*., 2018, Cerè *et al*., 2017, and Chandler and Coaffee, 2017). The socio-ecological perspective of "bouncing forward" takes on a more transformative concept of resilience in which a system is able to maintain key functions following a disturbance "while accepting that it is not always possible or desirable to return to previous conditions" (Meerow and Stults, 2016). The framing of resilience as "bouncing forward" has become the more preferred concept among academics as opposed to "bouncing back", which practitioners such as government officials and policymakers tend to favor (Meerow and Stults, 2016). These two concepts are often used to describe resilience of urban or city systems to climate risks.

Chelleri *et al*. (2015) further relate the engineering and socio-ecological resilience perspectives to temporal scales of short-term and long-term resilience, in which engineering perspective results to short-term resilience while socio-ecosystem perspective results to long-term resilience. Coping capacity in the form of system recovery, although seemingly short-term, may also lead to a system's long-term transition or reorganization in the rebuilding process (Chelleri *et al*., 2015).

Existing literature tend to neglect the temporal context of resilience (Frazier *et al*., 2013). Indicators must be able to capture short-term and long-term resilience of a system. As Cutter *et al*. (2008) noted, a system or community may be resilient to short-term environmental hazards (e.g. severe weather) but not to long-term hazards (e.g. climate change) or may be resilient to slow-onset disasters (e.g. sea level rise) and not rapid onset events (e.g. flash floods). Understanding the interactions of multiscale and temporal dimensions of resilience could also lead to a better grasp of sustainability challenges (Chelleri *et al*., 2015). Dynamic resilience tools exist that are able to assess resilience over time such as Simonovic and Peck, 2013b; Gotangco *et al*., 2016; and Feofilovs *et al*, 2020 through system dynamics models.

Simonovic and Peck (2013b) incorporates the various dimensions of resilience in a space-time dynamic resilience measure using system dynamics simulations. Their tool is designed such that the resilience of a system (e.g. a coastal city) starts at 1, which denotes no degradation in the system performance. If a disturbance such as flood occurs, which causes sufficient damage to infrastructure, the performance quality is immediately reduced. With such approach, they can simulate how a system recovers in time until the resilience score is back to 1 or possibly greater than 1.

Gotangco *et al*. (2016) used the same approach as approach as Simonovic and Peck (2013b), focusing on damage profile by simulating the change in system performance based on adverse impacts of a disturbance and the adaptive capacity to help the system cope and recover from disturbance. There were two calculating models: Household model and Local Government Unit (LGU) model. The household model quantified robustness based on income from regular occupations of household's working members, redundancy based on income derived from extra or alternative sources of income, resourcefulness based on additional help from LGUs or NGOs, and rapidity based on how quickly donations from external sources are can reach affected households. For the LGU model, robustness was quantified using expected inflows of funding, primarily quick response fund (QRF); redundancy through additional resources; resourcefulness as additional help from NGOs, etc.; and rapidity based on how quickly resources can be made available and mobilized. The tool was applied in a case study in Pasig City, Philippines. Similar to Simonovic and Peck (2013b), the system resilience is calculated as follows:

Equation 1. System resilience equation used in Gotangco *et al.* (2016).

$$System\ Resilience\ Measure(t) = 1 - \frac{\mathrm{RHO(t)}}{\mathrm{Baseline\ Performance\ \times Calculation\ Time}}$$

Where represents the change in system performance within a period based on the adverse impacts and adaptive capacity factors that enable a system to cope with and recover from the adverse impacts. If there are no adverse impacts, RHO is equal to zero, denoting that the system is unaffected. In this model, the resilience measure is 1 before the onset of the shock.

Feofilovs *et al*. (2020) present two system dynamics models to assess resilience over time that allow simulations of interactions between different aspects of an urban system. The first urban resilience index model (URI-I) is based on system functionality considering the effect social vulnerability on resilience and presents a resilience measure based on change in indicator values relative to a baseline. The second resilience index model (URI-S) is based on capacity of the system to provide socio-economic and ecosystem services, where the final score is a mean of the ratio of supply and demand of services. The first model more explicitly looks at the short-term shocks, while the second model intends to assess long-term impacts towards enhancing the delivery of service in an urban ecosystem.

2.2.4 Tools that allow benchmarking and comparisons

The resilience of different system components (i.e. dimensions) also differ depending on the context. Therefore, resilience assessment tools must be context-specific, especially at local scales, to facilitate effective allocation of resources and management of hazards and adaptation strategies (Frazier *et al*., 2013). However, it is also important for a tool to be able to allow for sound comparison across different systems or cities and benchmarking with standards or baselines. Cutter *et al*. (2010) points out that governments are beginning to recognize the need to evaluate performance of communities by looking at the comparative resilience, just as companies benchmark their performance against industry standards.

Cutter *et al*. (2010) used as basis the Disaster Resilience of Place (DROP) framework to develop baseline indicators for measuring and monitoring disaster resilience of counties under the US Federal Emergency Management Agency's (FEMA) Region IV (Alabama, Florida, Georgia, Kentucky, Mississippi, North Carolina, South Carolina, and Tennessee). Resilience scores are calculated by adding the scores of resilience subcomponents (social, economic, institutional, infrastructure, and community capital). An example of social resilience variable are education equity which at the ratio of population with college education to population with no high school diploma and health coverage which looks at the percent population with health insurance. The variables were normalized using a Min-Max rescaling scheme so that the indicators are on a similar measurement scale. In this scheme, each variable is "decomposed into an identical range between zero and one (a score of 0 being the worst rank for a specific indicator and a score of 1 being the best)." The subcomponent scores are equally weighted and aggregated towards the overall resilience score. Their application demonstrates the usefulness of the tool measure resilience of an individual county in comparison to other counties in the same region. The tool of Cutter *et al*. (2010) meets the need for multidimensional, measurable, and comparative approach, but explicitly lacks the criteria of being able to measure resilience over time.

Razafindrabe *et al*., 2015 carried out a flood risk assessment through the creation of flood risk profile using Disaster Risk Assessment guidelines of developed by country's National Economic and Development Authority (NEDA) together with United Nations Development Programme (UNDP) and Executive Committee on Humanitarian Affairs (ECHA). Their assessment involves three phases: flood risk assessment, assessment of barangay flood disaster resilience using Climate Disaster Resilience Index (CDRI) by Razafindrabe *et al*. (2009), computing the flood disaster risk index (FDRI). Flood risk assessment assesses the biophysical dimension of resilience by looking at the 'macro vulnerability' of the locality to flooding based on physical susceptibility and risk of fatality and property damage. The components in the assessment were flood hazard characterization, consequence analysis, risk estimation, and risk prioritization. In assessing barangay flood disaster resilience using CDRI, five components of resilience were analyzed: natural environment (but replaced with NEDA-UNDP-ECHA risk component), built environment, social environment, economic environment, and institutional environment. The assessment was carried out through a survey which asked respondents to rank the relative importance of indicators of each of the four components, then a weighted mean index was computed for each component. Computing the flood disaster risk index (FDRI) was accomplished by adding the scores of all five indices and dividing the sum by the total number of components. The FDRI score ranges from 1 to 5 (Eq. 1). A barangay with a high FDRI score is presumed to be more resilient to flood disasters. Conversely, a barangay with a low FDRI score is less resilient and is presumed to have difficulties in coping with a flood disaster.

Equation 2. Flood disaster risk index (FDRI) equation.

$$FLOODRIi = (FDRIi + SEIi + EEIi + BEIi + IEIi)/n$$

where FDRI is the risk based FDRI; SEI is the social environment index; EEI is the economic environment index; BEI is the built environment index; IEI is the institutional index; and n is the total number of components.

Kotzee and Reyers (2016) presents a tool which can be used to measure and map the spatial distribution of the levels of flood resilience across a landscape using indicators. The method involves the construction of index by assigning explicit and transparent weighting system "to account for the range of variance in social-ecological dataset and conduct sensitivity analyses. Principal Component Analysis (PCA) was used to generate weights. The variables used were based on Biggs *et al*. (2012). Twenty-four variables were then determined and grouped (Table 4). The method also involved a normalization and appropriateness procedure in which a min-max normalization technique was used to standardize variables. Normality was assessed using Kolmogorov-Smirnov statistic. Descriptive statistics of skewness was then used to assess data distribution. The principal component analysis was used to check correlation between variables using correlation matrix, identify latent components that represent data, screen test, and carry out factor loading. Institutional resilience was also assessed using a scoring system to determine organization capacity for resilience following safety chain approach (Brinke *et al*., 2008), which is based on compliance of the organization/municipality and whether policies/measures for disaster resilience are in place. The method was applied in a case study in South Africa (three municipalities in the study area: George, Knysna, and Bitou). Data needed were obtained from census, government publications, planning documents, online biodiversity databases – all data taken from online databases and are generally available especially in flood prone areas, which helps to compare resilience of the three municipalities.

Table 4. Twenty-four variables used by Kotzee and Reyers (2016).

Variable	Description
Access/ evacuation potential	Arterial roads/km2
Age dependency ratio	Pop aged under 15 or 65+ to total pop aged 15–64
Civic involvement	Number of civic organizations per ward/10,000 pop
Communication capacity	% Population owning a cell phone
Children under 5 years of age	Population aged 0–4
Ecological buffer	% Natural vegetation
Education	% Population with a high school diploma
Elderly	Population aged 65 and older
Employment	% Population employed

Employment equity	% Female labor
Employment sector diversity	TRESS index
Housing capital	Percent homeownership
Housing type	Percent formal housing
Income disparity	Percentage population earning >$400
Land use diversity	Proportion of land use categories per ward, multiplied by the natural logarithm. The resulting product is summed across wards, and multiplied by −1
Place attachment	% Population living in area for 10+ years
Political engagement	Voter participation in local elections
Recovery	% Public schools per ward
Soil retention	Percentage deep permeable soil per ward
Special needs	% Population without a sensory or physical disability
Transportation access	% Population with a vehicle
Water infrastructure	% Piped water % Flush toilets
Wetland diversity	Proportion of flood attenuating wetlands per ward, multiplied by the natural logarithm. The resulting product is summed across wards, and multiplied by −1

Resilience benchmarking and comparisons provide metrics that help governments in decision-making, set priorities and measure progress, as well as attract public interest in disaster loss reduction. The tools in this section allow for benchmarking and comparison, but do not explicitly assess resilience over time.

There is a lack of "agreed understanding" of the concept of resilience (Woolf *et al*., 2016) but academics agree that resilience is multifaceted (Cutter *et al*., 2010). This is evident in the number of cross-cutting dimension tools for resilience assessment. While there is a growing trend towards inclusion of all dimensions in resilience assessments, arriving at a resilience score in most tools involves merely aggregating or taking weighted averages of the dimension scores. There are tools that are able to provide a quantified resilience over time, but do not necessarily allow for benchmarking and comparison. There are tools that are flexible for benchmarking and comparison but are not dynamic. Given these gaps, there is a need and opportunity to develop a resilience assessment approach that is (1) holistic or multidimensional, (2) measurable or quantifiable, (3) dynamic, and (4) useful for benchmarking with targets, standards, or comparing with other system context.

3. Methodology for SERI

This focuses on the development of the Socio-Economic Resilience Index (SERI) model that focuses on a city's resilience in social and economic services. The IUSRI model that combines the SERI and UERI models is shown in Chapter 4.

3.1 Methodological flowchart

Figure 2 shows a flowchart of the methodology that this study used to develop the SERI Model with system dynamics.

First, the scope of the SERI model was defined, and conceptual models were drafted for each subsystem. Given that this is the second part to the Ecosystem Resilience Index (UERI) model (Campos, et al., 2020), the scope of the system was determined such that it covers services other than Urban Ecosystem Services (UES). The chosen scope complements the UERI model with the socio-economic perspective and provides a more holistic understanding of city resilience. Conceptual modeling of the determined subsystems was done through causal loop diagrams (CLDs) to explore the connections between variables that influence resilience within these systems. Given each CLD, a dynamic hypothesis was also developed to show the expected system behavior.

These conceptual models were then translated into mathematical stock-and-flow (SF) simulation models, working with the available data gathered from Pasig and Valenzuela City. SF model development is an iterative process, wherein the drafted model structure may call for additional data, and available data may in turn affect the possible model structure. Historical data also guides the structural validity testing, to ensure that the model is sound.

Finally, the SF model was used to test different policy scenarios and see the possible resilience performance outcomes. The goal was to develop a model wherein insights can be derived, and different scenarios can be simulated. This last step focused on identifying the scenarios and constructing a GUI for user-friendly scenario testing, so that users can easily modify the parameters and quickly see the effects of these modifications on other variables.

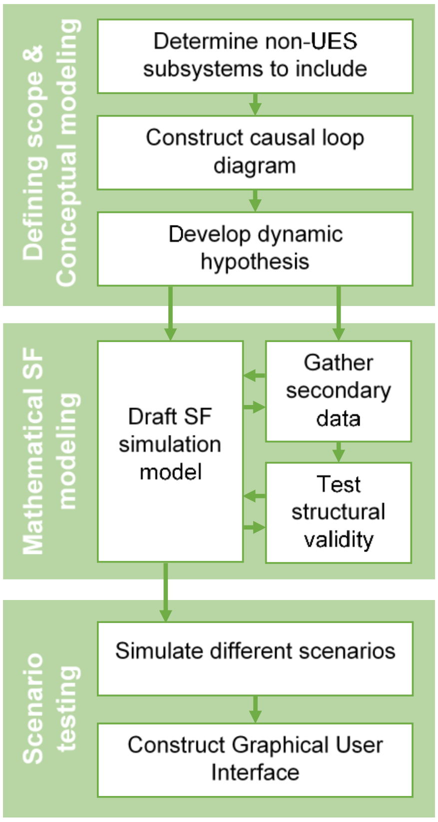


Figure 2. Methodological Flowchart of the Study

3.2 Selected subsystems

City resilience is driven by socio-economic factors as well as the city's ecosystem services. The UERI model covers ecosystem services, while the goal of this study is to supplement the UERI with socio-economic subsystems to develop an integrated urban services resilience model. The selected socio-economic subsystems are outlined in Table 5.

Table 5. Summary of selected subsystems under different dimensions of city resilience.

Dimension	**Subsystems**
1. Demographics	Population
2. Social	Health, Education, Protection, and Housing
3. Economic	Poverty and Employment
4. Shock (Pandemic)	Integrated into other subsystems

Demographics. The population subsystem was used to provide age-disaggregated inputs into the other subsystems. The UERI model did not need population by age, and thus did not need a population subsystem with age cohorts.

Social. Health, education, protection (law enforcement and firefighting), and housing were identified as the key public services provided by LGUs. The health, education, and protection subsystems cover the personnel and assets that enable the provision of each service. The housing subsystem covers the LGU's provision of in- and off-city low-cost housing for informal settler families.

Economic. Employment and poverty were identified as the key areas for economic resilience in the city. The employment subsystem covers the registered businesses in the city and the overall employment from within and outside the city, and the poverty subsystem covers poverty characteristics.

Shock. Potential shocks include flooding, earthquakes, and other physical hazards that affect the demographic, social, and economic subsystems. These can be tested by adjusting the model parameters but given current events, a pandemic is the main shock considered in this model. The effects of the COVID-19 pandemic were factored into the social and economic subsystems and a separate subsystem was dedicated to understanding the cost implications of the pandemic to the LGU.

3.3 Model development

3.3.1 Introduction to System Dynamics Modeling

System dynamics is a framework for modeling that emphasizes the dynamic and interconnected nature of the systems we aim to model. It consists of conceptual and mathematical modeling.

3.3.1.1 Conceptual modeling

Conceptual modeling is done mainly by identifying causal relationships between different variables in a system through a causal loop diagram (CLD). The possible behavior of key variables in the system is then projected based on these relationships, through a dynamic hypothesis.

In a CLD, arrows can be labeled with either positive or negative signs to indicate how one variable affects the other. Those labeled with positive signs indicate a direct relationship: an increase (decrease) in one variable leads to an increase (decrease) in the other. Those labeled with negative signs indicate an indirect relationship: an increase (decrease) in one variable leads to a decrease (increase) in the other.

When a variable is connected to itself through one arrow or a chain of arrows and other variables, feedback loops are created. These are either reinforcing or balancing feedback loops. When all the signs of the arrows forming the loop are multiplied and a positive sign results, this is a reinforcing feedback loop. This loop reinforces system behavior: increases (decreases) in a variable eventually lead to more increases (decreases). When the signs of the arrows result in a negative sign, this is a balancing feedback loop. This loop balances system behavior: increases (decreases) in a variable eventually lead to decreases (increases).

A dynamic hypothesis is simply what one thinks will happen in the CLD over time. This allows one to understand the dynamics behind the CLD and make a hypothesis for the mathematical model.

3.3.1.2 Stock-and-Flow modeling

Mathematical modeling for system dynamics consists of Stock-and-Flow (SF) modeling. This study used Vensim DSS for this application. Here, the CLD is translated into a SF model, programmed, and values are filled in.

The main components of an SF model are stocks, flows, and auxiliary variables. A stock, indicated by a square, is an accumulation and is modified by flows. A flow, indicated by an arrow with a spigot, is a rate of change that modifies the stock. An auxiliary variable, indicated by the plain variable name, is a variable that can be used as inputs to the stocks (initial values) or flows, or for calculating values using stock and flow outputs.

SF models use integration for the accumulation of stocks. All models run in time, and for this model the unit of time is Years and the time step for integration is 0.25.

3.3.2 Resilience and Self-Sufficiency Indices

This model used the same approach to quantifying resilience employed in the UERI model, which calculated both resilience scores and the self-sufficiency scores. Key indicators in each subsystem were given resilience scores that represent how they measure up to their ideal values. These ideal values are based on demand and/or national and LGU targets. Selected indicators were also given self-sufficiency scores that represent how much of the capacity served is contained within the city. Table 6 summarizes the equations of each score and the implications of the different values that each score can take on.

Table 6. Resilience and self-sufficiency score equations and value implications. UER Index, Adapted from *(Josol, 2014)*

Index	**Equation**	**Implications**		
		< 1	**= 1**	**> 1**
Resilience score	$= \frac{Actual\ capacity}{Ideal\ capacity}$	Ideal capacity not met	Ideal capacity met	Ideal capacity exceeded
Self-sufficiency score	$= \frac{In\ city\ capacity}{Actual\ capacity}$	Actual capacity partly served outside city	Entire actual capacity served in city	

3.3.3 Population subsystem

The city's population is one of the most important inputs in the model because the ideal capacities of different socio-economic services is dependent on the people who need these. Ideal values for indicators in the health, education, and employment subsystems depend on the population age structure given that health needs are greater for the aged, education needs are mostly for the young, and business employment is for the working age population.

3.3.3.1 CLD & Dynamic hypothesis

The population subsystem CLD is shown in Figure 3. The population is broken down into age brackets: children, fertile population, and old population. The fertile population gives birth and these children eventually mature into the fertile bracket. The fertile bracket also ages into the old bracket, and the old bracket eventually dies.

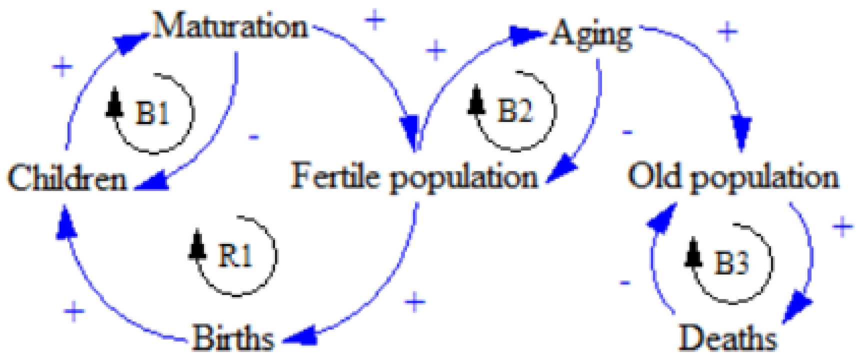


Figure 3. Population Subsystem CLD

Figure 4 shows the two dynamic hypotheses that can be derived from this CLD for growing populations. The graph on the left shows a population increasing at a decreasing rate. This happens if there are more fertile people than there are children that mature. This is characteristic of more mature or aging populations that have low fertility rates. The graph on the right shows a population increasing at an increasing rate. This happens if there are more children that mature than there are fertile people that age. This is characteristic of young populations that also have high birth rates. Pasig and Valenzuela can exhibit either of these, based on their specific population characteristics.

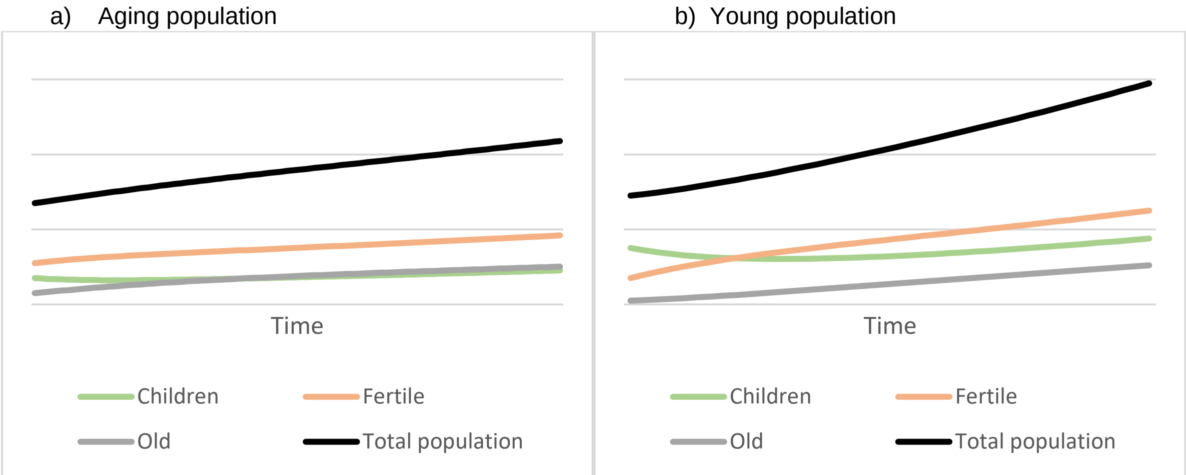


Figure 4. Population subsystem dynamic hypotheses: (a) an aging population and (b) a young population.

3.3.3.2 SF Model

The structure of the population subsystem with four age cohorts is shown in Figure 5. Maturation from one cohort to the next depends on the population in the cohort and the length of time that people stay in the cohort, e.g. 15 years for the "Age 0-14" cohort. Births depends on the population in the "Age 15-44" cohort, i.e. the fertile population, and the birth fraction, i.e. population aged 0-1 as a fraction of population aged 15-44. Deaths depends on the population in each cohort and the respective death fraction, i.e. deceased population as a fraction of total population within the age bracket. This is highest death fraction is that for "Age 65+".

Initial values for each age bracket and the birth fraction are based on the population by age found in the 2015 Statistical Tables from the 2015 Census of

Housing and Population (PSA) which are available for both Pasig and Valenzuela, while death fractions are based on the deaths by age in each city found in the 2016 Vital Statistics Report published by the Philippine Statistics Authority (PSA).

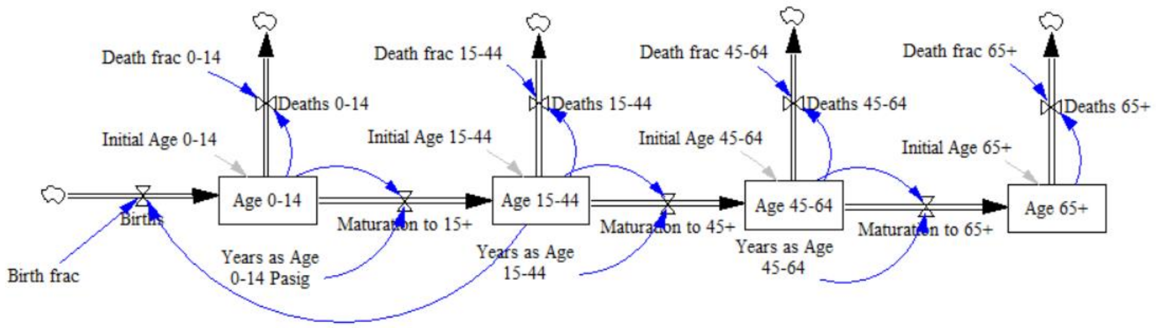


Figure 5. Population subsystem SF model.

3.3.4 Social subsystems

The capacity of the city to provide for health, education, and protection needs is explored in this subsystem. With health, it is important that health systems will not break down in disaster situations, e.g. due to being overwhelmed with patients, and that they adequately care for the wellbeing of constituents so that they can avoid additional vulnerability to disasters due to fragile health conditions. With education, is important that this is adequate, especially in early years with primary and secondary education, so that people can have higher human and financial capital down the road to better prepare for disasters and absorb shocks. With protection, i.e. law enforcement and firefighting, it is important for the LGU to become a safer place and to have the capacity to maintaining peace and order in disaster situations.

Capacity in the health, education, and protection subsystems are operationalized as the personnel and assets that the LGU needs to employ in providing these services. Table 7 shows the specific personnel and assets used as capacity indicators for each subsystem. The health services capacity is represented by the number of doctors, nurses, midwives, and hospital beds in public hospitals. The education services capacity is represented by the number of teachers, classrooms, and seats in public primary and secondary schools. The protection services capacity is represented by the number of policemen, firemen, and firetrucks employed by the city.

Table 7. Personnel and assets representing service capacity of the Health, Education, and Protection subsystems.

Subsystem	Personnel	Assets
Health	Doctors Nurses Midwives	Hospital beds
Education	Teachers	Classrooms Seats
Protection	Policemen Firemen	Firetrucks

The current and historical values for each of these service capacity indicators can be found in the city's Socio-Ecological Profiles (SEP). The ideal ratios for medical professionals and police are also taken from these profiles, while the ideal ratios for teachers, classrooms, seats, hospital beds, firefighters, and firetrucks are taken from various government documents and officials' statements. These ideal ratios are shown in Table 8 below, along with other key assumptions used in the SF model.

Each of the personnel and asset capacity indicators under the health, education, and protection services subsystem can be projected to change as they have historically, increasing each year by the average annual increase from available data. This method of projecting the indicators forward will result in a constant addition to capacity that is independent of any other factors besides the historically derived values.

This historical-based constant addition was used as one of the ways to project changes in capacity in each of the subsystems, but the primary mechanism for change that this SERI model explored is by way of goal-seeking behavior.

3.3.4.1 CLD & Dynamic hypothesis

In a goal-seeking behavior, the capacity is projected to increase or decrease (depending on its initial value) until it reaches the ideal value, or the goal. This ideal value is a target that should be based on the population that needs to be served. Instead of a constant addition based on historical data, the capacity indicator changes by considering (a) the gap, i.e. how far the current value is from the ideal, and (b) the adjustment time, i.e. how long it will take to close the gap.

A larger gap will require a larger magnitude of change, while a smaller gap will require a smaller magnitude of change. The rate at which this change occurs depends on the magnitude of the gap: as the gap closes and a smaller magnitude of change is needed, the rate of change slows down. The rate of change also depends on the adjustment time over which the change is spread out: a longer adjustment time means that the change will be slower and vice versa. In the case of personnel and assets employed by the LGU, adjustment time refers to how long it takes to make the necessary budget changes and hire/layoff personnel and procure/sell assets.

Goal-seeking will result in additions to the current capacity when it is insufficient, i.e. the goal is above its current value. The CLD for this is shown in Figure 6a, where the "action to close gap" is procurement of assets or hiring of personnel. On the other hand, goal-seeking will result in reductions to the current capacity when there is spare capacity, i.e. its current value is above the goal. The CLD for this is shown in Figure 6b, where the "action to close gap" to sell assets or layoff personnel. This represents a scenario in which resources are freed up to be rechanneled towards other needs that are still below the ideal.

Note the other factor that affects current capacity, "Personnel/assets retire". Besides the historical and goal-seeking changes, the CLDs also considered the natural decrease in capacity due to personnel or assets having to be retired over time.

a)

b)

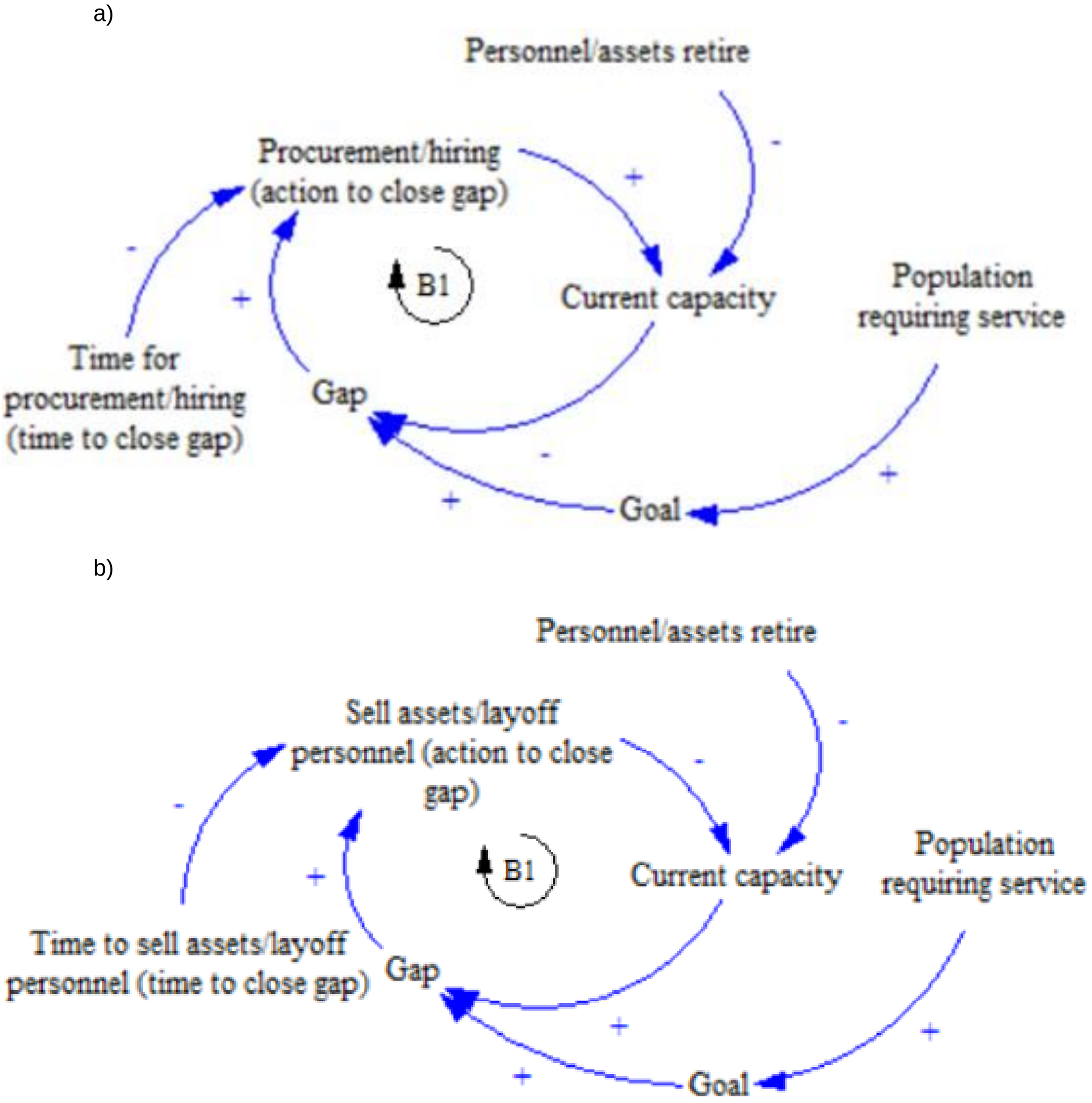


Figure 6. Health, education, and protection services subsystem CLD: (a) when the current capacity is below the goal and (b) when the current capacity is above the goal.

Figure 7 shows the dynamic hypotheses for the goal-seeking behavior of the capacity indicators and compares this goal-seeking behavior with what would happen if the capacity simply increased following the historical average (grey lines). This also assumes that the goal capacity is increasing because of a growing population that needs these social services.

Figure 7a shows the case when the current capacity is below the goal and change is positive. Figure 7b shows the case when the current capacity is above the goal and change is negative. In both cases, the rate of change slows down as the gap closes, i.e. incremental changes are smaller, because the difference between the current capacity and the goal decreases. A historical increase would not exhibit this pattern. Following the historical trend would result in changes that are irrespective of whether the goal has been attained, which is not necessarily what happens in practice. Thus, goal-seeking is the primary way that this subsystem will be modeled.

This shows that it is important for LGUs to set the right goals, because goals direct changes in actual capacity. Setting goals that are too high would result in misallocation of budget since the funding for extra capacity could have gone where it was more needed, while setting goals too low would result in slower improvements, stagnancy, or even reductions in capacity. Such insufficient goals would lead to a deceptively "resilient" system in terms of the index calculation.

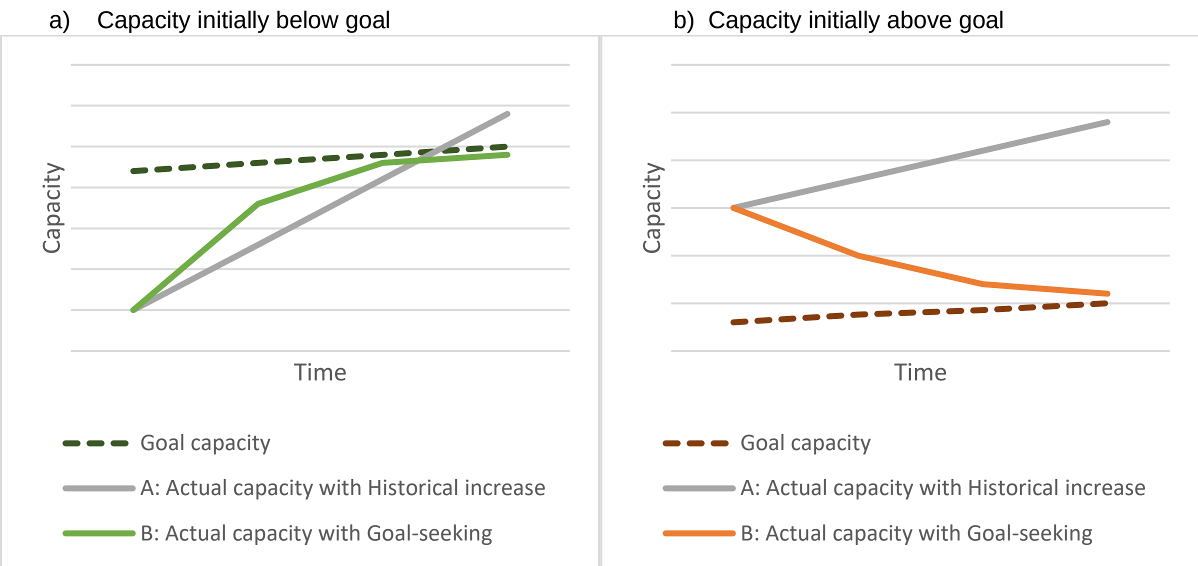


Figure 7. Health, Education, and Protection Services subsystem dynamic hypotheses: (a) when the current capacity is below the goal and (b) when the current capacity is above the goal

3.3.4.2 Core SF model structure

The capacity indicators for the health, education, and protection services each follow the same SF model structure. The template for personnel is shown in Figure 8a while that for assets is shown in Figure 8b.

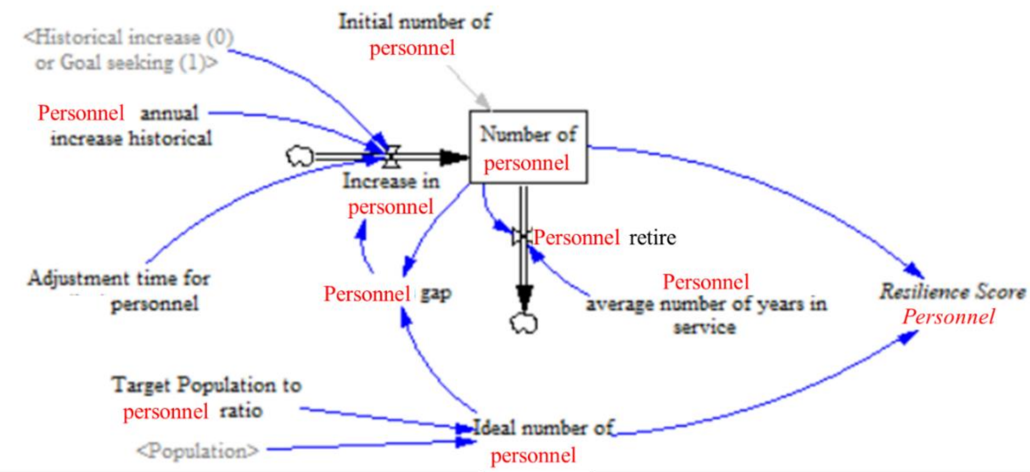
If "*Historical increase (0) or Goal seeking (1)*" is set to zero (0), then the increase in personnel or assets will follow a fixed change. For personnel where several years of data is available, this fixed change takes on the value of the variable "*<Personnel> annual increase historical*". For assets where data may not be sufficient to calculate an average historical change, this fixed change is estimated and takes on the value of the variable "*<Asset> annual increase estimated*". If it is set to one (1), then it will follow the goal-seeking model.

In the goal-seeking model, the stock will change by the value of the gap divided by the adjustment time. The goal is the "*Ideal number of personnel/assets*", and this is determined by the ideal ratio multiplied by the base population (values shown in Table 8). The adjustment time is an estimate of how long it may take to implement the actions to close the gap, such as budget proposals, procurement, or hiring. With the exception of adjustment time for medical personnel that was taken from a Malaysian healthcare study (Minato & Hassan, 2017), the rest of the adjustment times are the author's estimates (values shown in Table 8).

The number of personnel or assets decrease when they retire or are fully depreciated. This happens at a rate equal to the value of the stock divided by the average number of years in service for personnel or years of useful life for assets (values shown in Table 8). The years of useful life for assets are taken from Annex A of Memorandum Circular 2003-007 (Commission on Audit, 2003), while the average number of years in service for personnel are the author's estimates.

The initial values for indicator capacities are taken from the SEP's of each city. The ideal ratios are targets set by the LGU and/or government agencies (values shown in Table 8) and are the same for both cities. To get the ideal capacities, these ideal ratios are applied to the base populations for each social service, which in the total population for the case of Health services, the number of elementary and secondary school students for Education, and either the total population or the daytime population for Protection. Besides driving change, these resulting ideal capacities are also those used in calculating resilience scores. However, for the health subsystem there is an alternative ideal capacity used to calculate the resilience scores for medical professionals and hospital beds, described in detail in Section 3.3.4.2 Dynamic targets alternative".

a)



b)

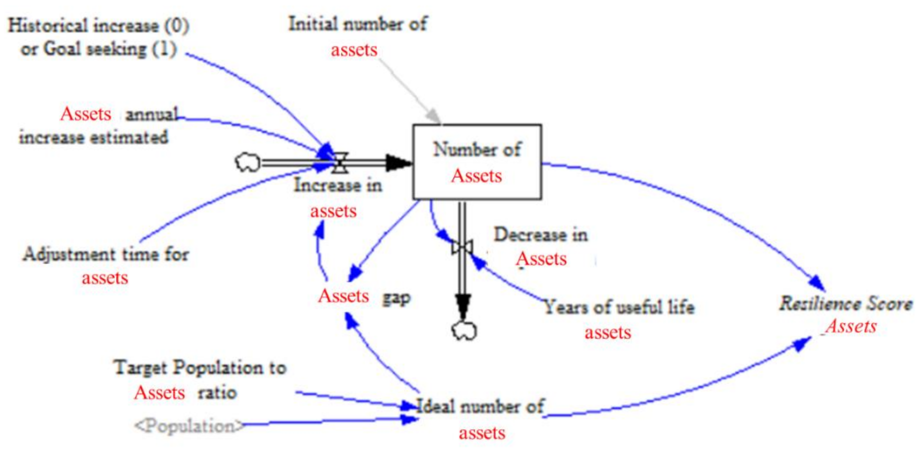


Figure 8. Health, Education, and Protection Services subsystem SF model structure for (a) personnel and (b) assets.

Table 8. Key assumptions for the Health, Education, and Protection Services subsystem.

Sub-system	Personnel/ Asset	Ideal ratio	Base population	Adjustment time (years)	Number of years in service / years of useful life
Health	Doctors	1:20,000	Total population	2	30
	Nurses	1:20,000		2	30
	Midwives	1:5,000		2	30
	Hospital beds	1:800		1	15
Education	Teachers	1:35	Elementary and secondary school students	2	25
	Classrooms	1:35		3	30
	Seats	1:1		1	10
Protection	Police	1:500	Total population/ Daytime population	1	30
	Firefighters	1:2,000		1	30
	Firetrucks	1:28,000		3	15

Data Sources:
1. Ideal ratios for personnel, classrooms, seats, and firetrucks are taken from the LGU's SEP's; hospital beds from a national news report (Ejercito, 2018). These are the same for both LGUs.
2. Adjustment time and number of years of service are author's estimates.
3. Number of years of useful life taken from the Philippine Commission on Audit (2003).

3.3.4.2 Dynamic targets alternative

For the health services subsystem, the LGU goals are driving the changes in personnel and hospital bed stocks. For the resilience scores, however, there are alternative benchmarks to compare these stocks with that are more sensitive to different factors that can affect ideal capacities such as hospitalization rates, number of births, and number of patients that each medical personnel can accommodate.

The number of outpatients is assumed to be a multiple of the number of inpatients, while the number of inpatients is based on the population of each age cohort multiplied by a constant annual hospitalization rate for each age cohort. This excludes maternal inpatient stays. Philippine data for these hospitalization rates by age cohort is unavailable, and so data for the United States in 2015 is used (Sun et al., 2018). The hospitalization rates are shown in Table 9.

The ideal number of doctors and nurses are based on the total number of patients and their capacity to accommodate patients, the ideal number of midwives is based on the number of births and their capacity to attend to deliveries, and the ideal number of hospital beds is based on the number of inpatients and bed utilization. The model structure for this was adapted from Minato & Hassan (2017) and can be seen in Figure 9. The personnel capacity and average days of inpatient stay are shown in Table 9.

To capture the effects of COVID-19 on the health capacity needed, COVID-19 admissions is considered in (a) the number of patients that doctors and nurses attend to and (b) the hospital bed benchmark to account for the additional bed days needed. The number of COVID-19 admissions for Valenzuela is taken from the LGU's list of confirmed cases that were hospitalized, while due to lack of data, that for Pasig was estimated from their total number of cases based on ratio and proportion with the Valenzuela statistics (data is as of September 2020). Note that there is also no data on the specific level of hospitalization, i.e. whether they were admitted to ICU or regular hospital beds, and this analysis also does not consider the different types of hospital beds. The average length of stay for COVID-19 patients is taken from a policy discussion paper from a Philippine hospital, The Medical City (Gonzales, 2020), also shown in Table 9.

.

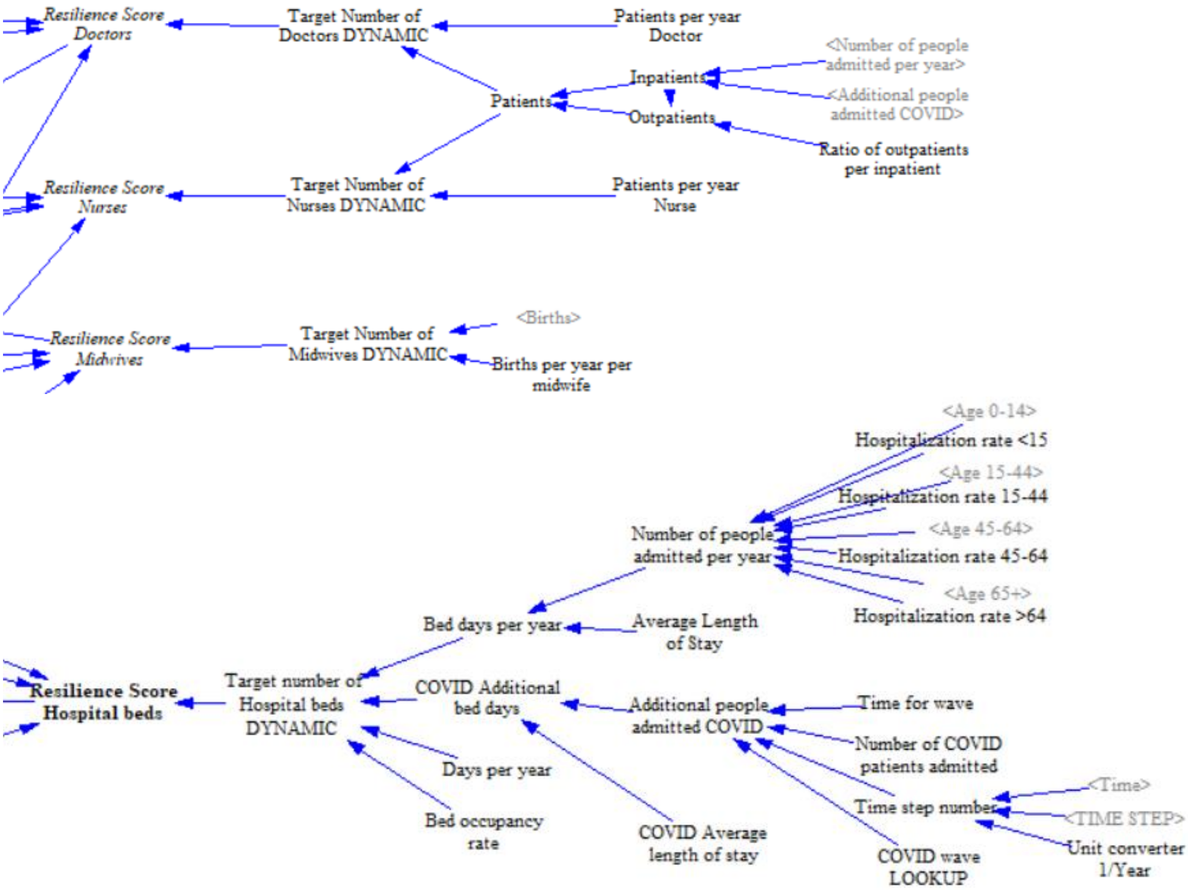


Figure 9. Alternative Benchmarks for Health Subsystem Resilience Scores

Table 9. Key assumptions used in alternative benchmarks for Health subsystem resilience scores.

Personnel	Patients or births per year	Hospital beds	Average days of stay	Age bracket	Hospitalization rate
Doctors	1,500	Regular inpatient	4	0-14	2%
Nurses	900	COVID-19 patient	20	15-44	4%
Midwives	29.5			45-64	10.5%
				65+	26.5%

Data Sources (due to lack of available sources, data from other countries is used):
1. Patients per year for doctors and nurses taken from a Malaysian SD study by Minato & Hassan (2017), Births per year taken from National Audit Office (2013) of the United Kingdom.
2. Average days of stay for regular inpatients taken from each LGU's SEP's, and for COVID-19 patients in The Medical City, Philippines taken from Gonzales (2020).
3. Hospitalization rates for the United States taken from Sun *et al.* (2018).

3.3.4.3 Auxiliary cost calculations

The costs of the selected indicators for the Health, Education, and Protection services are also calculated to give a sense of the financial implications of hiring personnel and acquiring assets. The cost of personnel is based on the yearly salary and the stock of personnel, while the cost of assets is based on price per unit and the *inflow* to the stock, i.e. the assets added to the stock instead of the sum of all assets. The flow is used instead of the stock for assets because these are only paid for when they are purchased (operating and maintenance costs were not estimated and are excluded to simplify these calculations). Personnel costs, on the other hand, use the stock because there are recurring payments to the whole workforce.

The salaries for personnel are based on the government mandated salaries, while the costs for seats, hospital beds, and firetrucks are based on ballpark selling prices for these. For classrooms, costs are based on the standard minimum floor area of a DepEd classroom, i.e. 7 m x 9 m, and the average cost of a commercial type building per square meter, according to first quarter 2019 construction statistics from approved building permits.

There are two things to note regarding these cost calculations.

First, these cost estimates represent a minimum--actual cost can be much higher. For personnel, the salaries used here are for the lowest salary grade for this profession while in practice those with higher ranks have higher salaries. For assets, actual costs could be higher because of the maintenance costs and the necessary surrounding infrastructure, i.e. hospital beds cost less than the construction of additional wings or hospitals that accommodate these hospital beds and classrooms are not built as standalone facilities.

Second, these costs are static for the entire period that the simulation runs—no inflation rate is applied. The forward projection does not cover the inflation or salary raises that would effectively change these rates over time.

The model structure for this is shown in Figure 10, using the example of personnel and assets under protection services. All cost assumptions are presented in Table 10.

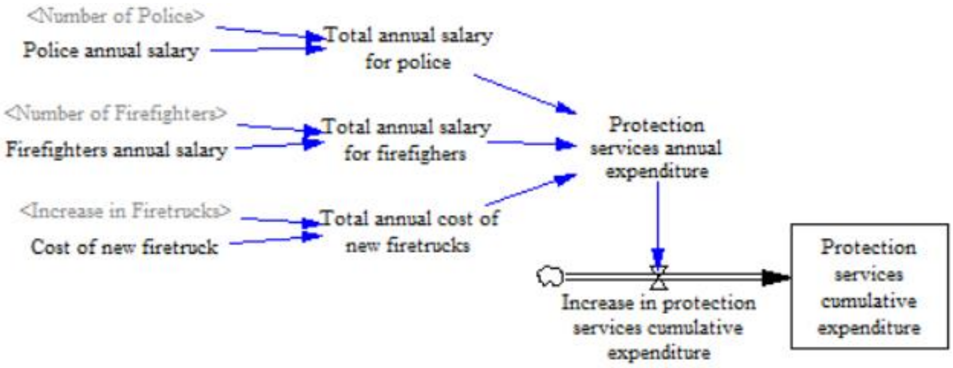


Figure 10. Auxiliary cost calculations model structure for the Health, Education, and Protection Services subsystem

Table 10. Salaries and asset costs used in auxiliary cost calculations for the Health, Education, and Protection Services subsystem

Subsystem	Personnel/Asset	Monthly Salary / Cost per unit in PHP
Health	Doctors	29,277
	Nurses	20,219
	Midwives	15,524
	Hospital beds	15,000
Education	Teachers	22,316
	Classrooms*	669,438
	Seats	800
Protection	Police	29,668
	Firefighters	29,668
	Firetrucks	2,500,000

Data Sources:
1. Monthly salaries are from the national government mandated salary grades (Department of Budget and Management, 2006).
2. Cost per unit for classrooms is based on the DepEd classroom minimum floor area of 63 sqm and an average building construction cost of P10,626 per sqm (Philippine Statistics Authority, 2019).
3. Cost per unit of all other assets are the author's estimates based on online listings for similar assets.

3.3.5 Housing

The housing situation of a city is an important indicator for city resilience. Informal settlements are often found in hazardous locations such as flood prone areas, riverbanks, and under electricity transmission lines. Unsafe construction and poor living conditions is also common in informal settlements. These make informal settler families (ISFs) more vulnerable to hazards. Most LGUs address this issue through the provision of low-cost housing along with the relocation of ISFs. This can either be inside or outside the city.

3.3.5.1 CLD & Dynamic hypothesis

The housing relocation subsystem CLD is shown in Figure 11. The number of ISFs increases as the city grows, both through the growth of families already living in informal settlements and through the migration of people into the city that end up living in informal settlements. As ISFs increase, greater demand is generated for housing projects. Once these are built, relocation can begin and ISFs are reduced.

The population growth adding to ISFs depends on housing affordability, which is a function of both income and cost of housing. If formal housing is unaffordable for a family, i.e. cost of formal housing is high or income is low, but they need to find housing in the city, they may choose to live in informal housing that costs less. Over time, as the population grows and more families need housing, continued unaffordability can result in these new families also ending up in informal housing.

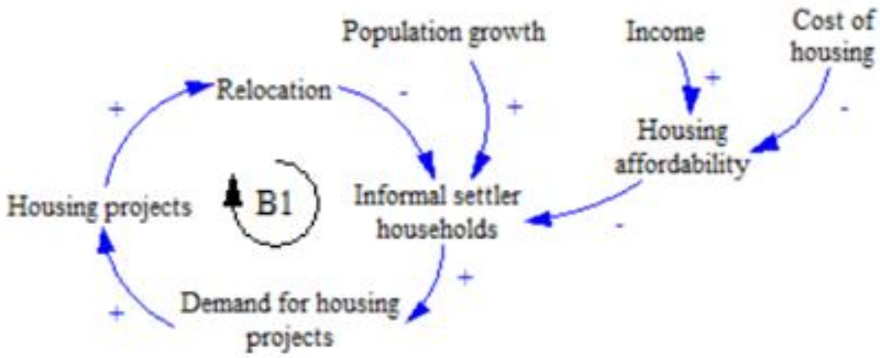


Figure 11. Housing relocation subsystem CLD

Figure 12 shows the two dynamic hypotheses for the housing relocation subsystem. The green line is the “supply” of housing projects where people can be relocated while the dashed gray line is the “demand” for relocation. The red line is the net amount of relocation needed, or the difference between the demand and supply, i.e. shortage. This assumes that housing projects increase at a constant rate and that each additional housing project is immediately occupied. The two graphs show the projected outcomes with two different ISF growth trends.

In Figure 12a, the total number of ISFs or the total demand increases at an increasing rate. This may happen if population also exhibits this growth and formal housing continues to be unaffordable and the new demand for housing from population growth adds to the demand for informal housing (new families from relocated ISFs also eventually look for informal housing). In this case, relocation may only be effective in the short run because the number of ISFs will eventually exceed the capacity of housing projects.

In Figure 12b, the total number of ISFs increases at a decreasing rate. This may happen if population growth tapers off. This may also happen if formal housing becomes affordable and the current demand for informal housing decreases and isn’t added to (ISFs start to be able to afford formal housing, and new families from relocated ISFs will not look for informal housing). In this case, the housing project capacity will eventually be able to cover the total number of ISFs because formal housing is more affordable.

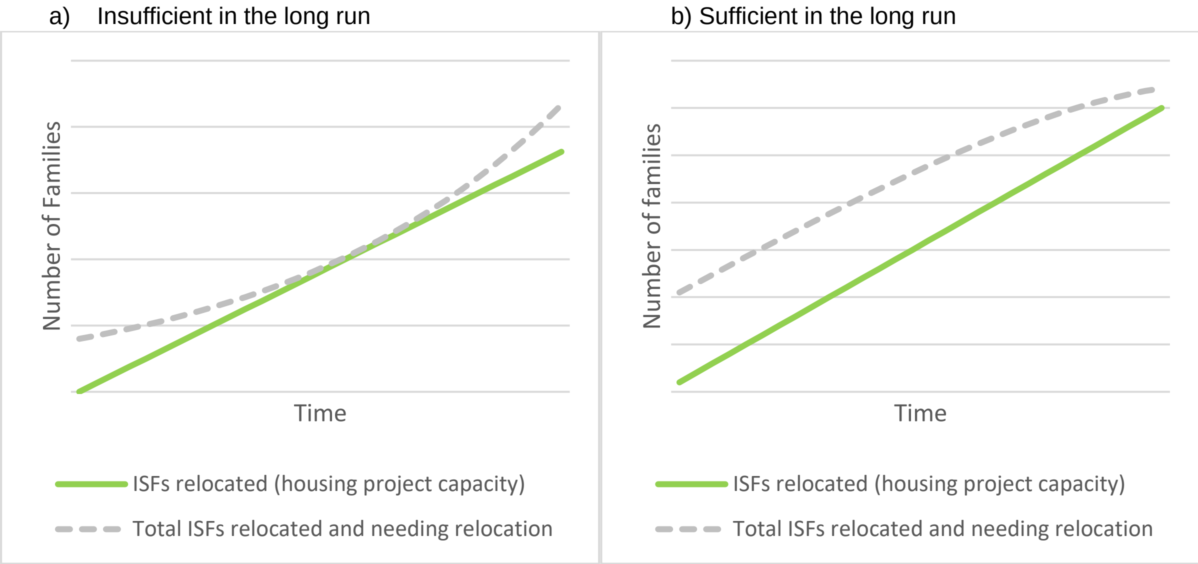


Figure 12. Housing relocation subsystem dynamic hypotheses: (a) when ISFs are increasing at an increasing rate due to low housing affordability and (b) when ISFs are increasing at a decreasing rate due to high housing affordability.

3.3.5.2 SF model structure

The housing relocation SF model structure is shown in Figure 13. The variable "Total number of housing project units needed" is the sum of (a) ISF households and (b) doubled-up households, i.e. sharing one housing unit with another household. Doubled-up households add to the demand for low-cost housing since each unit should ideally be occupied by only one household. These two variables are based on the current population and the city specific data from the 2015 National Census on the total household population to ISF ratio and total household population to doubled-up household ratio. This is effectively the total demand for low-cost housing and is compared with the total supply, the variable "Total number of housing project units", in the resilience score.

Housing project units are separated by location, with one stock for units within the city and another for units outside the city. This allows for the calculation of a self-sufficiency score that indicates how much of the total housing projects is provided for within the city. Both inflows are set to zero by default since the programming of future housing projects in Pasig and Valenzuela is unknown; this can be adjusted later by users of the model.

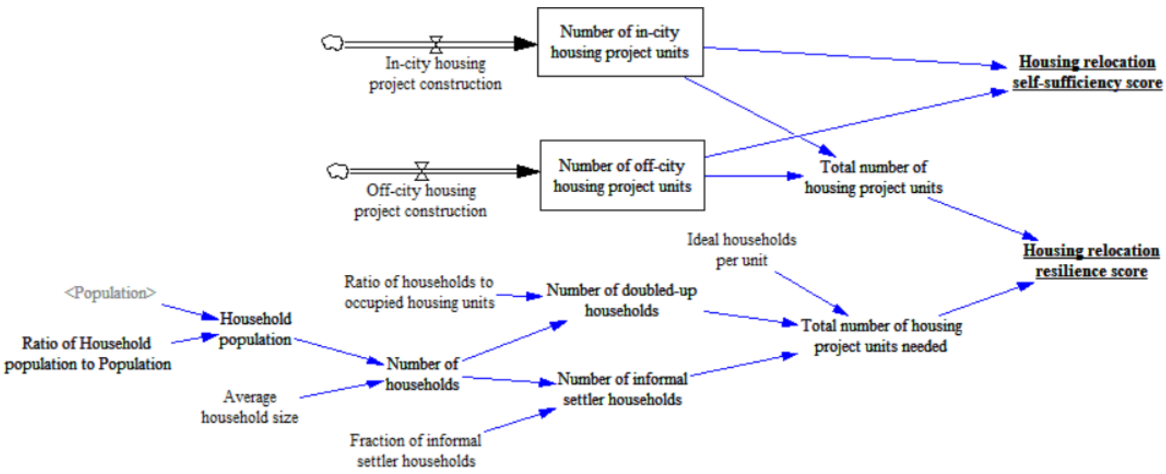


Figure 13. Housing relocation subsystem SF model

3.3.6 Economic subsystems

3.3.6.1 Employment

Economic factors within cities are also key drivers of resilience that work hand in hand with the social and ecological. Livelihood and poverty are interrelated, and the lack of financial capital drives the vulnerability of people to disasters and can influence their ability to prepare for and recover better from shocks (Krantz, 2001).

Businesses that provide local employment are also at risk when it comes to disasters, and it is important that they are resilient to maintain employment, provide goods and services, and contribute to the LGU budget through business taxes. In 2018, this tax on business accounted for 49% of Pasig City's total revenue and 25% of Valenzuela's total revenue (Bureau of Local Government Finance, 2018). This LGU income is what allows for the provision of social and ecological services, among others.

3.3.6.2 CLD and Dynamic hypothesis

The employment subsystem CLD is shown in Figure 14. The number of businesses in the city grows as the city becomes more attractive for businesses. More businesses in the city provides more jobs and higher business tax revenues for the LGU, and these can indirectly improve the various factors that make the city's business environment more attractive.

The enhancement of a city's attractiveness for business happens in several ways (Ghaffarzadegan, Lyneis, & Richardson, 2010).

1. *Ease of doing business.* Business attractiveness improves as the ease of doing business is improved, i.e. government processes and policies relevant to starting and running businesses are efficient.
2. *Demand*. Business attractiveness improves when there is a demand for the goods and services that businesses provide. This demand can also be external to the city; internally, demand increases as more people are employed and can purchase these goods and services.
3. *Human capital.* Business attractiveness improves when there is local human capital for businesses to employ. This can be improved as LGUs provide better

social services, namely education, as employed people provide better educational opportunities for their children, and as more people gain skills and training through employment.

4. *Other businesses*. Business attractiveness improves when there are more businesses that can make the city into a hub, which fosters collaboration, ease of access to goods and services, and creates a bigger market.
5. *Availability of space.* Finally, business attractiveness improves when there is available space, e.g. office space or land availability. This can also be the limiting factor to the growth of businesses if land becomes scarce. However, with the growth in vertical development, the city's land area can be leveraged to make more space, i.e. floor area, available.

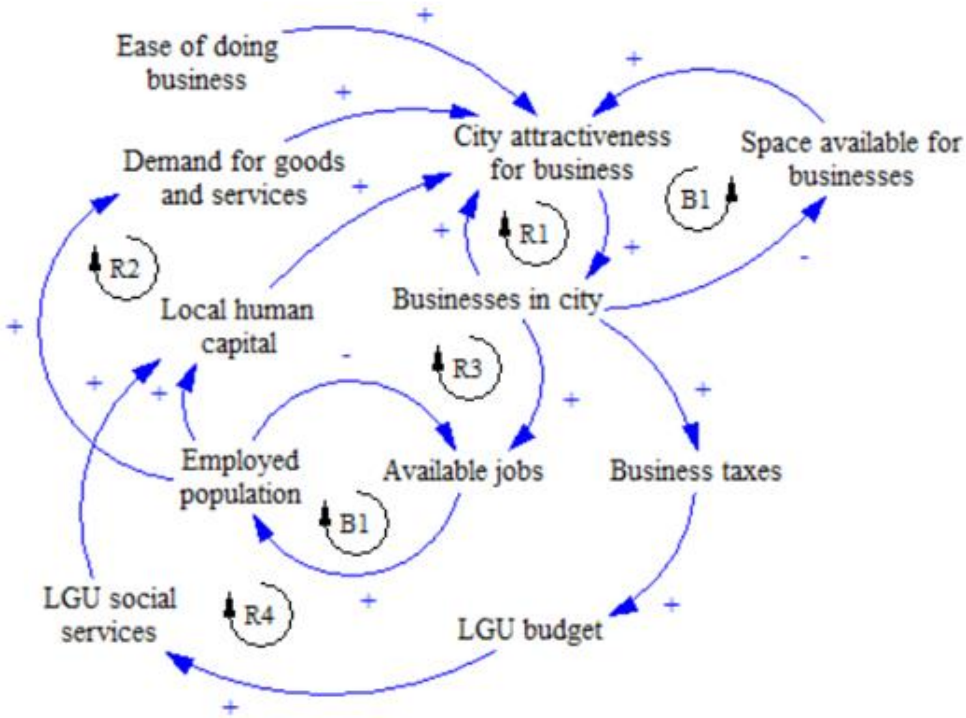


Figure 14. Employment subsystem CLD.

Figure 15 shows the dynamic hypothesis that can be derived from the employment subsystem CLD. Pasig and Valenzuela may exhibit different trends for these, because of the kinds of businesses present in each. Pasig can have a higher floor area for businesses (curve A) because they have more service-oriented businesses that are compatible with vertical development (medium-high rise office buildings, multi-level establishments). Valenzuela will be limited in its vertical development (curve B) because it has more industrial-oriented businesses that need land area for factories and warehouses.

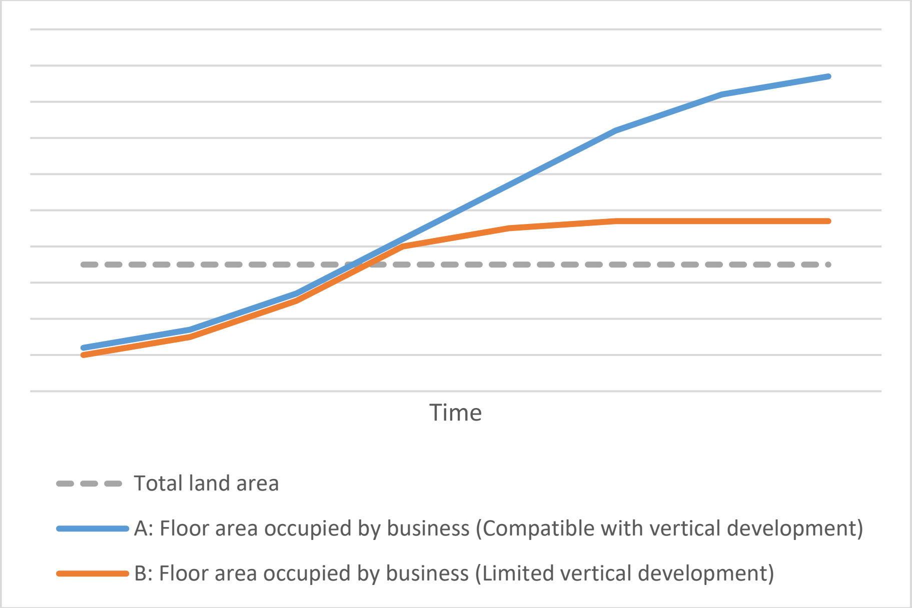


Figure 15. Employment subsystem dynamic hypotheses

3.3.6.3 SF Model structure

The employment subsystem SF model is shown in Figure 16. The stock "Number of businesses" is the total number of registered businesses in the city. The increase refers to the net increase—covering both the new registrations and the expiries of business permits. This lacks the link between available space and number of businesses because of the uncertainty in quantifying how vertical development affects the availability of space.

The number of businesses is multiplied with the average number of employees per business to determine the total number of jobs in the city. The average number of employees and initial number of businesses are taken from the 2015 business listings provided by each city.

The total number of jobs within the city refers to positions that can be held by both residents and people from outside the city. Thus, this is multiplied by the "Fraction of jobs in city held by residents" to determine how many of these jobs in the city are held by residents. This fraction is constant but can be increased or decreased to indicate better local employment outcomes from job fair programs in the short term or improved human capital in the long term. The number of jobs for residents outside the city is assumed to grow at the national average growth rate for jobs.

Initial values for jobs for residents in and out of the city are derived from the employment location fractions in the Socio-ecological Profiles and PSA statistics on population, fraction of population in the labor force, and fraction of labor force employed.

For the employment resilience score components, the actual capacity is the "Number of jobs for residents", while the ideal capacity is the "Working age population". The working age population is the sum of the stocks "Age 15-44" and "Age 45-64" from the population subsystem. For the employment self-sufficiency score components, the number of jobs for residents inside the city is compared to the total number of jobs for residents.

COVID-19 affects this subsystem because of the unemployment caused by the lockdown. It is assumed to only be a temporary effect. The rise in unemployment is 12% that is the difference between the national unemployment rates in the second and first quarters of 2020.

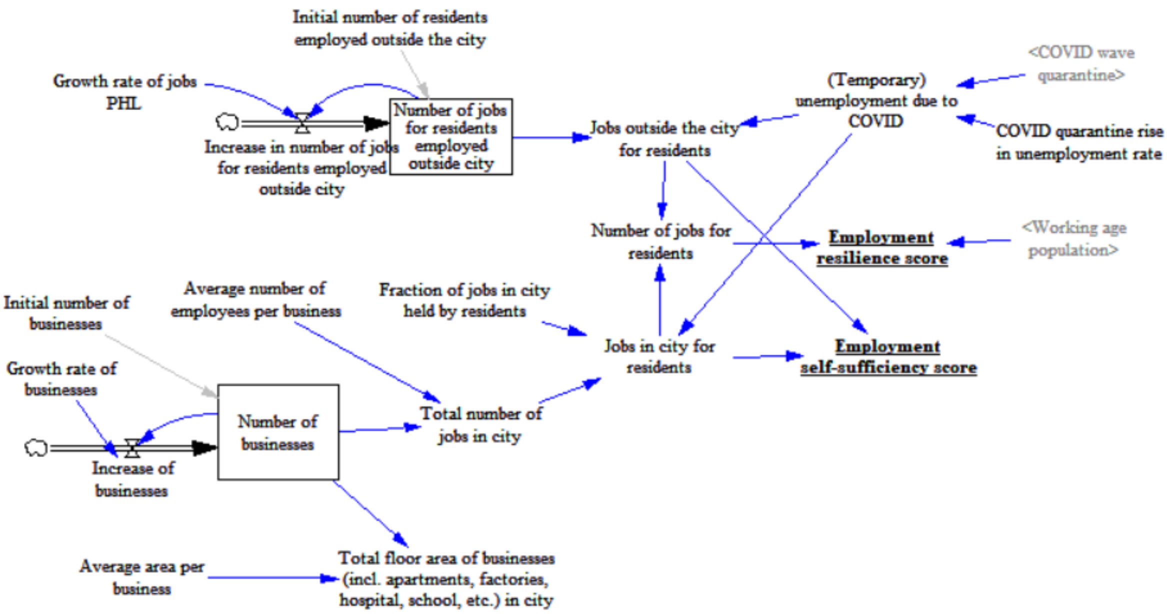


Figure 16. Employment subsystem SF model.

3.3.7 Poverty subsystem

Poverty is the lack of financial, human, and physical capital that people need to become resilient (Krantz, 2001). It is a multi-dimensional issue, and the LGU works in different ways to improve the socio-economic standing of the poor. Poverty is pervasive and challenging to escape because of the so-called poverty traps that keep people in reinforcing cycles that deepen their poverty.

3.3.7.1 CLD and Dynamic hypothesis

The poverty subsystem CLD is shown in Figure 17. This is based on the findings in the ADB (2009) report, "Poverty in the Philippines: Causes, Constraints, and Opportunities." This shows that poverty is aggravated by low income, high out of pocket health expenditure, low family planning, low recovery from disasters, and low access to credit. LGUs on the other hand can address poverty through improving access to credit, housing relocation, and effective poverty reduction programs in the areas of health, education for employability and family planning, and disaster exposure and recovery.

There are several poverty traps explored in this CLD:

1. *Health*. Health emergencies, required medication, and lab tests often drain financial resources. This can wipe out savings and comprise a large fraction of

the limited income of the poor, which would otherwise be used for food. Improper nutrition can in turn lead to even more negative health outcomes.

2. *Human capital*. Education is directly related to employment opportunities. Without prior primary and secondary school or technical and vocational skills training, it is less likely that people will find adequate employment. This in turn prevents people from investing in their education and in their children's education.
3. *Family planning*. Family planning can reduce the size of poor families and allow for higher per capita income through less distribution among members. Without family planning, it may become more difficult for the poor to support their families and invest in their health and education, that in turn limits their access to family planning education.
4. *Disaster risk.* Disasters include natural disasters and economic crises, such as the crisis arising from the lockdowns due to the recent COVID-19 pandemic. These can damage people's homes, wellbeing, and livelihood, and the less they are able to recover, e.g. if they do not have enough savings, the deeper into poverty they get. Risk is also driven by the exposure of the poor. They can experience greater losses from extreme weather if they live in poorly built houses.
5. *Credit*. Affordable credit can allow the poor to start entrepreneurial activities and improve their health or education status. The poor have limited access to credit because they are often outside the formal banking system and do not have enough collateral. Without access to credit, the poor will not have capital to earn more from or they will turn to informal lenders that charge high interest rates. This in turn can keep people in lack and drain their financial resources as they struggle to repay interest. Increasing access to credit can include the formation of cooperatives and community savings groups.

The LGU can intervene in any of these poverty traps and provide the stimulus for these cycles to result in better outcomes, i.e. reducing the number of people who are poor and reducing the income shortfall of the poor. The effectiveness of poverty targeting programs can be improved with a higher budget and better poverty monitoring and evaluation.

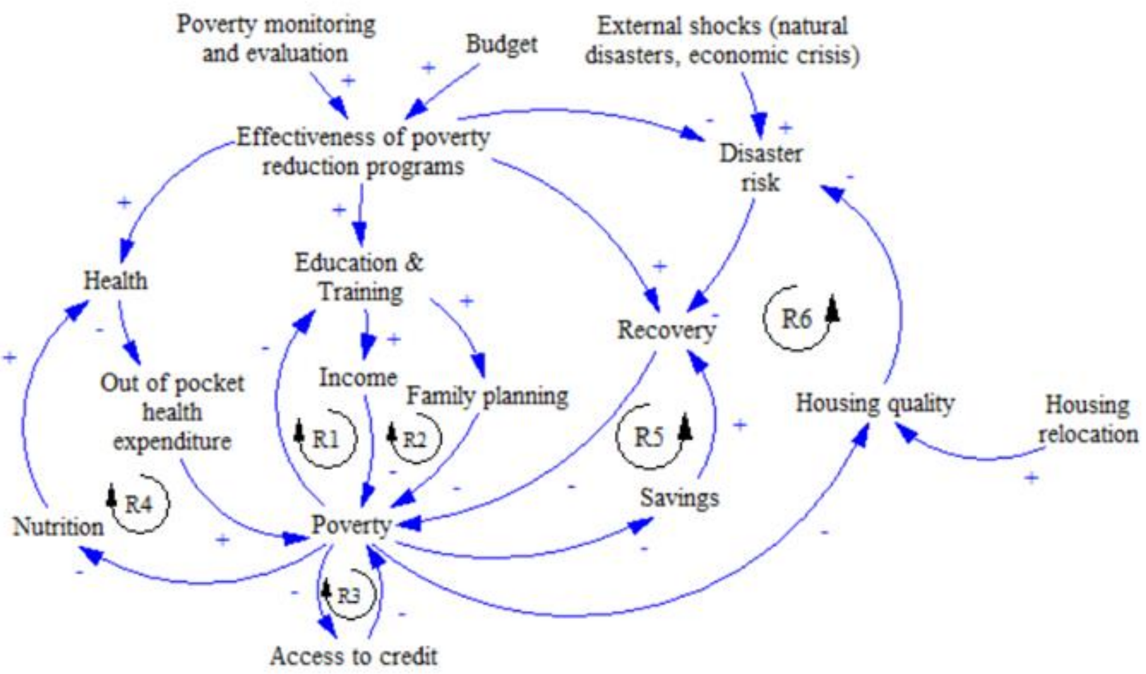


Figure 17. Poverty subsystem CLD.

Figure 18 shows the dynamic hypothesis that can be derived from the poverty subsystem CLD. It shows two curves. Curve A is the trend in poverty when there is no intervention. Poverty traps continue to deepen poverty, and more people become poor as shocks and other negative stimulus occur. Curve B is the trend in poverty when there is effective intervention. Shocks may occur to stimulate the poverty cycle, but poverty interventions prevent the poverty trap and instead cause a decline in poverty.

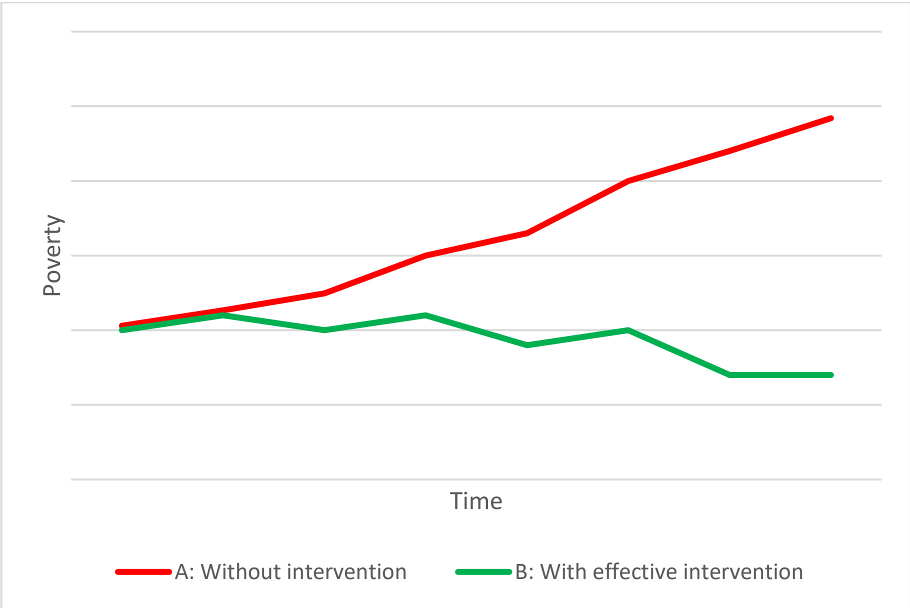


Figure 18. Poverty subsystem dynamic hypotheses.

3.3.7.2 SF Model structure

The poverty subsystem SF model is shown in Figure 19. As a limitation of this study, the poverty dynamics outlined in the CLD were not be covered in the scope of the SF model. Instead, statistics from the Philippine Statistics Authority were used to quantify income poverty.

Poverty is defined as having an per capita income below the poverty threshold which was PHP 28,682 per year for NCR in 2018 (Philippine Statistics Authority, 2018). The poverty incidence statistic is provided for both individuals and households. The poverty incidence for households is used to determine the “Number of households below poverty line” that is an input to the COVID-19 cost subsystem for the financial aid program. The poverty incidence for individuals is used to determine the “Total Annual Income Shortfall” that can give the LGU an idea of the annual aggregate amount that its poor constituents fall short of reaching the poverty threshold. “Income gap” here refers the fraction of shortfall from the poverty line for each average poor person.

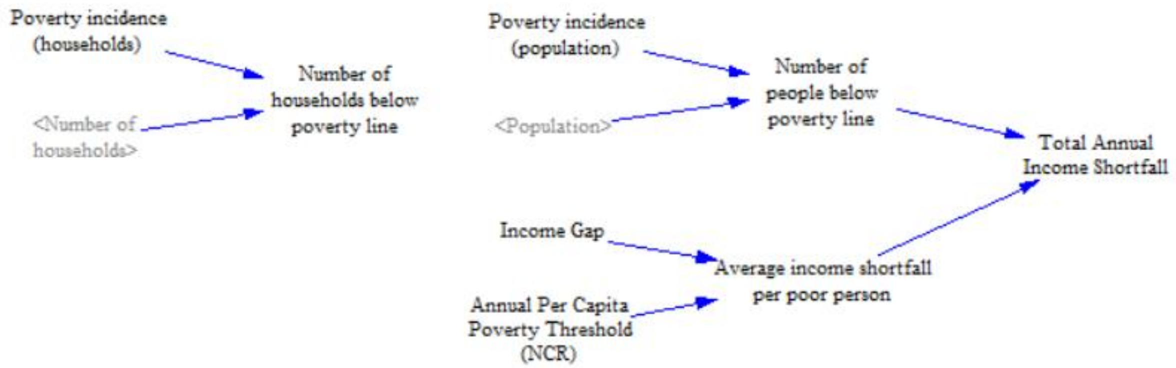


Figure 19. Poverty subsystem SF model.

3.3.8 COVID-19 cost subsystem

The COVID-19 pandemic has increased health system requirements and impacted all other sectors as efforts are made to contain the pandemic. This shock is considered in this model through its impact on the health system requirements and the additional costs that would be incurred within the LGU. This cost subsystem focuses on the latter.

3.3.8.1 CLD and Dynamic hypothesis

The COVID-19 cost subsystem CLD is shown in Figure 20. The four cost impacts within the LGU were identified as the online learning peripherals, personal protective equipment (PPE) for health workers, financial aid through the Social Amelioration Program (SAP), and PhilHealth coverage for those hospitalized due to COVID-19. Several of these actions, namely the use of PPE and lockdowns, also work to prevent the spread of COVID-19 and improve the situation, which should lead to less costs later but also have their own cost implications.

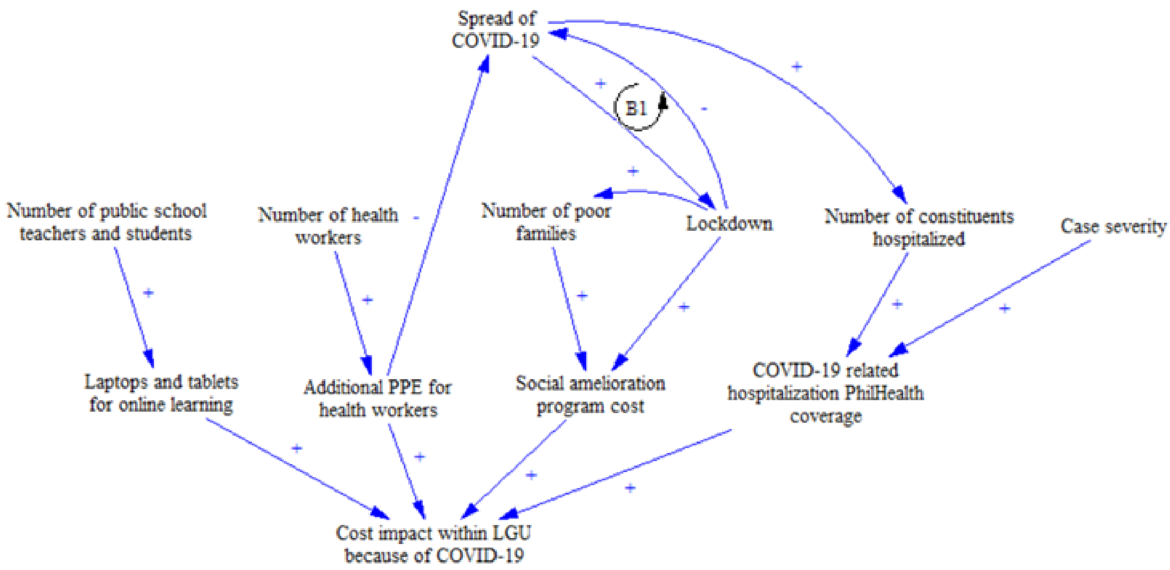


Figure 20. COVID-19 subsystem CLD.

Figure 21 shows the dynamic hypothesis that can be derived from the poverty subsystem CLD. The costs are incurred in “waves” because it follows the idea that infections come in waves. When the first infections occur, measures will be taken to reduce transmission rates. This can include lockdown, equipping health workers with PPE, social distancing, requiring the public to wear PPE, and work from home arrangements. The first two measures that were mentioned have cost implications to the LGU and are included in this CLD. As transmission rates are reduced and infections decrease, these measures to limit transmission may be relaxed—causing a resurgence of infection. The lockdown, as a measure to limit transmission, also affects the businesses in the city. In this model, it causes temporary unemployment in the employment subsystem as seen in Figure 16 above.

This cycle created by the balancing feedback between infection and public health measures results in the hypothesized waves of infection. Subsequent waves will incur lower costs because the laptops and tablets purchased for online learning is a one-time cost. Only new students and teachers in subsequent waves will be incurring additional costs. Subsequent waves are also assumed to infect less people and will have lower hospitalization costs. Figure 21 makes a simplifying assumption that costs are incurred at one point in time for each wave.

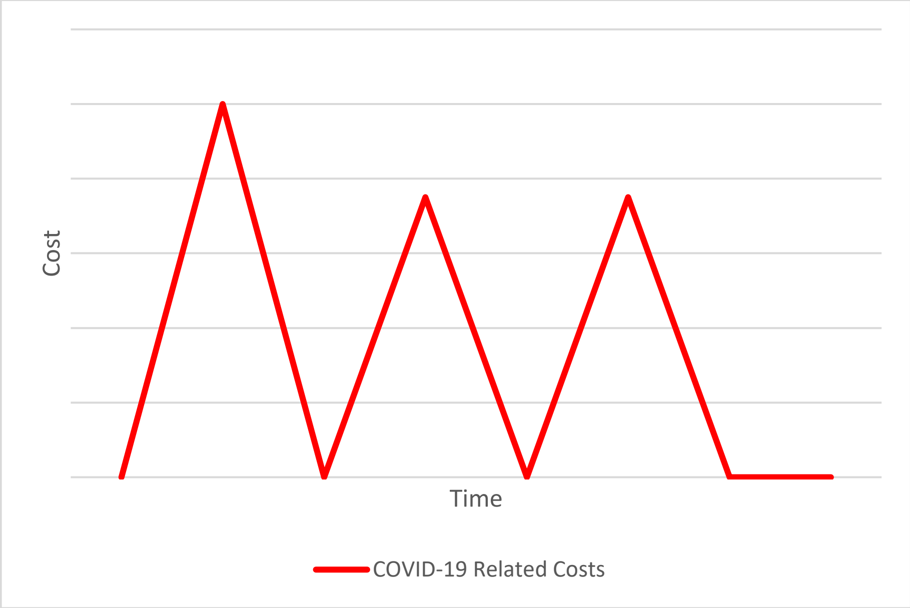


Figure 21. COVID-19 subsystem dynamic hypotheses

3.3.8.2 SF Model structure

For this model, only one wave was considered. Given that the time step of the model is 0.25 of a year, i.e. 3 months, the length of time for the wave is also considered to be 3 months. Figure 22 shows the model structure with each component's cost calculation.

The cost of PPEs is PHP 400 per set (Tantuico, 2020) and considers that each medical professional will need 365 sets of PPEs per year: two sets per workday and goes to work for half the number of days in a year.

The cost of COVID-19 hospitalizations considers an average coverage cost for each admitted COVID-19 patient. This average cost is based on the case rates of PhilHealth: PHP 43,000 coverage for mild pneumonia, PHP 143,000 for moderate pneumonia, PHP 333,000 for severe pneumonia, and PHP 786,000 for critical pneumonia (Billones et al., 2020). Due to the lack of data on case severity distribution, equal weights are assumed for each, resulting in an average case rate of PHP 326,250 per COVID-19 patient.

The cost of SAP considers the best case in NCR of PHP 8,000 per household per month for two months (Perez, 2020). The number of households that are beneficiaries of the SAP is assumed to be the number of poor families.

The cost of tablets and laptops is based on the estimation of the Pasig government, PHP 6,500 per tablet and PHP 20,000 per laptop (Alcober, 2020). One tablet is required per student and one laptop is required per teacher in elementary and secondary public schools within the LGU.

These cost assumptions are summarized in Table 11.

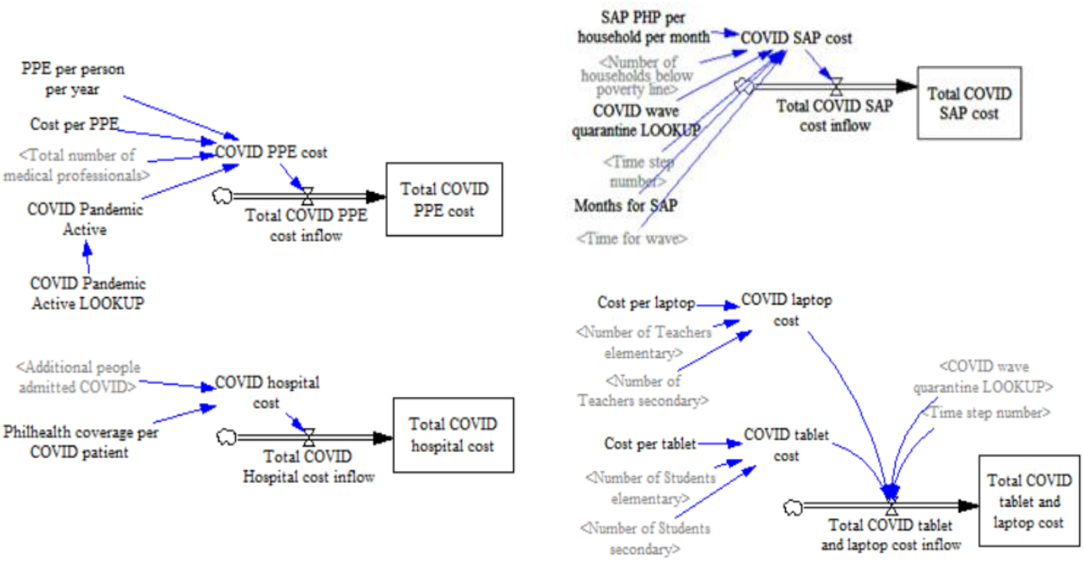


Figure 22. COVID-19 SF Model structure

Table 11. COVID-19 SF Model assumptions

Expenditure	Assumptions
PPE	PHP 400 per set
PhilHealth coverage	PHP 326,250 per case
Laptops for teachers	PHP 20,000 per laptop
Tablets for students	PHP 6,500 per tablet
Social Amelioration Program	PHP 8,000 per family for two (2) months

3.3.9 Scenarios

After constructing the model, the key scenarios were outlined, and the model parameters adjusted to test these scenarios.

The key scenarios that were explored in both Pasig and Valenzuela versions of the SERI model are the SERI Business-as-usual (BAU), SERI Priorities Scenario, and the SERI COVID-19 Scenario. For the SERI BAU Scenario, business-as-usual assumptions were retained, using the values as described in the model development section, without any COVID-19 impacts. The policy changes tested for in the SERI Priorities and COVID-19 Scenarios are shown in Table 12.

Table 12. Policy changes for Pasig and Valenzuela Priorities and COVID-19 Scenarios.

Subsystem	SERI Priorities - Pasig	SERI Priorities - Valenzuela	COVID-19
Demographics	-	-	-
Social services	Higher education and health services capacity. Ideal population per: Doctor – From 20,000 to 10,000 Nurse – From 20,000 to 10,000	-	COVID-19 patients admitted in: Pasig – 1,326 Valenzuela – 1,503 Increases ideal values in health service alternative

	Midwife – From 5,000 to 3,000 Hospital bed – From 800 to 600 Teachers – From 35 to 30 Classrooms – 30		benchmark by the number of COVID-19 admitted patients. Additional costs are incurred in this subsystem for medical professionals' PPE, hospitalized patients' PhilHealth coverage, and gadgets for online learning (See Table 11).
Housing	Higher in-city housing capacity. From zero to additional 50 units per year.	Higher out-of-city housing capacity. From zero to additional 50 units per year.	-
Economic	-	Higher agricultural activity and employment: From 9 to 10 Average number of employees per business.	Temporary unemployment of 12%. Additional costs incurred for SAP of families below the income poverty line (See Table 11).
Shock	No COVID-19.	No COVID-19.	One three-month "wave" of the COVID-19 pandemic and lockdown.

For priorities of Pasig, they indicated wanting to improve the education and health services, as well as provide more housing inside the city for those living in hazardous areas. Improving the education and health services capacities can be done in two ways. First, by increasing the targets. A higher goal will result in greater adjustments. Second, by decreasing the adjustment time. If procurement and hiring is more sensitive to the needs, i.e. gap between the actual and the goal, then the adjustments will be made faster. Note that only the targets and not the adjustment rates are changed in this scenario. For the priority of providing more housing, it can be implemented by increasing the in-city housing construction (Palermo, 2020).

For priorities of Valenzuela, they indicated wanting to provide more housing and increase agricultural production. For providing more housing, the outside of city housing construction will be increased, due to lack of ample space for this inside Valenzuela City (E. Reyes, personal communication, November 17, 2019). For increasing agricultural production, this cannot be tested directly because the model does not segregate different types of businesses. Instead, this scenario assumes that the LGU's promotion of agriculture will translate to an increase in the average number of people per business, presuming that agricultural production involves more workers than other businesses.

For the COVID-19 scenario, the three-month pandemic wave and lockdown affect the social and economic services requirements and costs. The pandemic wave brings about additional patients and costs for social services, while the lockdown itself causes unemployment and additional costs as well for aid through the SAP.

4. Results and Discussion for SERI

This chapter is divided into two parts. First is the baseline scenario and the insights derived from this model on the two cities' socio-economic resilience scores as operationalized in the SERI model. Second is the exploration of the city priority scenarios and the COVID-19 scenario. Sections may repeat analyses points when results for both cities are similar.

4.1 BAU

4.1.1 Pasig City

The results of the baseline run for Pasig City are shown and explained below.

4.1.1.1 Social services

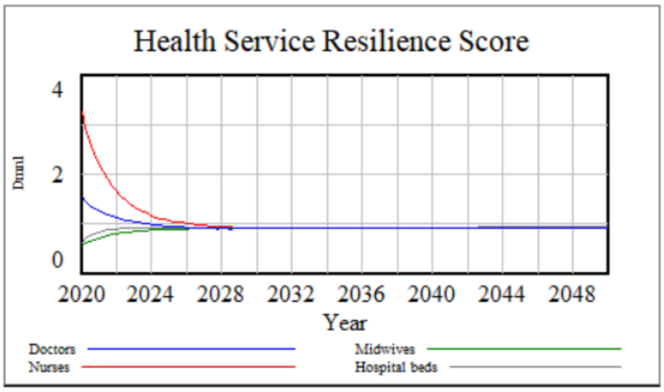
4.1.1.1.1 Health services resilience score

The health service resilience scores in Figure 23a show that doctors and nurses are initially above the LGU goal, while midwives and hospital beds are initially below the LGU goal. Following a goal-seeking model of change, doctors and nurses decrease and midwives and hospital beds increase to approach a resilience score of "1".

Figure 23b shows the case when the resilience score of health services is based on the alternative benchmarks. These benchmarks provide a better picture of the actual capacity needed, and are derived as shown in Figure 9. This shows that all personnel have resilience scores less than "1", indicating that they are insufficient.

If the LGU goals are the basis of the goal-seeking changes for the health service personnel and assets, only the number of hospital beds will have a resilience score that approaches "1" when compared to the alternative benchmarks. The health service capacity provided by the doctors, nurses, and midwives, will perpetually be lower than what is needed, as indicated by the alternative benchmarks. This shows that the LGU ideal ratios may not be a sufficient measure for the actual capacity needed.

a) Resilience Score based on LGU goal



b) Resilience Score based on alternative benchmarks

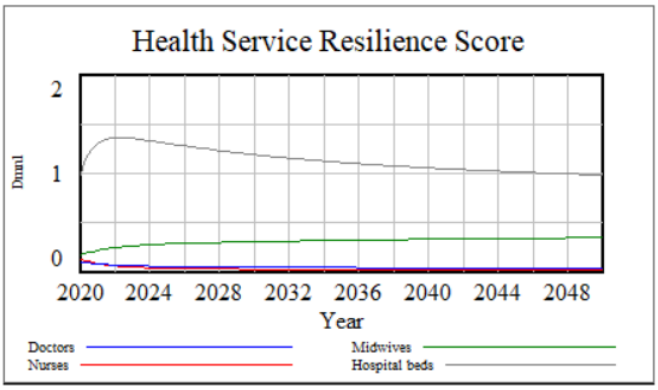


Figure 23. Pasig City Health Service BAU Resilience Scores based on (a) LGU goal and (b) alternative benchmarks.

4.1.1.1.2 Education services resilience score

The education service resilience score is broken down into the resilience scores for elementary and secondary education. This is an important distinction to make because there may be an uneven distribution of education service capacity between elementary and secondary. Figure 24 shows that for Pasig City, there is an uneven distribution, with secondary schools having an initial resilience score less than "1" while elementary schools have an initial resilience score above "1". This is due to the number of teachers, which are less than what is needed for secondary schools.

The convergence of both resilience scores towards "1" shows a redistribution of resources. This shows that it is important to set the right targets, because this would allow the proper re-allocation of resources. If targets are accurate and not set lower than what is actually needed, then a resilience score over "1" can indicate that the resources spent on maintaining this capacity (and possibly a buffer) can be better used elsewhere.

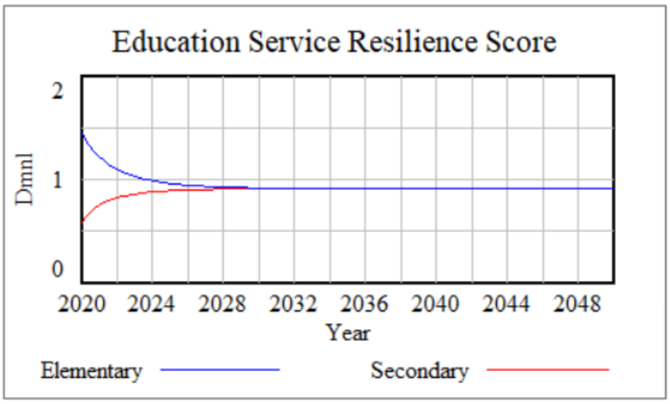


Figure 24. Pasig City Education Service Resilience Score.

4.1.1.1.3 Protection services resilience score

The protection services resilience scores for Pasig City in Figure 25 show that each of the Policemen, Firefighter, and Firetruck capacities are initially below the LGU targets. The resilience scores for Policemen and Firefighters improve and approach “1”, but that of the firetruck stays at a level much lower. Its resilience score is maintained at around 0.8. This is mainly because of the long adjustment time set for firetrucks of three years and a shorter years of useful life of 15 years, making it unable to catch up to the LGU’s target number of firetrucks that increases as population grows. The adjustment time is set longer because of the frictions that may exist in procurement for more expensive assets such as these.

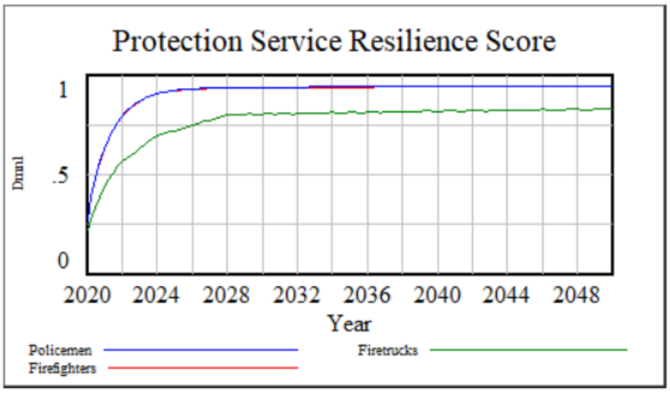


Figure 25. Pasig City Protection Services Resilience Score.

4.1.1.1.4 Cost implications

The cost implications of providing these social services are shown in Figure 26. The greatest costs are incurred by education, then by protection, and lastly by health services. These costs are mainly due to the salaries paid to personnel, which are incurred annually. Initially, in 2015, there are a total of 3,625 teachers; 407 police and 101 firefighters; and 58 doctors, 123 nurses, and 84 midwives. Annual salaries are highest for police and firefighters, followed by doctors, then teachers, nurses, and midwives (Figure 26).

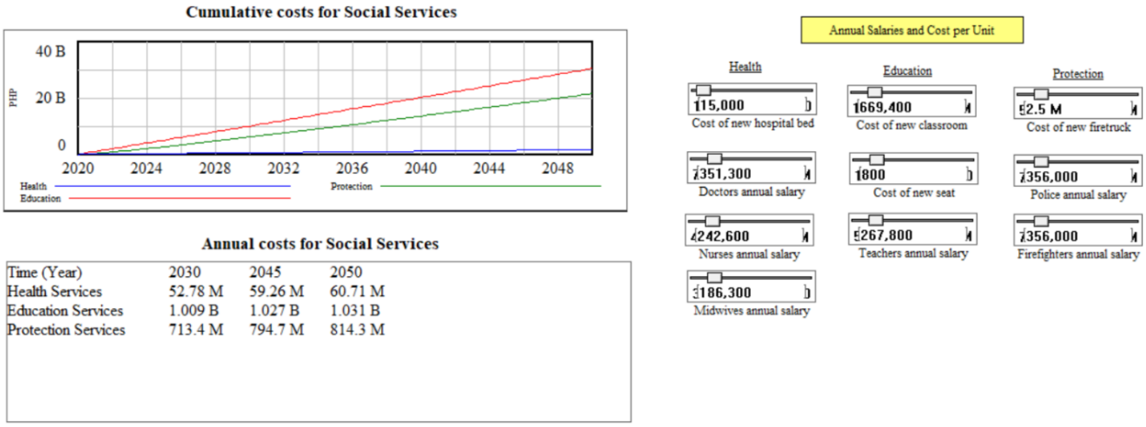


Figure 26. Cumulative and annual costs for Social Services and the corresponding annual salaries for personnel in Pasig City.

4.1.1.2 Housing and Employment

The social services previously mentioned were the public capacities provided by the LGU. Here, the housing and employment resilience scores refer to the total available to the LGU's constituents, whether the LGU's housing projects and jobs held by residents are inside or outside the city. The self-sufficiency score, on the other hand, shows how much of this capacity is within the LGU's jurisdiction. Figure 27 shows both resilience and self-sufficiency scores for Pasig city's housing and jobs.

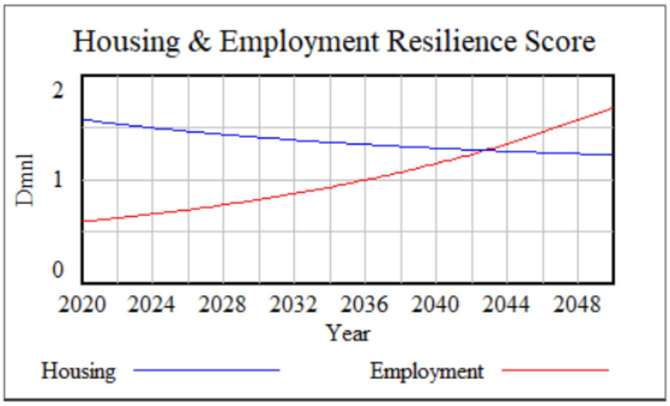
The housing resilience score is above "1" initially, and decreases over time (Figure 27a). This decrease in resilience score happens because the city's annual housing construction is set to "0" in the baseline case, so no housing capacity is added, while the ideal value for housing increases as population grows. Improving resilience here can mean either adding housing capacity or reducing the number of people who cannot afford formal housing or are living in hazardous areas.

Pasig City's housing self-sufficiency score of 0.35 shows that most of the housing constructed by the LGU is outside of the LGU itself (Figure 27b). It does not change in the baseline scenario because no new housing is added.

For the employment resilience score, it is initially below "1" and continues to grow over time (Figure 27a). This increase in resilience score occurs because the rate of job growth is higher than the rate of working-age population growth. This assumes that starting with the jobs currently available to residents both inside and outside of the city, the growth of businesses and employment will also mean that those jobs are available to residents as well.

Pasig City's employment self-sufficiency score is initially around 0.6 and decreases over time (Figure 27b). This happens because the growth rate of business and employment generation within the city is outpaced by the growth rate of jobs outside the city, i.e. national employment growth. These growth rates can change over time as business environments evolve, however in this model they are kept static.

a) Resilience Score



b) Self-sufficiency Score

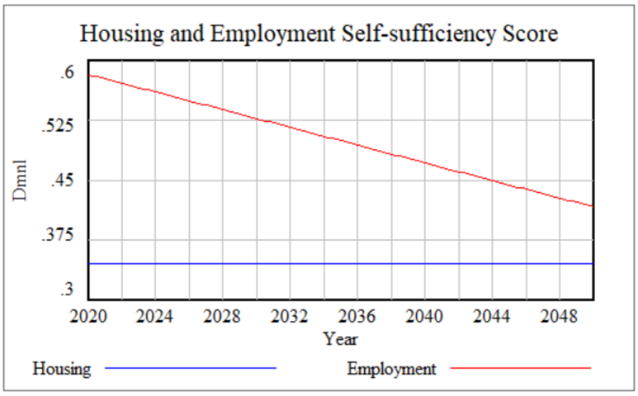


Figure 27. Pasig City Housing and Employment (a) Resilience and (b) Self-sufficiency Scores.

4.1.1.3 Overall socio-economic resilience

Overall, the baseline run of the SERI model for Pasig City shows a resilience score that is close to “1” initially and increases over time (Figure 28). This uses the LGU ideal ratios as benchmarks for the health services resilience scores instead of alternative targets, which are higher. The social service resilience scores that are less than “1” are mostly due to the adjustment times causing the “action to close the gap” to be slower than the growth of the respective goals, but these are offset by the higher housing and employment scores. This indicates that following the baseline growth rates for business and out-of-city job growth, the zero low-cost housing construction, and the goal-seeking model of change for social services, Pasig City will maintain a good resilience score over time.

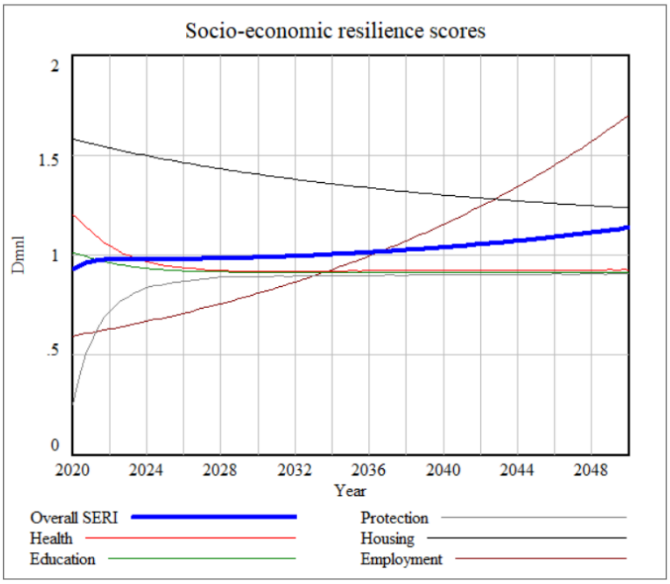


Figure 28. Pasig City overall socio-economic resilience score.

4.1.2 Valenzuela City

The results of the baseline run for Valenzuela City are shown and explained below.

4.1.2.1 Social services

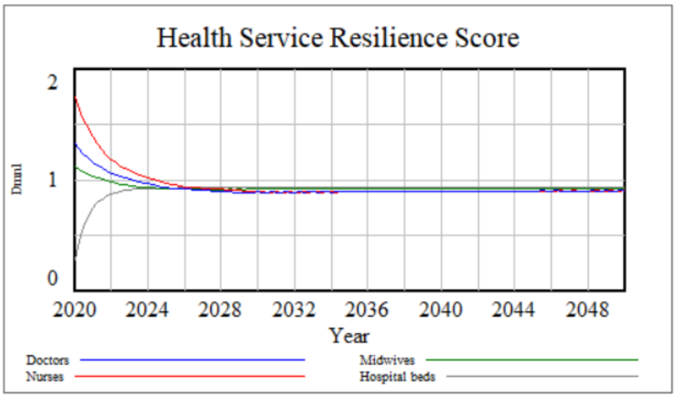
4.1.2.1.1 Health services resilience score

The health service resilience scores in Figure 29a show that doctors, nurses, and midwives are all initially above the LGU goal, while hospital beds is initially below the LGU goal. Following a goal-seeking model of change, doctors, nurses, and midwives decrease while hospital beds increase to approach a resilience score of “1”.

Figure 29b shows the case when the resilience score of health services is based on the alternative benchmarks. These benchmarks provide a better picture of the actual capacity needed, and are derived as shown in Figure 9. This shows that all personnel, including midwives, have resilience scores less than “1”, indicating that they are insufficient.

If the LGU goals are the basis of the goal-seeking changes for the health service personnel and assets, only the number of hospital beds will have a resilience score that approaches “1” when compared to the alternative benchmarks. The health service capacity provided by the doctors, nurses, and midwives, will perpetually be lower than what is needed, as indicated by the alternative benchmarks. This shows that the LGU ideal ratios may not be a sufficient measure for the actual capacity needed.

c) Resilience Score based on LGU goal



d) Resilience Score based on alternative benchmarks

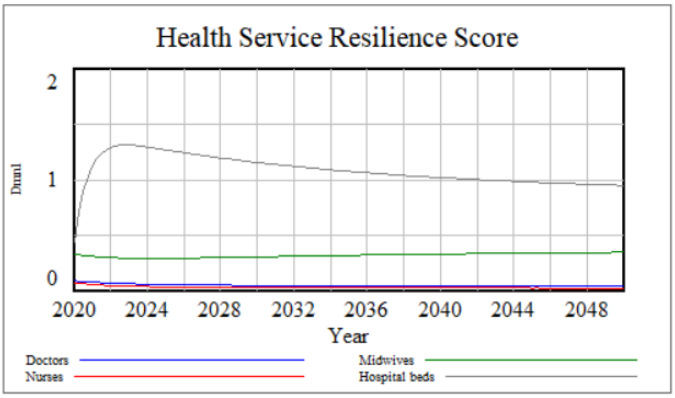


Figure 29. Valenzuela City Health Service Resilience Scores based on (a) LGU goal and (b) alternative benchmarks.

4.1.2.1.2 Education services resilience score

The education service resilience score is broken down into the resilience scores for elementary and secondary education. This is an important distinction to make because there may be an uneven distribution of education service capacity between elementary and secondary. Figure 30 shows that for Valenzuela City, there is an uneven distribution, with secondary schools having an initial resilience score less than "1" while elementary schools have an initial resilience score above "1". This is due to the number of teachers, which are less than what is needed for secondary schools.

The convergence of both resilience scores towards "1" shows a redistribution of resources. This shows that it is important to set the right targets, because this would allow the proper re-allocation of resources. If targets are accurate and not set lower than what is actually needed, then a resilience score over "1" can indicate that the resources spent on maintaining this capacity (and possibly a buffer) can be better used elsewhere.

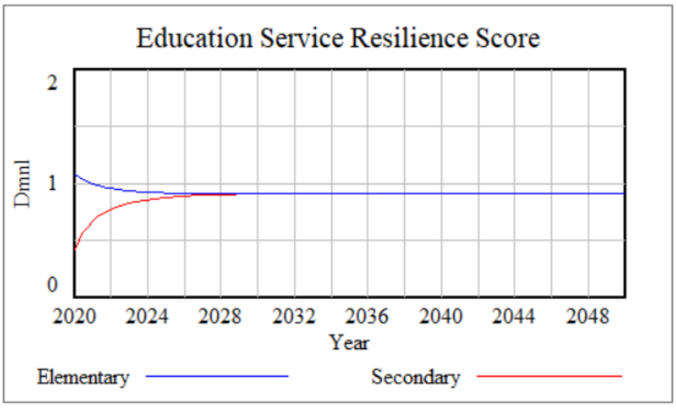


Figure 30. Valenzuela City Education Service Resilience Score.

4.1.2.1.3 Protection services resilience score

The protection services resilience scores for Valenzuela City in Figure 31 show that each of the policeman, firefighter, and firetruck capacities are initially below the LGU targets. The resilience scores for policemen and firefighters improve and approach “1”, but that of the firetruck stays at a level much lower. Its resilience score is maintained at around 0.8. This is mainly because of the long adjustment time set for firetrucks of three years and a shorter years of useful life of 15 years, making it unable to catch up to the LGU’s target number of firetrucks that increases as population grows. The adjustment time is set longer because of the frictions that may exist in procurement for more expensive assets such as these.

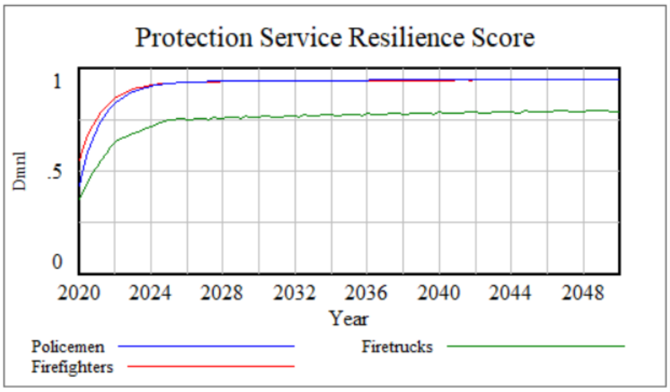
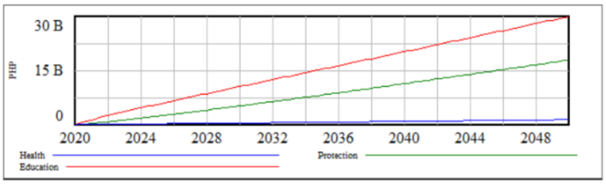


Figure 31. Valenzuela City Protection Services Resilience Score.

4.1.2.1.4 Cost implications

The cost implications of providing these social services are shown in Figure 32. The greatest costs are incurred by education, then by protection, and lastly by health services. These costs are mainly due to the salaries paid to personnel, which are incurred annually. Initially, in 2015, there are a total of 3,307 teachers; 535 police and 171 firefighters; and 41 doctors, 54 nurses, and 139 midwives. Annual salaries are highest for police and firefighters, followed by doctors, then teachers, nurses, and midwives (Figure 32).

Cumulative costs for Social Services



Annual costs for Social Services

Time (Year)	2030	2045	2050
Health Services	43.3 M	48.6 M	49.85 M
Education Services	963.3 M	977.1 M	980.6 M
Protection Services	589.3 M	657.7 M	676.8 M

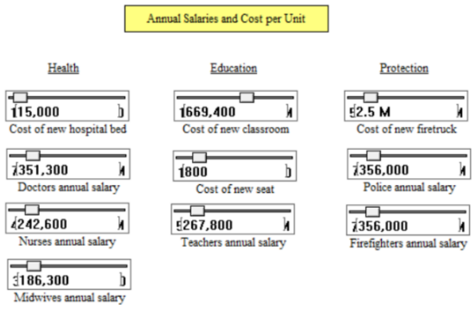


Figure 32. Cumulative and annual costs for Social Services and the corresponding annual salaries for personnel in Valenzuela City.

4.1.2.2 Housing and Employment

The social services previously mentioned were the public capacities provided by the LGU. Here, the housing and employment resilience scores refer to the total available to the LGU's constituents, whether the LGU's housing projects and jobs held by residents are inside or outside the city. The self-sufficiency score, on the other hand, shows how much of this capacity is within the LGU's jurisdiction. Figure 27 shows both resilience and self-sufficiency scores for Valenzuela City's housing and employment.

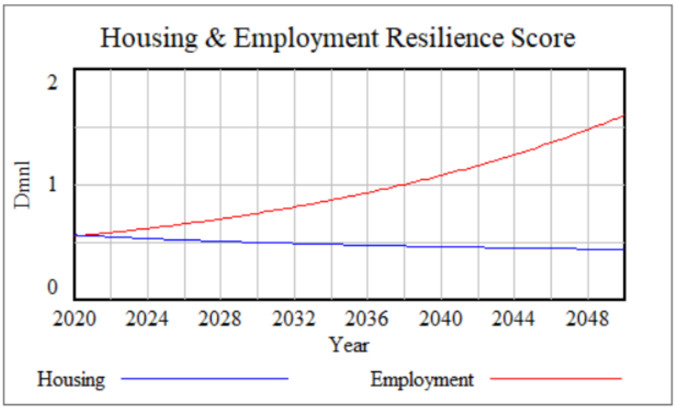
The housing resilience score is below "1" initially, and further decreases over time (Figure 33**Figure *27***a). This decrease in resilience score happens because the city's annual housing construction is set to "0" in the baseline case, so no housing capacity is added, while the ideal value for housing increases as population grows. Improving resilience here can mean either adding housing capacity or reducing the number of people who cannot afford formal housing or are living in hazardous areas.

Valenzuela City's housing self-sufficiency score of "1" shows that all of the housing constructed by the LGU is inside of the LGU itself (Figure 33b). It does not change in the baseline scenario because no new housing is added.

For the employment resilience score, it is initially below "1" and continues to decrease over time (Figure 33a). This decrease in resilience score occurs because the rate of job growth is lower than the rate of working-age population growth. This assumes that starting with the jobs currently available to residents both inside and outside of the city, the growth of businesses and employment will also mean that those jobs are available to residents as well.

Valenzuela City's employment self-sufficiency score is initially around 0.55 and decreases over time (Figure 33b). This happens because the growth rate of business and employment generation within the city is outpaced by the growth rate of jobs outside the city, i.e. national employment growth. These growth rates can change over time as business environments evolve, however in this model they are kept static.

a) Resilience Score



b) Self-sufficiency Score

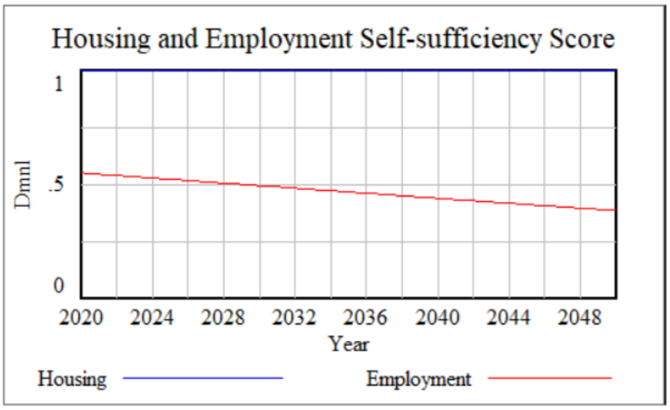


Figure 33. Valenzuela City Housing and Employment (a) Resilience and (b) Self-sufficiency Scores.

4.1.2.3 Overall socio-economic resilience

Overall, the baseline run of the SERI model for Valenzuela City shows a resilience score that is close to "0.5" initially and increases over time but stops short of reaching "1" within the simulation period (Figure 34). This uses the LGU ideal ratios as benchmarks for the health services resilience scores instead of alternative targets, which are higher. The social service resilience scores are mostly due to the adjustment times causing the "action to close the gap" to be slower than the growth of the respective goals, but these are offset by the higher housing and employment scores. This indicates that following the baseline growth rates for business and out-of-city job growth, the zero low-cost housing construction, and the goal-seeking model of change for social services, Valenzuela City's overall resilience score will not reach "1" but will increase slowly due to the employment resilience score.

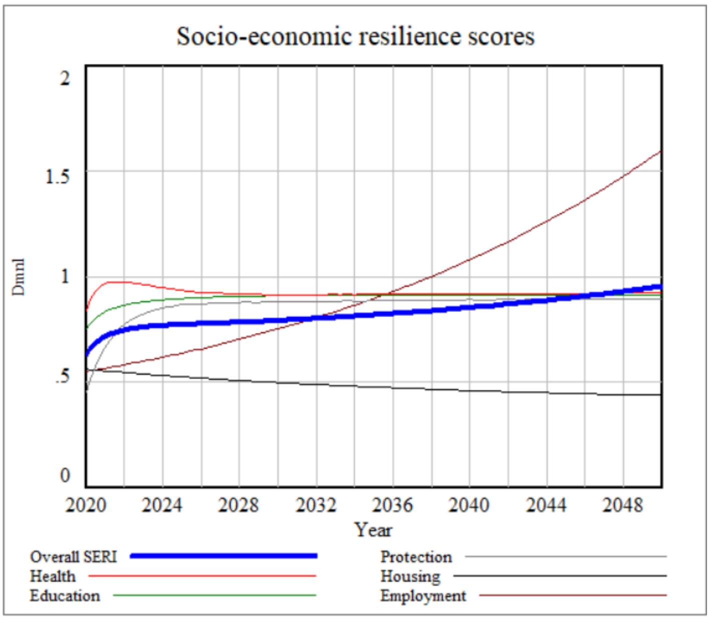


Figure 34. Valenzuela City overall socio-economic resilience score.

4.1.3 Discussion of goal-seeking model

Sections 4.1.1.1 and 4.1.2.1 are about the social services, and the growth of the stocks of personnel and assets under each social service are driven by the goal-seeking model. When change is based on this, it is important to set the right targets and to have good adjustment times.

Setting the right targets are important. The system will tend to close the gap, but the correct gap must first be recognized for this to be effective. Targets that are too low means that service capacities will either (a) not be increased enough (if this is initially below the target) or (b) be reduced due to an apparent inefficient allocation of resources (if this is initially above the target). Either way, actual resilience will suffer. On the other hand, targets that are too high may result in inefficient allocation of resources. The correct targets (considering buffers) must be set and maintained.

Not only do you need the right targets; you also need good adjustment times. Being responsive means that you can meet the goals quicker, while long adjustment times may mean that the goal could never be met (if the goal increases at the same rate of change or greater). Alternatively, if adjustment times are long and cannot be changed because of structural/systemic reasons, goals would need to be set higher than what is needed to make up for the long adjustment times.

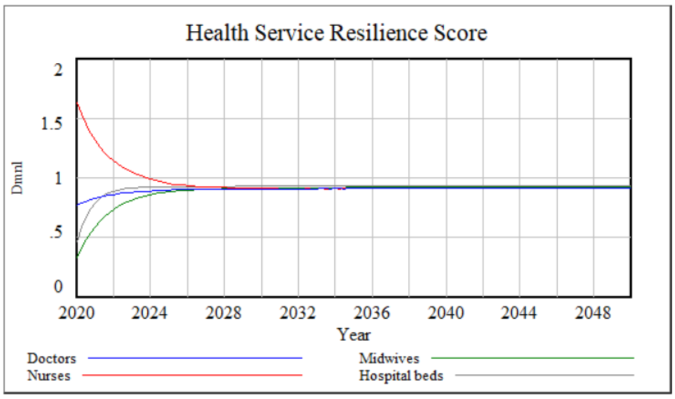
4.2 Priority Scenarios

4.2.1 Pasig City

Pasig City’s priority scenario consists of raising the LGU ideal ratios for health and education subsystems, as well as providing in-city relocation sites.

Figure 35a shows the resulting resilience scores when compared to LGU targets. While the BAU indicated doctors and nurses were initially above their ideal numbers, this Priority Scenario with higher targets shows that doctors are initially below the ideal number and only the number of nurses is above the ideal. For resilience scores calculated using the alternative benchmarks (Figure 35b), the same trend is observed as the BAU except that the resilience scores are approaching higher values. This is because the higher goal-seeking targets come closer to the actual capacities needed.

a) Resilience Score based on LGU goal



b) Resilience Score based on alternative benchmarks

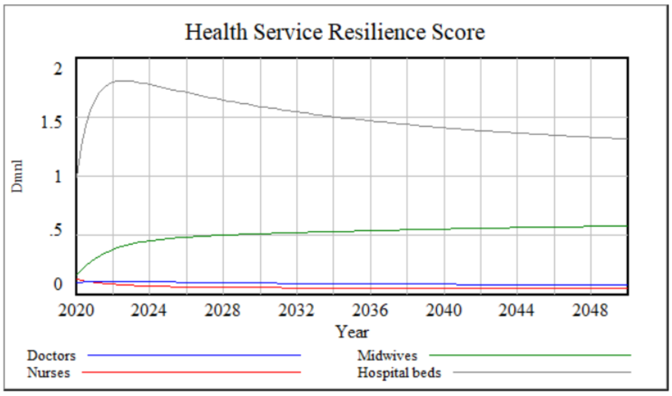


Figure 35. Pasig City Health Service Priority Scenario Resilience Scores based on (a) LGU goal and (b) alternative benchmarks.

Figure 36 shows the resilience scores of elementary and secondary education services with higher targets. The pattern is the same, wherein the elementary education service resilience score is still initially above the target and has to decrease, while that of secondary education is below and has to increase.

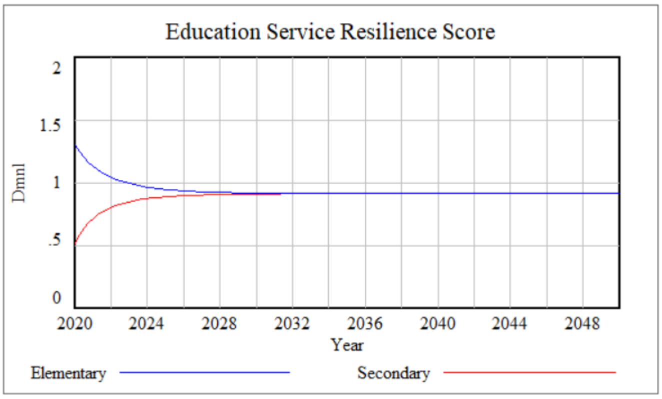


Figure 36. Pasig City Education Service Priority Scenario Resilience Scores

The construction of an additional 50 units of in-city housing per year results in improving resilience and self-sufficiency scores for housing (Figure 37). In the case of Pasig, the housing resilience score is already above “1” initially. This annual housing construction slows down the decline in the resilience score but does not cause the score to increase because required capacity is still growing at a faster rate. The self-sufficiency score of housing, on the other hand, grows steadily in this scenario (Figure 37) because the additional housing is being provided inside the city.

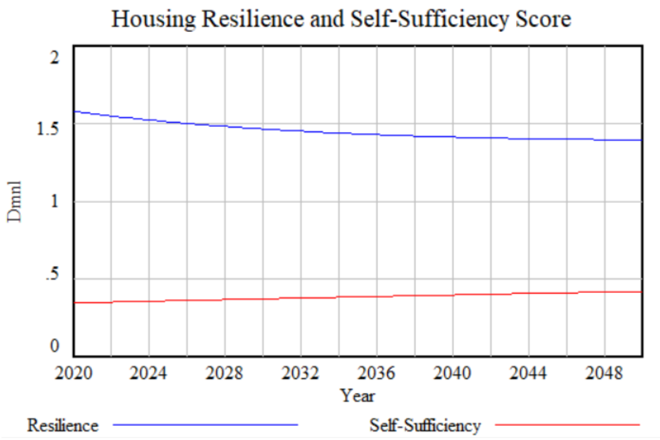


Figure 37. Pasig City Housing Priority Scenario Resilience and Self-sufficiency Score.

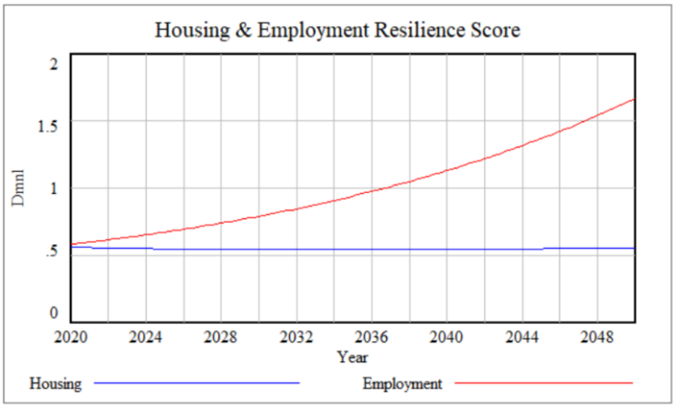
4.2.2 Valenzuela City

Valenzuela City’s priority scenario consists of increasing the number of employees per business (a way to operationalize a greater share of agricultural output by Valenzuela businesses) and constructing housing outside the city.

Figure 38a shows the resulting resilience scores for housing and employment. That of housing still decreases but eventually starts to increase. This increase in housing units eventually leads to an increase in the housing resilience score when the rate of growth of the population that needs housing becomes less than the rate of housing unit increase. Population does not grow exponentially but is projected to slow down.

Figure 38b shows the resulting self-sufficiency scores for housing and employment. Since the construction of housing occurs outside the City, the self-sufficiency score declines.

a) Resilience Score



b) Self-Sufficiency Score

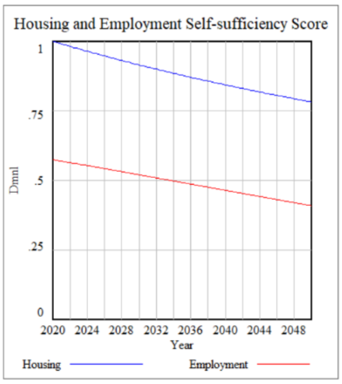


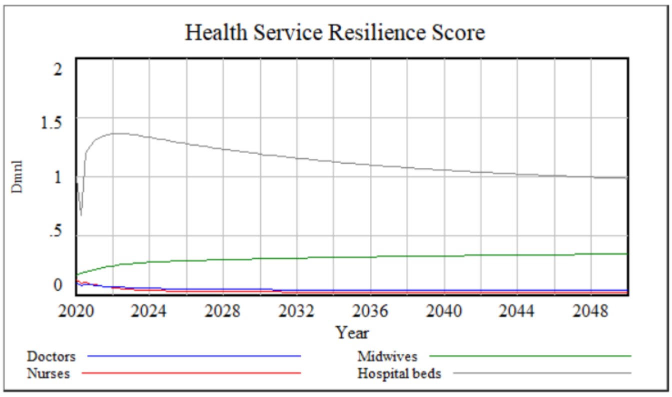
Figure 38. Valenzuela City Priority Scenario Housing and Employment (a) Resilience and (b) Self-Sufficiency Scores.

4.3 COVID-19 Scenario

The shock considered in this model is COVID-19. It affects the health service and employment subsystems and incurs costs. Specifically: this factors in a 3-month lockdown wherein (a) hospitalized COVID-19 patients are subsidized by PhilHealth and add to the requirements for health service capacity, (b) poor families are given SAP, (c) a portion of the population is unable to work and unemployment temporarily rises, and (d) schools begin online-based learning and students need tablets while teachers need laptops. This also considers a 1-year active period wherein medical personnel are required to wear PPE.

Alternative benchmarks are used for the health service resilience scores to see the impact of additional hospitalized patients (Figure 39). This shows the dip in the resilience score of hospital beds, doctors, and nurses due to COVID-19, which is not observable when measuring the resilience score using the LGU goal that is merely based on an ideal ratio to the total population. Most notable is that the hospital beds' resilience score dips below "1" following the impact of the extra bed days needed by COVID-19 patients. It quickly recovers because in this scenario, the pandemic affects only the demand and is only active for a short period of time. Other shocks that affect supply will have a longer recovery, according to the goal-seeking model.

a) Pasig City



b) Valenzuela City

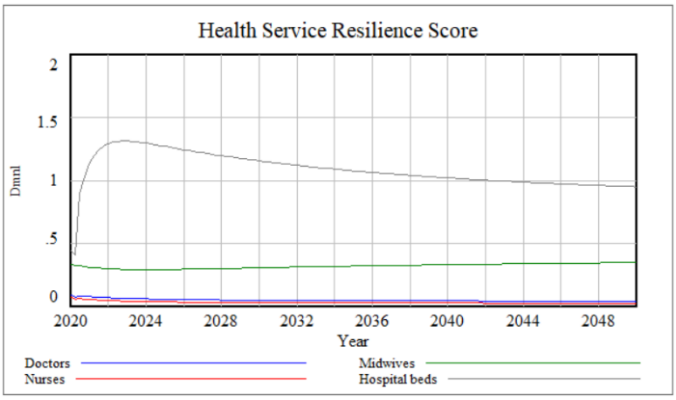
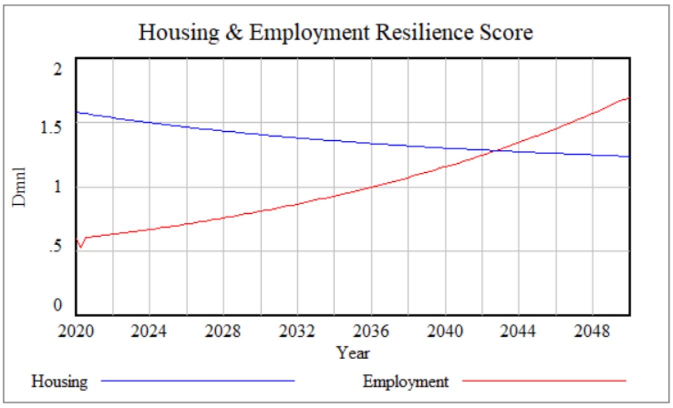


Figure 39. COVID-19 Scenario Health Service Resilience Scores of (a) Pasig City and (b) Valenzuela City.

The impacts of COVID-19 on employment can be seen in Figure 40. Pasig City and Valenzuela City show the same trends wherein the dip in employment resilience is followed by a quick recover to pre-COVID-19 levels. Other metrics can be affected such as business and employment growth rates, but only the temporary unemployment caused by COVID-19 is taken into consideration in this model.

a) Pasig City



b) Valenzuela City

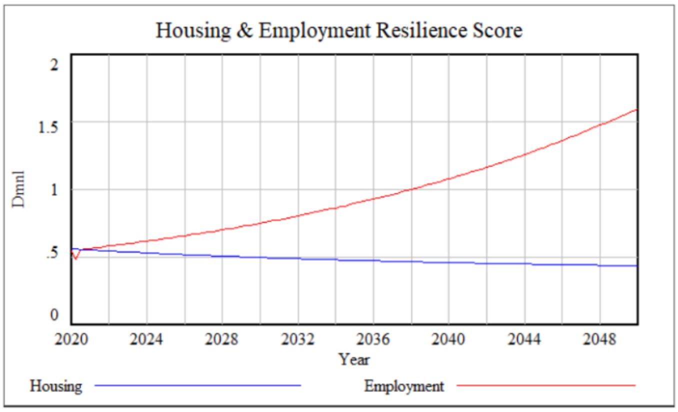


Figure 40. COVID-19 Scenario Employment Resilience Scores of (a) Pasig City and (b) Valenzuela City.

The costs incurred by COVID-19 are shown in Figure 41. Each of Pasig's costs are higher than Valenzuela's because of the higher populations and greater number of health personnel.

c) Pasig City

Total COVID PPE cost	45.27 M
Total COVID SAP cost	52.19 M
Total COVID hospital cost	272.2 M
Total COVID tablet and laptop cost	910 M

d) Valenzuela City

Total COVID PPE cost	39.31 M
Total COVID SAP cost	12.28 M
Total COVID hospital cost	308.6 M
Total COVID tablet and laptop cost	850.4 M

Figure 41. COVID-19 Scenario Health Service Costs incurred in (a) Pasig City and (b) Valenzuela City.

5. Integrated Urban Services Resilience Index

The IUSRI model integrates both SERI and UERI models to show the resilience score that factors in both socio-economic and ecological services. This chapter shows the process of integration, as well as sample simulations with this joint model.

5.1 SERI and UERI integration

The SERI model for each city was combined with its respective UERI model. UERI models for Pasig and Valenzuela have structural differences because of considerable differences in their systems for delivering ecological services, and thus differences in the data that they had available. The SERI model, on the other hand, has the same structure for both cities because of the similarities in the systems for providing socio-economic services. Only the city-specific variables are adjusted to customize the model for each city.

The population subsystem from the SERI model connects to the population inputs in the UERI model, replacing the UERI model's non-age-disaggregated model that uses a simple population growth rate. However, the UERI and SERI model development were limited in the possible feedbacks that could be built in, due to the lack of data that could connect variables from the ecological services to the socio-economic services.

The sample simulations for the IUSRI combine the resulting resilience scores from the UERI and SERI BAU Scenarios to gauge the overall Urban Services Resilience scores of each city. The component scores of the UERI and SERI are given equal weights by default in the calculation of the IUSRI.

5.2 Graphical User Interface

A graphical user interface (GUI) was created using Vensim® software to allow the members of the local government unit to interact with the model. The purpose of the GUI is to guide stakeholders in decision planning by assessing the impacts of different development plans to the overall Urban Ecosystem Resilience (UER). The GUI contains adjustable sliders assigned to selected variables from the different Urban Ecosystem Services (UES) modules that have significant influence on the UER scores. These changes are represented visually through the graphs of the UERI and the self-sufficiency, respectively.

There are five main views that were developed as the IUSRI's GUI's. The first is the IUSRI graph interface that combines the UERI and SERI resilience scores according to the determined weights (Figure 42). The second is the UERI Resilience Interface for Pasig (Figure 43a) and Valenzuela (Figure 43b). The third is the UERI Self-sufficiency Interfaces for Pasig (Figure 44a) and Valenzuela (Figure 44b). The fourth and fifth are the SERI Resilience Interface (Figure 45) and the SERI Self-sufficiency Interface (Figure 46) that are the same for both cities. Two additional views were developed to present the costs incurred by the social services (Figure 48) and the impact of the COVID-19 pandemic on the SERI and additional costs (Figure 48).

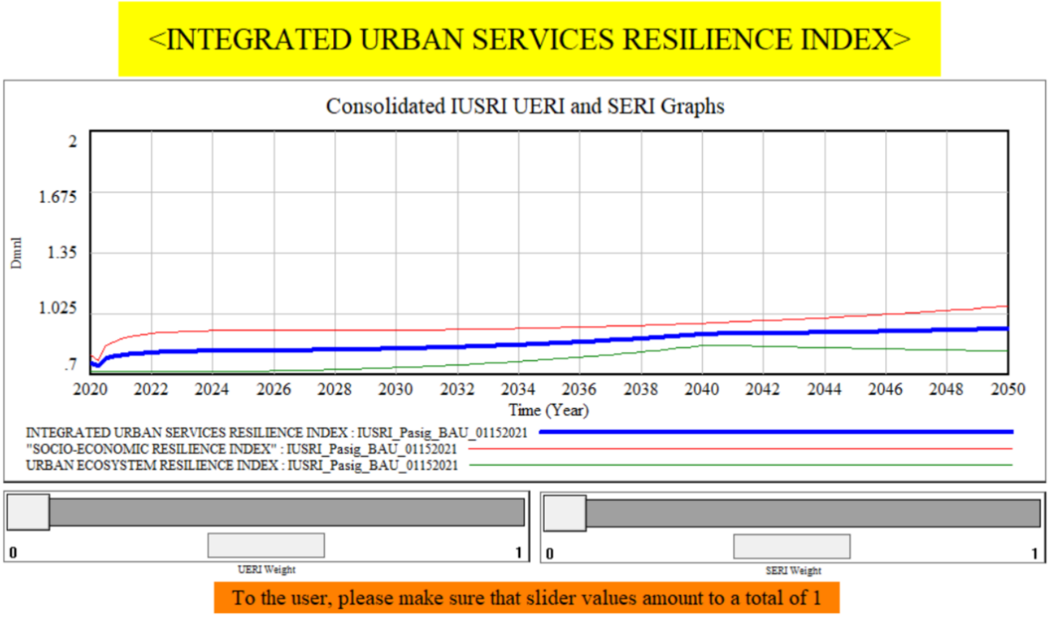
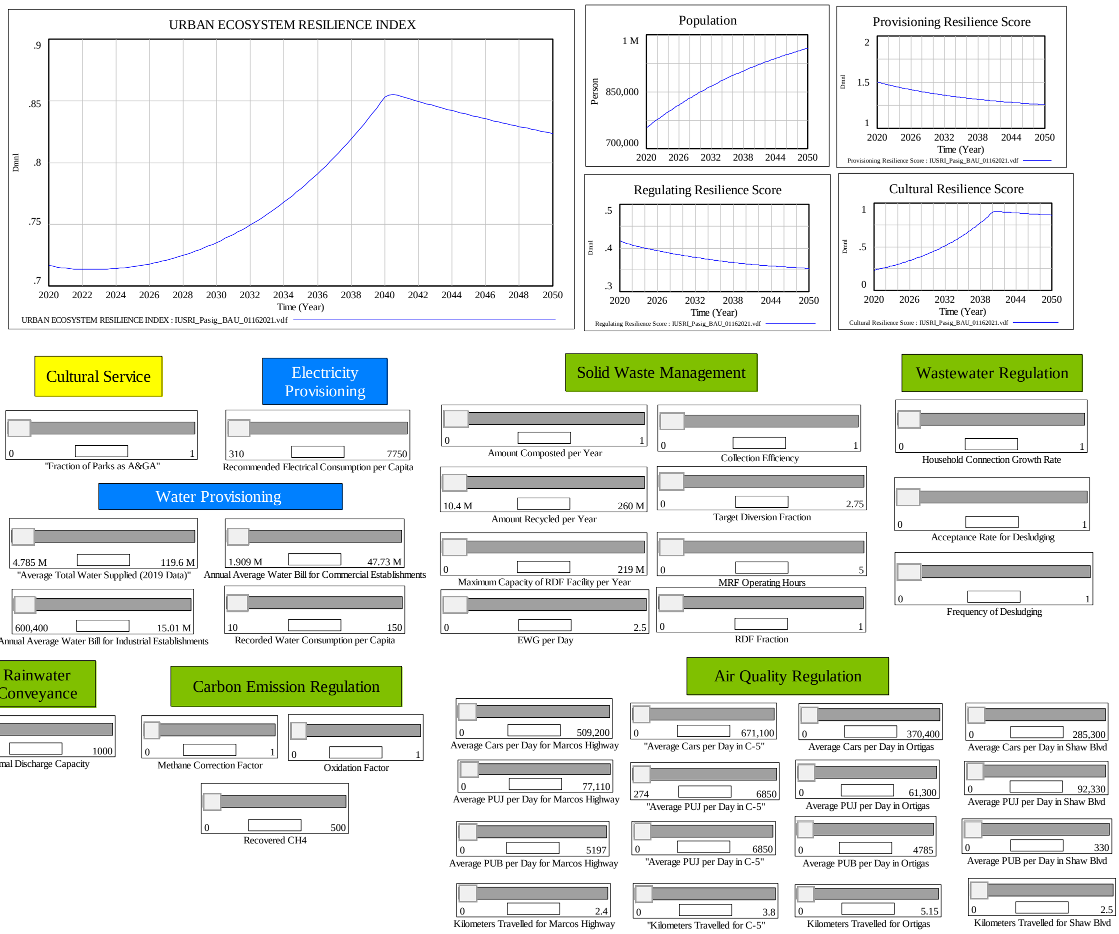


Figure 42. GUI View 1: Overall IUSRI graph.

a) Pasig City

UERI Resilience Interface



b) Valenzuela City

UERI Resilience Interface

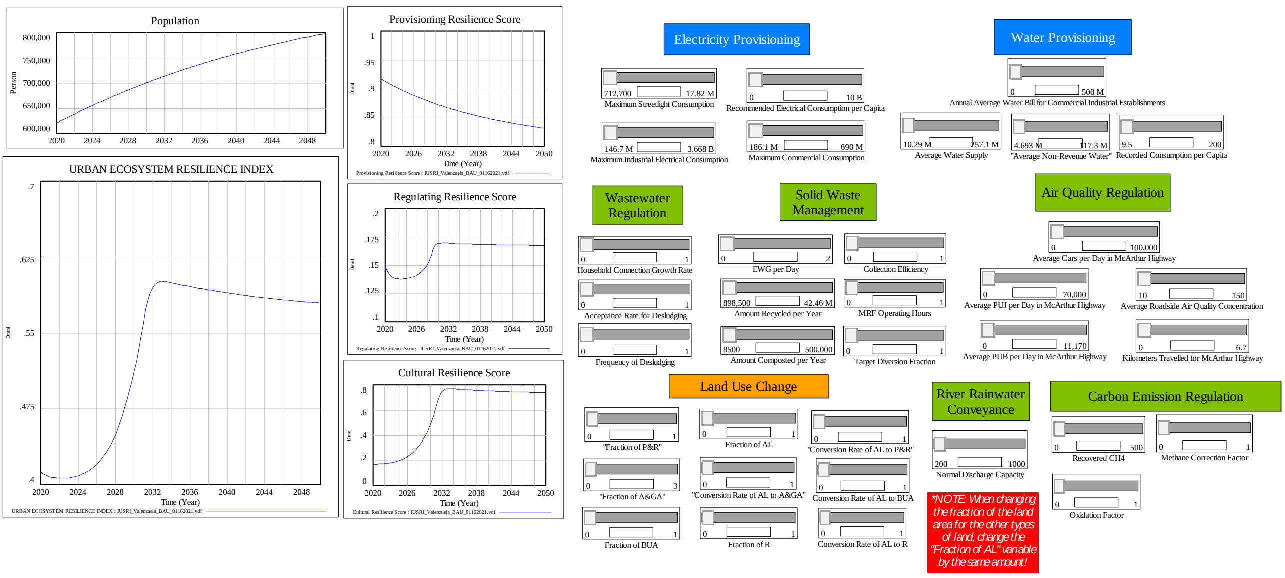
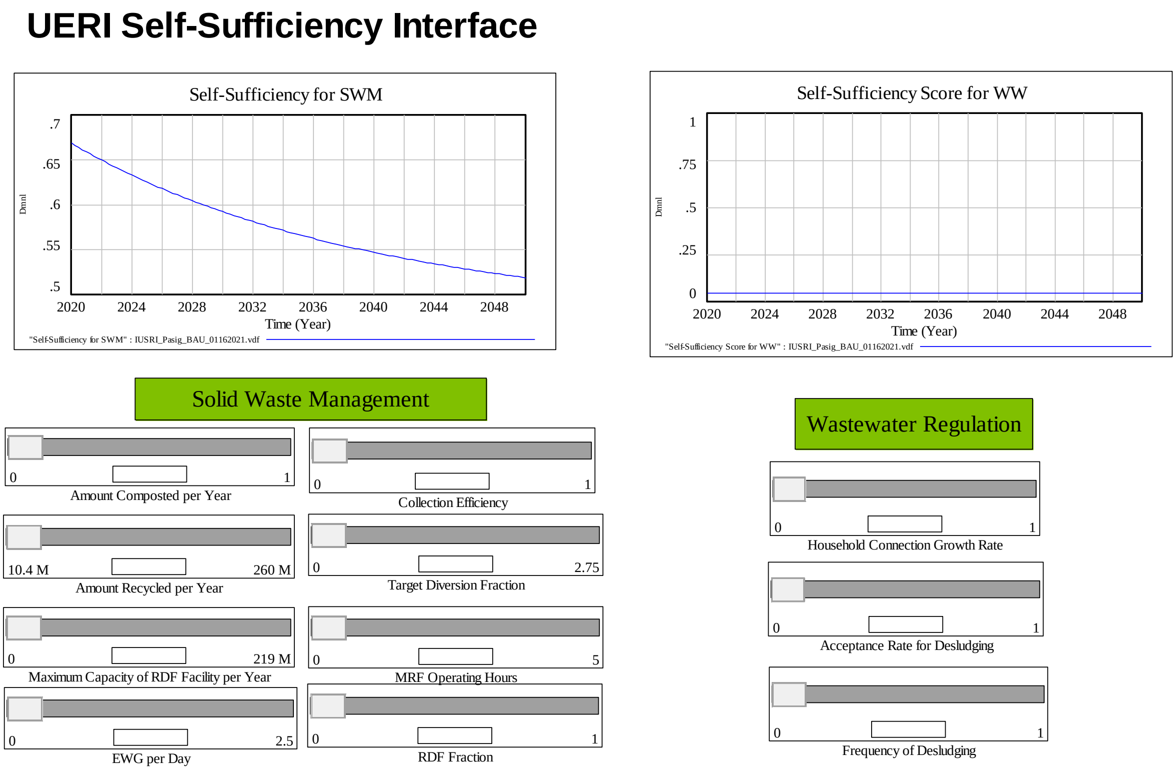


Figure 43. GUI View 2: UERI Resilience Interface for (a) Pasig and (b) Valenzuela City.

a) Pasig City



b) Valenzuela City

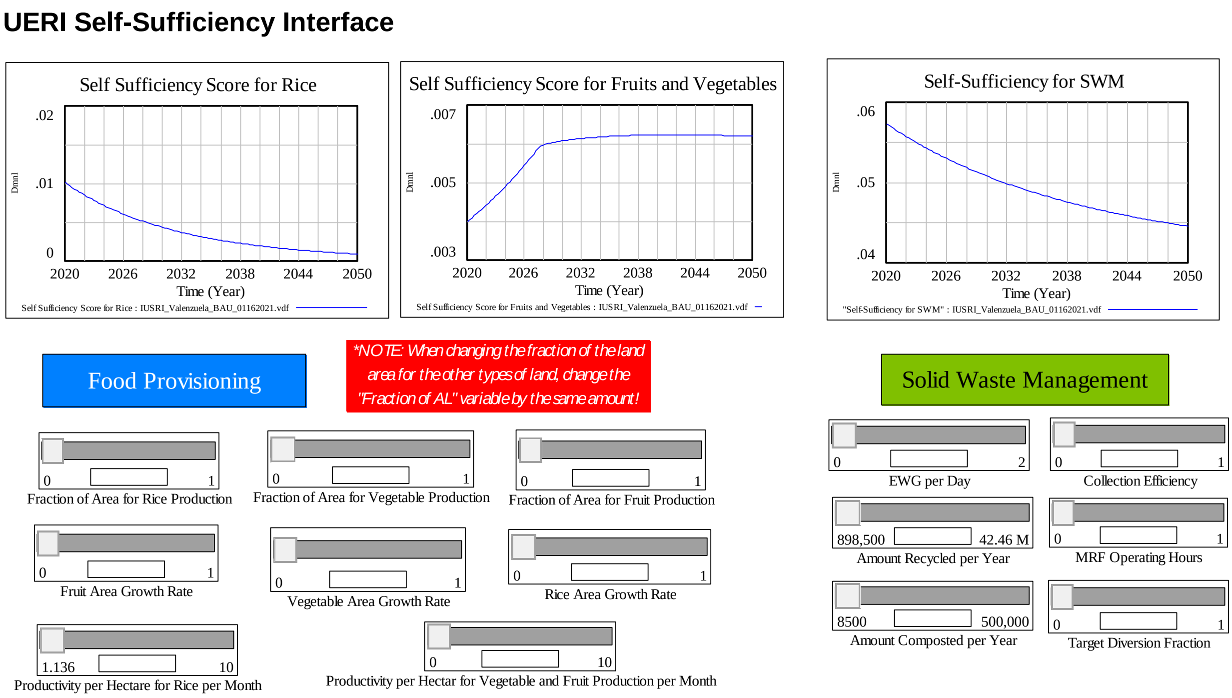


Figure 44. GUI View 3: UERI Self-Sufficiency Interface for (a) Pasig and (b) Valenzuela City

Figure 45. GUI View 4: SERI Resilience Interface.

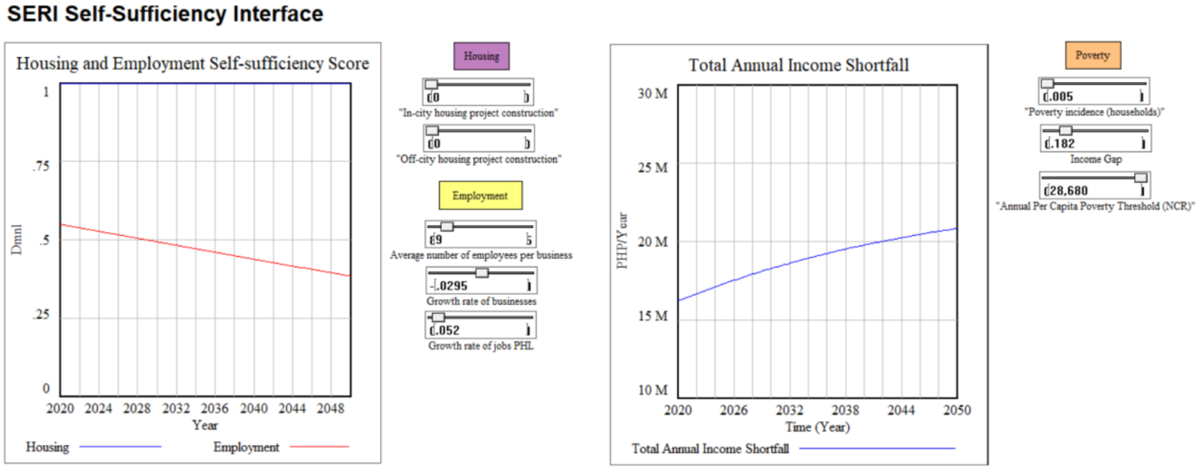


Figure 46. GUI View 5: SERI Self-sufficiency Interface.

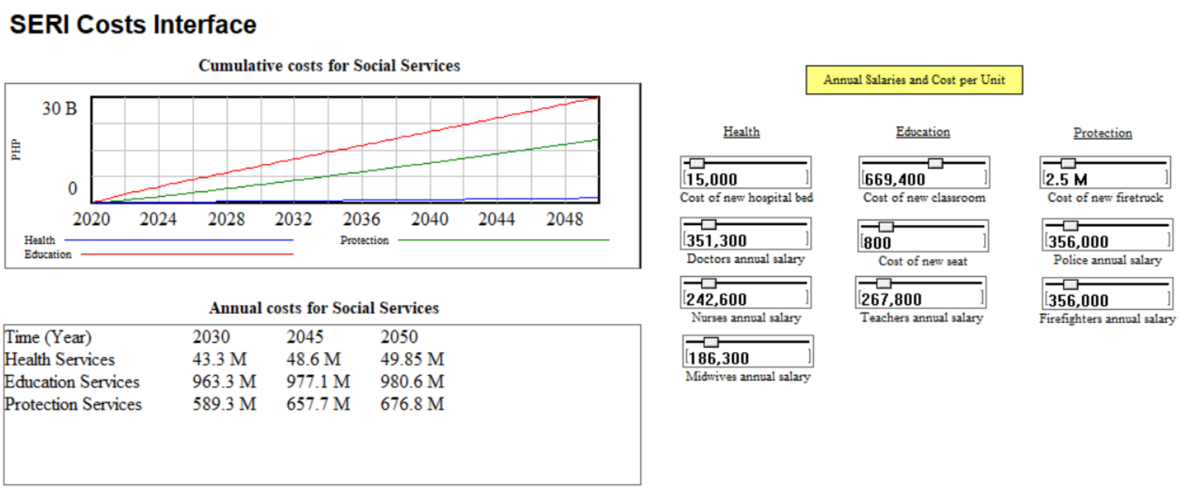


Figure 47. GUI Additional View: Cost of Social Services

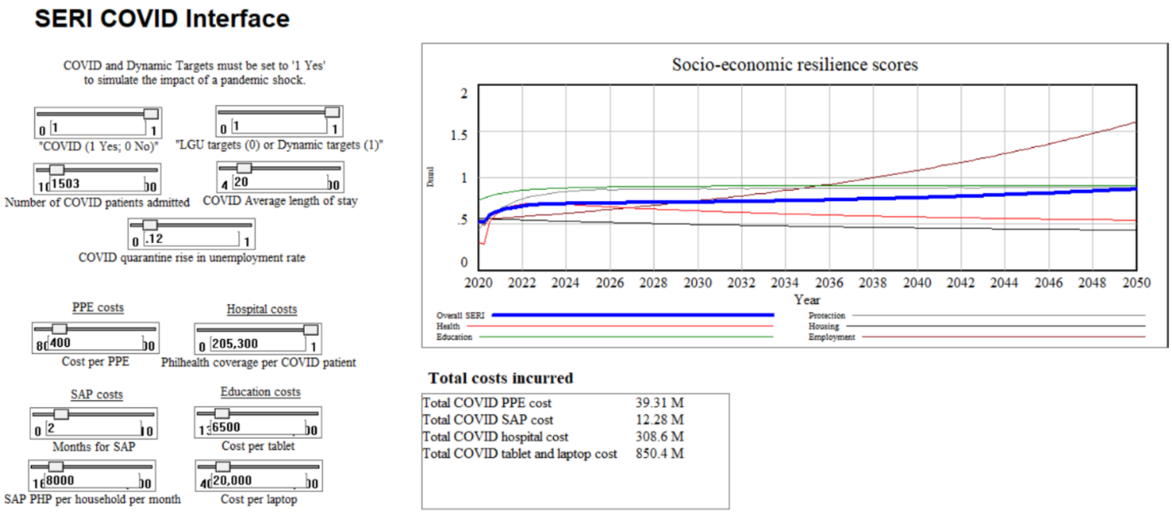


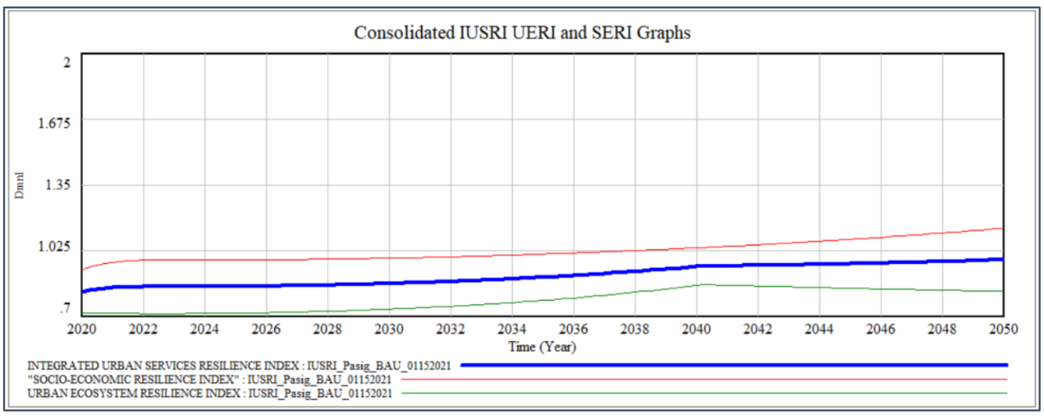
Figure 48. GUI Additional View: COVID-19 Impact on SERI and Costs.

5.3 IUSRI Sample Simulations

This combined IUSRI model can be used as a decision support tool because it can allow users to run and combine different scenarios in one model that considers both ecosystem services and socio-economic services. Sample simulations of the combined IUSRI model are shown in Figure 49 for Pasig City and Figure 50 for Valenzuela City. In both figures, the first graphs show the overall IUSRI resilience scores when BAU is simulated for both UERI and SERI models. The second graphs show the overall ISURI resilience score when each city's priority scenarios for the UERI and SERI models are considered.

For Pasig, the priority scenario with regard to the UERI is the land use change policy and refuse-derived-fuel utilization. On the SERI, the priority scenario includes the increase in ideal ratios set by the LGU for medical personnel, teachers, and classrooms and the additional units of in-city housing. Its IUSRI score eventually reaches "1", and this occurs at an earlier year when the Priority Scenario is applied. Looking at the component scores of the IUSRI, in both scenarios the SERI scores are higher than the UERI scores.

a) BAU UERI and SERI Scenario



b) Land Use & RDF UERI Scenario with Priority SERI Scenario

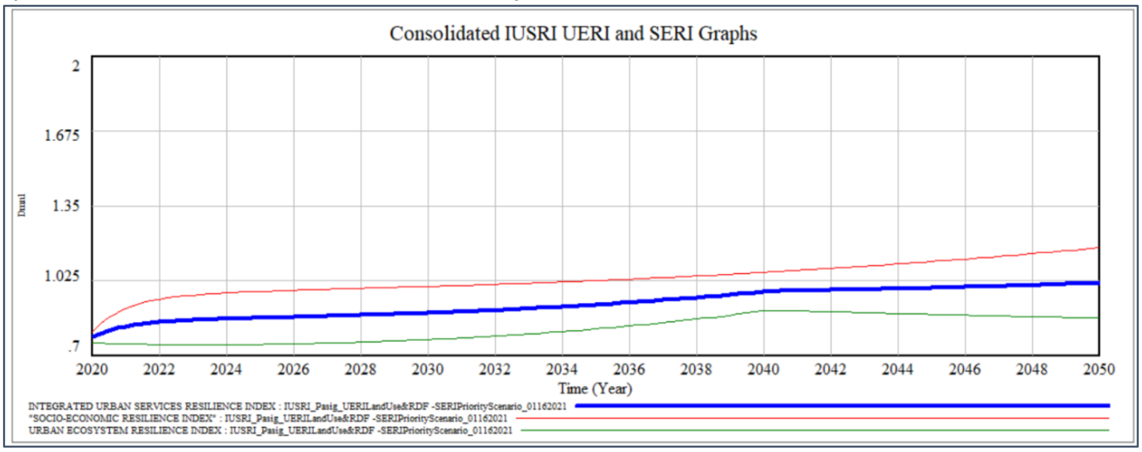
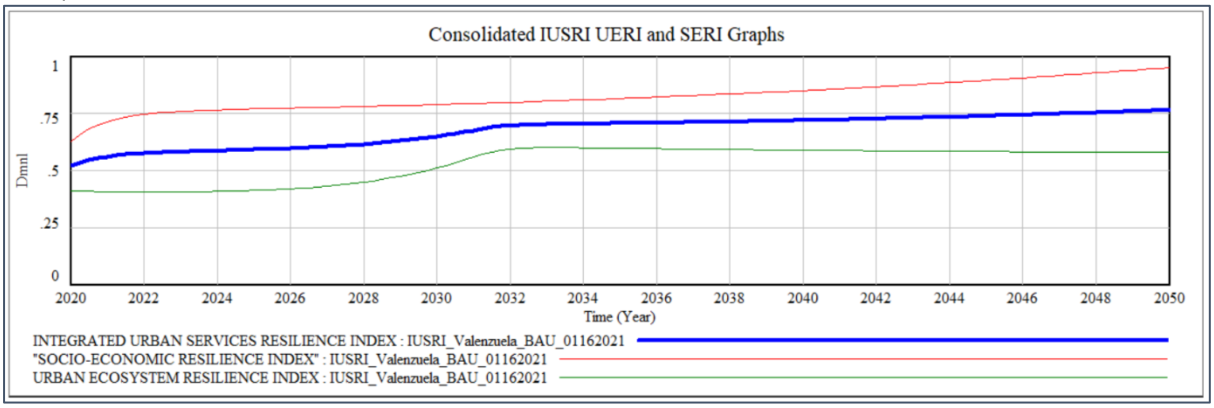


Figure 49. Pasig City sample simulations: (a) BAU UERI and SERI Scenario Sample Simulation and (b) Land Use & RDF UERI Scenario with Priority SERI Scenario.

For Valenzuela, the priority scenario is the land use change policy and siltation. On the SERI, the priority scenario includes the increase in off-city housing and an increase in the average number of employees per person. Its IUSRI score, however does not ever reach “1”, but it is still this Priority Scenario that shows faster improvements. Similar to Pasig, regardless of scenario the SERI score is higher than the UERI score.

a) BAU UERI and SERI Scenario



b) Land Use & Siltation UERI with Priority SERI Scenario for Valenzuela City

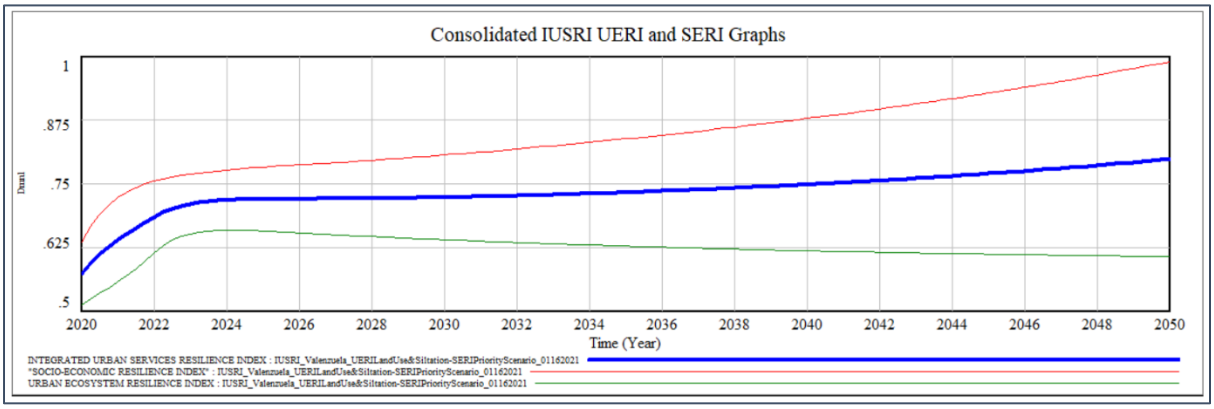


Figure 50. Valenzuela City sample simulations: (a) BAU UERI and SERI Scenario Sample Simulation and (b) Land Use & Siltation UERI Scenario with Priority SERI Scenario

6. Conclusion

The development of the SERI model allowed for the dynamic quantification of city resilience in aspects of the socio-economic services, namely health services, education services, protection services, housing, and employment. This was applied to two cities, Pasig City and Valenzuela City, and provided a means to compare the resilience between the two cities and across different scenarios that were tested, namely the Priorities Scenario that considers some aspects of each city's development plans and the COVID-19 Scenario that considers the impacts of a shock, in this case, the Coronavirus pandemic.

The structure of the SERI model itself showed the importance of an LGU's goal setting process for ideal ratios and target capacities. In a system where city services are provided in such a way that current capacities are assessed vis-à-vis a goal, the goal-seeking model of growth or change applies. The targets need to be high enough to consider having a buffer and to account for the length of time needed to adjust personnel and assets. The targets also cannot be too high such that resources are unnecessarily expended on these when they could have been used for another purpose.

For the non-service subsystems, i.e. housing and employment, changes are not as straightforward as the goal-seeking model previously used. There are many factors affecting these subsystems, as shown in the CLD's, that were not captured in the SERI model. Housing adjustments must be inputted manually, while employment determinants are subject to simple growth rates. These subsystems, however, clearly showed the distinction between in-city and out-of-city housing and employment, i.e. the self-sufficiency of the city to provide for these. These self-sufficiency scores are also indicators for resilience.

The base model was adjusted to accommodate the COVID-19 Scenario by integrating its impacts into each of the other subsystems as applicable. This shows that shocks, with the Coronavirus pandemic as an example, can be linked to several aspects of a city's resilience and must be considered in relation to each of the systems that it can affect. In addition, despite the steep recovery of resilience scores resulting from the treatment of this shock as temporary, in reality these may have longer term effects on resilience that were not captured in this model.

The models that were developed using system dynamics allows for a quantifiable and dynamic approach to assessing resilience. The way that the resilience index was designed allows the models to indicate not only the changes in resilience because of shocks, but also the inadequacies of system performance even without shocks. The models can individually be used as tools to benchmark, aid in goal setting, and compare cities. However, the combination of the SERI and UERI in the IUSRI provides for a resilience assessment tool that is also holistic, covering both ecosystem services and socio-economic services.

Lastly, this approach to assessing resilience must be accessible to those who need to understand the implications of different policy actions. These models were also intended to be tools to aid in the development planning of cities. Thus, the GUI that was developed allows for easy manipulation of different variables in the model to test different scenarios and immediately receive feedback on possible impacts of these changes.

7. Recommendations

The SERI model can be further improved to provide more insights into system performance and resilience. Future versions of the SERI model can incorporate more feedbacks between and within its subsystems, simulate budget allocations, and develop a more granular approach to poverty.

To incorporate more feedbacks, the built-up space from the UERI model can be disaggregated into residential and commercial/industrial so that the SERI model's housing and businesses growth can be constrained and more insight can be provided into the targets and allocations for such developments. Both vertical and horizontal development can be considered, and a spatial "carrying capacity" for the stock of houses and businesses can be determined.

Budget allocations can be simulated in a separate model so that the LGU can explore the constraints in the SERI's development services and the UERI's provisioning/regulating/cultural/supporting services. Investments are limited by budget constraints, and in this way, LGU's can test for the leverage points that will bring the best returns in terms of resilience. The current cost calculations are limited to the social service provision, but each of the subsystems in both SERI and UERI models can be incorporated into a Budget module. In turn, the employment or business subsystem in the model can also be connected to the Budget module so that business taxes can become endogenous to the model and considered as part of LGU income.

Lastly, the treatment of poverty in the SERI model is very limited and can be improved by simulating the extent to which the population can afford the services being made available. A better understanding of the implications of poverty can introduce a new dimension into the way that this model, and the users of this model, can understand resilience.

These recommendations can improve the model, but the model and index itself is still one that takes on a service approach. This has its limitations, because city resilience has other dimensions that are difficult to quantify and are not directly translatable into these various service capacities and targets. These dimensions include, for example, mental health and general well-being, trust networks in the community, diversity, and inclusion. Other approaches will still need to complement the model developed here for holistic decision-making.

REFERENCES

Acurentes, J. (2009). *Comprehensive Land Use Plan.* Valenzuela.

Alcober, N. (2020, June 5). Pasig City prepares P1.2B for educational tablets, laptops. *Tribune*, p. 1.

Alexander, D. E. (2013). Resilience and disaster risk reduction: An etymological journey. Natural Hazards and Earth System Sciences, 13(11), 2707–2716. https://doi.org/10.5194/nhess-13-2707-2013.

Audretsh, D. B., and Lehmann, E. (2016). The seven secrets of Germany: Economic resilience in an era of global turbulence. Oxford & New York, Oxford University Press, 229 p.

Bahadur A.V., Ibrahim M. and Tanner T. (2010). The resilience renaissance? unpacking of resilience for tackling climate change and disasters. CSR Discussion Paper No.1, Strengthening Climate Resilience programme, Brighton: IDS.

Balsells, M., Barroca, B., Becue, V., & Serre, D. (2015). Making urban flood resilience more operational: current practice. Proceedings of the Institution of Civil Engineers - Water Management, 168(2), 57–65. https://doi.org/10.1680/wama.14.00051.

Béné, C., Newsham, A., Davies, M., Ulrich, M., & Godfrey-Wood, R. (2014). Review Article: Resilience, Poverty and Development. Journal of International Development, 26(1), 598–623. https://doi.org/10.1002/jid

Bhamra, R., Dani, S., & Burnard, K. (2011). Resilience: The concept, a literature review and future directions. International Journal of Production Research, 49(18), 5375–5393. https://doi.org/10.1080/00207543.2011.563826.

Billones, R., Fenol, J., & de Guzman, W. (2020, April 13). How much does COVID-19 treatment cost, and how much will PhilHealth cover? *ABS CBN News*, p. 1.

Bloch, D. A., Silber, E., and Perry, S. E. (1956). Some factors in the emotional reaction of children to disaster. Am. J. Psychiat., 113, 416– 422.

Bruneau M., Chang S.E., Eguchi R.T., Lee G.C., O'Rourke T.D., Reinhorn A.M., Shinozuka M., Tierney K., Wallace W.A. & von Winterfeldt D. (2003). A framework to quantitatively assess and enhance the seismic resilience of communities. *EarthQ Spectra* 2003, 19, (4), 733–752.

Bureau of Local Government Finance. (2018). Statement of Receipts and Expenditures. Philippines. Retrieved from https://blgf.gov.ph/lgu-fiscal-data/

Cabell, J. F., & M. Oelofse. (2012). An indicator framework for assessing agroecosystem resilience. Ecology and Society 17(1): 18. http://dx.doi.org/10.5751/ES-04666-170118.

Campos, J. D., Litam, J. C., Gonzales, C. G., Josol, J. C., Jardaleza, J. P., & Abenojar, K. A. (2020, May 11). *Technical Report #1: Developing an Urban Ecosystem Resilience Index Using a System Dynamics Approach.* Coastal Cities at Risk in the Philippines (CCaRPH) project.

Cavallaro, M., Asprone, D., Latora, V., Manfredi, G., Nicosia, V. (2014). Assessment of urban ecosystem resilience through hybrid social–physical complex networks, Comput. -Aided Civ. Infrastruct. Eng. 29 (2014) 608–625, http://dx.doi.org/10.1111/mice.

Cerè, G., Rezgui, Y., Zhao, W. (2017). Critical review of existing built environment resilience frameworks: directions for future research, Int. J. Disaster Risk Reduct. 25 173–189, http://dx.doi.org/10.1016/j.ijdrr.2017.09.018.

Chandler, D., and Coaffee J. (Eds.). (2017). The Routledge Handbook of International Resilience. Routledge, New York.

Chelleri, L., Waters, J. J., Olazabal, M., & Minucci, G. (2015). Resilience trade-offs : addressing multiple scales and temporal aspects of urban resilience, 27(3), 181–198. https://doi.org/10.1177/0956247814550780.

Choptiany, J. M. H., Phillips, S., Graeub, B. E., Colozza, D., Settle, W., Herren, B., & Batello, C. (2017). SHARP: integrating a traditional survey with participatory self-evaluation and learning for climate change resilience assessment. Climate and Development, 9(6), 505–517. https://doi.org/10.1080/17565529.2016.1174661.

Cimellaro, G.P. (2016). Urban Resilience for Emergency Response and Recovery: Fundamental Concepts and Applications. AG, Switzerland: Springer International Publishing.

Cohen, O., Leykin, D., & Lahad, M. (2013). Technological Forecasting & Social Change The conjoint community resiliency assessment measure as a baseline for pro fi ling and predicting community resilience for emergencies. Technological Forecasting & Social Change, 80(9), 1732–1741. https://doi.org/10.1016/j.techfore.2012.12.009.

Commission on Audit. (2003, December 11). Revised Estimated Useful Life in Computing Depreciation for Government Property, Plant and Equipment. Philippines. Retrieved from https://coa.gov.ph/phocadownload/userupload/Issuances/Circulars/Attachments/2003/C2003-007_AnnexA.pdf

Cutter, S. L., Barnes, L., Berry, M., Burton, C., Evans, E., Tate, E., & Webb, J. (2008). A place-based model for understanding community resilience to natural disasters. Global Environmental Change, 18(4), 598–606. https://doi.org/10.1016/j.gloenvcha.2008.07.013.

Cutter, S. L., Carolina, S., Burton, C. G., Carolina, S., Emrich, C. T., Carolina, S., … Emrich, C. T. (2010). Disaster Resilience Indicators for Benchmarking

Baseline Conditions Disaster Resilience Indicators for Benchmarking Baseline Conditions, 7(1). https://doi.org/10.2202/1547-7355.1732.

de Bruijn, K., Buurman, J., Mens, M., Dahm, R., & Klijn, F. (2017). Resilience in practice: Five principles to enable societies to cope with extreme weather events. Environmental Science and Policy, 70, 21–30. https://doi.org/10.1016/j.envsci.2017.02.001

Department of International Development (DFID). 2011. Defining disaster resilience: A DFID approach paper. Available at https://www.fsnnetwork.org/sites/default/files/dfid_defining_disaster_resilience.pdf, Accessed 30 November 2018.

Di Caro, P. (2017). Testing and explaining economic resilience with an application to Italian regions. Papers in Regional Science, 96(1), 93-113. doi:10.1111/pirs.12168.

Feofilovs, M., Romagnoli, F., Gotangco, C.K., Josol, J.C., Jardeleza, J.M.P., Litam, J.E., Campos, J.I. and Abenojar, K. (2020). Assessing resilience against floods with a system dynamics approach: a comparative study of two models. International Journal of Disaster Resilience in the Built Environment https://doi.org/10.1108/IJDRBE-02-2020-0013

Ford, A. (2010). Modeling the environment, 2nd edition. Washington, DC: Island Press.

Fox-Lent, C., Bates, M. E., & Linkov, I. (2015). A matrix approach to community resilience assessment : an illustrative case at Rockaway Peninsula. Environment Systems and Decisions, 35(2), 209–218. https://doi.org/10.1007/s10669-015-9555-4.

Frazier, T. G., Thompson, C. M., Dezzani, R. J., and Butsick, D. (2013). Spatial and temporal quantification of resilience at the community scale. Applied Geography, 42, 95–107. https://doi.org/10.1016/j.apgeog.2013.05.004.

Ghaffarzadegan, N., Lyneis, J., & Richardson, G. P. (2010). How small system dynamics models can help the public policy process. *System Dynamics Review, 27*(1), 22-44.

Gonzales, J. B. (2020, August 5). Recommendations for fixing up health care and the economy under MECQ. The Medical City Philippines.

Gotangco, C. K., See, J., Dalupang, J. P., Ortiz, M., Porio, E., Narisma, G., … Dator-Bercilla, J. (2016). Quantifying resilience to flooding among households and local government units using system dynamics: a case study in Metro Manila. Journal of Flood Risk Management, 9(3), 196–207. https://doi.org/10.1111/jfr3.12222

Government, V. C. (2008). *Socio-ecological Profile.* Valenzuela.

Hegger, D. L. T., Driessen, P. P. J., Wiering, M., Van Rijswick, H. F. M. W., Kundzewicz, Z. W., Matczak, P., … Ek, K. (2016). Toward more flood resilience: Is a diversification of flood risk management strategies the way forward? Ecology and Society, 21(4). https://doi.org/10.5751/ES-08854-210452.

Helfgott, A. (2018). Operationalising systemic resilience. European Journal of Operational Research, 268(3), 852–864. https://doi.org/10.1016/j.ejor.2017.11.056

Hoffman, R. M. (1984). A generalised concept of resilience. Text. Res. J., 18, 141–148.

Holling, C. S. (1973). Resilience and stability of ecological systems. Annual Review of Ecology and Systematics, 4, 1–23. doi: 10.1146/annurev.es.04.110173.0 0 0245.

Holling, C. S. (1996). Engineering resilience versus ecological resilience. In Peter C. Schulze (Ed.), Engineering Within Ecological Constraints. Washington, DC: National Academy of Engineering, National Academy Press.

Joerin, J., Shaw, R., Takeuchi, Y., & Krishnamurthy, R. (2012). International Journal of Disaster Risk Reduction Assessing community resilience to climate-related disasters in Chennai, India. International Journal of Disaster Risk Reduction, 1, 44–54. https://doi.org/10.1016/j.ijdrr.2012.05.006.

Josol, J. (2014). Developing a Physical Hazard Index Model of Metro Manila for Climate Change Adaptation and Disaster Risk Management (CCA-DRM) Using a System Dynamics Approach. Quezon, Loyola Heights, Philippines: Ateneo de Manila University.

Kircher, C., Whitman, R., Holmes, W. (2006). HAZUS earthquake loss estimation methods. Nat. Hazards Rev. 7 (2006) 45–59, http://dx.doi.org/10.1061/(ASCE)1527- 6988(2006)7:2(45).

Kotzee, I., & Reyers, B. (2016). Piloting a social-ecological index for measuring flood resilience: A composite index approach. Ecological Indicators, 60, 45–53. https://doi.org/10.1016/j.ecolind.2015.06.018

Krantz, L. (2001). *The Sustainable Livelihood Approach to Poverty Reduction.* Stockholm: Swedish International Development Cooperation Agency. Retrieved from https://www.sida.se/contentassets/bd474c210163447c9a7963d77c64148a/the-sustainable-livelihood-approach-to-poverty-reduction_2656.pdf

Landscape-based Environmental System Analysis & Modeling (LESAM). (2016). PEOPLES Resilience Framework. Accessed July 31, 2018 from http://peoplesresilience.org/

Manyena, S. (2006). The concept of resilience revisited. Disasters, 30(4), pp.433–450.

Meerow, S., and Stults, M. (2016). Comparing Conceptualizations of Urban Climate Resilience in Theory and Practice, (Figure 1), 1–16. https://doi.org/10.3390/su8070701.

Midgley, G. (2000). Systemic Intervention: Philosophy, Methodology and Practice. New York: Kluwer Academic.

Minato, N., & Hassan, F. A. (2017). A system dynamics analysis of Malaysian healthcare resources. *International Journal of Japan Association for Management Systems, 9*(1), 61-69.

Morkunas, M., Volkov, A., and Pazienza, P. (2018). How resistant is the agricultural sector? Economic, 11(3), 321–333. https://doi.org/10.14254/2071-789X.2018/11-3/19.

Mostafavi, A. (2017). A System-of-Systems Approach for Integrated Resilience Assessment in Highway Transportation Infrastructure Investment. Infrastructures, 2(4), 22. https://doi.org/10.3390/infrastructures2040022

Orencio, P. M., & Fujii, M. (2013). A localized disaster-resilience index to assess coastal communities based on an analytic hierarchy process (AHP). International Journal of Disaster Risk Reduction, 3(1), 62–75. https://doi.org/10.1016/j.ijdrr.2012.11.006.

Ostadtaghizadeh, A., Ardalan, A., Paton, D., Jabbari, H., & Khankeh, H. R. (2015). Community disaster resilience: A systematic review on assessment models and tools. PLOS Current Disasters 2015 Apr 8. Edition 1. Assessment https://doi.org/10.1371/currents.dis.f224ef8efbdfcf1d508dd0de4d8210ed.Revisions.

Palermo, R. (2009). *Comprehensive Land Use Plan.* Pasig : Planning Office.

Palermo, S. (2020). Prioritization in Pasig. (J. Litam, Interviewer)

Parsons, M., Glavac, S., Hastings, P., Marshall, G., McGregor, J., McNeill, J., … Stayner, R. (2016). Top-down assessment of disaster resilience: A conceptual framework using coping and adaptive capacities. International Journal of Disaster Risk Reduction, 19, 1–11. https://doi.org/10.1016/j.ijdrr.2016.07.005.

Perez, R. (2020, April 15). MSN Social Amelioration Program: How to Qualify and how much can you receive. *Smart Parenting*, p. 1.

Philippine Statistics Authority. (2018). Full Year 2018 Official Poverty Statistics of the Philippines. Philippines.

(2009). *Poverty in the Philippines.* Mandaluyong: Asian Development Bank.

Rankine, W. J. M. (1867). A Manual of Applied Mechanics. London: Charles Griffin and Co.

Razafindrabe, B.H.N., Cuesta, M.A., He, B., Ranola, R.F.R. Jr., Yaota, K., Inoue, S., Saito, S., Masuda, T., Concepcion, R.N., Santos-Borja, A., and Kada, R. (2015). Flood risk and resilience assessment for Santa Rosa-Silang subwatershed in the Laguna Lake region, Philippines. Environmental Hazard 14(1), 16–35, https://doi.org/10.1080/17477891.2014.981497.

Rus, K., Kilar, V., & Koren, D. (2018). Resilience assessment of complex urban systems to natural disasters: A new literature review. International Journal of Disaster Risk Reduction, 31(March), 311–330. https://doi.org/10.1016/j.ijdrr.2018.05.015.

Sharifi, A. (2016). A critical review of selected tools for assessing community resilience. Ecological Indicators, 69, 629–647. https://doi.org/10.1016/j.ecolind.2016.05.023.

Sharifi, A., & Yamagata, Y. (2016). Principles and criteria for assessing urban energy resilience: A literature review. Renewable and Sustainable Energy Reviews, 60, 1654–1677. https://doi.org/10.1016/j.rser.2016.03.028

Siambabala, B. M., O'Brien, G., O'Keefe, P., and Rose, J. (2011). Disaster resilience: A bounce back or bounce forward ability? Local Environment, 16(5), 417–424. https://doi.org/10.1080/13549839.2011.583049.

Simonovic S. & Peck A. (2013a). Dynamic resilience to climate change caused natural disasters in coastal megacities quantification framework. Br J Environ Clim Change 3, (3), 378–401.

Simonovic S. & Peck A. (2013b). Coastal Cities at Risk (CCaR): generic system dynamics simulation models for use with city resilience simulator [online]. Report No. 083, Dept. of Civil and Environmental Engineering, University of Western Ontario, Canada. Retrieved August 8, 2018 from http://www.eng.uwo.ca/research/iclr/ fids/publications/products/83.pdf.Stephenson, V., and Finlayson, A. (2018). A Risk-Based Approach to Shelter Resilience following Flood and Typhoon Damage in Rural Philippines. Geosciences 8, 76, https://doi.org/10.3390/geosciences8020076.

Sison, B. (2017). *Ecological Profile.* Valenzuela.

Sun, R., Karaca, Z., & Wong, H. (2018). *Trends in Hospital Inpatient Stays by Age and Payer, 2000-2015.* Rockville: Agency for Healthcare Research.

Tantuico, V. (2020, April 3). EXPLAINER: The PPE keeping our healthcare workers safe. *Rappler*, p. 1.

The National Academies. (2012). *A national imperative*. National Academies Press. http://www.nap.edu/catalog/13457/disaster-resilience-a-national-imperative.

Ulrich, W. (1987). Critical heuristics of social systems design. European Journal of Operational Research, 31 , 276–283. doi: 10.1016/0377- 2217(87)90036- 1 .

UNISDR. (2015). *Sendai Framework for Disaster Risk Reduction 2015-2030*. Retrieved January 23, 2019 from https://www.preventionweb.net/files/43291_sendaiframeworkfordrren.pdf.

UNISDR. (2018). *Economic losses, poverty and disasters 1998-2017*. Retrieved January 23, 2019 from https://www.preventionweb.net/files/61119_credeconomiclosses.pdf.

van der Leeuw, S. , and Aschan-Leygonie, C. (2005). A long-term perspective on resilience in socio-natural systems. Hans Liljenstrom, and Uno Svedin (Eds.), Micro, Meso, Macro: Addressing complex systems couplings. Singapore: World Scientific Publishing Co.

Woolf, S., Twigg, J., Parikh, P., Karaoglou, A., & Cheaib, T. (2016). International Journal of Disaster Risk Reduction Towards measurable resilience : A novel framework tool for the assessment of resilience levels in slums. International Journal of Disaster Risk Reduction, 19, 280–302. https://doi.org/10.1016/j.ijdrr.2016.08.003.

Zhou, H., Wang, J., Wan, J., & Jia, H. (2010). Resilience to natural hazards: A geographic perspective. *Natural Hazards*, 53(1), 21–41. https://doi.org/10.1007/s11069-009-9407-y.

Zobel, C. W., & Baghersad, M. (2020). Socio-Economic Planning Sciences Analytically comparing disaster resilience across multiple dimensions. Socio-Economic Planning Sciences, 69(December 2018), 100678. https://doi.org/10.1016/j.seps.2018.12.005.

APPENDIX: Table of Variables

Variable Name	Type	Equation	Units	Notes
"SOCIO-ECONOMIC RESILIENCE INDEX"	Auxiliary variable	(Education Services Resilience Score+Health Services Resilience Score+Protection Services Resilience Score+Housing relocation resilience score+Employment resilience score)/5	Dmnl	Simple average of the socio-economic resilience scores
Health				
"COVID (1 Yes; 0 No)"	Auxiliary variable	0	Dmnl	Default is 0 or no COVID effects for BAU and Priorities Scenarios. Can be adjusted to 1 to apply COVID effects.
Additional people admitted COVID	Auxiliary variable	COVID wave LOOKUP(Time step number)*Number of COVID patients admitted/Time for wave*"COVID (1 Yes; 0 No)"	Person/ Year	The number of people hospitalized per year due to COVID-19. This returns the number of additional patients if this were extended for a year (admitted/quarter * 4 quarters/year) on the quarter that the COVID wave is active. Value is zero when COVID is "off".
Adjustment time for hosp facilities	Auxiliary variable	1	Year	Time to close the gap. Author's estimation.
Adjustment time for medical personnel	Auxiliary variable	2	Year	Time to close the gap. Generalized for all medical personnel from assumption of 1.5 years for doctors and 2 years for nurses. From HASSAN, F. A., & MINATO, N. (2017). A system dynamics analysis of Malaysian healthcare resources. *International*

				Journal of Japan Association for Management Systems, *9*(1), 61-69.
Average Length of Stay	Auxiliary variable	Pasig: 4 Valenzuela: 5	Bed*Day/Person	Number of days of hospitalization per inpatient on average. Calculated from cities' 2018 SEPs.
Bed days per year	Auxiliary variable	Number of people admitted per year*Average Length of Stay	Bed*Day/Year	Total number of bed days needed by all inpatients per year.
Bed occupancy rate	Auxiliary variable	Pasig: 0.75 Valenzuela: 0.9	Dmnl	Occupied bed days divided by available bed days per year. A measure of capacity utilization.
Births	Auxiliary variable	Birth frac*"Age 15-44"	Person/Year	Number of births per year, based on the fertile population.
Births per year per midwife	Auxiliary variable	29.5	Person/Year/Person	Ideal number of births a midwife can attend to per year. From *Maternity services in England* (2013). National Audit Office. https://www.nao.org.uk/press-release/maternity-services-england/
Cost of new hospital bed	Auxiliary variable	15,000	PHP/Bed	Estimated cost of based on available listings in online marketplaces.
COVID Additional bed days	Auxiliary variable	Additional people admitted COVID*COVID Average length of stay	Bed*Day/Year	Additional number of bed days per year required due to COVID-19 hospitalizations.
COVID Average length of stay	Auxiliary variable	20	Bed*Day/Person	Average number of days of hospitalization for COVID-19 patients. From policy discussion paper, "Recommendations for fixing up health care and the economy under MECQ" by The Medical City chairman J. Xavier B. Gonzales (August 5, 2020).
COVID wave LOOKUP	Auxiliary variable	([(0,0)-(140,4)],(0,0),(1,1),(21,0),(22,0),(140,0))	Dmnl	Returns "1" during the time that the COVID-19 wave is active, i.e. second quarter of 2020 or time step 1, where time step 0 is the 1st quarter of 2020.

Days per year	Auxiliary variable	365	Day/Year	Number of days in a year.
Decrease in Hospital beds	Flow	Number of Hospital Beds/Years of useful life hospital beds	Bed/Year	Decrease due to retirement of asset.
Doctors annual increase historical	Auxiliary variable	Pasig: 4 Valenzuela: 2	Person/Year	Number of additional doctors per year on average, over 2015 to 2018. From cities' 2018 SEPs.
Doctors annual salary	Auxiliary variable	351,324	PHP/Person/Year	Monthly salary of P29,277; minimum for doctors according to government mandated salary grades. From https://www.dbm.gov.ph/wp-content/uploads/OPCCB2/SalaryGrade_2006.htm
Doctors gap	Auxiliary variable	Ideal number of Doctors-Number of Doctors	Person	Gap to close.
Doctors retire	Flow	Number of Doctors/Medical professionals average number of years in service	Person/Year	Decrease due to retirement of personnel.
Health services cumulative expenditure	Stock	INTEG (Increase in health services cumulative expenditure, 0)	PHP	Cumulative expenditure for health services personnel and assets.
Health Services Resilience Score	Auxiliary variable	IF THEN ELSE("LGU targets (0) or Dynamic targets (1)"=0,(Resilience Score Hospital beds +Resilience Score Medical Professionals)/2, Health Services Resilience Score DYNAMIC)	Dmnl	Average of component resilience scores.
Health total annual expenditure	Auxiliary variable	Total annual salary for medical	PHP/Year	Annual expenditure for current personnel salary and asset additions.

		professionals+Total annual cost of new hospital beds		
"Historical increase (0) or Goal seeking (1)"	Auxiliary variable	1	Dmnl [0,1,1]	Switch to determine how personnel/assets will change.
Hospital beds annual increase estimated	Auxiliary variable	PULSE TRAIN(2025, 1, 10, 2050)*100	Bed/Year	Historically 0... Data doesn't go far back enough.
Hospital beds gap	Auxiliary variable	Ideal number of beds-Number of Hospital Beds	Bed	Gap to close.
"Hospitalization rate 15-44"	Auxiliary variable	0.04	1/Year	Fraction of population within this age bracket that is hospitalized.
"Hospitalization rate 45-64"	Auxiliary variable	0.105	1/Year	Fraction of population within this age bracket that is hospitalized.
"Hospitalization rate <15"	Auxiliary variable	0.02	1/Year	https://hcup-us.ahrq.gov/reports/statbriefs/sb235-Inpatient-Stays-Age-Payer-Trends.jsp
"Hospitalization rate >64"	Auxiliary variable	0.265	1/Year	Fraction of population within this age bracket that is hospitalized.
Ideal number of beds	Auxiliary variable	Population/Target Population to Bed ratio	Bed	LGU goal for the capacity of this service component.
Ideal number of Doctors	Auxiliary variable	Population/Target Population to Doctor ratio	Person	LGU goal for the capacity of this service component.
Ideal number of midwives	Auxiliary variable	Population/Target Population to Midwife ratio	Person	LGU goal for the capacity of this service component.
Ideal number of nurses	Auxiliary variable	Population/Target Population to Nurse ratio	Person	LGU goal for the capacity of this service component.
Increase in Doctors	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Doctors	Person/ Year	Change for a given year. Either follows goal seeking or historical increase.

		annual increase historical , INTEGER(Doctors gap/Adjustment time for medical personnel))		
Increase in health services cumulative expenditure	Flow	Health total annual expenditure	PHP/Year	Inflow to the cumulative expenditure stock.
Increase in Hospital beds	Flow	IF THEN ELSE("Historical increase (0) or Goal seeking (1)"=0,Hospital beds annual increase estimated ,INTEGER(Hospital beds gap/Adjustment time for hosp facilities))	Bed/Year	Change for a given year. Either follows goal seeking or an estimated fixed annual increase.
Increase in Midwives	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0,Midwives annual increase historical ,INTEGER(Midwives gap/Adjustment time for medical personnel))	Person/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Nurses	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Nurses annual increase historical , INTEGER(Nurses gap/Adjustment time for medical personnel))	Person/Year	Change for a given year. Either follows goal seeking or historical increase.

Initial number of doctors	Auxiliary variable	Pasig: 58 Valenzuela: 41	Person	Pasig data for 2015 taken from the Pasig City Profile 2018. Valenzuela data for 2015 taken from the Valenzuela SEP 2016.
Initial number of midwives	Auxiliary variable	Pasig: 84 Valenzuela: 139	Person	Pasig data for 2015 taken from the Pasig City Profile 2018. Valenzuela data for 2015 taken from the Valenzuela SEP 2016.
Initial number of nurses	Auxiliary variable	Pasig: 123 Valenzuela: 54	Person	Pasig data for 2015 taken from the Pasig City Profile 2018. Valenzuela data for 2015 taken from the Valenzuela SEP 2016.
Initial number of hospital beds	Auxiliary variable	Pasig: 584 Valenzuela: 217	Bed	Pasig data for 2015 taken from the Pasig City Profile 2018. Valenzuela data for 2015 taken from the Valenzuela SEP 2016.
Inpatients	Auxiliary variable	Additional people admitted COVID+Number of people admitted per year	Person/ Year	Total number of inpatients per year during each time period.
"LGU targets (0) or Dynamic targets (1)"	Auxiliary variable	0	Dmnl [0,1,1]	Switch to show health resilience score based on LGU targets (ratio to total population) or Dynamic targets (based on concerned population).
Medical professionals average number of years in service	Auxiliary variable	30	Year	Author's estimate.
Midwives annual increase historical	Auxiliary variable	Pasig: 9 Valenzuela: 13.2	Person/ Year	Number of additional midwives per year on average, over 2015-2018 for Pasig and over 2013-2018 for Valenzuela. From the cities' 2018 SEPs.
Midwives annual salary	Auxiliary variable	186288	PHP/Person/Year	Monthly salary of P15,524; minimum for midwives according to government mandated salary grades. From https://www.dbm.gov.ph/wp-

				content/uploads/OPCCB2/SalaryGrade_2006.htm
Midwives gap	Auxiliary variable	Ideal number of midwives-Number of Midwives	Person	Gap to close.
Midwives retire	Flow	Number of Midwives/Medical professionals average number of years in service	Person/ Year	Decrease due to retirement of personnel.
Number of COVID patients admitted	Auxiliary variable	Pasig: 1326 Valenzuela: 1503	Person/ Wave	Valenzuela: 1503 hospitalized out of 6403 total confirmed (23.5% hospitalization rate) Pasig total: 5649 total confirmed, by ratio and proportion 1326 are hospitalized. Data from Pasig City website as of September 15, 2020 and Valenzuela City websites as of September 20, 2020
Number of Doctors	Stock	INTEG (Increase in Doctors-Doctors retire, Initial number of doctors)	Person	Number of doctors employed by public LGU hospitals.
Number of Hospital Beds	Stock	INTEG (Increase in Hospital beds-Decrease in Hospital beds, Initial numer of hospital beds)	Bed	Number of hospital beds in public LGU hospitals.
Number of Midwives	Stock	INTEG (Increase in Midwives-Midwives retire, Initial number of midwives)	Person	Number of midwives employed by public LGU hospitals.

Number of Nurses	Stock	INTEG (Increase in Nurses-Nurses retire, Initial number of nurses)	Person	Number of nurses employed by public LGU hospitals.
Number of people admitted per year	Auxiliary variable	"Age 0-14"*"Hospitalization rate <15"+"Age 15-44"*"Hospitalization rate 15-44" +"Age 45-64"*"Hospitalization rate 45-64"+"Age 65+"*"Hospitalization rate >64"	Person/ Year	Given 584 beds x 365 days *.75 bed occupancy rate / 4 days / patient , # of people should be 40k at start
Nurses annual increase historical	Auxiliary variable	Pasig: 27 Valenzuela: 2.4	Person/ Year	Number of additional nurses per year on average, over 2015-2018 for Pasig and 2013-2018 for Valenzuela. From the cities' 2018 SEPs.
Nurses annual salary	Auxiliary variable	242,628	PHP/Person/Year	Monthly salary of P20,219; minimum for nurses according to government mandated salary grades. From https://www.dbm.gov.ph/wp-content/uploads/OPCCB2/SalaryGrade_2006.htm
Nurses gap	Auxiliary variable	Ideal number of nurses-Number of Nurses	Person	Gap to close.
Nurses retire	Flow	Number of Nurses/Medical professionals average number of years in service	Person/ Year	Decrease due to retirement of personnel.
Outpatients	Auxiliary variable	Inpatients*Ratio of outpatients per inpatient	Person/ Year	Number of outpatients as a multiple of inpatients.
Patients	Auxiliary variable	Inpatients+Outpatients	Person/ Year	Total number of inpatients and outpatients.
Patients per year Doctor	Auxiliary variable	1500	Person/ Year/Person	Number of inpatients and outpatients that a doctor can see per year. From HASSAN, F. A., & MINATO, N. (2017). A system

				dynamics analysis of Malaysian healthcare resources. *International Journal of Japan Association for Management Systems*, *9*(1), 61-69.
Patients per year Nurse	Auxiliary variable	900	Person/ Year/Person	Number of inpatients and outpatients that a nurse can attend to per year. From HASSAN, F. A., & MINATO, N. (2017). A system dynamics analysis of Malaysian healthcare resources. *International Journal of Japan Association for Management Systems*, *9*(1), 61-69.
Ratio of outpatients per inpatient	Auxiliary variable	20	Dmnl	Number of outpatients per inpatient
Resilience Score Doctors	Auxiliary variable	Number of Doctors/IF THEN ELSE("LGU targets (0) or Dynamic targets (1)"=0,Ideal number of Doctors,Target Number of Doctors DYNAMIC)	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population OR the target number “DYNAMIC” calculated using public health statistics.
Resilience Score Hospital beds	Auxiliary variable	Number of Hospital Beds/IF THEN ELSE("LGU targets (0) or Dynamic targets (1)"=0,Ideal number of beds,Target number of Hospital beds DYNAMIC)	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population OR the target number “DYNAMIC” calculated using public health statistics.
Resilience Score Medical Professionals	Auxiliary variable	(Resilience Score Doctors+Resilience Score Midwives+Resilie	Dmnl	Average resilience score of medical professionals

		nce Score Nurses)/3		
Resilience Score Midwives	Auxiliary variable	Number of Midwives/IF THEN ELSE("LGU targets (0) or Dynamic targets (1)"=0,Ideal number of midwives,Target Number of Midwives DYNAMIC)	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population OR the target number “DYNAMIC” calculated using public health statistics.
Resilience Score Nurses	Auxiliary variable	Number of Nurses/IF THEN ELSE("LGU targets (0) or Dynamic targets (1)"=0,Ideal number of nurses,Target Number of Nurses DYNAMIC)	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population OR the target number “DYNAMIC” calculated using public health statistics.
Target Number of Doctors DYNAMIC	Auxiliary variable	Patients/Patients per year Doctor	Person	The number of doctors needed to adequately service the total number of patients per year.
Target number of Hospital beds DYNAMIC	Auxiliary variable	(Bed days per year+COVID Additional bed days)/Days per year/Bed occupancy rate	Bed	The number of hospital beds needed to adequately service the total number of bed days needed by inpatients per year.
Target Number of Midwives DYNAMIC	Auxiliary variable	Births/Births per year per midwife	Person	The number of midwives needed to adequately service the total number of births per year.
Target Number of Nurses DYNAMIC	Auxiliary variable	Patients/Patients per year Nurse	Person	The number of nurses needed to adequately service the total number of patients per year.
Target Population to Bed ratio	Auxiliary variable	800	Person/ Bed	Philippine standard from news article *PHL patient-to-hospital bed ratio at 1:1,000 —Ejercito* (2018). Manila: GMA News.
Target Population	Auxiliary variable	20,000	Dmnl	LGU standard indicated in the SEP.

to Doctor ratio				
Target Population to Midwife ratio	Auxiliary variable	5,000	Dmnl	LGU standard indicated in the SEP.
Target Population to Nurse ratio	Auxiliary variable	20,000	Dmnl	LGU standard indicated in the SEP.
Time for wave	Auxiliary variable	0.25	Year/Wave	Number of years the pandemic wave lasts.
TIME STEP	Auxiliary variable	0.25	Year [0,?]	The time step for the simulation.
Time step number	Auxiliary variable	((Time-2020)/TIME STEP)-MODULO(((Time-2020)/TIME STEP),TIME STEP*"Unit converter 1/Year")	Dmnl	Ordinal number of time step.
Total annual cost of new hospital beds	Auxiliary variable	Increase in Hospital beds*Cost of new hospital bed	PHP/Year	Cost of the year's increase in hospital beds.
Total annual salary for doctors	Auxiliary variable	Number of Doctors*Doctors annual salary	PHP/Year	Cost of salary for the year's employed doctors.
Total annual salary for medical professionals	Auxiliary variable	Total annual salary for doctors+Total annual salary for midwives+Total annual salary for nurses	PHP/Year	Total cost of salary for the year's employed medical professionals
Total annual salary for midwives	Auxiliary variable	Midwives annual salary*Number of Midwives	PHP/Year	Cost of salary for the year's employed midwives.
Total annual salary for nurses	Auxiliary variable	Nurses annual salary*Number of Nurses	PHP/Year	Cost of salary for the year's employed nurses.
"Unit converter 1/Year"	Auxiliary variable	1	1/Year	Unit converter.

h	Auxiliary variable	15	Year	Number of years that a hospital bed can be used. From https://www.depreciationrates.net.au/furniture
Education				
Adjustment time classrooms	Auxiliary variable	3	Year	Time to close the gap. Author's estimation.
Adjustment time seats	Auxiliary variable	1	Year	Time to close the gap. Author's estimation.
Adjustment time teachers	Auxiliary variable	2	Year	Time to close the gap. Author's estimation.
Annual cost of new classrooms elementary	Auxiliary variable	Increase in Classrooms elementary*Cost of new classroom	PHP/Year	Cost of the elementary school classrooms added in that given year.
Annual cost of new classrooms secondary	Auxiliary variable	Cost of new classroom*Increase in Classrooms secondary	PHP/Year	Cost of the secondary school classrooms added in that given year.
Annual cost of new seats elementary	Auxiliary variable	Cost of new seat*Increase in Seats elementary	PHP/Year	Cost of the elementary school seats added in that given year.
Annual cost of new seats secondary	Auxiliary variable	Cost of new seat*Increase in Seats secondary	PHP/Year	Cost of the secondary school seats added in that given year.
Annual salary for teachers elementary	Auxiliary variable	Number of Teachers elementary*Teachers annual salary	PHP/Year	Cost of salary for the year's employed elementary teachers.
Annual salary for teachers secondary	Auxiliary variable	Number of Teachers secondary*Teachers annual salary	PHP/Year	Cost of salary for the year's employed secondary teachers.
Classroom years of useful life	Auxiliary variable	30	Year	Estimated useful life of a concrete building. From Annex A of Memorandum Circular 2003-007: https://www.coa.gov.ph/phocadownload/userupload/Issuances/Circulars/Attachments

				/2003/C2003-007_AnnexA.pdf
Classrooms annual increase elementary historical	Auxiliary variable	Pasig: 160 Valenzuela: 5	Classroom/Year	Average increase from 2010-2014 for Pasig and 2015-2018 for Valenzuela. From the Pasig 2018 SEP and Valenzuela's MDG CBMS 2015 & SEP 2018.
Classrooms annual increase secondary historical	Auxiliary variable	Pasig: 94 Valenzuela: -5	Classroom/Year	Average increase from 2015-2018 for both Pasig and Valenzuela. From the Pasig 2018 SEP and Valenzuela's MDG CBMS 2015 & SEP 2018.
Cost of new classroom	Auxiliary variable	669,438	PHP/Classroom	Estimated cost of a new classroom with minimum floor area of 63 sqm according to DepEd standards, and an average construction cost of 10,626 PHP/sqm according to the 2019 first quarter construction statistics from approved building permits.
Cost of new seat	Auxiliary variable	800	PHP/Seat	Estimated cost based on available listings in online marketplaces.
Decrease in Classrooms elementary	Flow	Number of Classrooms elementary/Classroom years of useful life	Classroom/Year	Decrease due to retirement of asset.
Decrease in Classrooms secondary	Flow	Number of Classrooms secondary/Classroom years of useful life	Classroom/Year	Decrease due to retirement of asset.
Decrease in Seats elementary	Flow	Number of Seats elementary/Seat years of useful life	Seat/Year	Decrease due to retirement of asset.
Decrease in Seats secondary	Flow	Number of Seats secondary/Seat years of useful life	Seat/Year	Decrease due to retirement of asset.
Education services cumulative expenditure	Stock	INTEG (Increase in education services	PHP	Cumulative expenditure for education services personnel and assets.

		cumulative expenditure,0)		
Education Services Resilience Score	Auxiliary variable	(Elementary Education Services Resilience Score+Secondary Education Services Resilience Score)/2	Dmnl	Average of component resilience scores.
Education total annual expenditure	Auxiliary variable	Total annual cost of new classrooms+Total annual cost of new seats+Total annual salary for teachers	PHP/Year	Annual expenditure for current personnel salary and asset additions.
Elementary classrooms gap	Auxiliary variable	Ideal number of classrooms elementary-Number of Classrooms elementary	Classroom	Gap to close.
Elementary Education Services Resilience Score	Auxiliary variable	(Resilience Score Classrooms elementary+Resilience Score Seats elementary+Resilience Score Teachers elementary)/3	Dmnl	Average of component resilience scores.
Elementary seats gap	Auxiliary variable	Ideal number of seats elementary-Number of Seats elementary	Seat	Gap to close.
Elementary teacher retire	Flow	Number of Teachers elementary/Teacher average number of years in service	Person/Year	Decrease due to retirement of personnel.
Elementary teachers gap	Auxiliary variable	Ideal number of elementary teachers-Number	Person	Gap to close.

		of Teachers elementary		
"Fraction of 0-14 Population in Public Elementary School secondary"	Auxiliary variable	Pasig: 0.3842 Valenzuela: 0.45	Dmnl	Fraction of school age population in public elementary school. Ratio of total elementary school students in 2015 (from the city 2018 SEPs) to the total population the 0-14 age bracket.
"Fraction of 0-14 Population in Public School elementary"	Auxiliary variable	Pasig: 0.2253 Valenzuela: 0.25	Dmnl	Fraction of school age population in public secondary school. Ratio of total secondary school students in 2015 (from the city 2018 SEPs) to the total population the 0-14 age bracket.
Ideal number of classrooms elementary	Auxiliary variable	Number of Students elementary/Target Student to Classroom Ratio	Classroom	LGU goal for the capacity of this service component.
Ideal number of classrooms secondary	Auxiliary variable	Number of Students secondary/Target Student to Classroom Ratio	Classroom	LGU goal for the capacity of this service component.
Ideal number of elementary teachers	Auxiliary variable	Number of Students elementary/Target Student to Teacher Ratio	Person	LGU goal for the capacity of this service component.
Ideal number of seats elementary	Auxiliary variable	Number of Students elementary/Target Student to Seat Ratio	Seat	LGU goal for the capacity of this service component.
Ideal number of seats secondary	Auxiliary variable	Number of Students secondary /Target Student to Seat Ratio	Seat	LGU goal for the capacity of this service component.
Ideal number of elementary secondary	Auxiliary variable	Number of Students secondary /Target Student to Teacher Ratio	Person	LGU goal for the capacity of this service component.

Increase in Classrooms elementary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Classrooms annual increase elementary historical , INTEGER(Elementary classrooms gap/Adjustment time classrooms))	Classroom/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Classrooms secondary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Classrooms annual increase secondary historical , INTEGER(Secondary classrooms gap/Adjustment time classrooms))	Classroom/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Seats elementary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0,Seats annual increase elementary historical, INTEGER(Elementary seats gap/Adjustment time seats)	Seat/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Seats secondary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0,Seats annual increase secondary	Seat/Year	Change for a given year. Either follows goal seeking or historical increase.

		historical, INTEGER(Secondary seats gap/Adjustment time seats)		
Increase in Teachers elementary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Teachers annual increase elementary historical, INTEGER (Elementary teachers gap/ Adjustment time teachers))	Person/ Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Teachers secondary	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0, Teachers annual increase secondary historical, INTEGER (Secondary teachers gap/ Adjustment time teachers))	Person/ Year	Change for a given year. Either follows goal seeking or historical increase.
Initial number of classrooms elementary	Auxiliary variable	Pasig: 2250 Valenzuela: 957	Classroom	Value for 2015 for Pasig from Pasig 2018 SEP. Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Initial number of classrooms secondary	Auxiliary variable	Pasig: 1374 Valenzuela: 604	Classroom	Value for 2015 for Pasig from Pasig 2018 SEP. Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Initial number of seats elementary	Auxiliary variable	Pasig: 54935 Valenzuela: 40002	Seat	Value for 2015 for Pasig from Pasig 2018 SEP. Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Initial number of	Auxiliary variable	Pasig: 38359 Valenzuela: 26567	Seat	Value for 2015 for Pasig from Pasig 2018 SEP.

seats secondary				Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Initial number of teachers elementary	Auxiliary variable	Pasig: 2108 Valenzuela: 1876	Person	Value for 2015 for Pasig from Pasig 2018 SEP. Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Initial number of teachers secondary	Auxiliary variable	Pasig: 1517 Valenzuela: 1431	Person	Value for 2015 for Pasig from Pasig 2018 SEP. Value for 2014 for Valenzuela from Valenzuela MDG 2015 CBMS.
Increase in education services cumulative expenditure	Flow	Education total annual expenditure	PHP/Year	Inflow to the cumulative expenditure stock.
Number of Classrooms elementary	Stock	INTEG (Increase in Classrooms elementary-Decrease in Classrooms elementary, Initial number of classrooms elementary)	Classroom	Stock of elementary classrooms. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement from finishing the estimated years of life.
Number of Classrooms secondary	Stock	INTEG (Increase in Classrooms secondary-Decrease in Classrooms secondary, Initial number of classrooms secondary)	Classroom	Stock of secondary classrooms. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement from finishing the estimated years of life.
Number of Seats elementary	Stock	INTEG (Increase in Seats elementary-Decrease in Seats elementary, Initial number of seats elementary)	Seat	Stock of elementary school seats. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement from finishing the estimated years of life.
Number of Seats secondary	Stock	INTEG (Increase in Seats secondary-Decrease in Seats secondary,	Seat	Stock of secondary school seats. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement

		Initial number of seats secondary)		from finishing the estimated years of life.
Number of Students elementary	Auxiliary variable	Age 0-14"*"Fraction of 0-14 Population in Public School elementary"	Person	Estimated number of elementary school students based on school age population.
Number of Students secondary	Auxiliary variable	Age 0-14"*"Fraction of 0-14 Population in Public School secondary"	Person	Estimated number of secondary school students based on school age population.
Number of Teachers elementary	Stock	INTEG (Increase in Teachers elementary- Elementary teacher retire, Initial number of teachers elementary)	Person	Stock of elementary school teachers. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement.
Number of Teachers secondary	Stock	INTEG (Increase in Teachers secondary - Secondary teacher retire, Initial number of teachers secondary)	Person	Stock of secondary school teachers. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement.
Resilience Score Classrooms elementary	Auxiliary variable	Number of Classrooms elementary/Ideal number of classrooms elementary	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.
Resilience Score Classrooms secondary	Auxiliary variable	Number of Classrooms secondary/Ideal number of classrooms secondary	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.
Resilience Score Seats elementary	Auxiliary variable	Number of Seats elementary/Ideal number of seats elementary	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.
Resilience Score	Auxiliary variable	Number of Seats secondary/Ideal	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU

Seats secondary		number of seats secondary		ideal ratio and number of students.
Resilience Score Teachers elementary	Auxiliary variable	Number of Teachers elementary/Ideal number of elementary teachers	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.
Resilience Score Teachers secondary	Auxiliary variable	Number of Teachers secondary/Ideal number of secondary teachers	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.
Seat years of useful life	Auxiliary variable	10	Year	Estimated useful life of furniture. From Annex A of Memorandum Circular 2003-007: https://www.coa.gov.ph/phocadownload/userupload/Issuances/Circulars/Attachments/2003/C2003-007_AnnexA.pdf
Seats annual increase elementary historical	Auxiliary variable	Pasig: 632 Valenzuela: 3647	Seat/Year	2008-2013 Pasig SEP. Valenzuela data: 2015-2018 MDG CBMS - SEP
Seats annual increase secondary historical	Auxiliary variable	Pasig: 686 Valenzuela: 1526	Seat/Year	2015-2018 Valenzuela data: 2015-2018 MDG CBMS - SEP
Secondary classrooms gap	Auxiliary variable	Ideal number of classrooms secondary-Number of Classrooms secondary	Classroom	Gap to close.
Secondary Education Services Resilience Score	Auxiliary variable	(Resilience Score Classrooms secondary+Resilience Score Seats secondary+Resilience Score Teachers secondary)/3	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ideal ratio and number of students.

Secondary seats gap	Auxiliary variable	Ideal number of seats secondary-Number of Seats secondary	Seat	Gap to close.
Secondary teacher retire	Flow	Number of Teachers secondary/Teacher average number of years in service	Person/ Year	Number of secondary school teachers who retire.
Secondary teachers gap	Auxiliary variable	Ideal number of secondary teachers-Number of Teachers secondary	Person	Gap to close.
Target Student to Classroom Ratio	Auxiliary variable	35	Person/ Classroom	LGU standard indicated in the SEP.
Target Student to Seat Ratio	Auxiliary variable	1	Person/ Seat	LGU standard indicated in the SEP.
Target Student to Teacher Ratio	Auxiliary variable	35	Dmnl	LGU standard indicated in the SEP.
Teacher average number of years in service	Auxiliary variable	25	Year	Author’s estimate.
Teachers annual increase elementary historical	Auxiliary variable	Pasig: 77 Valenzuela: 99	Person/ Year	Average increase over 2015-2018 for both Pasig and Valenzuela. From Pasig SEP 2018 and Valenzuela SEP 2018 and MDG 2015 CBMS.
Teachers annual increase secondary historical	Auxiliary variable	Pasig: 198 Valenzuela: 74	Person/ Year	Average increase over 2015-2018 for both Pasig and Valenzuela. From Pasig SEP 2018 and Valenzuela SEP 2018 and MDG 2015 CBMS.
Teachers annual salary	Auxiliary variable	267792	PHP/Person/Year	Monthly salary of P22,316; minimum for teachers according to government mandated salary grades. From Bueza, M. (2020). *Is the salary increase for*

				teachers, gov't workers enough? Manila: Rappler.
Total annual cost of new classrooms	Auxiliary variable	Annual cost of new classrooms secondary+Annual cost of new classrooms elementary	PHP/Year	Cost of the year's increase in classrooms.
Total annual cost of new seats	Auxiliary variable	Annual cost of new seats elementary+Annual cost of new seats secondary	PHP/Year	Cost of the year's increase in seats.
Total annual salary for teachers	Auxiliary variable	Annual salary for teachers elementary+Annual salary for teachers secondary	PHP/Year	Cost of salary for the year's employed teachers.
Protection				
Adjustment time firetruck	Auxiliary variable	3	Year	Time to close the gap. Author's estimation.
Adjustment time for protection personnel	Auxiliary variable	1.5	Year	Time to close the gap. Author's estimation.
Cost of new firetruck	Auxiliary variable	2.5e+06	PHP/Firetruck	Estimated cost based on available listings in online marketplaces.
Daytime population	Auxiliary variable	Population-Population working outside city+(Total number of jobs in city-Population working in city)	Person	Population in the city during the day when residents working outside the city are gone and non-residents working inside the city are present.
Decrease in Firetrucks	Flow	IF THEN ELSE(Number of Firetrucks/Years of useful life firetruck>=1,INTEGER (Number of Firetrucks/Years of useful life firetruck),0)	Firetruck/Year	Decrease due to retirement of asset.
Firefighers retire	Flow	Number of Firefighters/Firefi	Person/Year	Decrease due to retirement of personnel.

		ghter average number of years of service		
Firefighter annual historical increase	Auxiliary variable	Pasig: 10 Valenzuela: 4	Person/ Year	Number of additional firefighters per year on average, over 2013-2016 for Pasig and 2008-2017 for Valenzuela. From cities' 2018 SEPs.
Firefighter average number of years of service	Auxiliary variable	30	Year	Author's estimate.
Firefighter gap	Auxiliary variable	Ideal number of firefighers-Number of Firefighters	Person	Gap to close.
Firefighters annual salary	Auxiliary variable	356016	PHP/Person/Year	29668*12
Firetruck annual increase estimated	Auxiliary variable	PULSE TRAIN(2020, 1, 5, 2050)	Firetruck /Year	Not enough data for average historical increase. Fixed yearly increase here is the author's estimation.
Firetruck gap	Auxiliary variable	Ideal number of firetrucks-Number of Firetrucks	Firetruck	Gap to close.
Ideal number of firefighters	Auxiliary variable	Population/Target Population to Firefighter ratio	Person	LGU goal for the capacity of this service component.
Ideal number of firetrucks	Auxiliary variable	Population/Target Population to Firetruck ratio	Firetruck	LGU goal for the capacity of this service component.
Ideal number of police	Auxiliary variable	IF THEN ELSE("Use daytime population? yes 1, no 0"=1,Daytime population,Population)/Target Population to Police ratio	Person	LGU goal for the capacity of this service component.

Increase in Firefighters	Flow	IF THEN ELSE("Historical increase (0) or Goal seeking (1)"=0,Firefighter annual historical increase, INTEGER(Firefighter gap/Adjustment time for protection personnel))	Person/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in Firetrucks	Flow	IF THEN ELSE("Historical increase (0) or Goal seeking (1)"=0,Firetruck annual increase estimated ,INTEGER(Firetruck gap/Adjustment time firetruck))	Firetruck /Year	Change for a given year. Either follows goal seeking or estimated fixed annual increase.
Increase in Police	Flow	IF THEN ELSE ("Historical increase (0) or Goal seeking (1)"=0,Police annual historical increase , INTEGER(Police gap/Adjustment time for protection personnel))	Person/Year	Change for a given year. Either follows goal seeking or historical increase.
Increase in protection services cumulative expenditure	Flow	Protection total annual expenditure	PHP/Year	Inflow to the cumulative expenditure stock.
Initial number of firefighters	Auxiliary variable	Pasig: 101 Valenzuela: 171	Person	Value for Pasig as of 2015 and for Valenzuela as of 2017. From Pasig SEP 2018 and Valenzuela SEP 2017.
Initial number of firetrucks	Auxiliary variable	Pasig: 6 Valenzuela: 8	Firetruck	Value for Pasig as of 2015 and for Valenzuela as of 2010. From Pasig SEP 2018 and Valenzuela SEP 2017.

Initial number of police	Auxiliary variable	Pasig: 407 Valenzuela: 535	Person	Values for 2015 from Pasig SEP 2018 and Valenzuela SEP 2018.
Number of Firefighters	Stock	INTEG (Increase in Firefighters-Firefighers retire,Initial number of firefighters)	Person	Stock of firefighters. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement.
Number of Firetrucks	Stock	INTEG (Increase in Firetrucks-Decrease in Firetrucks,Initial number of firetrucks)	Firetruck	Stock of firetrucks. Inflow is the additions due to goal seeking or fixed estimated yearly increase. Outflow is due to retirement as years of useful life are passed.
Number of Police	Stock	INTEG (Increase in Police-Police retire, Initial number of police)	Person	Stock of police. Inflow is the additions due to goal seeking or fixed historical yearly increase. Outflow is due to retirement.
Police annual historical increase	Auxiliary variable	Pasig: 85 Valenzuela: 53	Person/ Year	Number of additional police per year on average, over 2012-2017 for Pasig and 2013-2018 for Valenzuela. From the Pasig SEP 2018 and Valenzuela SEP 2017.
Police annual salary	Auxiliary variable	356016	PHP/Person/Year	Monthly salary of P29,668; starting for police according to government mandated salary grades. From https://governmentph.com/modified-base-pay-schedule-military-uniformed-personnel-mup/
Police average number of years of service	Auxiliary variable	30	Year	Author's estimate.
Police gap	Auxiliary variable	Ideal number of police-Number of Police	Person	Gap to close.
Police retire	Flow	Number of Police/Police average number of years of service	Person/ Year	Decrease due to retirement of personnel.

Protection total annual expenditure	Auxiliary variable	Total annual salary for police+Total annual salary for firefighers+Total annual cost of new firetrucks	PHP/Year	Annual expenditure for current personnel salary and asset additions.
Protection services cumulative expenditure	Stock	INTEG (Increase in protection services cumulative expenditure,0)	PHP	Cumulative expenditure for protection services personnel and assets.
Protection Services Resilience Score	Auxiliary variable	(Resilience Score Firefighter+Resilience Score Firetruck+Resilience Score Police)/3	Dmnl	Average of component resilience scores.
Resilience Score Firefighter	Auxiliary variable	Number of Firefighters/Ideal number of firefighters	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population.
Resilience Score Firetruck	Auxiliary variable	Number of Firetrucks/Ideal number of firetrucks	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total population.
Resilience Score Police	Auxiliary variable	Number of Police/Ideal number of police	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU ratios to total (or daytime) population.
Target Population to Firefighter ratio	Auxiliary variable	2000	Dmnl	LGU standard indicated in the SEP.
Target Population to Firetruck ratio	Auxiliary variable	28000	Person/ Firetruck	LGU standard indicated in the SEP.
Target Population to Police ratio	Auxiliary variable	500	Dmnl	LGU standard indicated in the SEP.
Total annual cost of new firetrucks	Auxiliary variable	Increase in Firetrucks*Cost of new firetruck	PHP/Year	Cost of the year's additions in firetrucks.

Total annual salary for firefighers	Auxiliary variable	Firefighters annual salary*Number of Firefighters	PHP/Year	Cost of salary for the year’s employed firefighters.
Total annual salary for police	Auxiliary variable	Number of Police*Police annual salary	PHP/Year	Cost of salary for the year’s employed police.
"Use daytime population? yes 1, no 0"	Auxiliary variable	0	Dmnl	Switch to use either total or daytime population as the input for ideal number of police
Years of useful life firetruck	Auxiliary variable	15	Year	Numer of years a firetruck can be used.
Business				
"(Temporary) unemployment due to COVID"	Auxiliary variable	COVID wave quarantine*COVID quarantine rise in unemployment rate*”COVID (1 Yes; 0 No)”	Dmnl	Fraction of people unemployed during the lockdown. Takes on a value of 0 if COVID effects are not considered in the scenario.
Average area per business	Auxiliary variable	Pasig: 289.514 Valenzuela: 512	M*m/Unit	Average floor area occupied by each business. From business listings of Pasig and Valenzuela as of 2015.
Average number of employees per business	Auxiliary variable	Pasig: 8.04841 Valenzuela: 9	Person/Unit	Average employment of each business. From business listings of Pasig and Valenzuela as of 2015.
COVID quarantine rise in unemployment rate	Auxiliary variable	0.12	Dmnl	Increase in national unemployment from first to second quarter of 2020, from the PSA Labor Force Survey. First quarter is before lockdown, second is during lockdown.
Employment resilience score	Auxiliary variable	Number of jobs for residents/Working age population	Dmnl	Ratio of actual to ideal value of this key indicator. Ideally, there is enough employment within the city (net of non-residents working within the city) for its working age population.
"Employment self-sufficiency score"	Auxiliary variable	Jobs in city for residents/(Jobs outside the city for residents+Jobs	Dmnl	Ratio of jobs held by residents inside the city to total jobs held by residents. Indicates how self-sufficient

		in city for residents)		the city is for its residents' employment.
Fraction of jobs in city held by residents	Auxiliary variable	Pasig: 0.8711 Valenzuela: 0.92	Dmnl	For Pasig: Total number of residents employed in the city divided by the total number of jobs in the city. Number of residents employed in the city is from the employed population (Latest unemployment and labor force participation rates of NCR applied to the 2015 ">=15 population" of the city) multiplied by the SEP indicated population working in the city. Total number of jobs in the city is based on business listings as of 2015. For Valenzuela: No data. Local employment is simply estimated to be 5% higher than Pasig due to the nature of industries located in Valenzuela.
Growth rate of businesses	Auxiliary variable	0.0295	1/Year	Growth rate of businesses in Pasig from 2015-2018 based on registered businesses in SEP 2018. No data available for Valenzuela; Pasig figure is used.
Growth rate of jobs PHL	Auxiliary variable	0.052	1/Year	Based on the growth of total employed persons in the Philippines from 2015-2018, from the PSA table "Number of Establishments and Total Employment by Industry, Region and Employment Grouping (MSMEs)".
Increase in number of jobs for residents employed outside city	Flow	Number of jobs for residents employed outside city*Growth rate of jobs PHL	Person/ Year	Inflow to stock number of jobs for residents employed outside the city. This assumes that the number of jobs available starts off as equal to the number of people working outside the city, and that it grows at the national growth rate for jobs.

Increase of businesses	Flow	Number of businesses*Growth rate of businesses	Unit/Year	Inflow to the stock number of businesses. This simply applies a historical growth rate to the current stock.
Initial number of businesses	Auxiliary variable	Pasig: 25451 Valenzuela: 15521	Unit	Number of businesses in 2015. Pasig figure from registered business statistics; Valenzuela figure from business listings.
Initial number of residents employed outside the city	Auxiliary variable	Pasig: 128161 Valenzuela: 105600	Person	Calculated from 2015 working population (Latest unemployment and labor force participation rates of NCR applied to the 2015 “>=15 population” of the city) multiplied by 41.8%, or the fraction of working population employed outside the city. This 41.8% is for 2008, taken from the Pasig 2018 SEP. The same is used for Valenzuela due to lack of available data.
Jobs in city for residents	Auxiliary variable	Total number of jobs in city*Fraction of jobs in city held by residents*(1-"(Temporary) unemployment due to COVID")	Person	Number of jobs generated by in-city businesses that are held by residents. During the COVID lockdown, this number is reduced by the percentage increase in unemployment due to COVID.
Jobs outside the city for residents	Auxiliary variable	Number of jobs for residents employed outside city*(1-"(Temporary) unemployment due to COVID")	Person	Number of jobs outside the city that are held by residents. During the COVID lockdown, this number is reduced by the percentage increase in unemployment due to COVID.
Number of businesses	Stock	INTEG (Increase of businesses, Initial number of businesses)	Unit	Stock of number of in-city businesses.
Number of jobs for residents	Auxiliary variable	Jobs in city for residents+Jobs outside the city for residents	Person	Total number of jobs held by residents, both inside and outside the city.
Number of jobs for residents	Stock	INTEG (Increase in number of jobs for residents	Person	Number of jobs for residents outside the city.

employed outside city		employed outside city,Initial number of residents employed outside the city)		
"Total floor area of businesses (incl. apartments, factories, hospital, school, etc.) in city"	Auxiliary variable	Average area per business*Number of businesses	m*m	Total floor area of in-city businesses.
Total number of jobs in city	Auxiliary variable	Average number of employees per business*Number of businesses	Person	Total number of jobs provided by in-city businesses.
Population				
“1 year delay”	Auxiliary variable	1	Year	Input for delay function.
"Age 0-14"	Stock	INTEG (Births-"Deaths 0-14"-"Maturation to 15+", "Initial Age 0-14")	Person	Number of residents aged 0-14 years.
"Age 15-44"	Stock	INTEG ("Maturation to 15+"-"Deaths 15-44"-"Maturation to 45+","Initial Age 15-44")	Person	Number of residents aged 15-44 years.
"Age 45-64"	Stock	INTEG ("Maturation to 45+"-"Deaths 45-64"-"Maturation to 65+","Initial Age 45-64")	Person	Number of residents aged 45-64 years.
"Age 65+"	Stock	INTEG ("Maturation to 65+"-"Deaths 65+","Initial Age 65+")	Person	Number of residents at or above the age of 65.
"Age >=15"	Stock	"Age 15-44"+"Age 45-64"+"Age 65+"	Person	Number of residents at or above the age of 15.
Age dependency Ratio	Auxiliary variable	Dependent age population/Worki	Dmnl	Ratio of dependent population to working population.

		ng age population		
Birth frac	Auxiliary variable	0.037389	1/Year	Ratio of below 1 year population to “Age 15-44” or fertile population. From the PSA 2015 National Census.
Births	Flow	Birth frac*"Age 15-44"	Person/ Year	Number of births in a year, based on the fertile population and birth fraction.
Daytime population	Auxiliary variable	Population-Jobs outside the city for residents+(Total number of jobs in city-Jobs in city for residents)	Person	Number of people present in the city during the day, i.e. population plus the non-residents work in the city and less the residents working outside the city.
"Death frac 0-14"	Auxiliary variable	1.61291/1000	1/Year	Fraction of population in this age bracket that dies per year. From the PSA Vital Statistics Report 2015.
"Death frac 15-44"	Auxiliary variable	1.69166/1000	1/Year	Fraction of population in this age bracket that dies per year. From the PSA Vital Statistics Report 2015.
"Death frac 45-64"	Auxiliary variable	10.6315/1000	1/Year	Fraction of population in this age bracket that dies per year. From the PSA Vital Statistics Report 2015.
"Death frac 65+"	Auxiliary variable	57.9665/1000	1/Year	Fraction of population in this age bracket that dies per year. From the PSA Vital Statistics Report 2015.
"Deaths 0-14"	Flow	"Age 0-14"*"Death frac 0-14"	Person/ Year	Number of deaths in this age bracket per year.
"Deaths 15-44"	Flow	"Age 15-44"*"Death frac 15-44"	Person/ Year	Number of deaths in this age bracket per year.
"Deaths 45-64"	Flow	"Age 45-64"*"Death frac 45-64"	Person/ Year	Number of deaths in this age bracket per year.
"Deaths 65+"	Flow	"Age 65+"*"Death frac 65+"	Person/ Year	Number of deaths in this age bracket per year.
Dependent age population	Auxiliary variable	"Age 0-14"+"Age 65+"	Person	Number of people who are considered dependents or not working.
"Initial Age 0-14"	Auxiliary variable	Pasig: 211419 Valenzuela: 172289	Person	Initial number of city residents in this age bracket. From PSA 2015 Census.

"Initial Age 15-44"	Auxiliary variable	Pasig: 394287 Valenzuela: 329946	Person	Initial number of city residents in this age bracket. From PSA 2015 Census.
"Initial Age 45-64"	Auxiliary variable	Pasig: 120491 Valenzuela: 96842	Person	Initial number of city residents in this age bracket. From PSA 2015 Census.
"Initial Age 65+"	Auxiliary variable	Pasig: 29103 Valenzuela: 21345	Person	Initial number of city residents in this age bracket. From PSA 2015 Census.
"Maturation to 15+"	Flow	"Age 0-14"/"Years as Age 0-14 Pasig"	Person/ Year	Number of people moving from one age bracket to the next per year.
"Maturation to 45+"	Flow	"Age 15-44"/"Years as Age 15-44"	Person/ Year	Number of people moving from one age bracket to the next per year.
"Maturation to 65+"	Flow	"Age 45-64"/"Years as Age 45-64"	Person/ Year	Number of people moving from one age bracket to the next per year.
Population	Auxiliary variable	“Age 0-14"+"Age 15-44"+"Age 45-64"+"Age 65+"	Person	Total population.
"Population (t-1)"	Auxiliary variable	DELAY1(Population, “1 year delay”)	Person	Population in the previous year.
Population Growth Rate	Auxiliary variable	(Population/"Population (t-1)")-1	Dmnl	Growth rate of population based on current and previous year.
Total Land Area	Auxiliary variable	Pasig: 3432 Valenzuela: 4459.41	Ha	Hectarage of the city.
Working age population	Auxiliary variable	"Age 15-44"+"Age 45-64"	Person	Number of working age residents.
"Years as Age 0-14 Pasig"	Auxiliary variable	15	Year	Number of years covered by this age bracket.
"Years as Age 15-44"	Auxiliary variable	30	Year	Number of years covered by this age bracket.
"Years as Age 45-64"	Auxiliary variable	20	Year	Number of years covered by this age bracket.
Poverty				
"Annual Per Capita Poverty Threshold (NCR)"	Auxiliary variable	28682	PHP/(Person*Year)	Poverty threshold or minimum cost of living per person per year in NCR. From PSA for 2018.
Average income	Auxiliary variable	Income Gap*"Annual Per Capita Poverty	PHP/(Person*Year)	Average amount each poor person needs to meet the poverty threshold.

shortfall per poor person		Threshold (NCR)"		
Income Gap	Auxiliary variable	0.182	Dmnl	Fraction of poverty threshold that poor people fall short by, on average.
Number of households	Auxiliary variable	Household population/Average household size	Household	Number of households in the city.
Number of households below poverty line	Auxiliary variable	Number of households*"Poverty incidence (households)"	Household	Number of households living below the poverty line in the city.
Number of people below poverty line	Auxiliary variable	Population*"Poverty incidence (population)"	Person	Number of people living below the poverty line in the city.
"Poverty incidence (households)"	Auxiliary variable	Pasig: 0.018 Valenzuela: 0.005	Dmnl	Fraction of the number of households that are below the poverty threshold. From PSA for 2018.
"Poverty incidence (population)"	Auxiliary variable	Pasig: 0.027 Valenzuela: 0.005	Dmnl	Fraction of the population below the poverty threshold. From PSA for 2018.
Total Annual Income Shortfall	Auxiliary variable	Number of people below poverty line*Average income shortfall per poor person	PHP/Year	Total income shortfall of all people with income below the poverty threshold in the city.
Housing				
Average household size	Auxiliary variable	Pasig: 4.17 Valenzuela: 4.05	Person/Household	Average number of people per household in the city. From PSA 2015 Housing Tables.
Fraction of informal settler households	Auxiliary variable	Pasig: 0.0109295 Valenzuela: 0.0229	Dmnl	Ratio of informal settler households (tenure status being “without consent of owner”) to total number of households. From PSA 2015 Housing Tables.
Household population	Auxiliary variable	Population*Ratio of Household population to Population	Person	Fraction of the population counted as household population. This is to consider the statistics which show that the household

				population is actually less than the total population.
Housing relocation resilience score	Auxiliary variable	Total number of housing project units/Total number of housing project units needed	Dmnl	Ratio of actual to ideal value of this key indicator. Ideal value here is based on LGU population that are informal settlers or are living with another household in the same unit.
"Housing relocation self-sufficiency score"	Auxiliary variable	"Number of in-city housing project units"/("Number of in-city housing project units" +"Number of off-city housing project units")	Dmnl	Ratio of housing project units inside the city to total housing project units built for residents' relocation. Indicates how self-sufficient the city is for its residents' housing relocation.
Ideal households per unit	Auxiliary variable	1	Household/Unit	Ideally each unit is occupied by only one household.
"Initial number of in-city housing project units"	Auxiliary variable	Pasig: 4024 Valenzuela: 5386	Unit	Initial number of housing project units for residents built in the city. From the Pasig SEP 2018 and Valenzuela Housing and Resettlement Office 2019 report.
"Initial number of off-city housing project units"	Auxiliary variable	Pasig: 7638 Valenzuela: 0	Unit	Initial number of housing project units for residents built outside the city. From the Pasig SEP 2018 and Valenzuela Housing and Resettlement Office 2019 report.
"In-city housing project construction"	Auxiliary variable	0	Unit/Year	Number of housing project units constructed inside the city per year. Set to zero (0) by default.
"Number of doubled-up households"	Auxiliary variable	Number of households*(Ratio of households to occupied housing units-1)	Household	Difference between number of households and number of housing units, i.e. number of households that need their own housing unit.
Number of households	Auxiliary variable	Household population/Average household size	Household	Number of households in the city.

"Number of in-city housing project units"	Auxiliary variable	INTEG ("In-city housing project construction","Initial number of in-city housing project units")	Unit	Number of housing project units for residents built in the city.
Number of informal settler households	Auxiliary variable	Number of households*Fraction of informal settler households	Household	Number of households who are informal settlers. This is simply a fraction of the total number of households.
"Number of off-city housing project units"	Auxiliary variable	INTEG ("Off-city housing project construction","Initial number of off-city housing project units")	Unit	Number of housing project units for residents built outside the city.
"Off-city housing project construction"	Auxiliary variable	0	Unit/Year	Number of housing project units constructed outside the city per year. Set to zero (0) by default.
Ratio of Household population to Population	Auxiliary variable	Pasig: 753030/755300 Valenzuela: 619324/620422	Dmnl	Ratio of the population counted as part of households to the total population. From the PSA 2015 Housing Tables.
Ratio of households to occupied housing units	Auxiliary variable	Pasig: 1.03 Valenzuela: 1.04	Dmnl	Ratio of households to housing units. From the PSA 2015 Housing Tables.
Total number of housing project units	Auxiliary variable	"Number of off-city housing project units"+"Number of in-city housing project units"	Unit	Total number of housing project units for residents, both inside and outside the city.
Total number of housing project units needed	Auxiliary variable	(Number of informal settler households+"Number of doubled-up households")/Ideal households per unit	Unit	Total number of housing project units needed.
COVID-19 Cost				

Additional people admitted COVID	Auxiliary variable	COVID wave LOOKUP(Time step number)*Number of COVID patients admitted/Time for wave*"COVID (1 Yes; 0 No)"	Person/Year	Effective persons per year admitted due to COVID. Takes on a value of 0 if COVID effects are not considered in the scenario.
Cost per PPE	Auxiliary variable	400	PHP/set	Cost per personal protective equipment (PPE) set. Lowest cost among alternatives according to Tantuico, V. (2020, April 3). EXPLAINER: The PPE keeping our healthcare workers safe. Rappler, p. 1.
COVID hospital cost	Auxiliary variable	Additional people admitted COVID*Philhealth coverage per COVID patient	PHP/Year	Cost paid by PhilHealth for resident patients admitted due to COVID.
COVID Pandemic Active	Auxiliary variable	COVID Pandemic Active LOOKUP(Time step number) *"COVID (1 Yes; 0 No)"	Dmnl	Returns 1 during the time when the pandemic is active. Returns 0 all throughout if COVID effects are not considered in the scenario.
COVID Pandemic Active	Auxiliary variable	LOOKUP([(0,0)-(1000,10)],(0,0),(1,1),(5,1),(6,0),(26,0),(1000,0))	Dmnl	Lookup graph indicating that the pandemic is active on the 21st to 24th quarter year. This is from second quarter 2020 until second quarter 2021, indicating that people have to stay on guard for a year, i.e. wear PPE, after the pandemic began.
COVID PPE cost	Auxiliary variable	COVID Pandemic Active*Total number of medical professionals*Cost per PPE*PPE per person per year	PHP/Year	Total PPE cost per year, will determine the inflow to the cumulative COVID PPE cost.
COVID SAP cost	Auxiliary variable	COVID wave quarantine LOOKUP(Time step number)	PHP/Year	Total Social Amelioration Program (SAP) cost per year. During the lockdown, we assume that the SAP

		*Number of households below poverty line*SAP PHP per household per month*Months for SAP/Time for wave*"COVID (1 Yes; 0 No)"		financial relief is given to each family below the poverty line. Takes on a value of 0 if COVID effects are not considered in the scenario.
Months for SAP	Auxiliary variable	2	Month/Wave	Number of months of financial relief provided per household for the quarantine period.
Philhealth coverage per COVID patient	Auxiliary variable	326250	PHP/Person	Those with mild pneumonia are entitled to P43,000 coverage, P143,000 for moderate pneumonia, P333,000 for severe pneumonia, and P786,000 for critical pneumonia. Due to the lack of data on case severity distribution, equal weights are assumed for each. From Billones, R., Fenol, J., & de Guzman, W. (2020, April 13). How much does COVID-19 treatment cost, and how much will PhilHealth cover? ABS CBN News, p. 1.
PPE per person per year	Auxiliary variable	365	Set/Person/Year	Number of PPE sets each person needs per year. We assume that each medical professional needs two sets a day and goes to work for half the number of days in a year.
SAP PHP per household per month	Auxiliary variable	8000	PHP/Household/month	Financial relief per month provided for each qualified family, maximum for NCR. From Perez, R. (2020, April 15). MSN Social Amelioration Program: How to Qualify and how much can you receive. Smart Parenting, p. 1.

Total COVID hospital cost	Stock	INTEG (Total COVID Hospital cost inflow,0)	PHP	Cumulative COVID hospitalization cost covered by PhilHealth for residents.
Total COVID Hospital cost inflow	Flow	COVID hospital cost	PHP/Year	Inflow to the cumulative COVID cost.
Total COVID PPE cost	Stock	INTEG (Total COVID PPE cost inflow,0)	PHP	Cumulative COVID PPE cost for medical professionals.
Total COVID PPE cost inflow	Flow	COVID PPE cost	PHP/Year	Inflow to the cumulative COVID PPE cost.
Total COVID SAP cost	Stock	INTEG (Total COVID SAP cost inflow,0)	PHP	Cumulative COVID SAP cost to the city to provide financial relief.
Total COVID SAP cost inflow	Flow	COVID SAP cost	PHP/Year	Inflow to the cumulative COVID SAP cost.
Total number of medical professionals	Auxiliary variable	Number of Doctors+Number of Nurses+ Number of Midwives	Person	Total number of medical professionals in need of PPE.
Cost per laptop	Auxiliary variable	20000	PHP/laptop	Estimated cost from Alcober, N. (2020, June 5). Pasig City prepares P1.2B for educational tablets, laptops. Tribune, p. 1.
Cost per tablet	Auxiliary variable	6500	PHP/Unit	Estimated cost from Alcober, N. (2020, June 5). Pasig City prepares P1.2B for educational tablets, laptops. Tribune, p. 1.
COVID tablet and laptop cost	Auxiliary variable	COVID wave quarantine*(((Number of Students elementary+Number of Students secondary)*Tablet per person*Cost per tablet)+((Number of Teachers elementary+Num	PHP/Year	Total tablet and laptop cost for public school students and teachers.

		ber of Teachers secondary)*Cost per laptop*Laptop per person))/TIME STEP		
COVID wave quarantine	Auxiliary variable	COVID wave quarantine LOOKUP(Time step number) *"COVID (1 Yes; 0 No)"	Dmnl	Returns 1 when the time step number equals the time step number when there is a lockdown. Returns 0 all throughout the run if COVID is not considered in the scenario.
COVID wave quarantine LOOKUP	Auxiliary variable	LOOKUP([(0,0)-(140,10)],(0,0),(1,1),(2,0),(22,0),(140,0))	Dmnl	Lookup graph for COVID wave quarantine. Returns 1 when time step number is equal to the 1st quarter year since 2020, or second quarter of 2020.
Laptop per person	Auxiliary variable	1	Laptop/Person	Number of laptops needed per teacher.
Tablet per person	Auxiliary variable	1	Unit/Person	Number of tablets needed per student.
Total COVID tablet and laptop cost	Stock	INTEG (Total COVID tablet and laptop cost inflow,0)	PHP	Cumulative cost of Tablets and Laptops purchased for online learning capability required because of COVID.
Total COVID tablet and laptop cost inflow	Flow	COVID tablet and laptop cost	PHP/Year	Inflow to the cumulative COVID tablet and laptop cost.