Assessing Infrastructure Interdependency in Jakarta, Indonesia: Using Critical Asset Surveys to Advance Urban Decision Support Systems

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ABSTRACT

Due to climate change and high urbanization rates, developing megacities like Jakarta, Indonesia, have experienced an increased number and intensity of climatic disasters like flooding, which can be mitigated by resilient infrastructure systems. However, as cities grow larger, infrastructure systems become more interdependent with one another, and the risk of cascading failures increases. Using questionnaire responses from in the Jakarta Provincial Government (JPG) and United Nations Development Programme (UNDP) Indonesia, I show that governments and intergovernmental organizations may not be fully aware of this risk during urban planning. I also identified that several barriers to constructing more robust infrastructure models that address infrastructure interdependency include the lack of human resources, availability and credibility of data, and coordination between affiliated parties. Furthermore, I propose a critical asset survey (CAS) prototype that aims to collect appropriate data on critical infrastructure, so that governments can make more rational, data-based policy decisions and to provide more credible data to run infrastructure models. I modified the CAS based on my questionnaire responses, literature review and assessment on the implementation of the prototype. Foreign aid agencies that aim to help cities like Jakarta adapt to climate change through infrastructure projects can increase the likelihood that their funds are allocated to investments that are less likely to fail due to infrastructure interdependency by requiring the use of the CAS and infrastructure models. The conclusions from this paper and the CAS can also be applied to developing cities that also face the problem of data scarcity like Jakarta.

KEYWORDS

Urban environment, urban planning, water management, flooding, foreign aid policy

INTRODUCTION

Climate change has increased the need for resilient infrastructure systems due to heightened risk of extreme weather events, which may lead to infrastructure failures. Developing cities like Jakarta, Indonesia, have experienced increasingly severe flooding events in recent decades due to natural and anthropogenic factors. Climate change increases the occurrence of extreme weather events and increases ocean surface temperatures that lead to thermal expansion of water, which causes sea level rise that affect coastal cities like Jakarta (Hijioka et al. 2014; Loukas et al. 2002; Vermeer and Rahmstorf 2009). Urbanization in Jakarta has increased the city's weight and groundwater extraction, leading to greater land subsidence rates that cause Jakarta to sink further below sea level and increases its risk to flooding (Abidin et al. 2011; Firman et al. 2011). It is therefore important to develop infrastructure systems that are resilient to the future changes caused by climate change.

Infrastructure interdependency is an important and understudied issue that affects the resilience of infrastructure systems. Infrastructure interdependency arises when infrastructures are interconnected and dependent on each other and the state of each infrastructure influences the state of the other (Kelly 2011). Even developed countries, like the United Kingdom (UK), face challenges in addressing infrastructure interdependencies. The subject of infrastructure interdependency became increasingly important after a power failure in Birmingham, England, led to a temporary loss of broadband service that affected many businesses on October 3rd, 2011 (BBC 2011). The UK Infrastructure Transitions Research Consortium (ITRC) has highlighted the importance of addressing interdependencies across infrastructure sectors when planning and making models for infrastructure provisions (Tran et al. 2014). Furthermore, in the developing city of Yogyakarta, Indonesia, it has been demonstrated that incorporating infrastructure interdependency into infrastructure planning models was an effective means of mitigating and responding to flood risk (Wismadi et al. 2012). However, governments are often unaware of the consequences of interdependencies when adding new infrastructure to current aging infrastructure systems, which reduces the resilience of the whole system (CST 2009). Hence, it is important to provide governments with a means to conduct a more rational decision making framework (by the ability to run more robust infrastructure models, etc) that addresses infrastructure interdependency to improve infrastructure planning and systems.

In recent years, Jakarta's devastating floods have led to growing awareness of the need for investments in water management infrastructure, but funds for addressing these needs are allocated inefficiently. Floods are associated with disease outbreaks, deaths, hindrance of economic activity and property destruction (Jha et al. 2012), and Jakarta is predicted to experience an Economic Average Annual Loss (AAL) of US$1.75 billion by 2050 due to future floods (Hallegatte et al. 2013). The World Bank has allocated US$139.64 million to the Jakarta Provincial Government (JPG) for the Jakarta Urgent Flood Mitigation Project, which aims to improve the operation and maintenance of Jakarta's flood management system (Worldbank.org 2015). Despite the availability of such funds, in 2015, preventable floods continued to occur in Jakarta due to infrastructure interdependency (Jakarta Globe 2015). Although Jakarta's Governor, Basuki Tjahaja Purnama (Ahok), understands that the city's ability to prevent and respond to floods is impaired by the interdependence of the city's pumps with the electrical grid, it is unclear if infrastructure managers and other urban planners are aware of such phenomenon. After the February 2015 floods, when awarded US$545,968 in grants by businessmen and the Tahir Foundation, Ahok prioritized purchasing generators to support the city's pumps to address the problem of the water pumps' interdependence with the electrical grid (The Jakarta Post 2015). Through this event, there is evidence that Jakarta's current infrastructure planning decisions has failed to thoroughly identify interdependencies, and this paper aims to analyze Jakarta's decision makers' awareness towards infrastructure interdependency and what they are currently doing to incorporate it into their current decision-making framework, and identify what can be done in order to provide a more rational decision making framework.

I used Jakarta as a case study to understand how infrastructure interdependency is addressed in the context of infrastructure planning and implementation in developing countries. I also assessed the efficacy of a critical asset survey as a tool for decision-makers concerned with addressing interdependency in infrastructure planning and development. There are three main parts to the study:

I. **INFRASTRUCTURE INTERDEPENDENCY IN THE CONTEXT OF MEGA CITIES**: I introduce key terms and definitions to describe infrastructure interdependency, especially in mega cities.

II. **JAKARTA CASE STUDY:** I present the February 2015 floods as a case study for infrastructure interdependency in Jakarta, supported by some of my findings about the Pluit pumps from my Travel Grant trip to Jakarta during the summer of 2015. I also discuss how individuals in organizations and agencies in Jakarta perceive infrastructure interdependency, what kinds of actions are being done to address it, and what they think are the key barriers to addressing it.

III. **THE CRITICAL ASSET SURVEY**: I assess the critical asset survey prototype as a tool for infrastructure planning that can help decision-makers better address infrastructure interdependency in cities like Jakarta through data collection. First, I present the critical asset survey prototype and explain the rational behind uploading the data onto Java Open Street Map (JOSM), an open source application. Then I identify the perceived usefulness of the CAS, and discuss how to optimize the CAS prototype.

METHODS

Here I present a framework created by Steven M. Rinaldi, James P. Peerenboom, and Terrence K. Kelly (Rinaldi et.al 2001) that aims to analyze and address infrastructure interdependency, which I used to better understand infrastructure interdependency and how addressing it requires a lot of data, a problem for data scarce developing countries like Indonesia. Rinaldi et al.'s framework identifies different types of interdependencies, infrastructure characteristics, environment, coupling and response behavior, failures, and states of operation relating to infrastructure interdependency. Limited data accessibility, model development and model validation constraints the ability to address infrastructure interdependency during infrastructure modeling (Figure 1). Furthermore, interdependency modeling is complicated by the need for large and disparate cross sector analysis (Pederson et al. 2006). This framework reflects the complexity of infrastructure interdependency, and highlights the importance of data in infrastructure planning.

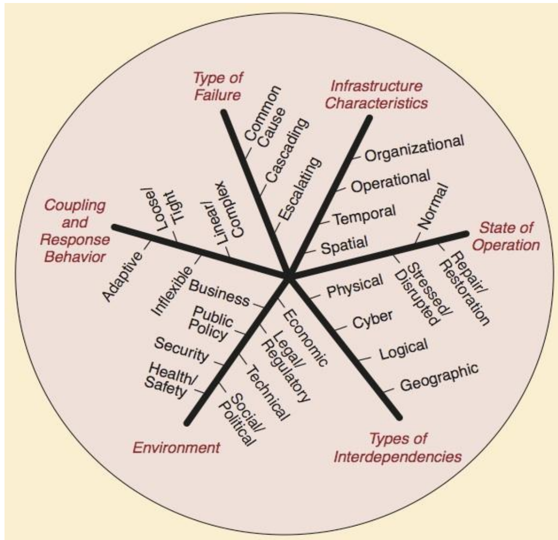

Figure 1. Framework that addresses infrastructure interdependencies developed by Rinaldi et al. (2001).

Questionnaire

I distributed questionnaires (Table A.1 and A.2) through Google Forms in English and Indonesian to a total of eleven individuals from the JPG and the United Nations Development Program (UNDP) in Indonesia to determine how those working in different organizations and agencies in Jakarta perceive infrastructure interdependency, what kinds of actions are being done to address it, what they understand to be the greatest barrier(s) to addressing it, how they perceive the CAS prototype and their suggestions for optimizing the prototype. UNDP is an intergovernmental organization that aims to aid governments in various actions that include building resilience, responding to climatic disasters and developing policies that encourage sustainable growth (UNDP 2016).

I used Jakarta's February 2015 flood as an example of an incident in which infrastructure interdependency can be a problem, in order to identify the level of awareness my respondents and their organizations or agencies have towards infrastructure interdependency, how current planning and implementation decisions about water pumps are being made in Jakarta, and means of optimizing a critical asset survey. I distributed the questionnaires to both government officials and people working at UNDP Indonesia to document the level of awareness these organizations and agencies have towards infrastructure interdependence in Jakarta.

I administered the questionnaire in English, and I translated the questionnaire into Indonesian (Appendix A.2) with the help of Ibu Ninik Lunde, an Indonesian lecturer at UC Berkeley. The questionnaire gathered information on:

1. the Jakarta Government and NGOs in Indonesia understanding of infrastructure interdependency in Jakarta and how are they addressing it;
2. the key barrier(s) faced by the Jakarta Government and NGOs in addressing infrastructure interdependency;
3. the perceived usefulness of the CAS in gathering data to solve infrastructure interdependency by the Jakarta Government and NGOs, particularly in terms of appropriate contents of the critical asset survey to gather needed data.

I optimized the critical asset survey prototype by incorporating questionnaire responses.

Surveyors' review

During the summer of 2015, I worked with a group of undergraduates from the University of Indonesia who were interning at an organization called PetaJakarta (an organization in Jakarta that provides real time flood maps for Jakarta citizens) to collect data on existing water pumps in Jakarta. I present the details of how the fieldwork was conducted in Section 3, and will provide a group and personal assessment of the deployment of the survey.

Prototype modification

I optimized the critical asset survey (CAS) prototype (Appendix B.1) that aims to provide governments with a framework for collecting data on critical infrastructure by drawing on my personal experience with the prototype during the summer of 2015, and by documenting the responses to my questionnaire from individuals from the JPG and UNDP. I also drew on literature to identify key characteristics of critical infrastructures, including their state of operation, in order to consider in addressing infrastructure interdependency, and determine the types of models that would be able to utilize the data collected from the survey.

I. INFRASTRUCTURE INTERDEPENDENCY IN THE CONTEXT OF MEGA CITIES

Critical infrastructure and Infrastructure interdependency

Infrastructure elements and systems comprise basic facilities such as transportation and communications systems, water and power lines, and public institutions including schools and prisons (Moteff and Parfomak 2004). Infrastructure is characterized by complex adaptive systems (CASs) that may change as a result of learning processes, implying that all infrastructure components are influenced by past events (Axelrod and Cohen 1999). It is important for the infrastructure planners and managers to be aware of the great complexity and emergent characteristic of infrastructure systems, which makes these systems larger than the sum of their individual parts (Bonabeau et al. 1999).

Critical infrastructure is "a framework of interdependent networks and systems comprising identifiable industries, institutions, and distribution capabilities that provide a reliable flow of products and services essential to national defense and economic security, the smooth functioning of governments at all levels, and society as a whole" (Dhs.gov, Kelly 2011). Critical infrastructures include but are not limited to telecommunications, electric power systems, natural gas and oil, banking and finance, transportation, water supply systems, government services, and emergency services (President's CCIP 1997).

Infrastructure interdependencies occur when at least two infrastructure features or systems are dependent on each other, and are manifested in four different types (Table 1) (Rinaldi et al. 2001). Failure in infrastructures due to infrastructure interdependency is a global problem faced even by developed countries like the United States. For example, in 1998, the Galaxy 4 telecommunications satellite failure in the U.S. led to an outage of 90% of all pagers nationwide. The problem was exacerbated by interdependence with other critical infrastructures, as it also disrupted a variety of banking and financial services, human services networks, such as communication between doctors and emergency workers (Rosenbush 1998). In 2001, another instance of such cascading infrastructure disruption involved an electric power outage that affected oil and natural gas production in California (Fletcher 2001). These kinds of cascading failures caused by interdependency lead to lost productivity and health and safety issues, which can be extremely costly (Rinaldi et al. 2001).

Table 1: Types of infrastructure interdependencies (Rinaldi et al. 2001)

Type	**Definition**
Physical	The state of each infrastructure is dependent on the material output(s) of the other.
Cyber	The infrastructure's state depends upon information transmitted through the information infrastructure.
Geographic	A local environmental event can create state changes in all of the infrastructures, and typically occurs when infrastructures are within close proximity of each other.
Logical	The state of each infrastructure depends on the state of the other via a mechanism that is not a physical, cyber, or geographic connection, and is greatly influenced by human decisions.

Information and Communication Technologies (ICT)

Information and Communication Technologies (ICTs) can collect data and improve communication efficiency between systems. With increasing cyber interdependency, critical infrastructure and ICTs are becoming more strongly coupled and interdependent (Hadjsaid et al. 2010). For example, although electrical infrastructure and ICTs are heterogeneous in nature (with different features, dynamics and communities), their interdependence exposes the electrical infrastructure to new vulnerabilities (hacking, etc.). Therefore, they need to be integrated during planning in consideration of global infrastructures security (Hadjsaid et al. 2010).

Infrastructure modeling

It is essential to model and conduct simulations (of potential failures) to ensure safe, reliable and continuous operation of critical infrastructure (Rinaldi 2004). These tools that analyze interdependent sectors help infrastructure owners operate and manage systems, and six examples are presented in Table 2. There is, however, a lack of tools that considers the risk and future behavior of the ICT sector in connection with other infrastructure (Ebrahimy 2014).

Table 2: Types of Modeling and Simulation Techniques (Ebrahimy 2014)

Technique	Description
Agent Based Model (ABM)	ABMs are computational models that simulate the actions and interactions of autonomous agents to assess their effects on whole systems. They are widely used in infrastructure and interdependency analysis to accurately and simply capture interactions, and can be used to analyze infrastructure condition and characteristics by modeling physical components as an agent.
Physical Based Models (PBM)	PBMs are modeled and analyzed with standard engineering techniques. For example, power flow and stability analysis can be performed on the electric power grids. The analysis can be more detailed and done at the component level to examine issues like power outage with single or multiple associated connected nodes.
Population Mobility Models	These examine entities through urban regions and their interaction with each other.
Economic Models	These include Leontief input-output models of economic flow.
Dynamic Simulations	These model the generation, distribution and consumption of infrastructure commodities and services as flows and accumulations.
Aggregate Supply and Demand Tools	These are used to evaluate total demand for infrastructure services in a region together with the ability to supply those services.

This paper highlights that failure to incorporate infrastructure interdependency thoroughly into infrastructure modeling in Jakarta, Indonesia, can result in the exacerbation of natural disasters like floods, and provides a recommendation to use the critical asset survey tool to address the problem. Despite the fact that Jakarta is the most populous city with the highest urbanization rate in southeast Asia, there is not much literature about urban planning in Jakarta (Cybriwsky and Ford 2001). High urbanization rates lead to various problems, including greater land subsidence from increased city weight and groundwater extraction that puts Jakarta further below sea level and at higher risk of flooding (Abidin et al. 2011; Firman et al. 2011), but not much research has been done in addressing how to counter this phenomenon. Resilient infrastructure is an effective means by which developing countries in Asia may adapt to climate change (Sovacool et al. 2012) and increasing rates of urbanization. As mentioned in the introduction, Indonesia receives a significant amount of foreign aid. Channeling foreign aid into developing resilient infrastructure was found to be an effective allocation of aid (Collier and Dollar 2002), whereas allocating aid to crisis management only increases the country's dependence on foreign aid, a phenomenon seen in Indonesia (Chowdhury and Sugema 2005).

II. JAKARTA CASE STUDY

The Capital City Special Region (Daerah Khusus Ibukota - DKI) of Jakarta is located on Indonesia's Java island, and is comprised of five municipalities: Central Jakarta, Jakarta North Jakarta, West Jakarta, South Jakarta and East Jakarta, which covers a total area of 661 km^2 (255 $mile^2$) (Cybriwsky and Ford 2001). Jakarta, formerly known as Batavia, is an estuary of thirteen rivers and is 40% below sea level. It was colonized by the Dutch, who built canals around the city to protect it against potential floods (DCIP Jakarta 2011). Urbanization rates in Jakarta increased, as Indonesian farmers migrated to the capital city seeking off-farm employment. High urbanization rates increased Jakarta's population and depleted its groundwater supply and caused salt water intrusions into the city's water system, which increased land subsidence and Jakarta's susceptibility to flooding (Douglass 2010).

Most of these rural migrants settled along rivers and canals, which were low-income areas of high environmental degradation and risk (Douglass 2010). Jakarta showed decreasing population density in the city center over time (198 persons/ha in 1970 to 153 persons/ha in 1998), and a rapidly increasing population density at 7km from the city center (from 63 persons/ha in 1970 to 156 persons/ha in 1998) (Murakami et al. 2005) (Figure 2). This change in spatial distribution may be explained by the spatial segregation that arose from the May 1998 riots between racial groups. The spatial segregation was inevitable as a result of socio-economic and political conditions of the urban society, and was understood as 'self segregation' or 'voluntary segregation' (Firman 2004). The spatial segregation led to a differentiated exposure to environmental risk among racial and income groups.

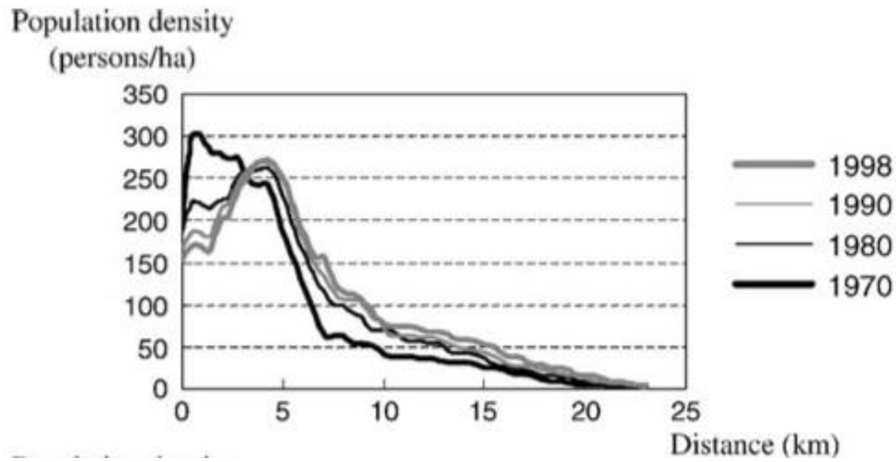

Figure 2: Jakarta Population growth in relation to distance to city center (Murakami et al. 2005)

The increasing environmental risks were not limited to Jakarta, but also spread to its surrounding regions. In the early 1980s, the Indonesian government established the expanded Jakarta mega urban region (Jabodetabek) (Figure 3) to include the cities Bogor, Tangerang and Bekasi, as an act to better ensure Jakarta's environmental sustainability (Douglass 2010). Jabodetabek covers 6418 km^2 (2478 mile^2) and has a population of 20,159,655 (Cybriwsky and Ford 2001). Despite global economic events and downturns, population growth in Jabodetabek intensified (Douglass 2010) (Figure 4), which emphasizes the need for effective regional planning.

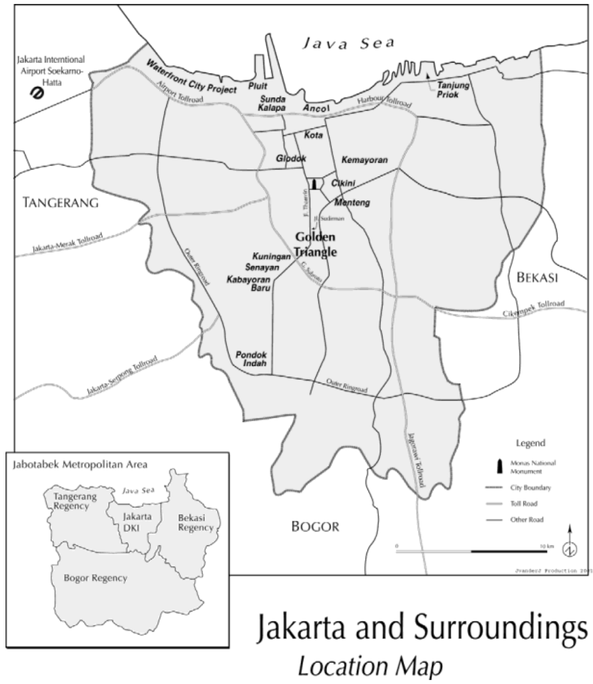

Figure 3: Jakarta mega urban region (Jabodetabek) map (Cybriwsky and Ford 2001).

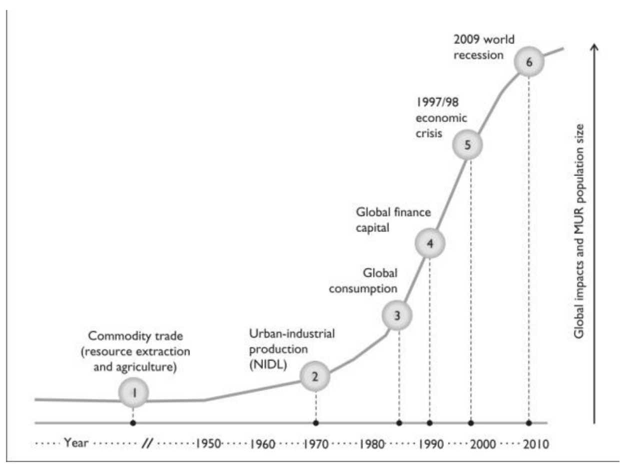

Figure 4: Growth in Jakarta mega urban region (MUR) with regards to global events. New international division of labor (NIDL) represents a shift from labor-intensive assembly and manufacturing to a small number of newly industrializing economies (Douglass 2010).

Climate change, sea level rise, extreme weather events, land use change, land subsidence, water pollution and clogging of waterways are a few factors that have led to increased floods that had major impacts on Jabodetabek, and especially DKI Jakarta (Douglass 2010). Flood control infrastructure in Jakarta was established in the Flood Control Master Plan in 1972, which includes the construction of the West Flood Canal and the East Flood Canal that serves to divert the flow of water from the thirteen upstream rivers to the surrounding suburbs of Jakarta. The City also built a polder system equipped with infrastructure such as pumps, water gates and dam reservoirs. The East Flood Canal, which was completed in late 2010, has a length of 23.5 km, a width of 100 meters, and runs across 13 villages and 4 districts. The East Flood Canal also serves as the drainage system for a catchment area of 207 km^2 that protects East Jakarta and North Jakarta (area of 160 km^2) from flooding due to the overflowing of the Cipinang, Sunter, Buaran, Jatikramat, and Cakung rivers.

In the February 2015 flood, there was a decision to shut down the electricity in the city to protect residents from electrocution, cutting off power supply to the water pumps in the city (Jakarta Globe 2015). Due to the interdependence between the electrical grid and the water infrastructure system in Jakarta, the water pumps in Pluit, which were essential for pumping flood water out of the city, could not operate, resulting in much more severe flooding that lasted for days. The lack of integrated planning by the Jakarta government is evident as the Pluit water pumps failed to perform their function.

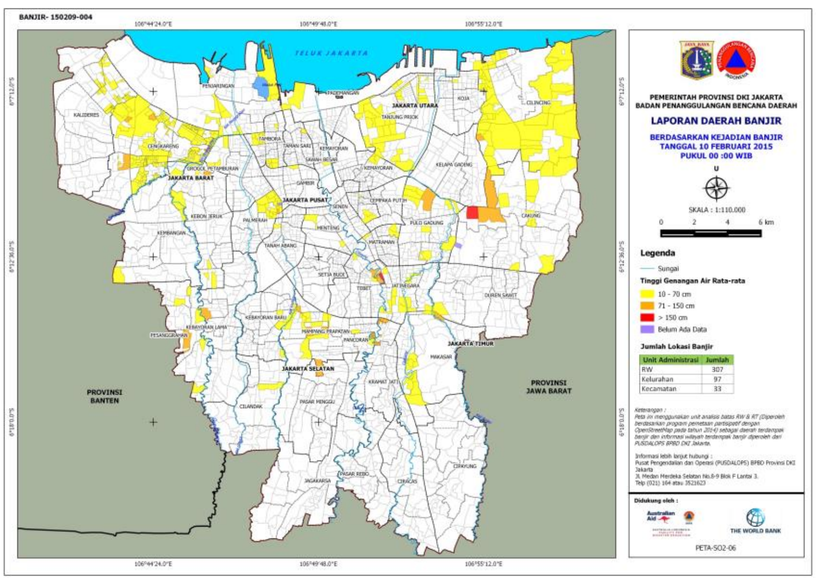

Figure 5: 9 February 2015 flood map. Colors indicate flood depth (BPBD Jakarta 2015).

The Jakarta government needs to develop means of integrated planning to address the rapid environmental degradation and flooding instead of their current strategy of adjusting plans to accommodate private sector plans on an ad hoc project-by-project basis (Douglass 2010). The

"Urgent Reconstruction of East Pump Station of Pluit in Jakarta" project was financed by the Grant Aid for 1.985 billion Japanese Yen (approximately US$16 million) from the Government of Japan, with the intend to prevent flood, especially in Central Jakarta and North Jakarta (Figures 6 and 7) (JICA Indonesia 2014). The pumps were initially built without a back up generator that has now been installed (Figure 8), which led to its failure during the February 2015 floods.

Figure 6*: Pluit pumps that pumps water out of Jakarta into the Java Sea.

Figure 7: The newest pump house in Pluit that was built as a result of foreign aid from Japan.

Figure 8: Generators for the pump, following the February 2015 flood incident, where the pumps failed because of electricity from the power grid was shut off.

Events such as the February 2015 flood raise the question of whether the JPG has taken infrastructure interdependency into account during infrastructure planning. Since the pumps that failed during the February 2015 floods were a product of foreign aid, the lack of integrated planning has also resulted in less than optimal allocation of foreign aid.

RESULTS AND DISCUSSION

Respondent biographies

I received survey responses from five individuals working in the Jakarta Provincial Government (JPG), and from three individuals who are a part of UNDP Indonesia. Although my respondents were given the option to remain anonymous, Matthieu Lux (ML) from UNDP, and Michael Victor Sianipar (MS) from JPG chose to revel their identities. I present their short biographies below. Unless labeled with MS or ML, the responses presented below summarize all the responses received from each respective group (JPG or UNDP), and are not the responses of these specific individuals.

Matthieu Lux, a French national who has worked with international organizations for over seven years, was previously a Monitoring and Reporting Specialist for the Environment

Unit of UNDP Indonesia, and is currently a Programme Specialist for the Reducing Emissions from Deforestation and Forest Degradation (REDD+) program at UNDP Indonesia. Lux provides technical guidance to senior management for a US$1 billion partnership between Norway and Indonesia for REDD+. Lux, who has worked as an advisor and junior advisor on Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH's Information Management for Climate Change Adaptation and Aid Effectiveness and Aid Information Management Systems respectively, provided valuable insights regarding urban planning for climate change adaptation and foreign aid optimization.

Michael Victor Sianipar has been the personal aide of the Governor of Jakarta, Mr. Basuki Tjahaja Purnama, since October 2012. Sianipar's personal mission is to promote a clean, effective and responsive government with integrity and strong rule of law. In 2011, Sianipar published a book titled "Caught Between the Dragon and the Eagle: The Limits of ASEAN's Hedging Strategy." He also served as a research assistant at Yonsei University's Center on US-China Relations. Since Sianipar works closely with the Governor of Jakarta, his perspective on decision-making in the JPG is informed and authentic.

Survey response summary

My survey responses confirmed that the electrical grid's infrastructure managers, and not a government official, shut off the electrical power during the February 2015 flood, suggesting the need to educate them about infrastructure interdependency and how their decisions can affect other infrastructure. I was unable to identify who initially designed the Pluit pumps, but there was a consensus among my respondents (from UNDP and JPG) that it was the Indonesian government's responsibility to adopt long term planning strategies and conduct risk analyses before building critical infrastructure (even if funded by foreign agencies). My respondents were generally aware of infrastructure interdependency and were able to provide examples to show their understanding. Infrastructure interdependency is understood by them to be more beneficial than harmful, as interdependencies can make systems more efficient. This indicates that there is a need to make individuals, especially at the urban planning level, more aware of the risk of failures due to infrastructure interdependency. In the context of infrastructure modeling, I learned that, even if new infrastructure are modeled before they are built and integrated into current systems, these models are likely to be underdeveloped because of the lack of data to run the models and the lack of coordination between the affiliated agencies that create and use these models. The barriers to incorporating infrastructure interdependency into infrastructure models mentioned by my respondents include the lack of data, difficulty of checking the authenticity of available data, bureaucratic issues, regulation constraints, limited human resource, and the lack of coordination between affiliated parties. Respondents provided helpful suggestions for overcoming these barriers, including educating infrastructure managers and new government officials about infrastructure interdependency, creating clearer communication among affiliated parties, requiring that government policies be made based on data, and establishing a holistic standard operating procedure for all parties to use.

The February 2015 flood

I presented the February 2015 flood to my respondents as a case where infrastructure interdependency may not have been incorporated well into urban planning models. It is important to understand who made the decision to shut off the power that altered the state of operation of the Pluit pumps to better understand which party lacks awareness their decisions affected the whole system (are unaware of infrastructure interdependency). Most of my respondents agreed that the interdependency of the water pumps with the electrical grid exacerbated the February 2015 flood, but ML stated that it merely "left the city administration helpless to cope with it." He went on to say that during floods, the pumps need to be fully operational even before water levels rise to a dangerous level, and other respondents from JPG and UNDP agreed that the pumps were necessary to pump water out of Jakarta. All respondents stated that the State Electricity Company, Perusahaan Listrik Negara (PLN), decided to shut off the electricity, although one UNDP respondent stated that it was the City Government's decision. Jakarta's Governor, Basuki Tjahaja Purnama (Ahok) publicly stated that he did not understand PLN's decision to cut off electricity to the twelve pumps in Pluit, since the area was not flooding and therefore the argument that it was to prevent people from getting electrocuted was invalid (Jakarta Globe 2015).

Although there was no information regarding the position or identity of the specific individual who made the decision, it seemed that at times of crisis, the decision to change the state of operation of the critical infrastructure is made by the infrastructure manager. Hence, it is important to educate these managers about how their infrastructure is interdependent with other infrastructure systems.

Pluit pumps planning and design

There is no literature to confirm how these pumps were initially designed, but the Japanese Government allocated approximately US$16 million to reconstruction of the East Pump Station in Pluit (JICA Indonesia 2014), an amount of money that should have been sufficient to purchase back up generators for the Pluit pump station, suggesting that the absence of these generators was probably due to a lack of long-term planning instead of a budgetary constraint. A respondent from the JPG and the media mentioned that there was an emergency back up generator present, but it was only able to power two pumps of the nine pumps (Jakarta Post 2015). The respondent from the JPG stated that the pumps were designed with back up generators in case of an emergency. My respondents stated that the water pumps were not designed with sufficient back up power generators due to poor planning, a lack of long term thinking, possible budget constraints and the fact that backup generators are also potential risks, in that they might electrocute residents near these areas. There were mixed responses regarding who initially designed these pumps without a back up power generator. A respondent from UNDP stated that the water pumps were initially designed as an intergovernmental effort between the Indonesian and Japanese Government, another stated that it was only the Japanese government, and one from the JPG stated it was the Indonesian Government.

Infrastructure interdependency in Jakarta

Failure to prepare for events like the February 2015 floods makes it questionable if the JPG and NGOs are aware of infrastructure interdependency. Therefore, I asked my respondents regarding their awareness towards infrastructure interdependency and give examples of infrastructure interdependency in Jakarta to back their claim for their level of understanding. JPG respondents rated their awareness of infrastructure interdependency to be an average of 4, while UNDP respondents rated an average of 3.33 (Figure 9).

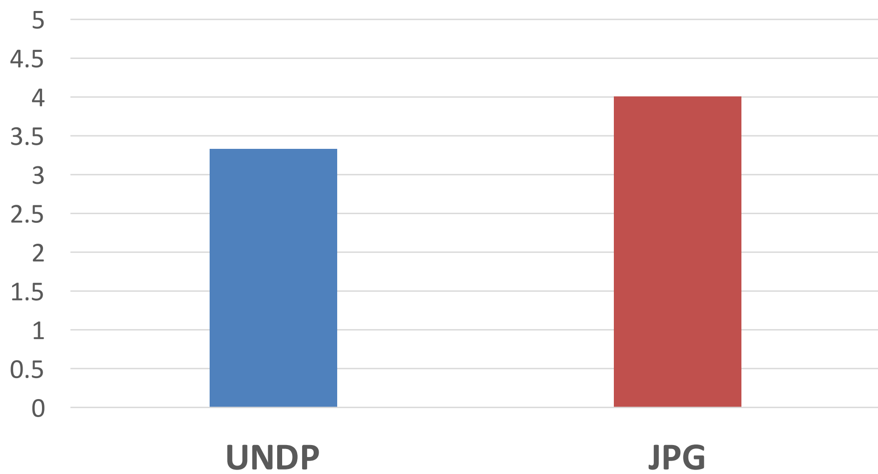

Figure 9. Self rated average awareness towards infrastructure interdependency on a scale of 1 to 5, 5 being aware.

Examples of infrastructure interdependency in Jakarta described by respondents from UNDP include the interdependency between the future underground mass transit system and water management systems, waste management systems in Jakarta and its neighboring city, Bekasi, and the affect of infrastructure like skyscrapers that reduce the water absorption efficiency of surrounding soils, causing environmental degradation. Respondents from JPG pointed to emerging cyber interdependency, giving examples of the integration of infrastructure systems with an information and communications technology (ICT) system, that can track and monitor changes (for example, the location of broken pipes in the water system). MS also mentioned the increasing interdependency of Jakarta's traffic system with the availability, timing, and distribution of the public transportation system and on the progress of public infrastructure projects (MRT, road maintenance, etc.). Another respondent from JPG gave the example of the interdependency between the waste management system and roads, as mismanaged waste may lead to floods that make roads inaccessible. And the lack of proper infrastructure to dispose and separate solid waste in Indonesia leads to an estimate of 3.22 million metric tons (MMT) of mismanaged plastic waste each year, making it the second largest contributor to plastic debris in the ocean (Aprilia et al. 2013; Jambeck et al. 2015). This implies that improvements in infrastructure systems can reduce the negative impacts on the global ecosystem. Additionally, together with mismanaged waste that clogs storm drains, human induced land use changes associated with urbanization may increase surface runoff and worsen the flood problem in Jakarta (Dorner et al. 2008; Jha et al. 2012), emphasizing that these systems are all interdependent.

My respondents stated that infrastructure interdependency was understood to be beneficial if it can create reliable systems that lead to cost, as there would be less need for building new whole systems, can just add more parts to an existing one. They also stated that it would lead to time savings, as it would be more efficient to solve system disruptions with the help of the internet and cyber interdependent systems. A respondent from the JPG also mentioned that infrastructure interdependency allows for the possibility of integrative planning, wherein one infrastructure's maintenance and capacity building is aligned with others. In addition to the case of the February 2015 flood, in which one system failed to function effectively, causing the whole system to fail (an example of what has been called cascading failure) (Ebrahimy 2014), respondents also stated that infrastructure interdependency may present problems if the infrastructures' qualities are not equalized, causing one to degrade the quality of another. Respondents from the government also stated that interdependency between infrastructure systems can make an already complicated megacity even more complicated.

It was surprising to receive more responses regarding the benefits of, rather than the problems associated with infrastructure interdependency. While infrastructure interdependency (especially with ICTs) can make systems more efficient and even resilient if carefully implemented, it seemed that my respondents were not aware of how these interdependencies can be a threat to national security and the functioning of society. ICT failures pose a significant national security risk, and they are particularly vulnerable to software limitations that are apparent when merging new and old computing systems, and these can create uncertainties and risks (Ebrahimy 2014).

Since intergovernmental agencies like UNDP help allocate foreign aid to governments, it was not surprising to discover that they were relatively aware of infrastructure interdependencies, making it questionable why some projects do not seem to consider this phenomenon. All respondents mentioned that their organization and agencies were concerned with and have addressed or are starting to address infrastructure interdependency. Examples of addressing infrastructure interdependencies by UNDP include energy efficiency programs, working with individuals in other organizations and using cloud and offline storage to keep a backup of documents in case of hardware or software failure. A respondent from the JPG stated that they are trying to reeducate government officials about infrastructure interdependency at different municipalities, as the previous official was unable to do this well. Another respondent stated that in the last three years, the JPG has implemented flood control activities such as normalization of rivers, dredging, construction of new pump stations, including the Ciawi reservoir development plan that will accommodate the flow of the Ciliwung River, which is located in the city of Bogor, in Megamendung Village.

The fact that the respondents from the government is aware of infrastructure interdependency raises the question of why they have not addressed it. One reason might be that the Jakarta government's current planning strategy involves adjusting plans to accommodate private sector plans on an ad hoc project-by-project basis, such as disaster preparedness, river clean-ups and improvements in water control infrastructure, instead of longer term integrated planning across different sectors (Douglass 2010). Even though these projects may be successful in reaching their objectives, they might divert attention away from solving the larger problem of infrastructure interdependency, which requires cross-sector planning.

Infrastructure modeling

Various models (Table 2) allow infrastructure modelers to better incorporate new or modified critical infrastructure into existing systems, by modeling out existing and future infrastructure interdependencies. The lack of preparedness regarding infrastructure system failures, as show in the February 2015 floods, makes it important for the JPG (disaster contingency or city planning agency) to model planned infrastructure before incorporating it into the current system. According to all but two JPG respondents, infrastructure interdependency has already been incorporated into infrastructure planning and development models in Jakarta, but all agreed that it is important to do so. A respondent from the JPG stated that there are models to monitor current systems, but new infrastructure projects are usually not assessed in terms of integration into existing infrastructure systems in the planning process. Respondents from UNDP pointed out that infrastructure models are part of Jakarta's disaster management contingency plans, and are run by a specialized team of experts and engineers within the government, not by a third party (to ensure data security). MS stated that infrastructure interdependency is inseparable from modeling, as any government functions under the premise that things are interdependent. However, a few respondents stated that this infrastructure planning and development model may not be thoroughly thought through and is still missing key elements needed to consider all infrastructure interdependencies. Respondents from the JPG stated that the models are underdeveloped and that the key barrier to running good models is that it involves inefficient communication between multiple stakeholders.

Barriers to running infrastructure models in Jakarta

ML, together with (75%) of my respondents from JPG, agreed that there was not enough data to run more robust infrastructure models. A few respondents believed there is enough data to run these infrastructure models, but just not enough coordination between affiliated parties and a lack of quality in the existing infrastructure design. When asked about what kind of data would be important to collect to incorporate infrastructure interdependency into models, my respondents mentioned data on traffic (commuter influx), water levels in rivers and canals, grid, available human resources, a blueprint of the entire infrastructure system, and a list of involved governments and parties. MS stated that any numerical data that explains anything relating to the infrastructure will be helpful.

In addition to a lack of data being a key barrier implement infrastructure planning and development models, respondents stated that other key barriers include a lack of publicly accessible data (data are rarely made available by local government, and requires ad hoc studies and research), the difficulty of checking the authenticity of available data, bureaucratic issues, regulation constraints, limited human resource, and the lack of coordination between affiliated parties. Individuals from UNDP stated that these barriers have not been overcome due to aversion to openness and transparency in data management, bad infrastructure management, and the lack of awareness of provincial governments. Respondents from JPG state that this barrier has not been overcome because of a lack of knowledge, awareness, skills, and discipline (as government officials refuse to change their mindset that was build by the previous governor). One respondent also stated that the complicated government system, in which there is little transfer of information, despite the frequent change in government officials, is a big hindrance to overcoming these barriers.

Overcoming barriers

Respondents from JPG contended that, in order to overcome these barriers of creating more robust infrastructure models, governments officials must educate infrastructure managers and new government officials to increase awareness about infrastructure interdependency, create clearer communication among affiliated parties, require that policy-making is based on data, establish a holistic standard operating procedure for all parties to use, and to restructure the government to be merit based and ensure sufficient transfer of knowledge during when officials are changed. Respondents from UNDP believe that these barriers can be overcome by taking a bottom up approach of retraining infrastructure managers in charge of the physical infrastructure system at their respective locations, conducting a review of the infrastructure system, and building better quality infrastructure.

The JPG initiated the Open Data initiative in 2014, which was optimized by the Jakarta Smart City Lab (JSCL) in December 2015 to start addressing infrastructure interdependency through data collection. The JPG works together with mobile applications like QLUE, WAZE and Twitter, through the JSCL to provide a portal that informs the residents of the current condition of Jakarta. This portal aims to provide an open data source for Jakarta residents to find real time data including population demographics, traffic conditions and location of governmental agencies (Jakarta Smart City 2016). The Smart City Portal is updated in real time, which allows people to become more aware of current issues occurring around the city.

Government policy and international aid

It is important for the government to realize that infrastructure interdependency should be considered when modeling and planning new infrastructure. This paper suggests that the government and foreign aid agencies regulate the completion of the CAS before an infrastructure can be built and incorporated into the current system. It is also important to create a holistic policy guide for decision makers, risk and vulnerability assessments that involves the collaboration between environmental scientists, scholars, planners, and engineers are needed to assess risks and to develop strategies that increases infrastructure resilience (McEntire et al. 2002). Other governments have tried a range of policies to address infrastructure interdependencies (McEntire et al. 2002). It was surprising that Japan did not play a huge hand in the planning of the pumps because literature shows that conventionally, they would ensure that their aid be strategically allocated to increase economic welfare instead of an act of philanthropy (Schraeder et al. 1998). Therefore, foreign aid agencies can also use the CAS and other tools as requirements for the allocation of funds, to ensure that their funds be allocated optimally.

III. THE CRITICAL ASSET SURVEY (CAS)

CAS prototype

Data scarcity was identified to be a key barrier to incorporate infrastructure interdependency into infrastructure models during urban planning. Therefore, data is crucial to allow governments to make more informed planning and policy decisions regarding developing megacities. To collect data on critical infrastructure in Jakarta, I developed a CAS prototype (Appendix B.1) in the summer of 2015 together with three undergraduates from the University of Indonesia who were interning at PetaJakarta, a collaborative research project led by the SMART Infrastructure Facility with BPBD DKI Jakarta and Twitter Inc., that utilizes social media information to provide real time flood data for people in Jakarta (PetaJakarta 2015). We initially developed a CAS tool to collect information on critical infrastructure in Jakarta, including geospatial locations, capacity, elevation and state of operation. We collected these characteristics for all water pumps in Jakarta, and uploaded the data onto Jakarta's Java OpenStreetMap (Josm.openstreetmap.de 2015), which allowed us to identify the proximity of these critical assets to other critical infrastructure like schools and hospitals. PetaJakarta will also use the data collected for a project in which real time flood data can help governments make immediate infrastructure decisions concerning major climate events like floods. However, the implementation and design of the critical asset survey prototype was imperfect because data collection was inefficient, and data on more infrastructure features should have been collected. Hence, I provide proposed modifications to the tool that can be implemented to give a more comprehensive assessment of infrastructure interdependency for each infrastructure asset in Jakarta.

RESULTS AND DISCUSSION

The literature highlights key dimensions of infrastructure interdependency that I drew upon to augment the survey, including infrastructure dependability, which is defined in terms of availability, reliability, safety, integrity and maintainability (Table 3) and recommends that the data be fed into one of six possible modeling techniques (Table 2) (Ebrahimy 2014).

Table 3. Properties of a dependable system (Avizienis et al. 2004).

Key Term	**Definition**
Availability	Readiness for correct service
Reliability	Continuity of correct service
Safety	Absence of catastrophic consequences on the user(s) and the environment
Integrity	Absence of improper system alterations
Maintainability	Ability to undergo modifications and repairs

As cyber interdependency is a new emerging field that exposes infrastructure systems to new kinds of vulnerabilities (hacking, etc.), an information and communications technology (ICT) system failure is measured by the lack of these properties (Ebrahimy 2014). The survey should also note potential or current interdependency types, what kind of modeling tool will be most beneficial and if an ICT system exists.

CAS effectiveness and suggestions to modify it

The Jakarta Government and NGOs looking to address infrastructure interdependency issues feel that a CAS will be useful to help solve the problem of the lack of data. On average, respondents from both the JPG and UNDP rated the effectiveness of the existing CAS as 4 on a scale of 1-5 (5 being most effective) (Figure 10).

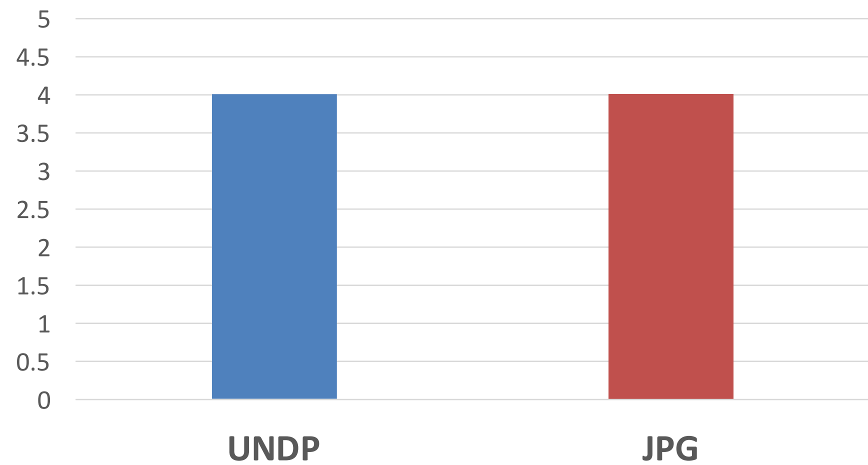

Figure 10: Respondents' average rating for CAS effectiveness in generating data to incorporate infrastructure interdependency into infrastructure models on a scale of 1 to 5, 5 being useful.

All my respondents thought that the geospatial location, capacity, state operation and elevation of an infrastructure were useful data that should be collected by the CAS. To improve the CAS, respondents suggested collecting data on the identity and contact information of infrastructure managers, affiliated parties and human resources available to improve the CAS. Furthermore, respondents from JPG suggested that the CAS collect data on the desired function of each critical asset, integrate demographic data on residents living near each critical asset and develop GIS resources to visually represent the data for people to plan for infrastructure failure.

Their responses suggest that documenting logical interdependency, which involves human decisions, is very important to addressing infrastructure interdependencies in general. This was evident in the February 2015 floods, during which a decision made by an individual led to system failure. Almost all the respondents from UNDP stated that in the future, the CAS should be presented to the JPG so that it can be incorporated into the Jakarta Smart City Lab.

Group and personal assessment of the CAS prototype

The group of surveyors (undergraduates from the University of Indonesia and I, who collected data on all 56 water pumps in Jakarta, and uploaded the data onto JOSM) found that the field survey could be completed relatively quickly, since survey administrators used a motorcycle to get around the city, and were able to collect data on about six pumps per person per day. Data collection was efficient because the surveyors already had knowledge about how to conduct the field survey and how to conduct basic spatial data analysis.

However, we felt that the process would have been more efficient had we initially decided on a format for our attribute table before we inputted and edited the spatial data, since it was difficult to reformat everything when we compiled the data. We also faced problems with internet connectivity during the GIS software training and briefing.

Due to these drawbacks, we suggest providing more GIS training to the surveyors, so that they can be more efficient during the spatial analysis portion of the survey, or only recruiting surveyors who already understand how to conduct basic spatial analysis using GIS software (ArcGIS - ESRI or QGIS) and are familiar with JOSM. For additional training, it would also be beneficial to provide the surveyors with similar datasets to work on during their own time before going into the field or editing spatial data.

We think that the surveyors should be provided with a motorcycle and transportation allowance for gas. The surveyors should have a motorcycle driver's license and a working GPS to be able to arrive at the infrastructure locations quickly. The field survey location based should be on each surveyor's home location, and it is important to ensure that a high-speed, secure internet connection is always available for efficient spatial analysis.

In addition to the group assessment, I personally think that the data collection procedure was effective because it ensured the veracity of the data collected, as each survey was conducted by a third party. However, I think that collecting data by having the surveyors personally visit each infrastructure unit to record the survey on paper, and later transfer the data into an electronic form at the PetaJakarta office, was extremely time consuming. This procedure can be improved by using an online platform that each surveyor can directly fill at each infrastructure location.

CAS modification

The CAS should collect information regarding the infrastructure managers, their contact information and who the affiliated parties are in the building and maintenance of the infrastructure. Data about population demographics surrounding each critical infrastructure should also be collected by the CAS, because obtaining information about the human side of the infrastructure can help address logical interdependencies. The CAS should also collect information regarding what kinds of models each critical infrastructure has been and should be put into to inform future planners.

We should also create a set of metrics to rate the infrastructures current availability, reliability, safety, integrity and maintainability (Table 3) that can be updated regularly by infrastructure managers to monitor the infrastructure's condition. Through ICTs, infrastructure managers should have a platform to upload data from the CAS immediately so that other experts can help monitor the state of critical infrastructure and have updated data when modelling new infrastructure. This implies that the CAS need not be done by third party surveyors, but can be done by the infrastructure manager on site.

Table 4: Proposed CAS Modifications based on literature review, questionnaire responses and surveyors' assessment.

<table>
<tr><th colspan="3">Modifications to the CAS Prototype</th></tr>
<tr><td rowspan="10">Other data to be collected</td><td rowspan="3">Identity and contact details</td><td>Infrastructure Managers</td></tr>
<tr><td>Government/Who funded the building and maintenance</td></tr>
<tr><td>Engineers who monitor infrastructure</td></tr>
<tr><td rowspan="5">State of Operation (create a set of metrics to rate)</td><td>Availability</td></tr>
<tr><td>Reliability</td></tr>
<tr><td>Safety</td></tr>
<tr><td>Integrity</td></tr>
<tr><td>Maintainability</td></tr>
<tr><td rowspan="2">Models</td><td>Existing models that each infrastructure has been incorporated into</td></tr>
<tr><td>Other models that it is compatible with</td></tr>
<tr><td rowspan="4">Implementation</td><td rowspan="3">Data collection</td><td>Be done by infrastructure managers</td></tr>
<tr><td>Electronically instead of paper-based</td></tr>
<tr><td>Ensure surveyors have motorcycle license and a motorcycle to commute to survey locations</td></tr>
<tr><td>Data analysis</td><td>ArcGIS - ESRI or QGIS training prior to analysis (provide training modules with old data sets, etc.)</td></tr>
</table>

		Surveyors to have prior knowledge about conducting basic spatial analysis using QGIS
		Recruit people who are familiar with JOSM

LIMITATIONS AND FUTURE DIRECTIONS

My study was limited to the number of respondents of my questionnaire, and that I depended on the fact that they were all truthful. I was unable to identify how critical infrastructure that is funded through foreign aid is designed. Further research should consider interviewing the Japan International Cooperation Agency (JICA) in Indonesia to identify how the Pluit pumps were initially designed and understand which agency should be better informed of long term planning. If the pumps were designed by any other agency than the Indonesian Government, the agency can motivate long term planning by ensuring that the funds be allocated to building infrastructure whose interdependencies have been considered (for example, using the CAS presented in this paper).

I was also unable to present a comprehensive introduction of the CAS during my questionnaires. My respondents were not provided with pictures and images of how the CAS prototype was conducted. In the future, studies should do a more comprehensive survey to different levels of the government and other intergovernmental organizations, and use more mediums to get more responses (paper survey, verbal interviews, etc.). Also, to better introduce the prototype, future studies should conduct a presentation that can include question-answer segments with the interested parties so that they can ask more specific questions. Future researchers should conduct a pilot study with the improved CAS prototype before presenting the final critical asset survey to the Indonesian government. The CAS can also be used in other developing mega cities that face the same problems as Jakarta, such as the lack of data. In addition to CAS, more research should be done about conducting workshops that can educate infrastructure managers, and improve communication and coordination between affiliated parties.

BROADER IMPLICATIONS

Urbanization rates in Jakarta are similar to those of other Asian megacities (e.g., Bangkok and Metro Manila) (Murakami et al. 2005). My Jakarta case study shows how changing urbanization rates require an integrative approach to urban planning strategies, and this can be a lesson to other rapidly urbanizing megacities (Douglass 2010). This study highlights the main barriers to addressing infrastructure interdependency in Jakarta, one being data scarcity. Individuals in the JPG and UNDP became more aware of infrastructure interdependency through answering the questionnaire, and therefore can address it during urban planning. The CAS presented in my paper and its proposed modifications (Table 4) can help governments collect data to address infrastructure interdependency in planning decisions by making more data based policy decisions. Furthermore, the data on all 56 water pumps in Jakarta collected using the CAS prototype is currently used by the JPG through the Jakarta Smart City Lab, where this data is publicly available and can be beneficial for a larger population (ordinary citizens, modelers, etc.). NGOs and foreign aid agencies should require the use of the CAS for fund allocation, to ensure that their funds are strategically placed in investments that have been carefully modeled and planned.

CONCLUSION

My study found that individuals in the JPG and UNDP are aware of infrastructure interdependency in Jakarta. However, many see infrastructure interdependency as a means of making existing systems more efficient, and are less aware of the risks associated with possible cascading failures due to infrastructure interdependency. Urban planning in Jakarta is characterized by a lack of data availability, uncertainty regarding the credibility of data and coordination challenges between different parties. I suggest ways to address these issues by using the CAS and conducting workshops to better educate planners and facilitate communication between affiliated parties. I optimized the CAS prototype in Section III based on my survey responses, drawing from literature and assessment of the deployment of the prototype. All the findings from my paper will help governments in data scarce cities like Jakarta to make more data-based rational policy decisions, especially in the context of infrastructure development, and also provide a tool for foreign aid agencies to ensure that their investments be optimally allocated to projects that are less likely to fail due to infrastructure interdependency.

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*All images in this project are attributed to Hillary Buntara, 2015.

APPENDIX A: QUESTIONNAIRE

Table A.1. Questionnaire with Objectives

Objective	**Question**	**Type of Question**
My name is Hillary Buntara. I am a 4th year Indonesian student at UC Berkeley, conducting research for my senior thesis on “infrastructure interdependency" in Jakarta. The answers to this survey will be used only for my senior thesis research Project. If you wish to remain anonymous, please tick 'Yes' below and I will ensure your confidentiality. Please answer all the questions honestly and ask for clarification when needed. Thank you for taking the time to complete this survey. Contact: hillarykb@berkeley.edu		
__ Please keep me Anonymous		
Full Name, Gender, Organization, Position		
To answer: What the Jakarta Government and/or NGOs in Indonesia think about infrastructure interdependency in Jakarta and how are they addressing it.		

In February 2015, heavy rains caused Jakarta to flood. Electricity in the city was shut down to prevent people from being electrocuted, and the Pluit pumps did not have any power to pump out flood water, resulting in much more severe flooding that lasted for a few days. This is an example of "infrastructure interdependency," involving the water pumps and the electrical grid.		
(Infrastructure interdependencies occur when at least two infrastructure features or systems are dependent on each other and include the following forms (Table 1, Rinaldi et. Al 2001)		
To ensure that the Feb 2015 flood was a result of infrastructure failure and not just heavy rains	Do you think that shutting off the electrical power to the pumps exacerbated the flood of February 2015?	Yes/No
	Why or why not? Please explain.	Open Ended
How decisions are made in Jakarta	What agency or government official made the decision to shut down the power to the pumps?	Open Ended
Understand the decision making mindset behind new infrastructure	Why do you think the pumps were initially built without a back up generator?	Open Ended
Understand how foreign aid is spent	Given that the Pluit pumps were a gift from the people of Japan, who designed the pumps (without a backup generator)? Choices: by Japan, the Indonesian government, both, do not know, do not wish to disclose	Multiple Choice
If participant is aware of what infrastructure interdependency is	Are you aware of other examples of infrastructure interdependency in Jakarta? If yes, please describe.	Open Ended
Understand if infrastructure interdependency is a problem/seen as something useful?	How can infrastructure interdependency be beneficial for cities like Jakarta? Please use examples if possible.	Open Ended

	How can infrastructure interdependency be a problem for cities like Jakarta? Please use examples if possible.	Open Ended
If organizations are aware of what infrastructure interdependency is, what has been done to address it	How aware of infrastructure interdependency is the organization you work for about? (Scale of 1 to 5, 1 being not aware)	Range Scale
	Is the organization/agency you are working for concerned with infrastructure interdependency?	Yes/No
	Does your organization address infrastructure interdependency?	Yes/No
	If yes, please explain how.	Open Ended
To answer: (The lack of data to incorporate infrastructure interdependencies to model the network) is the biggest barrier that the Jakarta Government and NGOs faces to address infrastructure interdependency.		
Understand if it is important to take infrastructure interdependency into account	Has infrastructure interdependency been incorporated into infrastructure planning and development models in Jakarta?	Yes/No
	Why or why not?	Open Ended
	Do you think that infrastructure interdependency should be incorporated?	Yes/No
Understand what data that they have right now and how they use it to assess interdependency	Are new infrastructure projects usually assessed in terms of integration into existing infrastructure systems in the planning process (through models)?	Yes/No
	If yes, Is there enough data to integrate infrastructure interdependency into these models?	Yes/No
Barriers (how do I explain this in a better way?)	Please identify key barriers to integrating infrastructure interdependency into flood modeling in Jakarta? (for example, a lack of data, infrastructure interdependency is not well understood)	Open Ended

	Why do you think these barriers have not been overcome?	Open Ended
	How do you think these barriers can be overcome?	Open Ended
Actions taken	What policies have been implemented to resolve the barriers you mentioned above? How effective have these policies been?	Open Ended
Critical Asset Survey	What kind of data is needed to be able to better incorporate infrastructure interdependency into models?	Open Ended
Answering the question above will provide an overview of the prototype of the survey: **I worked together with interns from PetaJakarta to develop a critical asset survey tool that was designed to collect information on critical infrastructure in Jakarta, including geospatial location, capacity, elevation and state of operation. We collected these characteristics for all water pumps in Jakarta, and uploaded the data onto Jakarta's Java OpenStreetMap (Josm.openstreetmap.de 2015), which allowed us to identify the infrastructures' proximities to other critical infrastructure like schools and hospitals.**		
Critical Asset Survey	Do you think such a survey can be helpful in generating data that will be useful for modeling infrastructure interdependency? (Scale of 1 to 5, 1 being least helpful)	Range Scale
	Of these choices please select all the characteristics of the infrastructure that you think are useful to be collected by such a survey: geospatial location, capacity, elevation and state of operation	Multiple Choice
	What other data would you suggest collecting so that the survey can be improved?	Open Ended
Other	Other than the critical asset survey, what else do you think would be useful to help address infrastructure interdependency in Jakarta?	Open Ended

Table A.2. Indonesian Translation of Questionnaire

Indonesian Translation
Perkenalkan nama saya Hillary Buntara. Saya adalah mahasiswi Indonesia tingkat akhir di Universitas Califofrnia di Berkeley, Amerika Serikat. Saya sedang melakukan/menulis skripsi akhir saya tentang 'interdependensi infrastruktur' di Jakarta. Jawaban anda kepada survei ini hanya akan digunakan untuk proyek skripsi akhir saya. Jika anda ingin terdata sebagai anonim dalam proses pengambilan data, harap menjawab 'Iya' pada pertanyaan dibawah dan saya akan pastikan identitas anda terjaga. Tolong jawab semua pertanyaan sejujurya dan silahkan bertanya kepada saya jika Anda tidak pasti. Terima kasih untuk kesediaan untuk menjawab survey ini. Kontak: hillarykb@berkeley.edu
_ Daftar saya sebagai Anonim
Nama lengkap, Jenis kelamin, Organisasi, Posisi
Pada bulan Febuari 2015, Jakarta banjir karena hujan deras. Listrik dipadamkan untuk menghindari orang kesetrum, dan pompa air di daerah Pluit tidak punya tenaga untuk memompa air keluar dari Kota Jakarta, dan mengakibatkan banjir yang lebih parah untuk berberapa hari. Ini adalah contoh sebuah 'interdependensi infrastruktur,' yang melibatkan infrastruktur pompa air dan sistem listrik.

Interdependensi infrastruktur terjadi ketika dua atau lebih fitur atau sistem infrastruktur bergantung pada satu sama lainnya dan bisa dikategorikan dalam bentuk yang terlampir di bawah: (Rinaldi et. Al 2001) (table)
Apakah Anda merasa bahwa pemadaman listrik terhadap pompa Pluit menyebabkan banjir Febuari 2015 lebih parah?
Kenapa atau kenapa tidak? Tolong jelaskan.
Lembaga atau pejabat pemerintah apa yang membuat keputusan untuk mematikan listrik?
Mengapa Anda pikir pompa Pluit dibangun tanpa generator cadangan pada awalnya?
Mengingat bahwa pompa Pluit adalah hadiah dari rakyat Jepang, siapakah yang medesain pompa (tanpa generator cadangan)? Pilihan: pemerintah Jepang, pemerintah Indonesia, kedua pemerintah, tidak tahu, tidak ingin mengungkapkan
Apakah Anda mengetahui contoh lain interdependensi infrastruktur di Jakarta? Jika ya, tolong jelaskan.
Menurut Anda, bagaimana interdependensi infrastruktur bisa bermanfaat bagi kota-kota seperti Jakarta? Silakan gunakan contoh.
Menurut Anda, bagaimana interdependensi infrastruktur bisa menjadi masalah bagi kota-kota seperti Jakarta? Silakan gunakan contoh.
Sebarapa sadarnya organisasi Anda terhadap interdepensi infrastruktur? (Skala 1 sampai 5, 1 = Tidak sadar)
Apalah organisasi / lembaga Anda peduli dengan interdependensi infrastruktur?
Apakah organisasi Anda membahas interdependensi infrastruktur?

Jika ya, tolong jelaskan bagaimana.
Apakah interdependensi infrastruktur telah dimasukkan ke dalam model perencanaan dan pembangunan infrastruktur di Jakarta?
Mengapa atau mengapa tidak?
Apakah Anda pikir bahwa interdependensi infrastruktur harus dimasukkan ke dalam model perencanaan dan pembangunan infrastruktur di Jakarta?
Apakah proyek infrastruktur baru biasanya dievaluasi dalam hal integrasi ke dalam sistem infrastruktur yang ada dalam proses perencanaan (dengan model)?
Jika ya, apakah ada cukup data untuk mengintegrasikan interdependensi infrastruktur dalam model ini?
Tolong identifikasikan kesulitan-kesulitan utama untuk mengintegrasikan interdependensi infrastruktur dalam pemodelan banjir di Jakarta? (Misalnya, kurangnya data, interdependensi infrastruktur tidak dipahami dengan baik)
Mengapa Anda berpikir kesulitan ini belum diatasi?
Bagaimana menurut Anda kesulitan tersebut dapat diatasi?
Kebijakan apa yang telah dilaksanakan untuk mengatasi hambatan yang disebutkan di atas? Seberapa efektifkah kebijakan ini?
Jenis data apakah yang dibutuhkan untuk dapat menintegrasikan interdependensi infrastruktur dengan lebih baik ke dalam model perencanaan?

Saya bekerja sama dengan murid magang dari PetaJakarta untuk mengembangkan alat survey aset yang dirancang untuk mengumpulkan informasi tentang infrastruktur di Jakarta, termasuk lokasi geospasial, kapasitas pompa, elevasi dan keadaan operasi. Kami mengumpulkan karakteristik ini untuk semua pompa air di Jakarta, dan mengupload data kepada Java OpenStreetMap Jakarta (Josm.openstreetmap.de 2015), untuk mengidentifikasi proximitas infrastruktur degan infrastruktur penting lain (seperti sekolah dan rumah sakit).
Apakah Anda pikir survei tersebut dapat membantu dalam menghasilkan data yang akan berguna untuk interdependensi infrastruktur modeling? (Skala 1 sampai 5, 1 adalah tidak berguna)
Silahkan pilih semua karakteristik dari infrastruktur yang menurut Anda akan berguna untuk dikumpulkan oleh survei seperti: lokasi geospasial, kapasitas, elevasi dan keadaan operasi
Data lain apakah yang Anda sarankan untuk dikumpulkan agar survei ini dapat menjadi lebih berguna?
Selain survei yang kami telah kembangkan, hal lain apakah yang Anda pikirkan akan berguna untuk membantu mengatasi interdependensi infrastruktur di Jakarta?

APPENDIX B: CRITICAL ASSET SURVEY

B.1. CAS Prototype

1. Prior to meeting, the surveyors were split into groups of two and informed of their respective pumps (pumps were grouped in clusters, based on their physical proximities).
2. Surveyors gather at the PetaJakarta office.
3. GPS devices – Garmin eTrex 30 (Figure B.1), printed questionnaire surveys (Appendix B.2, Figure B.2) are distributed among the surveyors
4. Surveyors walked or rode motorbikes (depending on location of their pump cluster) to get to the pump location (Figure B.3).
5. Once all assigned pumps were surveyed, the surveyors returned to the PetaJakarta office and transferred the handwritten data onto an Excel spreadsheet.
6. Coded and uploaded data collected onto Jakarta's Java OpenStreetMap, used QGIS to box out the pump houses to evaluate their proximities to other critical infrastructure.

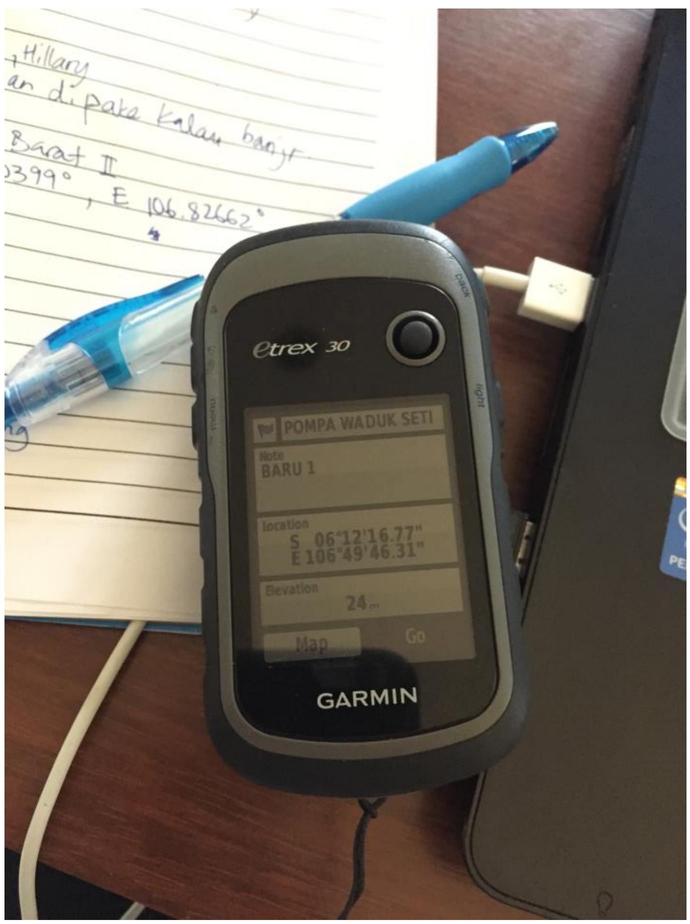
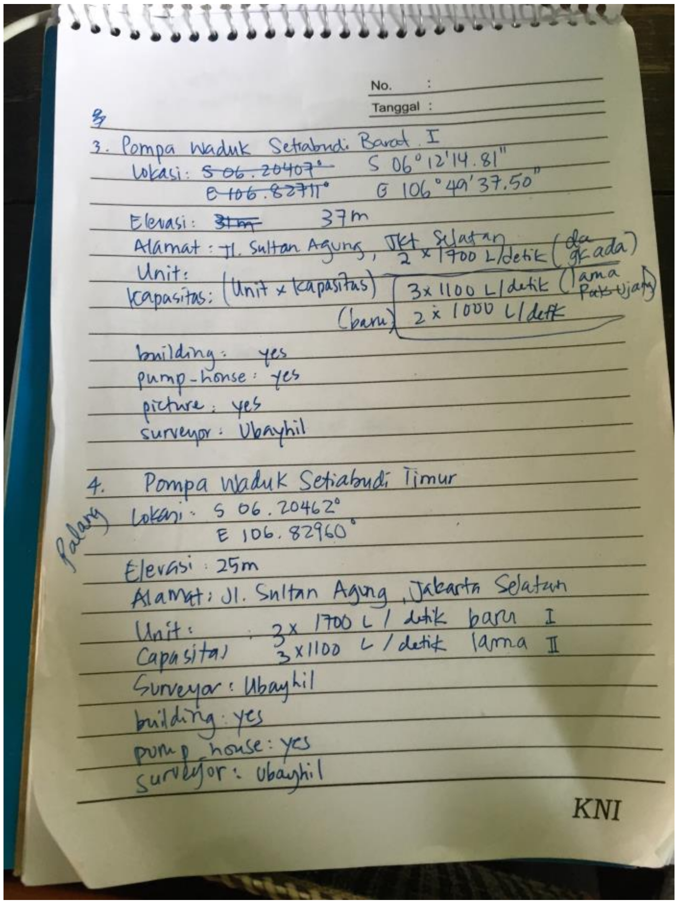


Image B.1: Garmin eTrex 30, Screen showing GPS results from a water pump in South Jakarta.



No. :
Tanggal :

3. Pompa Waduk Setiabudi Barat I
Lokasi: ~~S 06.20407°~~ S 06°12'14.81"
~~E 106.82711°~~ E 106°49'37.50"
Elevasi: ~~31m~~ 37m
Alamat: Jl. Sultan Agung, JKT Selatan
Unit: 2 x 1700 L/detik (dengan ada)
Kapasitas: (Unit x kapasitas) 3 x 1100 L/detik (lama Paks ujan)
(baru) 2 x 1000 L/detik
building: yes
pump-house: yes
picture: yes
surveyor: Ubayhil

4. Pompa Waduk Setiabudi Timur
Lokasi: S 06.20462°
E 106.82960°
Elevasi: 25m
Alamat: Jl. Sultan Agung, Jakarta Selatan
Unit: 3x 1700 L/detik baru I
Capasitas 3x1100 L/detik lama II
Surveyor: Ubayhil
building: yes
pump house: yes
surveyor: Ubayhil

KNI

Image B.2: Handwritten Questionnaire results.

Image B.3: Example of Image taken at each survey location.

B.2. Critical Asset Survey Questionnaire

Questionnaire Form	
Surveyor:	Date:
Name of Pump House	
Coordinates	
Address	
Building (For Infrastructure Managers)	Yes/No
Pump House	Yes/No
Elevation (meters)	
Number of Pumps (Units)	
Capacity (Liters/second)	
Picture	