Path dependency of infrastructure: implications for the sanitation system of Phnom Penh, Cambodia

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Acronyms
ADB Asian Development Bank
CMDP Community Managed Development Partners
DoE Department of Environment
DPWT Department of Public Works and Transport
DWR Department of Water Resources
JICA Japan International Corporation Agency
MIME Ministry of Industry, Mines and Energy
MoE Ministry of Environment
MoH Ministry of Health
MOWRAM Ministry of Water Resources and Meteorology
MPP Municipality of Phnom Penh
PPWSA Phnom Penh Water Supply Authority
WHO World Health Organization
WSP Water and Sanitation Program
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Summary
Phnom Penh’s sanitation system is a combination of the drainage system and sewage system. Storm water, household wastewater, and industrial wastewater all flow together out of the city to the detriment of the natural environment and the humans that depend on it. This continued persistence of an inefficient and harmful system is explored using path dependency theory. Path dependency constrains the system to linear development and reflects the historical context in which decisions were made. Phnom Penh’s sanitation system is used to exemplify components of path dependence and their effect on implementing change.

To incorporate room for change into Phnom Penh’s sanitation system, the inherent longevity in built infrastructure must be overcome. Building infrastructure is expensive and the learning and coordination that is associated with it is not easily replaced. The social context is ultimately responsible for the investments made and the type of system expressed. Phnom Penh’s sanitation system reflects a historical legacy of colonial rule, decades of war, political chaos, and an influx of international aid contributing to an inefficient system being developed. The presence of unpredictability and inflexibility in the system can result in an inefficient system being sustained.

Introduction
In Khmer, “Lou Tak” is the word for drainage, as well as, sewerage. These two concepts don’t only overlap linguistically in Phnom Penh. Physically, Phnom Penh’s drainage system and sanitation system are one in the same. This is due to an open canal system engineered by the French and completed in the 1970’s. Because of this combined system, storm water becomes sewage flow. On the surface, this may seem convenient for the city, but in fact it is inefficient and harmful to the health of the population and environment (WHO, ADB 2000, WSP 2008, Dany 2008, Nareth et al 2008). The inappropriateness of the current sanitation system is an axiom for this study. Phnom Penh now faces the challenge of providing this basic service of drainage and sanitation while taking into consideration the ever increasing environmental and health concerns.
In discussion of ‘Phnom Penh’s sanitation system,’ this paper implies the built infrastructure, as well as, the social context in which it exists. It is the choices made by society that ultimately decide what infrastructure systems are built. Political will combined with expertise, materials, time, and space available determined the pipe and canal system present in Phnom Penh today. It is also the institutional setting that decides how that infrastructure is maintained, expanded, or changed.

Aim
The aim of this study is to explain how a system can persist despite having so many disadvantages. The choice of path dependence as a theory was motivated by its encompassing nature. Path dependence theory uses both social and physical characteristics of the system to explain its persistence. The following questions seek to explore how inefficient systems are developed and sustained.

How do the components of path dependency explain the persistence of Phnom Penh’s sanitation system?

How does path dependency affect the implementation of change in Phnom Penh’s sanitation system?

Theoretical framework
The theoretical base for this study draws from a broad range of disciplines. Addressing Phnom Penh’s sanitation system as a socio-technical system gives a structure within which to discuss path dependence. Path dependence theory is chosen as a base because of its ability to discuss the capacity of the system to incorporate change. The ability to look beyond the more obvious physical challenges in changing infrastructure and discuss the social context makes path dependence a useful theoretical approach. The theoretical foundation will begin with first, the establishment of the relationship between society and infrastructure with a discussion of socio-technical systems. The idea of path dependence will then be established with a discussion of the importance of understanding path dependency within a system needing change.
Socio-technical
Discussing how society interacts with technology and how technology influences society reveals a complex relationship with many interdependent components. A socio-technical systems perspective as a theoretical foundation for this study allows for analysis of an infrastructure system, while including the complex adaptive process that constitutes the interdependencies between the material and social realms. The term ‘socio-technical’ emphasizes that there is a social dimension that is inherent in technology and infrastructure (Monstadt et al. 2005). Infrastructural systems facilitate the movement of different kinds of people, goods and information (Kaijser 2003). Incorporating the fact that they are socially influenced and influencing gives us ‘socio-technical’ (Hughes 2001). The distribution and development of technical infrastructure is a social process with varying degrees of political legitimacy, public demand, economic viability and support, technology, and institutions, all to fulfill some basic function in society (Pinch et al. 2001, Kaijser 2003, Monstadt et al. 2005, Smith et al. 2005a, Smith et al. 2005b, Mehta et. al 2007).

Institutions
The institutional setting of a system is how things get done. Institutions are often described as the ‘rules’ of the game, where organizations, governments, and individuals are the ‘players’ (North 1991). The institutional setting includes the rules that govern the behavior, as well as, defining the role of the various actors (Pahl-Wostl 2002). In this context, the institutional setting is used to represent the ‘socio’ in socio-technical system.

Institutions are the most important aspect of socio-technical systems; founding the base for all the activities (Berkhout et al. 2003). Institutions direct the investment that determines the infrastructure built, as well as, establish the rules for its use and control (Smith et al. 2005a). Institutions are the rules that determine human interaction, but are not static. They are also constantly influenced by those interactions. Changes in consumer demand, environmental pressure, human connectedness, and innovation can all influence the institutional setting (Berkhout et al. 2003).

Path dependency
The concept of path dependency was developed by Brian Arthur (1994) and Paul David (1985) within the field of economics as, “the presence of increasing returns” (Arthur 1994:33). Douglass
North (1991) expanded on the economic definition of path dependence to include the creation, evolution and embedding of institutions. Path dependency as a concept means that future states, actions, or choices depend on the decisions and actions of current or previous states (David 1985, Arthur 1994, Liebowitz et al. 1995, Pierson 2000, Page 2006).

There are specific characteristics of socio-technical systems that contribute to path dependency. Starting with the technical component, namely the built artifacts, there are four characteristics highlighted by Pierson (2000) as contributing to the generation of path dependence.

First, infrastructure entails large set-up costs. Generally, the fixed costs are high for built infrastructure because it requires an initial investment of money, time, expertise, space, materials, and political will. Once these costs are accounted for, the incentive to maintain the system to protect that investment is significantly higher. These large fixed costs discourage changing to alternative systems because a much longer time scale must be considered to see the benefits.

Secondly, as infrastructure is built and used over time learning effects arise. Managers and users learn how to build, maintain, and use the infrastructure more efficiently. Innovations that occur in the system are more often related to the existing technology rather than completely new technology (Smith et al. 2005a). Changes that take place are more linear or stepwise.

The coordination effect is a symptom of a broad reach of a technology, such that ensuring compatibility with that technology becomes important. Technology systems are not developed independently, and often depend on the existence of other supporting systems for their functionality. The more prolific one type of technology becomes, the greater the incentive for other systems to be compatible with it. This can make it hard for new less compatible technology to find a starting point and support.

Finally, technology becomes favorable to invest in when there is the expectation that it will have broad acceptance. This adaptive expectation means that often the technologies attractive to invest in are the ones already being supported. This also limits the success of competition much like the coordination effect.
“Technologies exert impacts on the societies in which they emerge. Conversely, discursive and material commitments in society help shape technology design…reinforcing development of certain technologies, effectively excluding other patterns of development” (Smith et al. 2005a:6). Within the social context of a socio-technical system the existence of unpredictability, inflexibility and non-ergodicity explain how and inefficient paths can exist and become entrenched. When working together they eliminate accountability and limit the effectiveness of alternative technologies (Pierson 2000).

The presence of unpredictability and uncertainty limits the efficiency of technology and the possibilities for innovation. The system is less responsive to changes in consumer demand, the environmental context, and new technologies when there is high uncertainty (Deprez 2000). This increases the incentives to maintain the status quo; implementing changes increases in difficulty as uncertainty increases (Page 2006).

Rigidness in the socio-technical system is a reflection of interdependence between the social, economic, ecological, and technological components of the system. The system’s institutions are stabilized by the consumer demands and technology in place. This interdependence creates a lock-in of the system. Figure 1, developed by Pahl-Wostl (2002), illustrates the interdependencies between the system components and the resulting lock-in effect. Changes or innovation in one component of the system will be resisted by the others. This inflexibility means the system is less adaptive to external forces. Rigidity and lock-in reinforce the current system (Page 2006).
Non-ergodicity is a concept that stresses the importance of history in socio-technical systems. A system is non-ergodic if the outcomes of an event in the system would be different from the outcomes of the same exact event occurring but at a different point in time (Deprez 2000). The social context of the system may have been different when the infrastructure investment choices were made. Non-ergodicity can help explain the presence of inefficient socio-technical systems; it may be that a change in the social setting made it inefficient. An example of this could be, new knowledge of environmental processes. Non-ergodicity is not just used to justify choices from the past, but can also highlight the importance of current choices (Pierson 2000). Due to the fact that today’s choices have implications for the future, non-ergodicity gives a way to think about uncertainty in the long term.

When considering path dependency’s implications for development, it is often not on explicitly one specific element. The technical infrastructure choice, for example, is important, but there is a whole ‘institutional matrix’ that created it (North 1991). This ‘institutional matrix is how North describes the complex web of interdependent social relationships that generate infrastructure (1991). Technical infrastructures are static artifacts, which gives them an inherent longevity. However, the surrounding web of complementary configurations of institutions and organizations provide the reinforcing and continued investment in that technology. The
distribution of infrastructure is a process that depends on technical and economic capabilities, as well as, organizations, political motives, and societal and cultural perceptions. The latter topics can be slower changing than technical innovations and inhibit advancement or dissemination. Large financial and technological investments are required for technical infrastructure. This gives built infrastructure an inertia excluding opportunities for radical change (Liebowitz et al. 1995). Path dependency means change is often incremental and along an established path, making the construction of infrastructure a critical moment in the development of a city and the future options it will have (Pinch et al. 2001).

The Case

Figure 2 Map of Cambodia

Phnom Penh is the capital of Cambodia and the country’s largest city with a population of just over one million people. It sits adjacent to the convergence of the Upper Mekong, Lower Mekong, Tonlé Sap, and Bassac rivers (see figure 2). Phnom Penh is subject to two temporal seasons, wet and dry. In the wet season, it is a city that lies below the water level and consequently has a system of dykes and pumps surrounding the urban city similar to that of New Orleans (Dany 2008). The municipality of Phnom Penh can be divided into two areas; inside the dykes and outside the dykes (M. S. Nareth 2008). The sub-urbanized area beyond the dykes contains wetlands or boengs used as a sewage sink for the city. 90% of wastewater from
households, storm water drains, and industrial plants, is gravity fed to pumping stations and pumped over the dykes into the wetlands. 10% flows directly into the Tonlé Sap and Mekong River (Nareth et al. 2008). The effluent levels in the wetlands exceed their filtering capacity and the concentrations of heavy metals is high (Nareth et al. 2008). Just over half (56%) of suspended solids are settled in the wetlands before reaching the rivers (Nareth et al. 2008). The concentration level of heavy metals (Cd, Pb, Cu, and Zn) found in the wetlands exceeded the World Health Organization standards (WHO, Nareth et al. 2008). These wetlands provide approximately 20% of the produce sold in Phnom Penh markets, grown by approximately 300 farmers (Nareth et al. 2008). The current sanitation solution is considered incomplete by the government of Cambodia (Dany pers. comm., Nareth et al. 2008, Chhay et al. 2009). It is considered inefficient by the World Bank. The estimated economic loss for Cambodia because of poor sanitation is 448 million US$ (WSP 2008). The system is also considered detrimental to the health of the population and the environment by the World Health Organization, Asian Development Bank and the Ministry of Environment (WHO, ADB 2000, Dany 2008). This study focuses particularly on the urban part of the city, inside the dyke system. This part of the city accounts for 10% of the total area (31 km2) and 60% of the population (600,000 people) (Nareth et al. 2008).

**Historical context of the infrastructure**

Cambodia was part of the French Indochina (1863-1953) and in this time the French laid the infrastructural foundation in Phnom Penh. The current drainage system was completed in the early 1970’s (Dany 2008). Bombings and spill-over conflict from the Vietnam War created upwards of 2 million Khmer refugees between 1969-1973; most of which moved to Phnom Penh. This brought the city’s population to its highest level ever. In 1975 the Khmer Rouge took power and began a genocide that would eventually kill a quarter of the population of Cambodia (WHO). One of their very first measures was to evacuate all urban centers, primarily Phnom Penh. People would not return to the city until 1979 and restoration and maintenance of or investment in infrastructure would not begin until the late 80’s and early 90’s because of continued political instability and conflict (WHO).
Methods

Development and Design
This research project was designed as a case study to exemplify the path dependency that socio-technical systems create and how that effects the implementation of changes into the system. The case study approach is partially functional as a method when applied to ‘how’ research questions, as in this case (Yin 1994). This allows for the consideration of contextual characteristics that are defining components of socio-technical systems. The design and development of the project was a flexible process combining theoretical studies and empirical work. As a qualitative study, it is able to address socially constructed system dynamics; perceptions, opinions, and history (Patton 1990).

Data Collection

Semi-Structured Interviews
During the fieldwork period, semi-structured interviews were done with people with expertise or direct involvement with the sanitation sector of Phnom Penh. The director of the department of Environmental Science at the Royal University of Phnom Penh, and the director of the department of Rural Engineering at the Institute of Technology of Cambodia, provided expertise of the field as well as contacts of important involved actors. On the municipality level, representatives from the Phnom Penh Water Supply Authority and the Department of Public Works and Transport were interviewed. Interviews with the director of Community Managed Development Partners (CMDP) as well as the World Bank’s Water and Sanitation Program representative for Cambodia gave a non-governmental perspective. In total 6 in-depth semi-structured interviews were conducted along with the visiting of a Japan International Cooperation Agency, JICA, sponsored flood protection and drainage improvement project site and email correspondence with a representative of the Municipality of Phnom Penh, who was unable to have an in-person interview.

An interview guide was used, but was continually adjusted based on new information or changes unforeseen. General topics of discussion were emailed to the interviewees before the interview to help them prepare as well as maximize the interview time. Each interview varied in length from 1 hour to just over 2 hours. Interviewees were chosen based on the organization they represent.
and their contact information was either obtained through the two university informants or by published contact information on written documents collected and used.

**Written documentation**
As government officials were the most difficult to contact and least willing to provide personalized information, the written documents about public projects, policy and projections prove to be valuable sources of data. Written documents obtained include the “Master Plan of Phnom Penh by 2020” (Chhay et al. 2009), and the “City Development Strategy 2005-2015” (2005).

**Secondary Data**
During several of the interviews, secondary data was also shared. This is data that was gathered and analyzed for a different purpose than this study, but has proved useful as a source of data that can be taken and reinterpreted for this context (Yin 1994). One example is the “Economic Impacts of Sanitation in Cambodia,” report given during the interview with the Water and Sanitation Program (2008).

Secondary data collected includes two scoping studies. The first of which was completed by the Department of Environmental Science at the Royal University of Phnom Penh, titled, “Phnom Penh City Development and Water-Related Environment” (Dany 2008). The other was completed by the Department of Rural Engineering at the Institute of Technology of Cambodia (Nareth et al. 2008). A preliminary summary, “The Institutional Setting in Cambodia,” was also prepared and used and a starting point for the following institutional assessment (Kjellén et al. 2009).

**Assistance**
During the time spent in Phnom Penh, I worked alongside Sam Chanthy, who is a researcher with the Stockholm Environment Institute. He accompanied me to 4 of the 6 interviews. The interviews were led by me, but they were also quite useful for Mr. Chanthy’s research. He is a speaker of both English and Khmer, which proved to be valuable when language barriers arose. He provided translation at two of the interviews, and the rest were held in English. His research provided him with previous knowledge of the topic and contact with key actors.
**Recording and Transcribing**
Written notes were taken during the interviews as well as digital voice recordings. The interviews were transcribed personally and then compared with the written notes. With the interviews that were done with translating the notes were sent to Mr. Chanthy for clarification.

**Analysis**
This paper attempts to give an analytic description, combining concrete information about the case with theory to explain particular events, in this case, the path dependency of the current Phnom Penh sanitation system (Rutherford 1999).

Literature provides the theoretical basis for discussing Phnom Penh’s sanitation system as a socio-technical system. Applying the characteristics outlined by Pierson (2000) to Phnom Penh’s sanitation system; unpredictability, inflexibility and non-ergodicity to the social context and fixed costs, learning, coordination, and adaptive expectations to the technical context, the path dependency of the system is explained.

**Bias and Errors**
Without being able to meet all actors involved in the sanitation sector, the information gathered can only be used to exemplify theoretical indicators of path dependency highlighted in the literature. Also, the people interviewed do not necessarily represent the full view of the organization in which they are employed. Entering the field as a researcher I was forced to take inventory of the individual perceptions and assumptions I carry with me. Understanding this helped me minimize the bias I bring to the study and be more descriptive. This being a qualitative study, there are inherent limitations in its repeatability and generalizability (Yin 1994). Despite this, the study retains its validity in its descriptive nature.

**Findings**

**Infrastructural setting**
The current canal and dyke system was designed by the French colonialists and completed in the early 1970’s. The network consists of about 160 km of pipe and canal (see Figure 3). There are seven pumping stations that are gravity fed waste water from the city via the pipe and canal network (Dany 2008). 80% of the canals are uncovered. Storm water, household waste and
industrial waste, travel together to be pumped over the dykes that surround the city or into the river system. On average the storm water contributes one-tenth of the sewage flow in the dry season and 2.6 times the sewage flow in the wet season (Nareth et al. 2008). The average annual discharge is 30 million m³ of household waste and 6 million m³ of industrial waste (Nareth pers. comm.).

Current infrastructural projects include maintenance and expansion. The majority of the department of public works and transport’s work with the sewage system is doing repairs. JICA reported that in 1999, 80% of the sewage network was damaged or blocked due to years of neglect (JICA, Country Profile on Environment, CAMBODIA 2008). Proper drainage to prevent flooding is cited as Phnom Penh’s number one priority (Nareth pers. comm., Chhay et al. 2009). Work to unblock the network also then became a high priority. JICA is also constructing new infrastructure with their “Flood protection and drainage improvement in the Municipality of Phnom Penh” project. When completed in 2010, it will increase the pumping capacity and underground reservoir space by 17500 m³/hr and 11025 m³ respectively in central Phnom Penh (JICA 2009). Construction is now imminent on the Boeng Kak lake. This is the main natural water body inside the city and is traditionally used as a water reservoir when water levels rise. The Municipality of Phnom Penh has sold the lake on a 99 year lease to Shukaku Inc. for 79 million US$. The lake’s average area is 90ha and Shukaku Inc. is planning to fill and develop on 80ha of that (Cambodia Development Watch 2007, Khatri pers. comm.).

Future infrastructure projects proposed include 5 new pumping stations and a wastewater treatment facility. The pumping stations would be built by the department of public works and transport and are waiting for funding (DPWT pers. comm.). The wastewater treatment facility is mandated in the Municipality of Phnom Penh’s City Development Strategy, but has no concrete proposal (2005). The regulations outlined for the construction of a treatment facility are that it must be financially self sufficient (Dany 2008). All technical assessments say a treatment facility would not be able to handle the waste load if storm water is included (Kopitopoulos 2005, Dany pers. comm., Rosenboom pers. comm.).
Figure 3 Drainage system in Phnom Penh (M. S. Nareth 2008)
Institutional setting
Sanitation is often considered a consequence of water supply and in this way the two systems are inherently connected (Graham 2000). In Phnom Penh this physical relationship is understood, but institutionally they are two very separate systems with the smallest of interactions.

The Phnom Penh Water Supply Authority (PPWSA) is an autonomous public enterprise as of 1996, parented by the Ministry of Industry, Mine and Energy (MIME) and the Ministry of Finance (MoF) (Dany pers. comm., Visoth pers. comm.). PPWSA supplies virtually 100% of the water supply in Phnom Penh city and its supply network extends into the sub-urban areas. PPWSA’s infrastructure, monitoring, and administration are completely independent from the Municipality of Phnom Penh (MPP) and the sanitation system (Visoth pers. comm.). The MPP on the other hand has named PPWSA as a potential future manager of a proposed wastewater treatment facility (City Development Strategy 2005-2015 2005). PPWSA has no expectation for this (Visoth pers. comm.). The one clear relationship between PPWSA and the sanitation system of Phnom Penh is the inclusion of a 10% charge on all of its water bills for ‘sanitation services’ (Visoth pers. comm.). This money has been collected by PPWSA for the past 10 years and then distributed to the MPP (Visoth pers. comm.). This money is used for expansion and maintenance of the sanitation infrastructure (DPWT pers. comm.).

On the national scale the sanitation system is vaguely mentioned in the mandates of several ministries. The Ministry of Industry, Mines and Energy (MIME), the Ministry of Water Resources and Meteorology (MOWRAM), and the Ministry of Environment (MoE) are the most significant participants in the Phnom Penh sanitation system. MIME is generally responsible for the urban water supply outside of Phnom Penh, but has just recently expressed interest in leading the development of a ‘sustainable waste water and sanitation plan’ (Rosenboom pers. comm.). However, this is just an expression of interest and nothing concrete has come from it yet. This is the first government body that has shown an interest in holding some responsibility for the sanitation system. MOWRAM is the main source of national water policy. They in work with the Asian Development Bank (ADB), developed the ‘National Water Policy’ (ADB 2000). MoE is responsible for the natural environment including the monitoring of water pollution. The MoE does consider the relationship between effluent levels and human health, but does not have communication with the Ministry of Health (MoH) (ADB 2000).
All municipal level activities are coordinated through the Municipality of Phnom Penh (MPP) (Dany 2008). The MPP is responsible for developing the vision and strategies for the municipality, delegate those activities to the various departments, and the allocation the departments’ budgets. Information from ministries is filtered through the MPP. Officially, responsibility for the Phnom Penh sanitation system rests with the MPP, but only to the extent that they have to delegate the various tasks to their respective departments (Dany 2008). The MPP released the “City Development Strategy 2005-2015” (2005), and the “Master Plan of Phnom Penh by 2020” (Chhay et al. 2009). These two documents outline the sanitation goals for Phnom Penh and strategies for achieving them.

Goal 2.3 “Achieve good access to safe water supply and well manage water resource” (2005:28)

- Support water related infrastructure and enforce effective monitoring with appropriate technologies
- Control and minimize water pollution at the source
- Enforce the construction of wastewater treatment facilities

Goal 3.1 “Construct and restore infrastructure as proposed in the Master Plan” (2005:31)

- Extend the water supply coverage area
- Minimize any construction on low land and improve the sewerage/drainage system and reservoirs

The Master Plan mandates, “Giving the priority to the realization of the basic infrastructures” to further encourage development, of which sanitation and drainage is an example (Chhay et al. 2009). It also required new business complexes to incorporate a block septic tank or filter into the construction and by 2020 block by block septic tanks or filters will also be required for new housing developments in Phnom Penh (Chhay et al. 2009). Block by block septic tanks are tanks attached to the sewage pipes just before they connect to a main canal (DPWT pers. comm.).

The body responsible for building, maintaining and repairing that infrastructure would be the Department of Public Works and Transport (DPWT). The DPWT holds the technical expertise with regards to infrastructure and its main focus is to keep the canals and pipes clear and the pumping stations functioning (DPWT pers. comm.). The Department of Urbanization (DoU) has
the responsibility to enforce the current and future block by block septic tank or filter policy (DPWT pers. comm.). Other departments that are involved in the sanitation system are the Department of Environment (DoE), which is responsible for the quality of the water bodies and the Department of Water Resources (DWR), being responsible for the size of the water bodies.

International aid organizations have been active in Phnom Penh for several decades. The World Bank’s Water and sanitation Program (WSP), the Japan International Cooperation Agency (JICA), and the Asian Development Bank (ADB) are the most predominate in Phnom Penh’s sanitation system. WSP produced the “Economic Impacts of Sanitation in Cambodia,” report that highlights the monetary loss from inaction in the sanitation sector for the whole of Cambodia (2008). MIME approached WSP in its interest to develop a ‘sustainable waste water and sanitation plan’ (Rosenboom pers. comm.). JICA are sponsoring and implementing the “Flood protection and drainage improvement in the Municipality of Phnom Penh” project that is taking place from 2007 to 2010 (JICA 2009). The ADB has consistently been a major financial contributor to the MPP (ADB 2000).

**Discussion**
Phnom Penh’s sanitation system, a socio-technical system, has characteristics that further the path dependency of the system and impede the implementation of changes.

**Technical**
The built components of the sanitation system have an inertia that contributes to the path dependency of the whole socio-technical system. This is consisting of four components of infrastructure that make initial investment choices extremely important, and changes difficult, costly, and incremental.

**Fixed costs**
First, the infrastructure, which includes Phnom Penh’s sanitation network, has very large setup and fixed costs. In Phnom Penh’s case, the setup costs were mainly paid in the 1960s and 1970s when the infrastructure was constructed. The French provide the engineering and technological foundation for the canal and dyke system present today. The material investment at the time of construction was significant. There is about 160km of pipe and canal making up the city’s sanitation system and was installed over several years.
The fact that the system is already in place and these initial costs covered makes repairs, maintenance and expansion of the existing system more attractive than changing to an alternative system. For example, changing the sanitation system to separate storm water from sewage, as suggested in the Asian Development Bank report, "Environments in Transition" (2000) and the World Bank report “A Strategy for Enhancing Urban Sanitation in Cambodia” (2005), would require replacing the entire network of pipes and canals or building a new parallel system, requiring the setup investment of materials, manpower, expertise, political backing, and time.

**Learning**

Another characteristic of large technical infrastructure that embeds the system and makes non-linear change difficult, are the learning effects that occur. There are two ways learning embeds the system; through efficiency and innovation. The Department of Public works and transport in Phnom Penh over time has learned how to maintain, repair, and expand the sanitation system more efficiently. They can do it faster and cheaper than if it was a new system that they didn’t have experience with. Innovation that happens in the sector is more often related to the current system rather than something completely new. Block by block sanitation is a new technology for the Phnom Penh sanitation system. It is a septic tank on a neighborhood scale that is added at the connection of neighborhood sewage pipes to main canals. This is stepwise change.

**Coordination**

One of the main inhibitors to the construction a sewage treatment facility, as suggested in the World Bank report “A Strategy for Enhancing Urban Sanitation in Cambodia” (2005) and mandated in the “City Development Strategy 2005-2015” (2005), is its incompatibility with the current combined sewage/drainage configuration. By all technical assessments, a treatment facility cannot handle the wastewater load when storm water is included (Kopitopoulos 2005, Nareth et al. 2008, Dany 2008). Coordination effects happen because once a large technical system is established, like Phnom Penh’s sanitation system, it is easier to build compatible additions, rather than try to change it to coordinate with a new technology, such as a treatment facility.

**Expectations**

Curing new housing construction in Phnom Penh, the same combined storm water/wastewater system is installed (Dany 2008). One reason for this is the final self-reinforcing characteristic of physical infrastructure; adaptive expectations. That specific type of technology is used and
invested in because the expectation is that it is what will be used in the future and only a small chance something else or new will be used or required. Individuals’ continued use of that type of pipe network perpetuates the expectation that that will be the type of pipe network in the future.

**Social**
The social component of the sanitation system also has positive feedbacks reinforcing the system. In some ways the social context of the sanitation system is the less obvious contributor to its path dependant nature, but that is exactly why its contributions are the most important.

Path dependency literature highlights key indicators of, and contributors to path dependency within the social context. Phnom Penh’s sanitation system exemplifies these. Uncertainty, inflexibility, and non-ergodicity combined, entrench Phnom Penh’s sanitation system on a detrimental and inefficient path.

**Uncertainty**
It is fairly trivial to say this socio-technical system contains uncertainty. The scale and scope of the sanitation system in Phnom Penh makes ‘perfect information' virtually impossible. That being said, coordination, transparency and accountability are not impossible, but the limit of these three attributes is increasing the uncertainty and entrenching the current sanitation setting.

**Coordination**
The ministries and departments do have defined responsibilities. The DPWT is responsible for the sanitation infrastructure maintenance, repair and expansion including the pumping stations, for example. The problem is that there is no communication between departments and decisions are often taken without discussion or consensus (Dany pers. comm., DPWT pers. comm.). Without communication with the other departments the only incentive is to maintain the status quo.

There is a lack of communication between departments even when their responsibilities are clearly related. The department of urbanization, among other things, is responsible for enforcement of construction codes and policy, including the new block by block septic tanks. Once the tanks are built they are then under the jurisdiction of the DPWT as sewage infrastructure. The DPWT has no communication with the department of urbanization. The DPWT has no knowledge to whether any block by block septic tanks have or have not been
built; let alone where they would be located or what maintenance or repairs they would require. This inhibits the effectiveness of this new technology.

This absence of communication and coordination between departments also negates innovation. Combining the expertise from various departments could produce solutions for the sanitation system problems that go beyond ‘end of pipe’ fixes, as well as, reveal options for implementing them. This is assuming that the different departments have a shared perception of the problem; often an outcome of increased coordination and communication (Pahl-Wostl 2002).

Accountability
Va Dany explicitly expressed her opinion that vague and unclear definitions are a strategy used to avoid accountability (2009). The lack of standardization of definitions is highlighted as a problem within the institutional setting of Cambodia by the World Bank, Asian Development Bank, and World Health Organization (Kopitopoulos 2005, ADB 2000, WHO). After the dangerous effluent levels were reported and the government’s general acceptance of the inefficiency of the system, the policies drafted to address the situation do not give any concrete solutions. The MPP as the responsible body established the policy to ‘improve and rehabilitate the sewerage system’ from 2005 to 2015 (City Development Strategy 2005-2015 2005). There is no definition given for ‘improve’ or ‘rehabilitate’ or strategy for determining if they are achieved. This linguistic uncertainty protects the MPP from being held responsible and further engrains the status quo.

Unpredictability of the system only compounds when contradictory policies are implemented. The City Master Plan and the DPWT both highlight flooding as the most urgent concern for Phnom Penh. Goal 3.1 of the City Development Strategy explicitly states, “Minimize any construction on low land base and improve sewerage/drainage system and reservoirs” (2005:31). At the very same time as the development of the City Master Plan, MPP sold the main lake within the city core for 72 million US$. 90% of this substantial water reservoir is to be filled in (Khatri pers. comm.). These contradicting actions taken by the MPP underscore the lack of perception of the problem, accountability, and transparency.

Transparency
The lack of transparency also keeps accountability at a minimum. As discussed above there is very little information shared between departments and even less available to the public. There is
virtually nothing available to the public from the governmental departments and only the City
development Strategy 2005-2015 and the City Master Plan from the MPP. Correspondence with
the MPP always was directed back to these documents.

Inflexibility
Rigidness occurs when alternatives become less and less desirable and/or achievable. The social,
economic, ecological, and technological components of the system are interacting and
interdependent. This interdependence results in a lock-in effect, a stabilization of the current
system dynamics. The current management regime is legitimized and secured by its critical role
fulfilling the consumer demand for a cheap and convenient sanitation solution that they are
accustom to, limited by the technology available. Figure 1, as discussed above, illustrates the
interdependencies between the system components and the resulting lock-in effect. This
demonstrates the ineffectiveness of having an engineering perspective and simply focusing on
technological solutions. The options for innovation to take hold are limited without system wide
change.

The lock-in and inflexibility in Phnom Penh’s sanitation system restricts the ability of innovation
to take hold. This limits the responsiveness to threats to the system. The entire sanitation system
is dependent on the wetland and river ecosystems to absorb the wastewater. As this underlying
assumption is increasingly challenged publicly, this inflexibility will inhibit rapid demand
change.

Non-ergodicity
Phnom Penh’s sanitation system is non-ergodic because the outcomes of an event (development
of infrastructure) are different from the outcomes if the same exact event occurred but at a
different point in time (Deprez 2000). That is to say, the same investment choices made by the
French in the late 1960’s would have different consequences, implications, and acceptance if
made today. Non-ergodicity stresses the importance of the historical context that the system
developed from (Pierson 2000). The institutional setting seen in Phnom Penh today reflects the
legacy left by years of conflict, international aid, and recent stability and independence.

Particularly in Phnom Penh, the institutional setting has changed quite drastically from when the
infrastructure was developed; around 30 years of war and conflict changed that. In the early
1990’s there was a human resource vacuum (ADB 2000). Institutional arrangements made at that
time reflect the funding and development agencies that provided the technical assistance in that moment. In most cases, this was a focus on developing Cambodia’s market based economy. As the United Nations Transitional Authority in Cambodia moved out, political parties jostling for position funded their campaigns with the use of natural resources (ADB 2000). This put environmental considerations in a secondary role at the time when key institutions were formed.

The sanitation system in Phnom Penh is detrimental and inefficient and the negative effects may be less obvious than the benefits received. At the time of installation the environment may or may not have been able to sequester the waste load, however, the gains for the city would have been clear. It provided improved sanitation and drainage for the city. The initial choice and investment may or may not have been the best choice at the time, but the context in which the resulting infrastructure exists has changed.

Non-erodicity is a way of comprehending path inefficiency and another reason why deviation from that path is difficult. Events that happen in the past are remembered in the system. Phnom Penh’s sanitation system was developed by a select powerful few in a society that at the time was not democratic. Today, Cambodia has a democratic political system, but the lack of transparency and accountability discredits consumer demand (Dany 2008). The unpredictability created by the lack of communication leaves no incentive to deviate from the status quo. The interdependencies’ of the economic, social, and technological components of the system stabilize and legitimize each other locking-in the inefficient path.

**Making a transition**
The implications of the unpredictability, inflexibility, and non-erodicity in Phnom Penh’s sanitation system are greater barriers to directing the system towards sustainability. Theoretically and legislatively Phnom Penh’s goal is to achieve a sustainable sanitation system that is just, efficient, and ecologically sound. To achieve this, the system must overcome the multitude of characteristics and positive feedbacks embedding the current arrangement.

To find a solution to the problem there must be a shared and accepted perception of what the problem is (Pahl-Wostl 2002). Once this consensus is reached an ‘alliance of interests’ is more attainable. As Keijser (2003) explains, it is not enough to just have this agreement in the institutional setting. The system is path dependent and a multitude of factors are further
embedding it. The inherent longevity of technical infrastructure means that innovation and change happens in incremental steps. Fundamental changes require large investments of time, money, political will, and technology. Understanding the historical legacies present in the current system and the historical context in which development decisions were made effect potential consequences of changes implemented and should not be ignored. In order for change to be effective in a socio-technical system, an understanding of how society and the technology interact and its historical context is crucial (Kaijser 2003).

**Conclusion**
The components of path dependency explain the inertia of the system in two parts; physically and institutionally. The infrastructure, as the physical piece, has a more obvious longevity, because it is a tangible artifact. Built structures require an investment of money, time, materials, and space. This investment is more often nurtured and expanded on, rather than abandoned for an alternative technology. Adjacent infrastructure systems are built to be compatible and the expectations for the continuance of the system expand along with the infrastructure. Institutionally, the presence of unpredictability and inflexibility diminishes accountability and gives incentive to maintain the status quo. The historical context of Phnom Penh’s sanitation system can validate the inception of this inefficient system, but it is the current social setting that enables the persistence of it.

Path dependency affects the implementation of change in Phnom Penh’s sanitation system by diminishing the benefits of alternative systems. A sewage treatment facility would be an alternative for Phnom Penh’s sanitation system; resistance is seen both physically and institutionally. Physically, the combination of storm water and waste water exceeds the capacity of a treatment facility, necessitating a complete change in infrastructure. Institutionally, requiring 100% financial self-sufficiency halts any attempt at designing or constructing of a treatment facility. Attempts to establish a substitute structure are negated by the path dependency of the established system. Implementing change also requires institutional accountability. The presence of uncertainty, unpredictability, and rigidity diffuses blame preventing initiatives for change.

While most elements of Phnom Penh’s sanitation system show no sign of diverging from the present path, the initiative taken by the Ministry of industry, mines and energy to begin the
development of a sanitation system strategy is an essential step forward in fostering a transition to a path with less detrimental health and environmental impacts.

It is difficult to change the direction of large socio-technical systems such as Phnom Penh’s sanitation system. Attempting to restructure the system without a thorough understanding of how the fixed costs, learning effects, coordination effects, expectations, uncertainty, inflexibility, and non-ergodicity are working together to resist that change will be in vein. The interdependency between the users, institutions, technology and infrastructure require that change be applied to the entire system: consumer demand may need to be established, public policy enforced, or innovation in technology developed (Kaijser 2003). The choices made within the system of what to invest in or what to support may very well be influenced by coordination effects and expectations, but those choices always represent a critical moment in the development of the system and the future options it will have.
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