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The Role of Network Science in Analyzing Slums in Rapidly Growing Urban Areas

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Introduction

In the coming decades the United States military will find itself operating in increasingly complex environments. New concepts of operations and new language in military doctrine are needed to address the complexities of these tactical, operational, and strategic environments. In particular, the complexities of urban and peri-urban—areas located in the "urban-fringe"—regions require new tools and concepts to develop more effective operations and supporting doctrine. Rapidly evolving social, economic, and physical structures throughout the world suggest that future operations will involve complex systems, unexpected scenarios, and nonlinear processes. As a basis for military decision-making, these systems have been described as having four components: volatility, uncertainty, complexity, and ambiguity (VUCA) (Kail 2010). VUCA features help explain political, social, informational, organizational, and physical infrastructure networks within complex environments.

The recent focus on the four VUCA features highlight the complex nature of modern military operational environments. This perspective calls on particular strategic approaches to deal with VUCA characteristics: *Volatility* refers to rapid, drastic changes in the environment-—strategic plans that assume static environments become ineffective; *Uncertainty* refers to the unexpected and unclear environments faced by soldiers—military units cannot create useful situational awareness because past experiences do not necessarily help predict the future situation; *Complexity* refers to systems that are interactive, interdependent, and often multi-layered. Not accounting for the interdependencies and multiple dimensions of these systems will produce inaccurate assessments, which can be disastrous, setting off a cascade of unanticipated events. *Ambiguity* refers to the difficulty in determining, delineating, defining, and classifying the true problem—uncertainty must be quantified and accounted for in analysis. Supporting nation-building and humanitarian activities necessitates a deeper understanding of how these societal systems function.

Methods used to analyze VUCA environments are growing beyond traditional descriptive statistics, which inherently assume independence among components. During the past decade some of the most important advances towards understanding VUCA have been provided in context of network theory. Network science models capture a dynamic understanding of the interdependence among components, and the evolution of these relationships over time. Developing network models and theoretical approaches is critical to understanding, navigating and leveraging unfamiliar and complex social and physical terrains,

particularly in large urban and peri-urban areas.

The megacity has quickly become a symbol of the 21st century human environment, with over 24 megacities in existence across the world in 2013. The rise of the megacity has brought forth significant issues in planning, authority, and stability as these rapidly expanding urban centers outpace the capacities of their municipalities. With populations in excess of 10 million, there are often extreme limitations in the abilities of formal municipal governments to plan space, infrastructure, and resources. This leads to issues of large-scale unplanned habitations, extreme stress on environmental resources, uncontrolled sprawl, pollution, informal governance structures, and dangerous power conflicts.

As this demographic shift to an urban society continues to cascade, it becomes increasingly important to understand this new terrain. As General Odierno, former Chief of Staff of the Army, and Michael O'Hanlon, a prominent Brookings Institute researcher, discuss in their recent article: "Scale is a major contributor to the complexity of urbanization. As cities grow, their vulnerabilities grow—often in nonlinear ways." (Odierno and O'Hanlon 2016) Massive growth creates new weakly governed spaces where criminals and extremists can flourish unabated. The challenge, as suggested by Pike and Brown (2016) is to operationalize existing military intelligence concepts so that intelligence analysts at all levels can gain understanding. For example, the Intelligence Preparation of the Battlefield (IPB) which is the systematic process of analyzing the four mission variables (enemy, terrain, weather, and civilian considerations), should consider the interconnectedness of the variables (Wolfel et al. 2016).

This paper stresses the importance of using network theory in analyzing the interconnectedness of different components of the operational and strategic environments. This type of analysis is particularly important in weakly governed spaces, such as slums and gang-controlled neighborhoods, where interactions between variables are mostly outside government control.

Weakly Governed Spaces in Urban Areas: Slums

Urbanization increasingly means that the poorest, most vulnerable people move into large, highly distressed slums. As a consequence, urban areas exhibit high levels of poverty and inequality. The risk is that these informal urban areas will detach themselves even further from effective government service and control, and instead build local political and military power structures that may come to constitute a threat to the city and ultimately, the state itself. The UN defines a slum household as a group of individuals living under the same roof lacking one or more of the following conditions (UN Habitat 2003):

- Access to improved water
- Access to improved sanitation
- Sufficient-living area
- Durability of housing
- Security of tenure

Often, all five of these factors are present. Slums are a clear manifestation of a poorly planned and managed urban sector. In rapidly growing cities, such as many sub-Saharan African cities, the majority of the population live in slums. Fifty-five million new slum dwellers have been added to the global population since 2000. ("UN HABITAT State of the World Cities" 2012)

There are five major components that perpetuate slum conditions and consequently contribute to household vulnerability. First, these **settlements lack basic infrastructure** such as waste management systems, sanitation, improved water sources, they have unpaved and poorly maintained roads and lack access to emergency services. Lack of adequate emergency services, such as functioning fire trucks, place these populations at a great risk in the event of a disaster. Even if emergency services were able to support the population, access to many of these slum neighborhoods is significantly restricted, if not impossible because of poor and non-existent transportation infrastructure. In many slum areas there are dwellings that do not have access to a single road because landlords have sold off adjacent plots with no room in between for vehicle traffic. To compound this, squatters set up their homes haphazardly leaving barely any room to walk effectively restricting vehicle access and reducing roads to footpaths. Municipalities cannot keep pace with the settlement process resulting in unorganized, densely populated, poverty ridden urban areas.

Second, **land rights are exceedingly complicated** in slum areas, resulting in differential access to land, water, and sanitation. In some cases, entire slums can be owned by just a handful of people who charge rent costs that the urban poor struggle to afford. In other cases, a convoluted legal system can make it almost impossible to legally determine who has rights to the land. Land is not only critical for providing residence but is also a means for growing food. One example of a functional informal economic system is urban agriculture, which is a key component of the urban mosaic and provides a significant source of nourishment, as food prices at local markets are often too high for the low-income population.

Third, **rapid population growth**, propelled by migration and high birthrates, results in both overcrowding and even more urban sprawl. The problem is exacerbated by the government's inability to implement or enforce zoning restrictions and building. Overcrowding therefore results in the inability of the municipality to provide crucial services such as garbage collection, which results in the accumulation of solid waste, and increases the risk of rapid spread of contagious diseases. Furthering the problem, sprawl encroaches on marginal lands, to include wetlands, steep hillsides, and low-lying areas, making inhabitants more vulnerable to natural disasters.

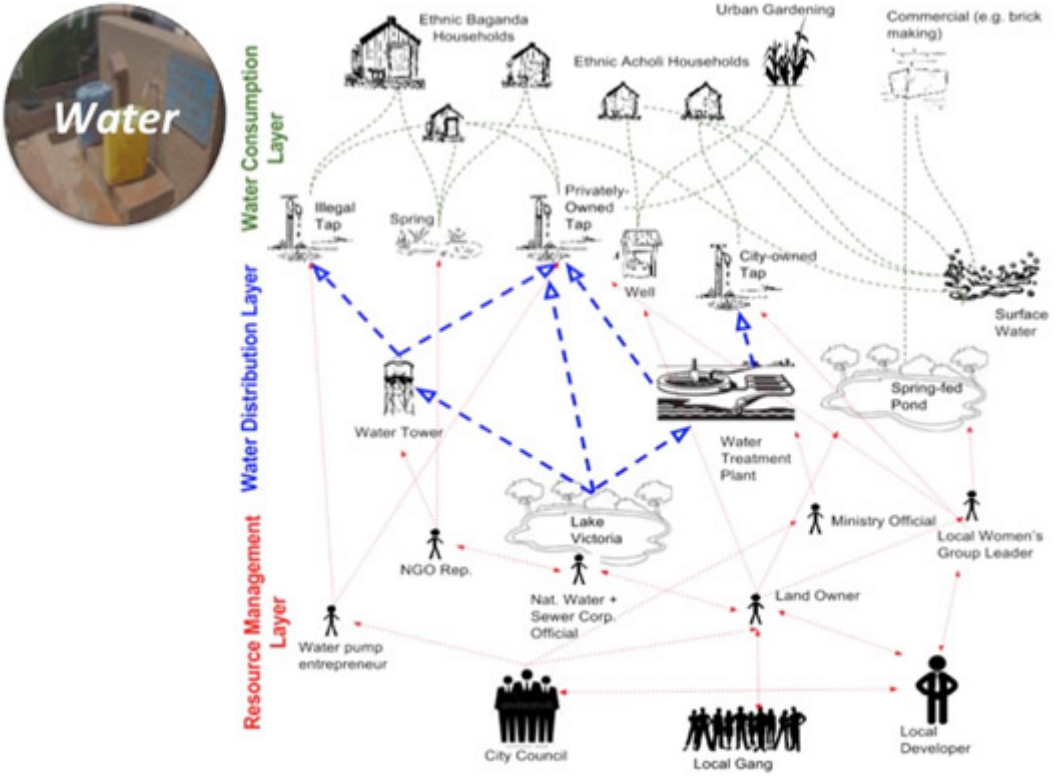
Fourth, the majority of **slum dwellers operate in the informal economy**—the part of the economy that is

not regulated or taxed by the government. Many of the economic and infrastructural agreements are carried out with limited oversight of the government, therefore equity and safety of services cannot be ensured. Informality is an inevitable occurrence in developing countries simply because the formal sector cannot manage the sheer magnitude of the population. Informal sectors have become a critical component for the formal sector by providing essential distribution mechanisms. For instance, an unregistered kiosk owner might sell mobile money and cell phone airtime from a multinational telecom company. These entities have become so intertwined that they are often difficult to disentangle from one another. Informal sectors can also be sufficiently organized to affect political outcomes of the formal sector.

Finally, **lack of reliable, clean water and sanitation** is another crucial component in slums. Without established critical infrastructure, physical proximity and pollution frequently limit access to clean water. For example, in Kampala, Uganda, a city that is growing rapidly, and where 70 percent of the population lives in a slum, pollution from pit latrines, inadequate sanitation facilities, low ground water supply during the dry season, and the high cost for piped water from public taps all contribute to increasing household level vulnerability.

Using network concepts of governance, we propose that the underlying relationships that drive informal governance—a hierarchical system of power existing outside of state structure—to a large degree, drive the other factors of poor infrastructure, incongruent land rights, and overcrowding. We use network analytic perspectives to map what these informal power structures look like, and suggest a quantitative framework for how to determine the impact of informal power networks on water sustainability. Quantitative network based approaches may provide invaluable information for improving situational awareness and providing strategies for developing effective solutions. For example, if a natural disaster or a civil conflict were to occur, who would the US military or NGOs talk and coordinate with at the community level? Who in the city has the real influence and power in these situations? The complex and intertwined relationships between the informal to formal sectors lead to tactical and operational challenges. Tactical elements in these environments are likely to find they are mostly working within the informal network. At the operational level, host nation counterparts are more likely part of the formal structure of the city. The potential for alignment of mission elements and coordination of the US military's tactical/operational elements and cities' informal/formal networks may represent the most significant opportunity for mission effectiveness in urban operations.

Using Water Resources to Explain Informal Governance Structure



As water is critical for health and wellness of any community, its distribution is absolutely central for maintaining peace and coordination of a region. Urban and peri-urban communities of developing societies offer insights about how both formal government and informal power hierarchy can determine access and control of limited resources. We illustrate the utility of network models by exploring network maps of water availability in urban and peri-urban regions in the developing world. Historically, tension has been fueled when disparate social classes with numerous ethnic affiliations from distinct regions of a state are brought into close proximity and forced to rely on restricted resources. In many cases, political and other influential entities can act as informal gatekeepers, whose role can either aggravate or alleviate such tensions. The complexity of the problem is only made worse by the lack of centralized oversight of the various natural resources, such as water, food, and energy, as well as the physical land upon which these resources are drawn. We suggest that this problem be examined from a systems perspective, by mapping, quantifying and evaluating how well various interdependent systems related to water supply are maintained and balanced. In the figure above we show the various networks that are likely involved in the access and consumption of water.

The **water access and consumption network** isolates where and how the resources directly impact the population. This network is bi-modal as it is made up two types of nodes: water consumers and water sources. The links indicate which households get water from which source(s). Water is consumed primarily by three sectors: agriculture, households and commercial operations. This network directly reflects constraints to water access—--how far and how many sources can households access. Households can obtain water from multiple sources. In sub-Saharan Africa for example, a significant portion of the population lacks access to piped water and therefore households rely primarily on springs, communal taps, and open water sources such as lakes and rivers. Analysis of this network can show how water consumption relies on particular types of sources and which suppliers in turn wield the most economic and

possibly social and political influence.

The **water distribution infrastructure network** traces how communal taps and other point-of-service water sources obtain their water. In most cities this supply network consists of multiple connected components of varying sizes and capacities. Successfully mapping the city's water distribution network could have important implications for residents' vulnerability in the event of conflict or the outbreak of a waterborne illness such as cholera. Understanding this layer of the network could be significant for the tactical forces in a military operation of any nature.

The **resource management network** shows which actors control and govern the use of communal resources, including food, water, sanitation, and land. For water, these actors include the city's official piped water supplier, city-wide agencies, local municipal councils, community organizations, local "strongmen" and their associates, as well as individuals who own or control particular taps, toilets, plots of land, and so forth. Understanding these connections can explain what barriers exist and which actors are needed to be included before operational changes can be implemented. In addition, network analysis can identify potential flashpoints for conflict over these resources, be they "turf wars" over the right to sell services, land-ownership disputes, resistance against the expansion of city services into new areas, or a conflict over resource control.

Importance of System Planning

Successful planning relies on good governance, yet city and national authorities are often unorganized, ineffective, and not trusted by local residents. Planning should not just focus on physical infrastructure but also on social sustainability. Mapping water consumption and management networks and their interdependencies would enable us to identify vulnerabilities to better understand the role of social factors in the governance of natural resources. For example, we can integrate these data to develop a multi-dimensional model that captures the interdependencies across resources and social structures. Multi-layer networks have been successful in modeling transportation infrastructure, optimizing traffic flow in a congested urban area, and forecasting water demand in a European city (Adamowski and Karapataki 2010). As Lily Kong at Singapore Management University states: when millions of people with different backgrounds and cultures come into contact with each other, managing social tensions becomes as important as providing essential infrastructure (such as housing and plumbing) and resources (such as food and water) (Yap 2016).

We can use these network approaches to quantify distribution strategies, and evaluate specific approaches for how aid is provided in these regions. For example, there is debate over whether top-down state-led programs or privatization is better for improving water access in peri-urban settlements. A top-down approach of simply bulldozing unofficial squatter districts fell out of favor in the international community in the 1970s, giving rise to smaller, cheaper incremental improvements, such as "slum upgrading" projects such as building new wells, sanitation systems or footpaths. Though this approach achieved widespread popularity throughout the developing world from 1970s-90s, according to a recent continent-wide study, "the long-term sustainability of these projects is now seen as doubtful because of poor maintenance, lack of community capacity, difficulties of cost-recovery and deep-rooted social divisions" (Dagdeviren and Robertson 2011). By understanding how distribution strategies change the configurations of the various networks, we can estimate the effectiveness of the two approaches—top-down state-led versus locally driven— in terms of the second and third order effects.

Conclusion

Whether operating as small teams of specialized enablers or as a larger formation responding to crisis, US military forces engaging in a dynamic urban terrain must be able to find and interpret informal centers of

gravity and spheres of influence. Moreover, the situational challenges may be *how* and *where* and at *what level* informal and formal powers mesh. Through network analysis of the connectivity of these systems, can we be more effective in this challenging operational environment, lowering the risk to our forces and the population, and increasing the likelihood of mission success.

Applications of network theory have the potential to generate new tools for the military in its efforts to facilitate stability in volatile urban environments, perhaps avoiding the need for costly military intervention. Mapping the networks of power, control, and resource-dependence in developing world slums, may soon be relevant to the U.S.'s efforts to keep terrorist groups from capitalizing on urban tensions, especially in African cities. From the perspective of international development, network theory has the potential to help researchers, decision-makers and warfighters understand how social networks control access to resources, so that they are better prepared to address the challenges facing the rapidly-growing cities within the developing world.

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