Methodology to Model and Understand the Complexities of Social, Economic, and Governance Interactions for Regional Assessment in Kenya

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ABSTRACT

Complex systems level analysis and modeling techniques to include diagramming and simulation are explored as a means for understanding, modeling, and quantifying how local events with regards to security, governance, and economic development can have a regional impact for developing countries. Specifically, we researched the development of an assessment tool to simulate the butterfly effect across different regions in Africa, with the central point of interest in Kenya. The resulting technique which is based upon using complex systems diagramming tools to develop systems dynamics models will be useful in determining the effects across a wide class of variables such as investment, security, governance, etc., to determine a country's capacity.

Specifically, we will investigate the use of complex systems level methods, processes, and tools to determine the most influential inputs in the broad categories of economics, security, essential services, and government services for strategic planning and investments. We will use these inputs to measure their effects on the capacity of the region, the amount of essential services, the security of the region, the economics of the region, and the government legitimacy. Ultimately, the stakeholders will be able to determine what inputs cause the highest amount of change in country capacity that drives government legitimacy. This methodology should have enough fidelity that it can be used to help prioritize investment and other activities to influence US interests.

INTRODUCTION

In support of AFRICOM and the US Army Corps of Engineers, Engineering, Research and Development Center (ERDEC) we were asked to develop an assessment tool using systems diagramming and complex system modeling to simulate the butterfly effect[1] across different regions in Africa. Africa is not only of strategic importance because it is a battleground in the fight against terrorism and HIV/ AIDS, but its natural resources are making it as important as the Middle East as a supplier of oil and natural gas. The U.S. is currently in competition for access to energy and mineral resources in Africa along with China, India, Europe and much of the Middle East. Given the national strategic focus of containment that is focused on U.S. foreign policy to diminish the economic and political growth of China, Africa plays a key role.

An analytical tool is needed to support strategic policy and investments, resource prioritization, and to try and fundamentally understand first and second order interactions of economics, security, and governance and how they are affected by investments, policies, processes, internal and external drivers, etc. By using complex systems diagraming techniques to help build system dynamics models, the results methods, processes, and tools (MPTs) should produce a valuable toolkit for analyzing these types of problems.

[1] In chaos theory, the butterfly effect is the sensitive dependence on initial conditions; where a small change at one place in a nonlinear system can result in large differences to a later state. According to Encarta World English Dictionary, the butterfly effect is defined as the "large output from small input: the supposed influence exerted on a dynamic system by a small change in initial conditions." The effect derives its name from the theoretical example of a hurricane's formation being contingent on whether or not a distant butterfly had flapped its wings several weeks before. Taken from Wikipedia at http://en.wikipedia.org/wiki/Butterfly_effect accessed 15 November 2011.

Our initial proposed demonstration study focused on Kenya since it shares borders with many countries with emerging terrorist organizations. Kenya also acts as a buffer country between unstable and stable governments with its predominantly non-Muslim population and failing tourism based economy. Ultimately our research will consist of Systemigrams, causal loop diagrams, and swim lane charts to help develop the interdependencies of the actors, processes, external and internal stakeholders, investment, etc. (herein we will refer to these as model variables). Once the first and second order effects and synergies can be defined using systems diagraming tools we developed a comprehensive system dynamics models to look at the behavior of Kenya. The details of this model will be presented later in the paper; however, the model is unique in that we used the capacity of a country to deliver goods and services to the populace as a means for assessing how the model variables affect the legitimacy of the government. Also, the model is all encompassing and meant to look at all aspects of a countries capacity.

SOLUTION METHODOLOGY

Kenya, like any nation state, is a complex social, economic, and political system. As shown in in Figure 1, we can borrow from formal systems theory and use that taxonomy and MPTs to describe and model it as a complex system. Given the complex nature of the relationships between the variables of interest in Kenya, the systems models used produce outcomes that are not always intuitive results. In order to better visualize and understand how Kenya behaves, the use of complex systems techniques will help uncloak its hidden relationships and second order effects. Once these levels are broken down into simpler models, which are at the system and system of systems (SoS) levels, the complex system can be formulated. When breaking it down into more simple relationships, not only are risks being mitigated with potential hidden failures in the models, but also conceptually the relationships between the variables that represent Kenya's analysis are easier to understand and describe.

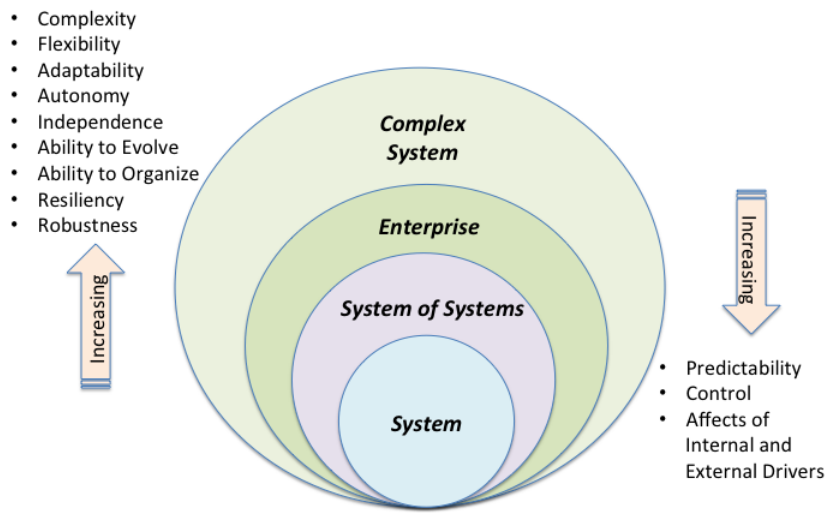


Figure 1. *Hierarchy of systems*

We took the approach shown in Figure 2 to develop our MPTs for this class of problems. We first used various system diagraming tools to try and understand the interdependences of the various actors, processes, resources, external and internal threats in defining the behavior of Kenya. This iterative approach was needed before we could develop our final behavioral model of Kenya. An example of one of our complex system diagrams is shown in Figure 3. Systemigrams like this one (see Boardman and Sauser, 2008, Blair et a, 2007, and Sauser et al, 2011 for discussions on the use of Systemigrams to illustrate the interrelationships of complex systems) are useful in capturing interdependencies.

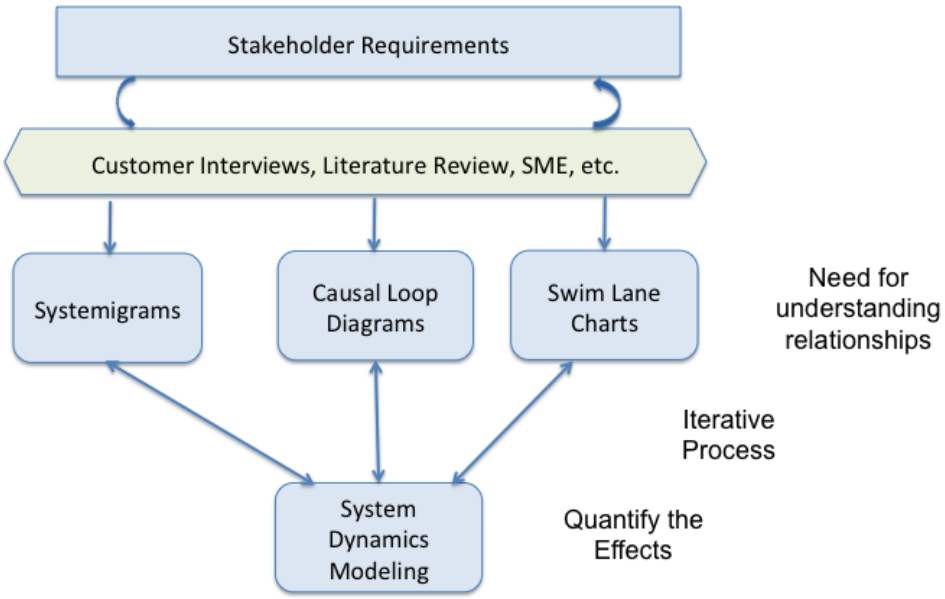


Figure 2. *System diagraming techniques used to develop our analytical models*

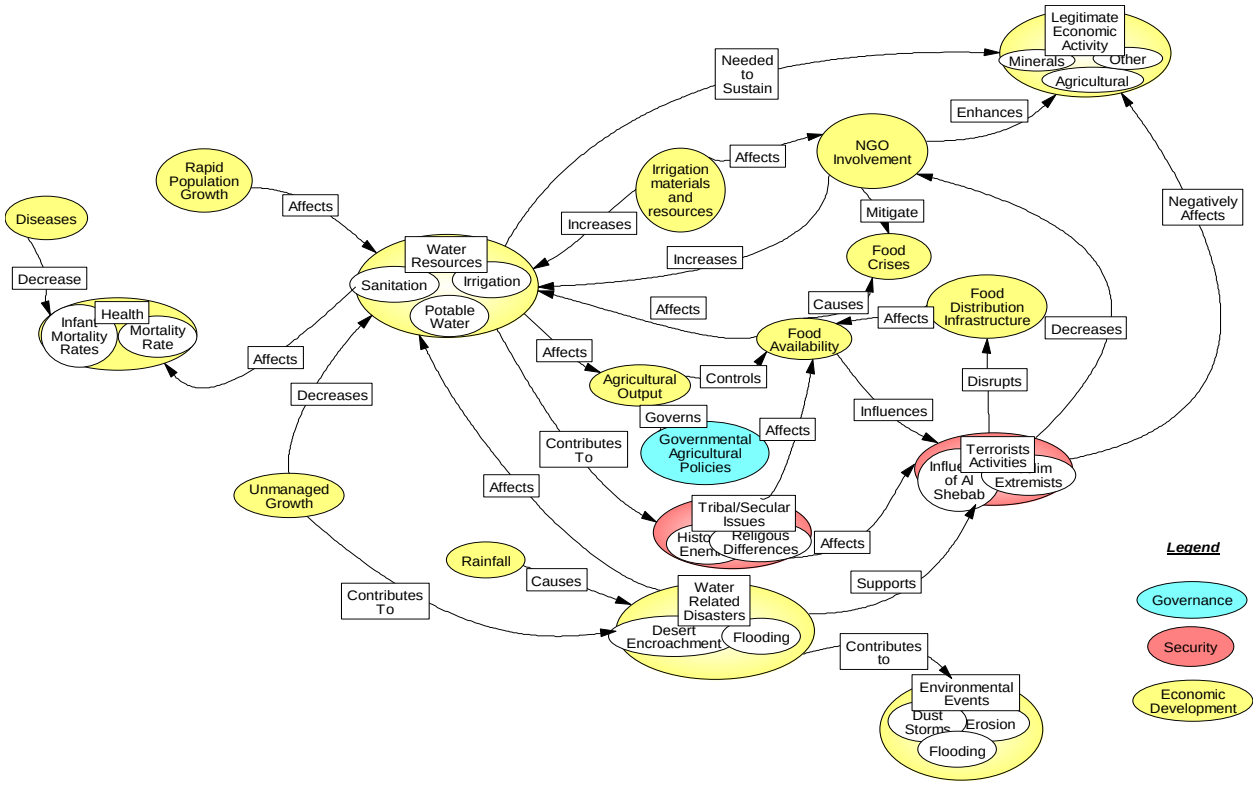


Figure 3. *Systemigram illustrating the effects of water on economic development, security, and governance*

Analyzing it on the complex system level will allow for more visibility on the relationships between layers that will be used to describe a nation state. Also, this transparency will allow for defensible policy and investment strategies.

Causal loops are useful to the Kenya problem in both their adaptability and transformability from qualitative into a more quantitative state. Causal loops provide a visual model displaying both relationships and affects between variables. Once the variables that influence the system are identified, interrelationships can be established. In the case of Kenya where the key areas of focus in this problem are too complex to immediately be built into a single quantitative model that would provide a reliable output; instead each key area must be broken down into the specific variables that influence it; the causal loop diagram does not have a limit to the number of variables or loop structures that can be displayed. Causal loops provide an outlet to show a breakdown in the relationships between variables that influence the key areas such as water, security, essential services, government legitimacy, economics, or country capacity without oversimplifying the output. As a secondary benefit for a quick basic understanding of the solution breakdown, the causal loop is a visual tool for easy communication purposes to be used in identifying the interdependences of variables in the system that directly result in a butterfly affect across the surrounding areas to Kenya. Lastly, what the causal loop diagrams provide is a stepping stone for the system dynamics modeling process. The causal loop is transformable into a system dynamics model, which uses the variables interdependencies identified in the causal loops along with rates of change in a system to achieve a working model with a quantitative output that can be analyzed to understand the overall behavior of the system. In terms of Kenya the causal loops will be useful in piecing together a working system dynamics model which will show the sensitivity in the key areas of focus and how they relate to one another as variables' initial values are altered in the system. The ***Government Legitimacy*** causal loop diagram is shown in Figure 4. Note that our final systems dynamics model had the same five layers: gross domestic product (GDP) or economics, country capacity, essential services, security, and government legitimacy.

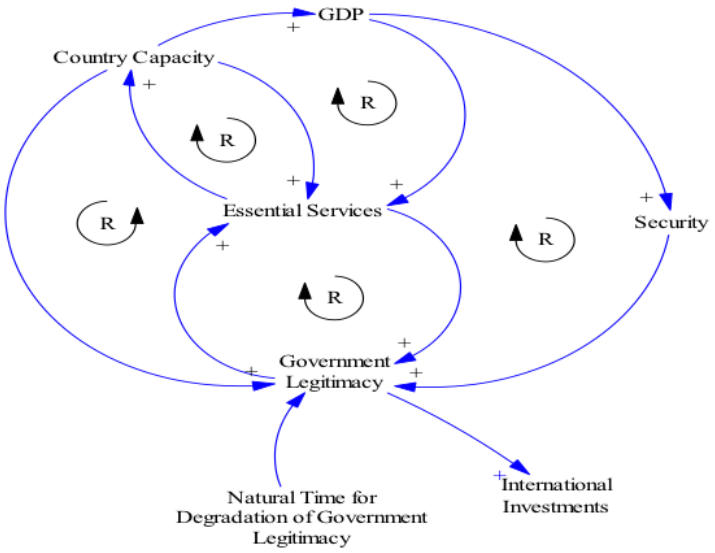


Figure 4. *Government legitimacy causal loop diagram*

System Dynamics Model

The next step in our solution methodology was to take the qualitative diagrams (i.e., Systemigrams, swim lane charts, and causal loops) to develop quantitative behavioral models based upon a methodology that would capture the cause and effects. System dynamics is one approach to modeling the behavior of complex systems over time. It deals with internal feedback loops and time delays that affect the behavior of the entire system. "What makes using system dynamics different from other approaches to studying complex systems is the use of feedback loops and stocks and flows. These elements help describe how even seemingly simple systems display baffling nonlinearity."[2] Several authors have developed domain (what we call layers for our model). Choucri et al., (2007) and Grynkewich and Reifel (2006) discuss research focused on developing system dynamics models for a nation state but for only one element or layer. What we earlier defined as model variables all drive this model through mathematical relations. Note that we develop a spreadsheet with links to all data sources. Figure 5 shows that data sources for economic development layer. These all affect the stocks, which are the variables with a bordered box around them, which have an equation that integrates these variables in to one outcome. The stocks are affected by flows which either increase or decrease the stock, and are also associated with an equation, unit, and definition. Furthermore, the system dynamics model allows us to move from a qualitative model in to a quantitative model that can produce results as behaviors and values. Our model allows us to put the interdependencies in to practice and see the affects.

We modeled each one of these layers as previously presented and structured as identified from our systems diagraming efforts. We found where they were related to connect the layers. Figure 6 below is the system dynamics model for ***Government Legitimacy***. We did not present the other layers and that research can be found at Han et al (2012). The Government Legitimacy model is associated with the causal loop diagram above and is our main layer of the model.

The ***Government Legitimacy*** model measures the perceived legitimacy of the government by the host nation population in the country based on the four other layers; ***Essential Services, Country Capacity, Security, and Economics***. This ***Government Legitimacy*** model is the main model, and ties in the other four layers. The ***Government Legitimacy*** model is created with two simple stocks and flows as shown in Figure 5. The center of the model is the stock labeled ***Government Legitimacy***.

RESULTS

As shown in Figure 7 we are qualitatively capturing the expected behavior of the desired layers. The comparison shown in this figure shows what we expected and what the model is producing. As discussed in great detail in the Future Research section more work is needed to calibrate the model before a production study can be undertaken.

[2] Taken from Wikipedia at http://en.wikipedia.org/wiki/System_dynamics accessed June 4, 2012.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
1	**Variables of the Consolidated Model**																	
2	**Economics**	($=USD)																
3	**Data**	**Figure**	**Source**															
4	Working age population	18390000	http://www.theodora.com/wfbcurrent/kenya/kenya_economy.html															
5	Average wage / salary	$4,812	http://www.payscale.com/research/KE/Country=Kenya/Salary															
6	International Investments	$3,012,400,000	CIA Factbook															
7	Unemployment Rate	40.00%	CIA Factbook															
8	Time for Unemployment Rate to Change	3 years	http://www.indexmundi.com/g/g.aspx?c=ke&v=74															
9	Previous Year's Average Household Income	$8,160	CIA Factbook															
10	Average # of Working Age Adults per Household	2.8101	CIA Factbook															
11	Government Investment	$14,729,000,000	CIA Factbook															
12	Private Consumption of Goods	$37,655,641,432.37	http://www.tradingeconomics.com/kenya/household-final-consumption-expenditure-ppp-us-dollar-wb-data.html															
13	Commodities Exported	$5,443,000,000	CIA Factbook															
14	Population in Service Sector	10,753,335	CIA Factbook															
15	Income per Person in Technology sector	$15,367	http://www.payscale.com/research/KE/Country=Kenya/Salary															
16	Education Level	11 years		a shadow variable**														
17	International Loans' Interest and Payments	$321,400,000	https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html															
18	National Debt	$34,677,500,000	CIA Factbook															
19	Total Imports as % of GDP	0.166	CIA Factbook															
20	Time to Change GDP	3 months	Inferred from CIA Factbook															
21	Current GDP (Purchasing Power Parity)	$71,500,000,000	https://www.cia.gov/library/publications/the-world-factbook/geos/ke.html															

Figure 5. *Data sources for the economics layer of the system dynamics model*

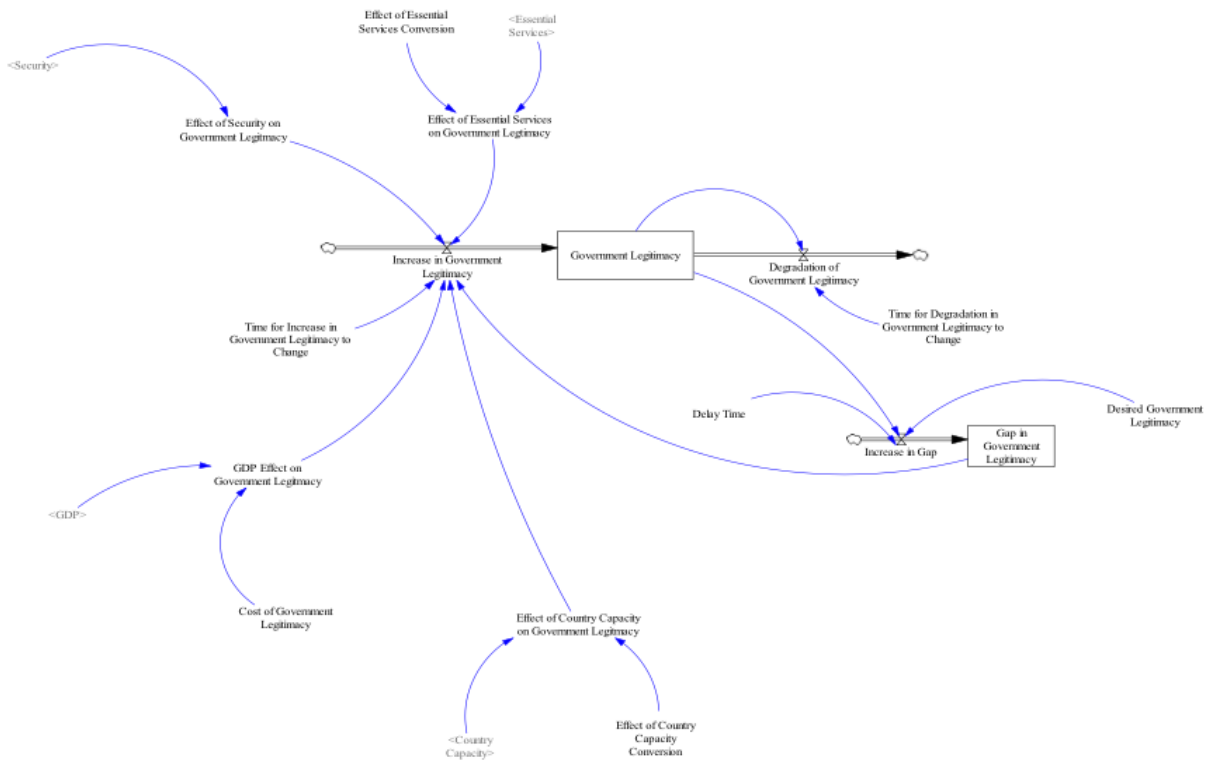


Figure 6. *System dynamics model for* ***Government Legitimacy***

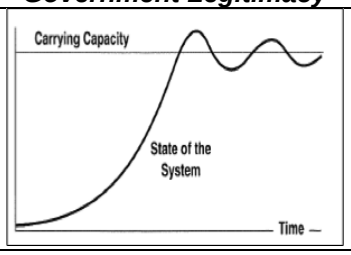
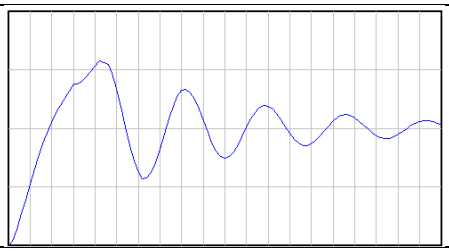
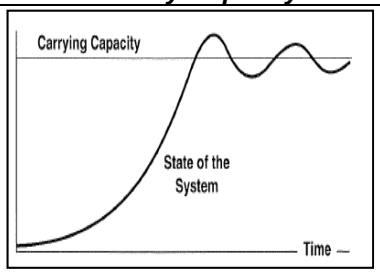
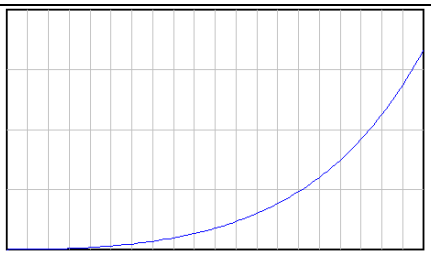
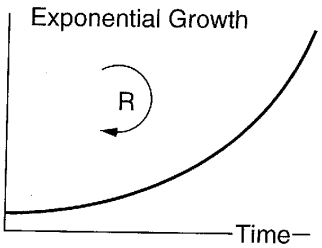
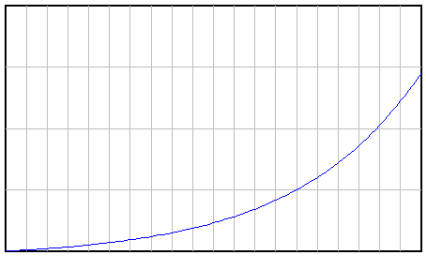
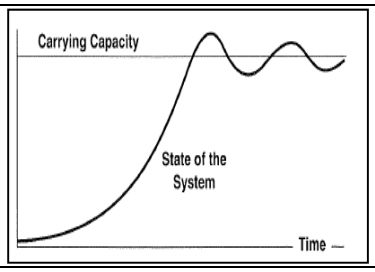
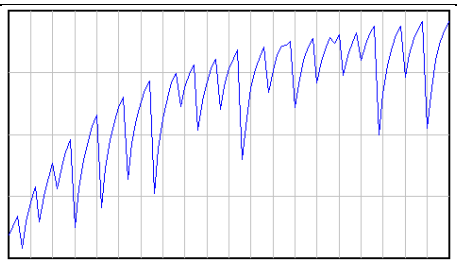
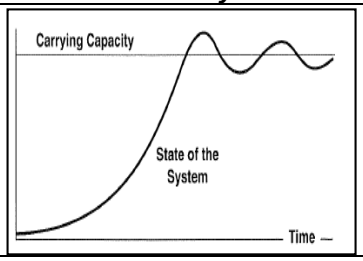
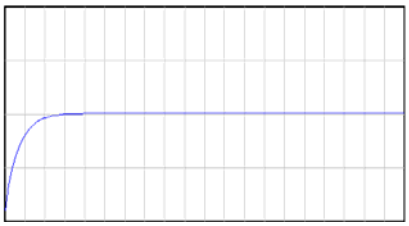
Expected	Model Produced
Government Legitimacy	
	
Country Capacity	
	
Economics	
	
Essential Services	
	
Security	
	

Figure 7. *Predicted and actual behavior of the 4 layers and the total systems behavior layer*

SUMMARY

The system dynamics model we have created relates five different aspects of Kenya into one complex model. Each "layer"; ***Government Legitimacy, Country Capacity, Essential Services, Economics,*** and ***Security*** is modeled independently and then interdependencies between each layer are found and they are connected. This modeling technique allows the user to see more aspects of such a complex problem. It also allows the user to see how different layers affect one another. In our research and literature reviews, our group was not able to find a system dynamics model that shows the interdependencies of multiple layers in as much detail. We believe that the integration of multiple layers into one solution model using system of systems diagramming and modeling techniques is a new and novel approach, with much promise, to help quantify investments in various regions.

The model we have created has shown the ability of system dynamics to model across various layers for an integrated solution. It has exemplified that complex problems can be modeled using system of systems modeling techniques. We believe that this model has the ability to eventually be adjusted to fit other countries, as well as used by other organizations such as Non-Governmental Organizations if some of the variables are adjusted. This research showed that such a methodology would work in modeling such complex systems, and we believe that we have done just that. Basically, our group has attempted to prove the utility of system of systems and complex systems tools in modeling such in-depth problems. Our goal, which we believe was accomplished, was to demonstrate the utility of such a model using real life and meaningful data.

However, there were some challenges associated with such a modeling technique. First off, it was very difficult to determine where interdependencies were linked. By this we simply mean that it was difficult to discover where each layer impacted one another. We believe that through our research we were able to get a good understanding on where these relationships took place; however, we also believe that there are some areas that interdependencies were not found. Our second challenge was finding accurate data to input into the model. To do this we first exhausted sources such as CIA Factbook (2011) to get the hard numbers. If the value for a variable could not be found through this method, we then researched and read various reports, and where we found matching data, we used this value. We also looked at historical graphs and saw where changes in data occurred to get our time variables. The next challenge we had was validating the model. This was difficult because we had to discover a way that would prove our model is correct. We believe that the most accurate way to do this is through inputting historical data and seeing if the outcome matches the historical proven outcome or value.

This research shows that the MPTs presented can be used in a variety of ways to analyze this nation state. First, and most importantly, it can be used to quantify investments, basically, determine the "biggest bang for your buck." For example, the investor will be able to simulate the overall effect on the country or a specific area from their investment; therefore, they will be able to input their investment in to the variable that has the most overall affect. Second, the model will be capable of providing insight into unforeseen consequences. In the past water wells have been dug in areas with water shortages; however, the wells cause tribal disputes and increased violence. A model measuring only the water layer would not be able to predict the tribal violence; however, we believe that by linking layers together, we will be able to provide some insight in to these types of unforeseen results. Third, this model can help with strategic planning. It allows the user to model scenarios without having to encounter them. Therefore, this model can be a useful tool in planning for investments before it actually occurs.

In conclusion, we believe that the model we have created helps the understanding of how complex systems work. The model gives us the ability to simulate across numerous layers, thus exposing the interdependencies between different aspects of a region. From our research, we have not been able to find anything with as much complexity that models across different layers; this process can advance the methodology used in modeling complex systems. Our model proves the usefulness of modeling interdependencies between aspects of complex problems, and it is our belief that this will help in the advancement of system of systems modeling techniques.

FUTURE RESEARCH

The way forward for our research consists of calibrating our model, attaining more exact results and variables, expanding the model within the layers, and finally applying the model to other countries. In regards to calibrating the model we would focus on three tiers of structure, equations, and input variables which would work towards ensuring that each specific layer generates expected fundamental modes of dynamic behavior; with carrying capacity on the "y-axis" and time on the "x-axis." As shown in Figure 7, our ***Government Legitimacy*** and ***Country Capacity*** layers indicate purely exponential behavior with our desired state being exponential behavior with oscillation over time. Additionally, the ***Essential Services*** layer of the model has a purely oscillating behavior that is not ideal since the desired state for the layer is to have an exponential growth behavior with minimal oscillation after a period of time.

The way forward for our research also consists of expanding the models within the layers. This expansion would add complexity to the layer so that each output would be a more representative and accurate representation of the outcome. Lastly, further research would apply our model to other countries in order to analyze multi layer security, governmental, economic, and development related issues.

ACKNOWLEDGEMENTS

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