Modeling Honduran Illicit Drug Networks

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ABSTRACT
In 2009, U.S. assistance to Honduras was suspended due to a staged coup d’etat by the Honduran military. As a result, drug trafficking activity steadily increased in Honduras, as police and military forces within the country became less effective in combating this cartel-related activity. Several other factors, including physical location and limited resources, contribute to Honduras’ growing problem which poses a threat both to its stability and to the United States’ national interests in Honduras. A West Point senior capstone, sponsored by the Engineering Research and Development Center (ERDC) Construction Engineering Research Lab (CERL) and the Center for Nation Reconstruction and Capacity Development (CNRCRD) at West Point, is investigating whole of government approaches in support to Civil-Military Operators (CMO) that address the illicit ground trafficking problem. The capstone team is specifically focused in two distinct areas: network flow modeling and system dynamics modeling. Using these approaches, we present a holistic assessment of the complex illicit trafficking networks operating within and throughout Honduras. We argue that by using network flow modeling and system dynamics we can provide insights into interdiction strategies for illicit ground trafficking in Honduras that operate on a holistic scale.

I. INTRODUCTION
Honduras has proven to be one of the unstable countries in the world, and currently stands as the murder capitol of Latin America with 20 people murdered every day [1]. While there are many aspects of the country’s society that generate this instability, cocaine trafficking is likely the largest contributor. In highlighting the drug crime problem, General Douglas M. Fraser, United States Southern Command (USSOUTHCOM), recently emphasized that “the violence and corruption stemming from the global drug trade in countries south of the United States has, in many cases, destroyed law enforcement and judicial processes” [2].

Illicit cocaine trafficking routes from South America to North America have continued to evolve for years in response to interdiction efforts. Recent counterdrug efforts in Mexico have pushed routes into Central America, with Honduras becoming one of the main transshipment countries for traffickers. In turn, crime associated with cocaine trafficking has become a significant problem. Organizations such as USSOUTHCOM and associated Civil-Military Operators (CMO) continue to look for ways to improve the country’s harrowing condition using cost-effective investment in infrastructure and essential services. This investment in infrastructure and essential services is also intended to serve as a means of interdiction, influencing the population away from supporting illicit trafficking and the resulting negative consequences.

The purpose of this effort is to conduct a detailed modeling investigation into the illicit drug trafficking networks in Honduras based on a holistic systems analysis. Our goal is to develop viable models of the illicit trafficking network in Honduras and conduct interdiction analysis from a whole of government approach. Through abundant research, analysis, and systems engineering problem solving, we propose some initial models. We recommend that additional focused data development of targeted areas and an iterative model development approach can result in fruitful tools to inform whole of government interdiction approaches, ensuring Honduras becomes a more stable nation.

II. PREVIOUS RESEARCH WORK
During the previous academic year (2010 – 2011), a cadet team developed a holistic, systems understanding of the illicit trafficking problem within Honduras. The team utilized a Systemigram. A Systemigram is a portrayal of a number of different “scenes of interaction” within a system and the scenes’ relationships to one another in the system [3]. The team highlighted the following seven scenes: 1. The Illicit Trafficking Problem; 2. Current Enemy Operations; 3. International Aid; 4. Traffickers Tactics; 5. Local Support; 6. Economy; 7. Education. Figure 1 portrays the complete Systemigram.

The value of the Systemigram is that it helps outline relationships among many different aspects within Honduras and international society and it highlights the complexity of the illicit trafficking problem. On the other hand, the Systemigram is not built based on strong quantifying relationships or grounded in empirical data. Clear relationships, such as correlation or causation, have not been investigated. The Systemigram is the first model in a modeling iteration process, providing an initial basis of knowledge to guide the more detailed process of quantitative modeling.
III. PROBLEM STATEMENT

In order to frame the problem in Honduras, we first conducted a broad base literature review on the subject and leveraged the previous capstone group’s effort, gaining an initial understanding of the problem. Keeping in mind the needs and desires of our stakeholders we developed the problem statement for this research:

*Develop viable models that can be incorporated into ERDC tools and techniques, and offer insights into the allocation of resources to infrastructure and essential services to affect illicit trafficking.*

Understanding the complex interactions of the different variables, we made a conscious decision to broaden our initial modeling perspective to a whole of government approach. We established some larger scale modeling approaches, with embedded requirements for smaller scale, viable models, intended to be derived from empirical data. These models would be intended to predict the likely effects on the population of various whole of government interdiction actions. Ultimately this effort will be used to complement ongoing research at ERDC-CERL, which is focused on the development of tools, and techniques to rapidly prototype localized agent models for the analysis of infrastructure and essential services improvements on the local population.

IV. MODELING APPROACHES

*Network Flow*

Network flow models have wide applicability to real-world problems, and they are well matched for military or anti-terrorism scenarios [4]. Network flow modeling has been a counternarcotics tool through case studies in other Central American countries. The components of the drug trafficking problem in Honduras also very closely resemble those of antiterrorism scenarios.

Network models consist of arcs and nodes. In most cases, nodes can come in the form of facilities, buildings or junctions in a network, while arcs are channels connecting these nodes, such as roads or river beds. Each node and arc has attributes limiting or allowing its use, such as flow capacities or costs for arcs and establishment costs and supply/demand allowances for nodes. These are key assumptions in formulating our network flow model.  

*System Dynamics*

System dynamics is a methodology of analyzing complex feedback systems over time using time delays, feedback loops, and stock & flow diagrams. Although typically used in business modeling, the system dynamics analysis process can be used to model any type of system. The group’s overall mission, illicit drug trafficking in Honduras, is a complex system that encompasses many different aspects of society.
Many studies that have focused on similar topics such as crime, economic development, and government regulations have utilized System Dynamics to create models. In particular we found the study, “Mexico’s Cartel Problem: A Systems Thinking Perspective” useful in identifying many causal relationships within drug trafficking networks that may exist within Honduras [5].

Other Approaches Considered

While evaluating possible modeling solutions to our problem we considered Network Science and a Country Comparison Case Study. These systems analysis techniques were found to be viable tools but were not further developed because of lack of time and necessary resources to complete them. They may, however, provide problem solving ideas for future model iterations.

1) Network Science

In the words of Dr Arney, the Chair of the West Point Network Science Center, “Network Science is essentially looking for where in the flow of a network you can disrupt or impact the whole process” [6]. Given an essence of (1) reliable data, (2) identification of key players in the network that are for and against the trafficking, (3) the outlet and inlets of the system – the drug supply and collection locations, and (4) the hubs and relationships of the system, network science simulation tools can be used to portray the relationships and the interactions in the system.

According to Michael Kenney, author of The Architecture of Drug Trafficking: Network Forms of Organization in the Colombian Cocaine Trade, the drug trade in Colombia can be characterized as “a fluid social system where flexible exchange networks expand and retract according to market opportunities and regulatory constraints” [7]. We can apply this characterization to Honduras as well. Primary and/or secondary source data from Honduras and its surrounding countries involved in the trafficking could be utilized to explore the organizational structure and functioning of Honduran trafficking networks, focused on how these illicit players communicate, coordinate their activities, and make decisions. Kenney suggests performing this analysis “with an eye towards deflating some of the more persistent myths that have grown up around these transnational enterprises” [8].

2) Country Comparison Case Studies

Case studies allow researchers to take holistic and meaningful characteristics from a complex system and arrange them in such a way that they can better understand the situation [9]. Case studies could be utilized to direct our study into areas that exhibit potential for further quantifiable research. By looking deeply into the details of illicit trafficking and whole of government conditions across countries in Central America, we can start to pinpoint specific areas of interest where additional quantification and modeling can be fruitful.

V. CONSTRAINTS, LIMITATIONS, ASSUMPTIONS

In determining our way forward, we identified the inevitable obstacles surrounding the nature of our modeling approaches. Time was our main constraint for the research that was conducted. As a group, we only had limited time available during the course of each week to devote to research and modeling efforts. Our primary limitations include every researcher’s dilemma – data. While we strived to have readily available data sources, subject matter expert input, by its nature, illicit trafficking data is limited. Our limitations included a limited availability of specific data relating the local populace to illicit trafficking and a language barrier with Honduran local newspapers and other primary resource documents. Furthermore, to keep this study unclassified, we did not utilize any available information classified as SECRET or utilize any intelligence from operators in Honduras. Two key assumptions that we made were that the data available will be adequate to develop a holistic, systems understanding of illicit trafficking throughout the region, and that our general modeling approaches based on data available can be useful when applied to local conditions.

VI. UNDERSTANDING THE PROBLEM

In order to investigate modeling solutions to this complex and dynamic problem, it was necessary to gain a thorough understanding of the situation in Honduras. It was determined that the rise of narco-trafficking and the consequent criminal problem was caused by changes in regional influences and domestic enabling conditions within Honduras. We divided research efforts into identifying those regional influences, while focusing on the domestic domains of government, economics, society, and the act of illicit drug trafficking within Honduras. Ultimately our focus is limited to modeling domestic challenges and potential solutions for Honduras but an understanding of regional pressures is necessary to fully encapsulate the problem.

Regional Influences

The rise of narco-trafficking in Honduras is due, in large part, to the changing dynamics in the regional drug market flow across the Americas. Clearly the largest source of drugs is nations in South America with large rural areas and significant drug cartel power. The goal markets for these drugs lie in the United States. In order to reach these markets, drug trafficking networks are complex and extremely dynamic.

Drug trafficking is often explained using the “balloon effect” which essentially says that if a market is squeezed in one location or facet, it will grow in another. Similar behavior has been exhibited by the drug trafficking networks that flow into the United States. During the 1980’s and 1990’s the primary flow of drugs into the United States was the Caribbean. As maritime interdiction efforts decreased the feasibility of such routes, the drug networks were “squeezed” to change.

The shift in drug trafficking in the early 2000’s was characterized by increases in overland trafficking and the use of short flights from South to Central America [10]. This gave rise to increases in Mexican cartel strength. As United States and Mexican law enforcement forces have succeeded in limited drug flights into Mexican territory, the Mexican cartel networks were forced down into the
vulnerable Central American countries such as Honduras.

**Governmental Changes**

The lack of governance by Honduras’ elected officials plays an important role in the drug trade. Honduras’ weak central government lacks the resources to effectively investigate, convict, and imprison criminals. In addition, the Honduran national and local government agencies are plagued with corruption that has only increased as a result of the growing Mexican cartel influence.

Perhaps the most detrimental event to government control throughout Honduras was the Presidential coup that occurred in June 2009. Following the ousting of President Zelaya from office, domestic law enforcement resources were diverted to the major cities to quell protesters and prevent insurrection. This allowed trafficking through Honduras to increase at an exponential rate. In addition the Coup resulted in the loss of large sources of international monetary aid to Honduras which further hindered drug interdiction capabilities.

**Economic Forces**

Economics play a significant role in enabling and encouraging the illicit drug trade in Central America. Honduras is one of the poorest countries in the world with 65% living in poverty. Because of this poverty, locals can make a considerable amount of money by supporting traffickers and are easily hired for such things as clearing small airplane landing strips, loading/unloading, providing food/shelter, providing use of their generators, etc. Most people benefit from illicit trafficking because of the low availability of jobs. In order to get the local populace more resistant to the drug trafficking networks the Honduran economy must improve. If there are other economically viable forms of employment available for the local populace, a significant enabler of drug trafficking networks will be eliminated.

**Societal Effect**

With a population (2008 est.) of 7.6 million people, Honduras is comprised of 90% Mestizo (mixed Indian and European).

Medically, its health care system lies among the worst in Western Hemisphere. Up to 30% of the population has no access to medical care. Facilities for advanced surgical procedures are not available. Most medical facilities are in Tegucigalpa and San Pedro Sula. Public and private health care throughout the country is poor. The quality of all hospitals and clinics is well below US standards. Physicians generally are competent compared to U.S. standards; however, 66% of trained medical doctors work in private sector facilities that serve only 10% of the population. The country’s emergency medical response is limited. Although Tegucigalpa has an ambulance service, vehicular traffic, especially during workdays, makes timely patient transport to medical facilities difficult.

In regards to infrastructure, Honduras has poor public transportation safety, fair urban road conditions and maintenance, poor rural road conditions and maintenance, and poor availability of roadside assistance. Major highways have been rebuilt following the destruction caused by Hurricane Mitch in 1998, though many stretches are still under repair. Major cities are connected by an inconsistently maintained, two-lane system of paved roads, and many secondary roads in Honduras are unpaved. During the rainy season, even major highways are often closed due to rockslides and flooding. Hurricane Mitch washed out many bridges throughout the country, and temporary repairs are vulnerable to heavy rains. Two of the most dangerous stretches for road travel include: 1) Tegucigalpa to Choluteca – dangerous mountain curves; 2) Limones to La Union, Olancho (route 41) via Salama and northward to Saba – referred to by locals as the “Corridor of Death” because of frequent incidents of highway robbery [11].

While the infrastructure findings prove harrowing, the education situation is even more so. Honduras finds itself in a poor public education system state. Figures cited by the Ministry of Education suggest that Honduras suffers from widespread illiteracy (40%+ of the total population and 80%+ in rural areas). A significant percentage of children do not receive formal education. Schools are not readily accessible, especially in rural areas. When they are accessible, they often consist of joint-grade instruction through only the third grade. Schools are so understaffed that some teachers have up to 80 children in one classroom. Only 43% of children enrolled in public schools complete the primary level. Of all children entering the first grade, only 30% go on to secondary school, and only 8% continue to the university. Poor teacher training heavily impairs Honduran education. The situation is worsened by the extremely low wages paid to teachers, lack of effective and up-to-date instruction materials, outdated teaching methods, poor administration, and lack of physical facilities [12].

**Drug Trafficking and Associated Consequences**

In general, our resources for data have been limited. However, we have interacted with USSOUTHCOM, the Washington Office of Latin America, and UN Office of Drug Control, among others. Many of these organizations use the same data that we are utilizing for this report. These data resources include the World Bank Database and the Consolidated Counterdrug Database (CCDB).

Our findings from the CCDB were utilized to leverage our way forward in formulating a network flow model. The CCDB is a database consisting of various cocaine interdictions in the Caribbean between 2005 through 2011 (Quarter 1). The database captures the amount of drug flow (kg), destination country, source country, event type, and the type of transporting aircraft or vessel. Figure 2 represents all of the seizures broken down by type of seizure – maritime, land or air – and the amount of cocaine seized in kilograms of cocaine [13].
A main focus of ours remains on the drug trafficking seizure increase after 2007. It is important to note that the amount of the cocaine seizures in 2011 is smaller because only the 1st Quarter’s data is included in the database. In forecasting 2011 seizures through the end of the year, there is a continuation of the upward trend in seizures that began in 2007.

Figure 3 represents the amount of cocaine seized per year by mode of transport.

Most cocaine destined for Honduras comes from Columbia’s South American Coastal Area (COL_SOAM), Venezuela (VEN), and Panama (PAN). The countries consist of 36.36%, 26.26%, and 12.12% of cocaine flowing into Honduras respectively. In general, this pie chart is useful in helping us to more holistically understand our source nodes in network flow analysis of the Honduran cocaine trafficking.

Figure 5 represents the interdiction type based on frequency and origin country in transit to Honduras. It denotes the importance of maritime interdiction in Atlantic coast corridors. Additionally, Venezuela plays a significant role in air shipment of cocaine to Honduras. Yet the most important take away with this data representation is that Honduras is more of a transshipment destination rather than a supply or demand destination.

The exponential decay shows every country’s importance in developing source nodes. Colombia, Venezuela, and Panama are responsible for the majority of cocaine inflow to Honduras. In further research, we will scope our origin country research to those three source nodes of cocaine trafficking through Honduras.
Figure 5. Bar Chart of Number of Interdictions by Country and Interdiction Type

Figure 6. Pareto Chart of Drug Amounts by Origin Country

Figure 7. Cocaine Seizures versus Homicide Rate in Honduras

This data shows the compelling nature of the problem in Honduras. Additionally, analyzing other variables related to Honduran society with these data sets may provide additional insights or relationships to root causes from a whole of government approach that contribute to this situation. For instance, cocaine and homicide rate can be analyzed in comparison to literacy rates, or police ratio. These relationships between the different pieces of data can provide us with further insights into the effects of drug trafficking in Honduras.

In order to fully understand the level of instability in Honduras based on current cocaine flow and homicide rate, it is important to mention key events in the country’s history that might have contributed to the increases in these two measures of instability. For instance, Mexican drug wars pushed drug traffickers into Central America;
President Zelaya was ousted in a coup contributing to a lack of governance (June 2009); assassinations of government officials and news reporters have increased and contributed to increased corruption; 59% of Hondurans fall below poverty line causing them to seek employment with traffickers; and gangs control large territories of land contributing to Honduras having one of the highest levels of youth violence in world. All these factors contribute to this increased trend in cocaine flow and homicide rate. Overall, these factors have contributed to a doubling of the homicide rate since 2005 and threaten Honduras as a nation.

VII. NETWORK FLOW MODEL

A. Defining the Network

Drug trafficking organizations (DTOs) ship cocaine as a commodity flowing through a network of arcs and nodes, and they ship to minimize cost and maximize their profit. In the 1980s and 1990s, Caribbean routes were preferred for trafficking until improved airspace and maritime monitoring and intelligence sharing made arc costs prohibitive for the traffickers along those routes. “In the past, poorly maintained highways, volatile security conditions, and unpredictable local criminal organizations made it difficult for Mexican TCOs [Transnational Criminal Organizations] to move cocaine overland, so they relied mostly on shipping via air and sea. Pressure from Colombian airspace monitoring and Mexican-US maritime intelligence sharing, however, made air and sea smuggling difficult, so they began establishing new land-based smuggling routes” [16]. In the past decade, Central America has become the preferred transshipment point for cocaine moving north, and Honduras has emerged as a critical cocaine transshipment point between Colombia and the United States. Drug dealers have a variety of costs associated with transporting drugs over these new smuggling routes. As an example, from paying locals to prepare landing strips in designated landing areas to giving corrupt police members $2000-2500 for providing security and escort services, drug dealers accrue various amounts of costs.

From a whole of government approach, “costs” for the drug traffickers can also be modeled as a function of a certain variables, such as a subset of the operational variables used by the U.S. Army. The U.S. Army uses operational variables to understand and analyze the broad environment in which they conduct operations. These variables are abbreviated as PMESII-PT and represent six interrelated areas of the operational environment: political, military, economic, social, information, infrastructure, physical environment, and time. Utilizing open source information and data from the CCDB, we identified nodes of cocaine activity and associated trafficking routes to gain a better understanding of the intricacies of the cocaine trafficking network into, through, and out of Honduras. These nodes were identified as cocaine trafficking hotspots based on subject matter expert feedback from US南方COM, the Woodrow Wilson International Center for Scholars, the United Nations Office on Drugs and Crime, the Consolidated Counterdrug Database, and other integral research sources. Figure 8 is an example of the operational environment analysis of San Pedro Sula.

![Figure 8. Sample Nodal Analysis](image)

We conducted similar research and investigation for the remaining nodes in our network. Utilizing this information, we formulated a dynamic network of cocaine flow through Honduras as it is transported from South America to North America. It is depicted in Figure 9.
B. Mathematical Formulation

Given our initial network of the drug trafficking situation in Honduras, we formulated it as a mathematical model. Figure 10 is a representation of the network with associated costs along each arc.

![Network Flow Model](image)

**Figure 10.** Network Flow Model

The costs along these arcs are typically modeled as a function of actual costs in dollars. However, we suggest that modeling “costs” as a function of some grouping of operational variables, such as governance and security, may be more fruitful in identifying interdiction approaches. The primary challenge for both approaches remains the data available to directly model the network from a quantitative standpoint. We posit, however, that given appropriate data, arc cost along a route can be appropriately modeled as a function of these operational variables. We define the minimum-cost network below:

\[ x_{ij} = \text{number of units of flow sent from node } i \text{ to node } j \text{ through arc } (i,j) \]

\[ b_i = \text{net supply (outflow – inflow) at node } i \]

\[ c_{ij} = \text{cost of transporting 1 unit of flow from node } i \text{ to node } j \text{ via arc } (i,j) \]

\[ L_{ij} = \text{lower bound on flow through arc } (i,j). \text{ If no lower bound, } L_{ij} = 0 \]

\[ U_{ij} = \text{upper bound on flow through arc } (i,j). \text{ If no upper bound, let } U_{ij} = \text{infinity} \]

It can be written as

\[ \min \sum_{\text{all arcs}} c_{ij}x_{ij} \]
\[
\text{s.t. } \sum_j x_{ij} - \sum_k x_{kj} = b_i \text{ (for each node } i \text{ in the network)}
\]

\[
L_{ij} \leq x_{ij} \leq U_{ij} \text{ (for each arc in the network)}
\]

The first constraint means that the net flow out of node \( i \) must equal \( b_i \). This is the flow balance equation. The second constraint ensures that the flow through each arc satisfies the arc capacity restrictions. As we apply this formulation to our minimum cost flow model, the formulation for the objective function and the supply/demand constraints looks as follows:

\[
\begin{align*}
\text{Min } Z &= c_{ij} x_{ij} \\
x_{541} &= x_{15} + x_{1N4} \\
x_{542} &= x_{23} + x_{24} \\
x_{543} &= x_{37} + x_{36} \\
x_{54} &= x_{45} \\
x_{15} + x_{45} &= x_{59} \\
x_{36} &= x_{68} \\
x_{87} &= x_{78} \\
x_{68} + x_{78} &= x_{8N4} \\
x_{59} &= x_{9N4} \\
x_0 &= x_{1N4} + x_{8N4} + x_{9N4} \\
x_{541} + x_{542} + x_{543} &= x_0 \\
L_{ij} &\leq x_{ij} \leq U_{ij} \\
x_{ij} &\geq 0
\end{align*}
\]

The last two constraints represent the arc capacity restrictions and the non-negativity constraints. While we have been able to formulate flow balance constraints for the model, sufficient data does not yet exist to be able to quantify the arc capacity restriction constraints for each node. Although we have not yet been able to quantify the \( x_i \) for each arc in the network, we have been able to quantify an \( x_0 \) value that represents the cocaine flow (metric tons) entering Honduras per month. Additional modeling iterations will attempt to further refine develop work to date.

Given subject matter expertise data of average load sizes of maritime/air transports into Honduras, estimated tracks into the country per year and per month, and other viable information, we have calculated this total amount of cocaine flow into Honduras per year (508 metric tons per year) and per month (42.35 metric tons per month). We did have to make some relevant assumptions in calculating our tonnage value. For example, the Woodrow Wilson International Center for Scholars indicates that there were 500-800 kilograms of cocaine on one boat arriving in the Gracias a Dios region of Honduras [17]. So for our calculation, we stated that on average, a maritime track carries 650 kilograms of cocaine. By making some of these relevant assumptions, we calculated that approximately 508 metric tons are transported through Honduras per year, which is consistent with the 350-550 tons estimated by the Woodrow Wilson International Center for Scholars. This equates to roughly 42.35 metric tons per month (\( x_0 \)). This relevant data point allows for the introduction of a second approach to solving the drug trafficking problem in Honduras, the maximum-flow approach.

The drug trafficking dilemma in Honduras can also be modeled by a network in which the arcs have a capacity limiting the amount of a resource or product shipped through the arc. In this case, a trafficker desires to transport the maximum amount of flow from a start point (source) to an end point (sink). These are referred to as maximum flow problems. Max-flow problems are a special case of minimum-cost network flow problems. While the objective of the minimum-cost approach as applied to the drug trafficking problem attempts to increase trafficking costs, the objective of the maximum-flow problem focuses on decreasing capacities across the arcs. Given the complex nature of the problem, these capacities limiting shipment and resource amounts through an arc can also be modeled as a function of similar operational variables used to model cost in the minimum-cost approach.

The flow balance equations in any minimum cost network flow problem have an important property: each variable \( x_{ij} \) has a coefficient of +1 in the node \( i \) flow balance equation, a coefficient of -1 in the node \( j \) flow balance equation, and a coefficient of 0 in all other flow balance equations. For the maximum-flow problem, we can create an arc \( a_o \) joining the sink to the source, and \( b \) for all nodes = 0.

In the case of drug trafficking in Honduras, our targeted areas of the country act as nodes while the arcs act as channels of flow of drugs with limited capacities. In order to find the maximum flow, we assign flow to the arcs in the network so that the flow between the origin and destination is as large as possible. In reality, flow might differ according to direction. Therefore, we have simplified our model up front to assume there is drug transport through Honduras in only one direction from arc to arc. At this point, sufficient time and data availability have limited us in being able to model and quantify flows along each arc. Figure 11 shows an example network.

**Figure 11. Simple Example Network Structure**

In this type of problem, there is something referred to as the bottleneck effect. For example, over the route A-D-E-G, the maximum flow is 4 because there is a bottleneck of 4 from D-E. This effect plays a role in the simple...
method we use to solve the maximum flow problem. This method can be broken down into a few steps:

1) Find a path from the origin to the destination that has a strictly positive flow capacity remaining. If not, exit.
2) Determine the max flow along this path, which equals the smallest flow capacity on any arc within the path (bottleneck).
3) Subtract this value from the remaining flow capacity in the forward direction for each arc in the selected path. Add this value to the remaining flow capacity in the backwards direction for each arc in the selected path.
4) Go back to Step 1.

This method is referred to as the Ford and Fulkerson method, published by Ford and Fulkerson in 1956 in the Canadian Journal of Mathematics. After termination, the flow sums along the paths gives the maximum total flow between the origin and destination.

As problem solvers in direct support of ERDC-CERL, we would like to analyze the effect of stopping the flow of drugs through Honduras, especially over the land routes, so we implement working toward a solution by utilizing the max-flow/min-cut problem, which says that the max amount of flow from the source to the sink equals a minimum capacity, which when removed from the network, causes the flow from source to sink to be essentially infeasible.

A cut is any set of directed arcs containing at least one arc in every path from the origin node to the destination node. So, if the arcs in the cut are removed, flow from the origin node to the destination node is cut off completely. The sum of the flow capacities in the origin-to-destination flow over all the arcs in the cut is referred to as the cut value. The overall objective of this problem is to find the feasible cut that has the minimum cut value over all possible cuts in the network. For the max-flow/min-cut problem, the focus is where the cut is located. Figure 12 shows some basic cuts in a maximum flow network.

![Cutting the Network](image)

**Figure 12. Cutting the Network**

Based on the maximum flow problem described above, we can fairly easily apply the minimum cut approach to the max flow problem. We could identify all arcs that fulfill a flow capacity equal to its maximum flow capacity, then find a potential cut that consists of only identified arcs.

### C. Conclusions and Utility

As stated previously, while we have been able to quantify a total cocaine flow value through Honduras per year and per month, the limitation of data availability and our time constraint has hindered our efforts to quantify flow capacities and costs along each arc in the network. Thus far we have not directly applied the mathematical formulation to our model for Honduras. As time and resources permit we will continue to model iteratively, closing data gaps and developing sub-models of cost and capacity to enhance the overall network flow model. We do believe the approach has utility to inform interdiction efforts in a variety of locations or conditions. The initial model we have developed for the Honduran drug trafficking network is very transferable, and it is widely applicable to a variety of problems, locations, and scales. The model can also be updated and adjusted as the network adapts and changes. Ultimately, whole of government interdiction strategies that affect arc costs or arc capacities can be investigated to inform the allocation of resources to reduce the effect of illicit trafficking on the local populace.

### VIII. System Dynamics Model

#### Model Development

System dynamics provides a valuable tool to analyze complex systems but can often become infinitely complex. It is therefore necessary to define the scope and boundaries of the system being modeled. In order to categorize our areas of interest, we leveraged relationships identified in our Systemigram, our network flow modeling, and our other research and defined the four primary spheres of Honduran society which effect and are affected by the rise of drug trafficking. Figure 12 shows basic spheres of interactions.

![Base Spheres of Interaction](image)

**Figure 12. Base Spheres of Interaction**
Central to the system is the act of drug trafficking as it constitutes the primary focus for the investigation. There are four peripheral spheres that interact with the drug trafficking in Honduras as well as with one another. We used this sphere of interaction analysis in order to identify certain variables that were of particular importance to the study in question. From there, we developed those variables into a basic causal structure and a basic stock and flow structure depicted below in Figure 13.

![Figure 13. Preliminary System Dynamics Model](image)

Significant work needs to be done in order to develop this model further. We know that the causal relationships between these variables exist based on our research as well as previous cadet research but quantifying those relationships is the most difficult part and significant assumptions will need to be. Ultimately it is our goal to be able to produce a fully functional model that is capable of displaying how changes in the illicit drug trafficking network will echo across all of Honduran society.

IX. CONCLUSION

Summary of Findings

Through extensive research we were able to significantly analyze the qualitative aspects of Honduran illicit trafficking networks. An analysis into the quantitative aspects of the system, however, yielded significant limitations to our study. We were able to develop the preliminary structure of a network flow model, which can be used, given viable localized data, to produce drug interdiction strategies. We have also begun the process of leveraging system dynamics techniques in order to model the societal effects and feedback structures of the illicit trafficking network in Honduras.

We learned, during this investigation, that developing viable models to simulate dynamic systems is an iterative and complex problem. The drug trafficking system, in particular, is highly complex and highly responsive to changes in the drug markets and foreign influences. Consequently modeling can only provide significant insights into these systems if they are updated routinely with accurate data. Our baseline models can be used in such a manner given the availability of an appropriate level of data.

Way Forward

The next step in our modeling process is to continue to integrate data into the models we have developed. Modeling is an iterative process and therefore in order to create lasting usable models, these preliminary findings must be reviewed and enhanced by further capstone teams and researchers.

There are currently operations in Honduras to extend law enforcement, both domestic and international, into the rural areas of Honduras. This initiative is in an attempt to collect data, engage the local populace, and initiate drug interdiction strategies. This approach is similar to the Phoenix Operation that was utilized during the Vietnam War, in which United States Special Forces strategically placed outposts in order to gain increased law enforcement capabilities and localized intelligence resources. This model is also similar to the COIN
(counterinsurgency) doctrine that has been implemented in Iraq and Afghanistan [18].

The implementation of these outposts can be aided through the use of our models. Once localized data is obtained, our models can instruct where to place these outposts and tactical initiatives can be built to “cut the flow” of drugs through these area. From there, changes in localized information can help to revise the modeling approach and thus allow them to give more accurate insights. This is the interactive modeling process that was mentioned earlier in the conclusions.

X. ACKNOWLEDGMENTS

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XI. REFERENCES


[3] Systemigram was developed by Dr. James Boardman and Dr. Brian Sauser, derived from “system” and “diagram.”


[6] Dr Arney, the network science chair of West Point Network Science Center.


[13] Consolidated Counterdrug Database


[16] Knotts, Robert. USSOUTHCOM.
