MEASURING THE IMPACT OF COORDINATION IN DISRUPTING ILLICIT TRAFFICKING SUPPLY CHAINS

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ABSTRACT

In this thesis, an interdiction model is developed to assess the value of coordination in disrupting illicit trafficking supply chains, specifically large scale heroin networks. Coordination is a tool law enforcement and intelligence rely on to make informed and effective decisions in targeting transnational trafficking organizations. In this respect, it is important to assess which of various cooperative agreements (such as task forces) between law enforcement and intelligence agencies responsible for interdicting different segments of the illicit supply chain yield more a significant impact on interdiction efforts. This impact is assessed by measuring the improvement to the interdiction efforts that result from different levels of cooperation amongst agencies. An additional potential application of this thesis is to the disruption efforts of human trafficking networks, in which interaction and cooperation between potential interdiction agencies does not have significant precedence. The key findings include: (1) the most effective cooperative configuration for interdiction across multiple tiers consists of federal, state and municipal law enforcement, (2) full coordination between all agencies becomes particularly important as the network becomes less dense, finally (3) the impact of a particular coordinated environment more than doubles when you double the budget while the budgets are relatively small (2.5% and 5%).

1. INTRODUCTION

As transnational illicit trafficking supply chains work to smuggle narcotics and other illicit goods into the United States, law enforcement and intelligence agencies both home and abroad work to disrupt the operations of these organizations. In 2017, President Donald Trump declared the rapidly growing narcotic dependency crisis a national Public Health Emergency (The White House, United States Government, n.d.). In a letter addressed to President Trump in November of 2017, New Jersey Governor Chris Christie stated that the crisis was one of "epic proportion" in which more than 175 Americans lose their lives daily. While much of the demand for narcotic analgesics is comprised of medically prescribed and synthetically processed opioids, the relatively cheap and unregulated opiate heroin holds a significant portion of the market's attention. In the year 2016, approximately 630,000 Americans had a heroin use disorder. It is estimated that roughly 80% of these users transitioned from prescription opioid dependencies (Roster of Commissioners, 2017).

As the United States continues to manufacture and prescribe prescription opioids, heroin trafficking organizations will continue to experience a steady demand for their illicit supply. Disrupting these supply chains will involve multiple law enforcement and intelligence agencies of varying sizes and in varying geographic locations implementing their own interdiction efforts across the trafficking network(s). In traditional operations, task forces composed of multiple agencies have focused on targeting a specific portion of the transnational supply chain (for example, the distribution segment in a particular city or region). Less of a focus, however, has

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been on coordinating efforts across the different tiers of the transnational network. Such a focus would involve coordinating interdiction efforts targeting:

- Disrupting supply outside of a country of interest (In this case, the United States (U.S.)
- Disrupting the smuggling of goods across the border
- Disrupting the national distribution network
- Disrupting state distribution networks
- Disrupting city or regional distribution networks

The objective of this research is to provide a quantitative approach to assess the impact of coordinating a subset of these interdiction efforts in the context of disrupting the flow of illicit goods through the transnational supply chain.

This type of interagency coordination can be best defined under the broad term of information sharing, which refers to the distribution of information across the national security network. In the wake of the September 11th terrorist attacks, the United States Government drastically increased their utilization of information sharing through the Intelligence Reform and Terrorism Prevention Act of 2004, which legislates that the President establish "an information sharing environment for the sharing of terrorism information in a manner consistent with national security and with applicable legal standards relating to privacy and civil liberties;" (Intelligence Reform and Terrorism Prevention Act, 2004). The concept of the task force, used widely by the Drug Enforcement Administration, facilitates the practice of information-sharing at varying levels between a diverse group of government organizations focused on maintaining and improving national security; however, drug task forces typically focus on one area of the larger transnational illicit supply chain. In other words, a drug task force will typically organize interdiction efforts across agencies in a specific state or city rather than across the entire supply chain.

From a modeling perspective, the disruption of flows through a transnational illicit supply chain can be modeled as a network interdiction problem as found in Smith (2011) and Wood (2011). Network interdiction problems focus on two-player games where the attacker (e.g., law enforcement) changes the characteristics of a network (e.g., remove arcs from the network) and then the defender (e.g., the traffickers) operates as efficiently as possible over the altered network. The maximum flow network interdiction problem (MFNIP) is especially relevant in this paper as it models situations where the defender seeks to maximize the flow in the network (e.g., the amount of smuggled goods). The MFNIP was studied in Wood (1993) (including introducing a single-level reformulation of the problem) and has been used as a basis for efforts in modeling law enforcement efforts against city-level drug trafficking (Malaviya, Sharkey, & Rainwater, 2012). The MFNIP assumes that all interdiction resources (which are used to disrupt the network) are controlled by a centralized decision-maker. This is not the case when law enforcement agencies responsible for disrupting transnational illicit supply chains do not cooperate in their efforts since each agency will have control over its own interdiction resources in their own areas of responsibility with the supply chain. To the best of our knowledge, only Sreekumaran et al. (2016) have examined interdiction problems with more than one attacker making interdictions on the network where each attacker was their own independent decision-maker. Our quantitative framework examines the impact of multiple attackers (or interdictors) each independently making their own interdiction decisions without coordinating their efforts with other agencies in order to understand which agencies cooperating together have the most impact on improving the loss that results from un-coordinated or, equivalently, decentralized interdiction efforts.

The case study analyzed in this paper is one of a transnational heroin network involving drug organizations operating in multiple countries including Mexico and the United States. Intelligence reporting indicates that this network moved on average 13.5 metric tons per year, between the years 2001 and 2006 (Office of National Drug Control Policy, 2012). We focus on five different interdiction agencies that can target and disrupt this network:

- The 'international' agency (or agencies) that can disrupt supply in Mexico
- The border patrol agency (or agencies) that can disrupt trafficking across the U.S. border
- The federal agency (or agencies) that can disrupt the national distribution network
- The state agencies responsible for disrupting the various state distribution networks across the U.S.
- The local or municipal agencies responsible for disrupting the last mile of the supply chain

Although our case study is on illegal drug trafficking, it is important to note that there are other illicit smuggling networks where the agencies that could intervene to disrupt them have much less history in working together than law enforcement agencies. For example, we consider interdicting a network that could bring labor trafficking victims into the U.S. This situation is similar to the exploitation of Indian welders by Signal International after Hurricane Katrina (Desai, 2015). In this situation, Indian welders were required to pay a recruitment fee of between $10,000 and $20,000 to a broker that helped them obtain a H-2B visa to work for Signal International. This broker was located in India and this amount of money created a form of debt bondage in the sense that the welders would not be able to forfeit this amount. This created a situation where the workers would have to work regardless of the situation once they reached the U.S. no matter the work environment provided by Signal. The particular work environment included the fact that the welders had to live in trailers with up to 24 other men where $1,050 in rent were deducted from each laborer's paycheck per month by Signal (Desai, 2015). There were at least three agencies that could have intervened in such a situation: the U.S. embassy in the country of the brokers could disrupt the flow of trafficked victims out of the country, U.S. Citizenship and Immigration Services (USCIS) could disrupt the flow of trafficked victims into the U.S. and, finally, the Occupational Safety and Health Administration (OSHA) could disrupt HT victims at their workplaces. These three agencies would have little to no history working together (unlike law enforcement) and, therefore, understanding the potential impact from cooperation amongst them in disrupting labor trafficking is an important research question.

Our objective is to determine the configuration of cooperating agencies, in addition to the value that this cooperation would bring disrupting the network. This information will help to address the nation's call for increased cooperation as noted by Institute for National Strategic Studies (2011), and to provide insight into increasing the efficiency of cross-functional teams comprised of government law enforcement and intelligence agencies. While the work in this thesis was specifically designed around transnational heroin trafficking networks, it can certainly be applied to similar illicit drug trafficking operations, as well as a wide range of other illicit trafficking operations such as human trafficking.

The remainder of this thesis is organized as follows. First, in Section 2, a review of previous research in related fields has been conducted in order to understand the problem from a variety of different angles and establish a basis for modeling. Subsequently, in Section 3, we will use this information to develop a mathematical model to test the maximum flow network interdiction problem with coordinated and uncoordinated decision-making. In Section 4, we test the legitimacy of our modeling with a smaller scale semi-realistic case study, which further highlights our modeling constructs. In Section 5, we use information found in Section 2 to model a realistic transnational heroin network. Next, in Section 6, we discuss and analyze the interdiction results. We then use the analysis and discussion from Section 6 to make insights in into potential strategies for human trafficking interdiction in Section 7. In Section 8, we summarize the completed work and discuss related potential future work.

2. LITERATURE REVIEW

Prior to building the model, a threshold of knowledge needed to be developed on the fields directly relating to the project. In order construct a realistic representation the system as a whole four major areas were reviewed. These areas include the illicit heroin supply chain, human trafficking problem on a broad scale, interdiction modeling and law enforcement analytics, and interagency cooperation. The following subsections will summarize previous research conducted in these areas, as well as the data and realistic implications that can be applied to our work.

2.1 Illicit Heroin Supply Chain

While illicit trafficking organizations tend to be naturally elusive, insight into the possible structure of the organizations responsible smuggling heroin into and distributing it throughout the United States has been discerned through research of previously targeted trafficking networks. In particular, a study conducted by Natarajan (2006) uses an analysis of wiretap conversation to outline the general structure of a large heroin distribution network. In this research, it is stated that the heroin network followed a "flat, egalitarian structure" in which participants connected across tiers, but there was little dominance of one tier over another. The decision-making process for each entity was largely independent of hierarchy, described as "small groups of loosely linked entrepreneurs". Rather than describing the organization in hierarchical terms, the network is separated into tiers by role. Individuals involved with different tiers performed different functions. Roles found upstream in the supply chain (sellers) were responsible for sourcing large quantities of supply and had overseas connections, whereas roles downstream (brokers) were responsible for connecting on a local city level with street level distributors (retailers).

Networks like the one described in Natarajan (2006) have been rather successful operating as the leg of the distribution and smuggling operations stateside. On a transnational level, research conducted by the DEA Strategic Intelligence Section (2015) shows that opium poppy cultivation does not occur in the United States and, therefore, heroin must be smuggled into the county to meet demand. The DEA Strategic Intelligence Section (2015) states that there are four major areas in the world that grow opium poppy: Southwest Asia, Southeast Asia, Mexico and South America. Only two of these four regions, however, transport their heroin to the U.S.: Mexico and Columbia. Southeast and Southwest Asia distribute the majority of their heroin throughout Asia, Europe and Australia. The research further states that eight Mexican cartels are responsible for shipping the heroin through the Mexico-United States border. This research indicates that these Mexican organizations are the largest wholesale-level heroin traffickers to major cities and are rapidly expanding their reach throughout the nation.

The estimated amount of pure heroin entering the United States from these operations is outlined by Office of National Drug Control Policy (2012). Between the years 2000 and 2006, an average of 13.5 metric tons of pure heroin originating from opium poppy in South America entered the United States and was made available to the public annually. Nine regions throughout Columbia (Peraguas, Cauca, Huila, North Tolima, South Tolima, Tolima, Perijá, Urama, and Nariño) and two major regions of Mexico (Northern and Southern) were responsible for nearly all heroin entering the United States during these years. Interestingly, data provided by the Office of National Drug Control Policy (2012) shows that during those years Mexico's contribution to the annual supply was steadily increasing, an observation further supported by the research conducted by the DEA Strategic Intelligence Section (2015). This heroin was smuggled across the Mexico-United States border and distributed throughout the United States. For the purposes of this paper, the aforementioned data will be used as the basis for the general characteristics of the transnational heroin network.

2.2 Human Trafficking

One of the most complex forms of trafficking is that of human trafficking, which is driven by the demand for labor and sex slavery. Conservative estimates made by the International Labour Office & Walk Free Foundation (2017) indicate that 40.3 million individuals were victims of slavery in the year 2016 worldwide. This figure includes victims of forced marriage, which accounts for roughly 38.2% of human trafficking. Forced marriage cases that qualify under the definition of human trafficking refer to circumstances in which a person has been stripped of his or her individual right to sexual autonomy, and the oppressor has taken advantage of protections granted through marital laws. The other 61.8% of persons trafficked are victims of forced labor, which includes sex work. The International Labor Organization states that of the 29.4 million individuals trafficked for forced labor roughly 8 million were victims of debt bondage schemes, in which victims are bound to their oppressors through personal debt (International Labour Office & Walk Free Foundation, 2017). Given that the good is exploitable in a countless number of ways, human traffickers have been able to develop an array of methods to facilitate their trade, forced marriage and debt bondage being prime examples. This research outlines the high level of complexity of human trafficking operations calls for a more robust interdiction strategy.

To piece together how these traffickers may operate, it is important to discuss perpetrator typologies. In doing so, we can better understand the shape and interaction of the various layers and tiers of the human trafficking supply network. Research conducted by Busch-Armendariz, Nsonwu, & Heffron (2009) discusses the details of human trafficking operations. This research makes a distinction between two different categories of trafficking: “Shattering the American Dream: LABOR” and “John’s Demand: SEX”. In discussing the labor category of human trafficking, this paper states that there are “a wide variety of traffickers from this type, from small family operations to larger organized crime.” These types of traffickers are responsible for managing “labor crews” who are forced to work in various industries ranging from agriculture to manufacturing. In these types of cases Busch-Armendariz, Nsonwu, & Heffron (2009) indicates that there is a use of aggressive means of coercion and control, citing methods such as “U.S. vs. Evans - facilitating addiction to crack cocaine for homeless men working in the agriculture field”.

Additionally, perpetrators trafficking in this category can appear as a normal married couple who take advantage of a sole foreign-born victim by forcing them through coercion to carry out general household cleaning tasks and childcare. This specific case of labor trafficking is referred to as “Family-based Domestic Servitude”. It is interesting to note that this form of trafficking has significant network implications, as the “product” is not moving in a typical flow pattern as we would expect to see with heroin, but rather, remaining stationary for a long period of time. The findings in Busch-Armendariz, Nsonwu, & Heffron (2009) indicate that this period could last as long as 19 years.

The work in Busch-Armendariz, Nsonwu, & Heffron (2009) on sex-driven human trafficking also has notable implications for our purposes. This research states the important point that many of the victims of sex-driven human trafficking are “often chronic runaways or ‘throw away kids’ no longer sought by their parents.” When dealing with victims that fall into this category, there are significant psychological and physical considerations that must be taken into account. These considerations would likely be handled by a community/non-governmental organization (NGO), rather than a law enforcement/interdiction focused one. There is less history of coordination between law enforcement and NGOs and, therefore, an increased need to understand the impact of coordinated disruption efforts on human trafficking networks. As we begin to develop a general picture of the human trafficking problem, it becomes clear that the shape would likely resemble something more complicated than a single layer directed flow network. In this work, a human trafficking supply chain will not be modeled, but the results will be used to discuss potential implications for such networks.

To further discuss the immense range of illicit human trafficking practices, we review Polaris (2017). This report provides an extensive list of business models that employ human trafficking schemes, spanning twenty-three seemingly legitimate United States industries in addition to "illicit activities" and "personal sexual servitude" (listing a total of twenty-five types of operations). This wide range of industries includes but is not limited to health and beauty services, landscaping, forestry and logging, agriculture and animal husbandry, hotels and hospitality, carnivals, residential, health care, and recreational facilities. Polaris (2017) states "breaking up modern slavery into types allows us to expose the vulnerabilities in network business models and understand ways that traffickers leverage and exploit legitimate business or institutions". Working off of this idea, we can begin to build a picture of the variety of different agencies and organizations that may be expertly involved in identifying these "vulnerabilities" and assist in disruption efforts. Facilitation of these disruption efforts would begin by forming the appropriate cross-functional teams consisting of multiple organizations. Such cases involving human trafficking could include:

- Municipal building departments or housing authorities working with law enforcement and NGOs to disrupt brothel type "residential" operations

- The Department of Labor and the Food and Drug Administration working together to disrupt food processing facilities such as slaughterhouse type operations
- The Environmental Protection Agency working with law enforcement to disrupt logging or agricultural operations
- The Internal Revenue Service working with law enforcement to review suspected businesses' financial statements

This report also directly mentions the vulnerability of the LGBTQ community, specifically youths, to be victimized by multiple forms of human trafficking. In a tangential report expanding on LGBTQ victimization (Polaris 2016), the organization states that "nearly 40% of homeless youth identify as LGBTQ in comparison to 7% of the population. These youth may face homelessness for different reasons: family rejection, prior abuse or neglect, bullying in school or social discrimination and marginalization." This fact makes homeless youth extremely prone to falling victim to human trafficking schemes, particularly sex focused. In such a situation, an array of services could be utilized to advantage. Juvenile rights groups, LGBTQ rights groups as well as general homeless welfare groups would all be viable participants in a coordinated effort with law enforcement.

2.3 Interdiction Modeling and Law Enforcement Analytics

In order to address the challenge of interdicting these trafficking organizations, we will look to previous work as the basis for our mathematical modeling. Wood (1993) provides us with the formulation used to model the decision-making process of both the trafficker and the interdictor. Wood (1993) states that the trafficker aims to push the maximum amount of product through the network. This can be modeled using the maximum flow formulation, which moves the maximum amount of flow across the available arcs in a network from source to sink. In this paper, each node will represent a trafficker (or a set of traffickers) operating at some level within the supply chain. Each arc represents the transportation channel used to move illicit goods down the supply chain until those goods have reach the end user. With the trafficker's maximum flow objective in mind, Wood (1993) accounts for the interdictor's objective through the application of the maximum-minimum cut theory. The interdictor's objective, being to minimize the flow through a maximum flow network, creates a natural contradiction in the problem. Wood (1993) addresses this by applying the principal of duality to the problem. In order to align these objectives, while continuously modeling the appropriate decision-making behavior of both parties, Wood (1993) uses the minimum cut formulation. The minimum cut is the dual of the maximum flow, meaning the optimal values of both formulations will be equal to one another. The interdictor's objective is then modeled as minimizing the minimum cut within the network. This formulation then aligns both objectives and can design a model in which traffickers and interdictors are working towards their objectives concurrently in a single-level optimization problem.

The application of the formulation outlined in Wood (1993) has been tested in additional work focusing on drug trafficking, namely Malaviya, Sharkey, & Rainwater (2012). This work expands on Wood (1993) by examining a realistic city level-crack cocaine network case study. The realistic application in Malaviya, Sharkey, & Rainwater (2012) is ripe with interesting insights into improving the impact of law enforcement operations in efforts to disrupt these networks. Through the use of constraints and various input parameters to the model, the network is assessed across time periods. To accomplish this, a variable z_{ijt} is established to act as a "binary variable indicating whether arc (i, j) is interdicted in period *t*." Similar concepts can be found in Baycik, Sharkey, & Rainwater (2018) and Baycik, Sharkey, & Rainwater (2019). For our research, we will use this variable as an indicator that the agency responsible for targeting a tier has removed that arc from our network.

As our nation's intelligence network becomes increasingly more expansive, it is important that we familiarize ourselves with the diverse applications of this type of analytical modeling, particularly those of the Maximum Flow Network Interdiction Problem (MFNIP) when focusing on illicit trafficking networks. Shen, Sharkey, Szymanski, & Wallace (2018) review a number of these applications. This paper notes that Malaviya, Sharkey, & Rainwater (2012) have used a multi-period interdiction approach to city level narcotics networks, which allows for the modeling of "targeting" in which interdictors "must invest resource in order to build a case against an individual prior to their arrest." Additionally, a hierarchical structure is enforced so that criminals operating at a lower level of the organization must be arrested prior to criminals operating at a higher level. Another important application that Shen, Sharkey, Szymanski, & Wallace (2019) point out is provided in Baycik, Sharkey, & Rainwater (2018), in which the MFNIP is used to analyze layered networks. This refers to the idea that "smuggling networks can only operate if its operations are coordinated through an information (boss) network." These "bosses" may not be targeted for interdiction, but the network still depends on their operations supplying information, therefore interdiction would offer value. Shen, Sharkey, Szymanski, & Wallace (2019) propose a similarly layered network, detailing the interdependencies of money laundering and contraband networks, incorporating the MFNIP for interdiction analysis. The information reviewed and research conducted in Shen, Sharkey, Szymanski, & Wallace (2019) provides a strong motivation to build out robust models, capable of analyzing a variety of complex, realistic illicit networks and associated disruption strategies.

With that understanding, this thesis will aim to provide one approach to improving upon interdiction work modeled under the MFNIP, as well as contribute to the broader field of law enforcement analytics (Bahulkar et al., 2018).

2.4 Interagency Cooperation

In this thesis, we will direct our focus towards the interdictors, specifically, who they are and how they operate. To better understand the reality of interagency coordination, we will examine one of the nation's most effective interdiction organizations: the Joint Interagency Task Force – South (JIATF South) as detailed by Institute for National Strategic Studies (2011). This task force, operational under different titles since the 1980s, has set a crucial precedence for task force success in the "War on Drugs". In this research a call for a high level of interoperability is made clear, stating, "it is widely acknowledged that interagency collaboration within the U.S. government needs to improve and that interagency teams are promising means toward that end." Research indicates that while currently lacking in prevalence, the task force model is working extremely effectively where it does exist. JIATF-South, an organization comprised of all four branches of the military, nine law enforcement and intelligence agencies and eleven partner agencies, is responsible for U.S. Southern Command (USSOUTHCOM) and is a "cross-functional team in every respect". JIATF-South was responsible for the disruption of 220 metric tons of cocaine in the year 2009, while in the same year all other U.S. government entities only were able to disrupt a combined 40 metric tons. This task force has been dubbed the "gold standard for interagency operations" and is the "model for interagency collaboration as well as a widely cited example of effective intelligence fusion." Over the last 20 years, JIATF-South has proven coordination among agencies and "intelligence fusion" is a highly desirable strategy and has created a need for further research into the field cross-functional teams (Institute for National Strategic Studies, 2011).

For the purposes of this research, we will aim to build this type of collaboration into our model and assess different groupings or task forces to be included in the collaborated interdiction effort *across the entire transnational illegal smuggling network*. In order to deal with the complexities of a multi-agency approach to a network-based problem, various strategies of organization and management can be implemented to study this coordination. Research in modeling these types of cross-functional groupings has been conducted in the field of restoration efforts of interdependent infrastructure networks Sharkey et al. (2015). This paper assesses the value of information sharing between response-oriented organizations by comparing three alternative environments that dictate decision making in regards to disaster relief: the centralized decision-making environment, the decentralized decision-making environment, and the information-sharing decision-making environment. The centralized environment calls for a single entity to act as the decision-maker for all agencies involved. While some agencies may need to forfeit some efforts towards their objective, they do so in this case for the greater good of the total restoration across all infrastructures. The information-sharing environment has a more relaxed structure, in which agencies are privy to the decision-making of others but do not have to cooperate with one another. In this case, agencies can still make decisions aligned with their own objectives, but can do so strategically according to other decisions being made. The decentralized environment is one in which the organizations involved do not cooperate and therefore, make the least effective decisions in terms of the totality of the restoration effort. In this study Sharkey et al. (2015) finds that high levels of information sharing between response organizations are desirable and that the centralized decision-making environment is the "ideal situation" although not always feasible. We will model our coordination groupings in a similar manner to the centralized and decentralized environments. In this paper, our agencies will make interdiction decisions in a coordinated effort, where some agencies may have to sacrifice their objective for the totality of the effort and in an uncoordinated environment, where agencies will make their decisions based on the highest level yield for their specific objective. Note that we will explore situations under which only partial coordination is implemented, i.e., not all agencies coordinating with one another.

3. THE MAXIMUM FLOW NETWORK INTERDICTION PROBLEM WITH COORDINTED AND UNCOORDINAED DECISION MAKING

We model the operations of the illicit trafficking network by assuming that the traffickers are interested in maximizing the flows between the supply nodes and demand nodes in the network. Note that Malaviya, Sharkey, & Rainwater (2012) have observed that, at a city-level, illegal drug trafficking supply chains can meet all demand and, therefore, maximizing flow would be equivalent to maximizing profits. Each grow point would be a supply node, each territory point within a city (or region) would be a demand node, and all other nodes would be transshipment nodes (e.g., flow in need s to equal flow out at these nodes). Using standard network expansion techniques, we can convert this problem to a traditional maximum flow problem (Ahuja, Magnanti, & Orlin, 1993). We then model the actions of the attacker (interdictor) by assuming they wish to minimize the maximum flow or, equivalently, solving a MFNIP over the appropriate network. The MFNIP over network *G* can be reformulated as an equivalent single-level integer program by leveraging the dual relationship between the maximum flow and minimum cut problem. We refer the reader to Wood (1993) for the precise details of this reformulation.

It is now necessary to present the formal details of how we solve the MFNIP over the illicit trafficking network while considering both coordinated and uncoordinated interdiction efforts. We have our network, $G = (N, A)$, in which the defender will seek to maximize flow. Arc $(k,j) \in A$ has capacity u_{kj}. We will have a set of interdictors (e.g., law enforcement agencies), I, that each have their own interdiction budget, B_i, and set of arcs which they can interdict, A_i, within network G. In a fully coordinated environment, we will remove arcs across network G in order to minimize

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the maximum flow while respecting the interdiction budget constraints of each of the interdictors and ensuring that interdictor i only interdicts arcs in A_i (i.e., we only define interdiction decisions for interdictor i over arcs in A_i). The general formulation of the "min-max" objectives of this problem (after adding in super-source node s, super sink node t, and arc (t, s)):

$$\min_{z \in Z} \max_{x \in X(z)} x_{ts} \quad \mathbf{(3.1)}$$

In this formulation, z represents the binary state of all arcs in the network. In other words, if arc (i, j) has $z_{ij} = 1$, then that arc is available in the network and zero otherwise (i.e., it is interdicted). We then define the set of all feasible flows based on availability vector: $X(z)$. This allows us to look at the full set of arcs in the network, as well as the decisions made on those arcs by our interdictors. Note that s represents the network's source node and t represents the network's sink node. With this in mind, we define z_{ij} as a binary variable that when set to zero denotes our law enforcement has chosen to interdict its associated arc (when $z_{ij} = 0$, arc (i,j) has been has been fully removed from the network and its capacity will be defined by $u_{ij}z_{ij} = 0$). The formulation for Z with the involvement of interdictor i and the associated constraint relates to the budget required to break arc (i,j) and the total budget of all interdictors B_i:

$$Z = \{\sum_{(j,k) \in A^i} b_{ij}(1 - z_{ij}) \leq B_i \; for \; all \; interdictors \; i\} \quad \mathbf{(3.2)}$$

In an uncoordinated decision-making environment, interdictor i will focus only on the flow through *their portion* of the network. Therefore, we create subnetwork $G^i = (N^i, A^i)$ where we define N^i to be the set of all nodes j such that there exists arc $(j, k) \in A_i$ or $(k, j) \in A_i$ plus a super source node s^i and super sink node t^i. The super source node can be viewed as creating all flow that could flow into subnetwork G^i while the sink node can be viewed as "absorbing" all flow that can flow out of subnetwork G^i. Therefore, we will add arcs to A^i that represent the potential ways for flow to arrive into the subnetwork. In particular, we add all arcs in A_i to A^i with their original capacities plus arcs (i) from s^i to any node $j \in N^i$ with arc $(k,j) \in A$ and $k \notin N^i$ with capacity equal to $\sum_{(k,j)\in A: k \notin N^i} u_{kj}$ and (ii) from any node $j \in N^i$ with arc $(j,k) \in A$ and $k \notin N^i$ to node t^i with capacity equal to $\sum_{(j,k)\in A: k \notin N^i} u_{jk}$. In other words, these arcs have a capacity equal to the capacity of all arcs entering (or leaving) node j that do not belong to A_i in the original network. We solve the MFNIP over subnetwork G^i to determine the actions of interdictor i in this environment.

This process is general enough to allow us to examine different levels of cooperation between the agencies by properly defining our set of interdictors. Further, this process allows us to simulate an uncoordinated environment because each interdictor takes actions to best disrupt their own network without knowing precisely the actions of the other interdictors. In the future, it may be of interest to extend the analysis in this paper to situations where the agencies may not cooperate with each other in terms of their interdiction actions but they do share their planned interdiction actions. This would allow an interdictor to update the capacities of the arcs from their super source or into their super sink based upon the actions of the other interdictors. This is similar to the approach undertaken by Sharkey et al. (2015) in analyzing information-sharing in the context of network restoration.

4. THE CITY LEVEL EXAMPLE: A PRELIMINARY CASE STUDY

In order to test the legitimacy of our model, an initial case study was conducted. A hypothetical city level narcotics network was established. This network takes the shape of a small distribution operation in which one kingpin distributes product to a user market across three functional tiers. The kingpin, or top supplier, employs intermediary suppliers who turn product over to street level dealers for sale to the user market. The operation falls under the jurisdiction of three interdicting agencies, a federal law enforcement agency (at the kingpin level), the state police between the intermediaries and the dealers), and municipal police (between the dealers and the market users) targeting tiers I, II and III, respectively.

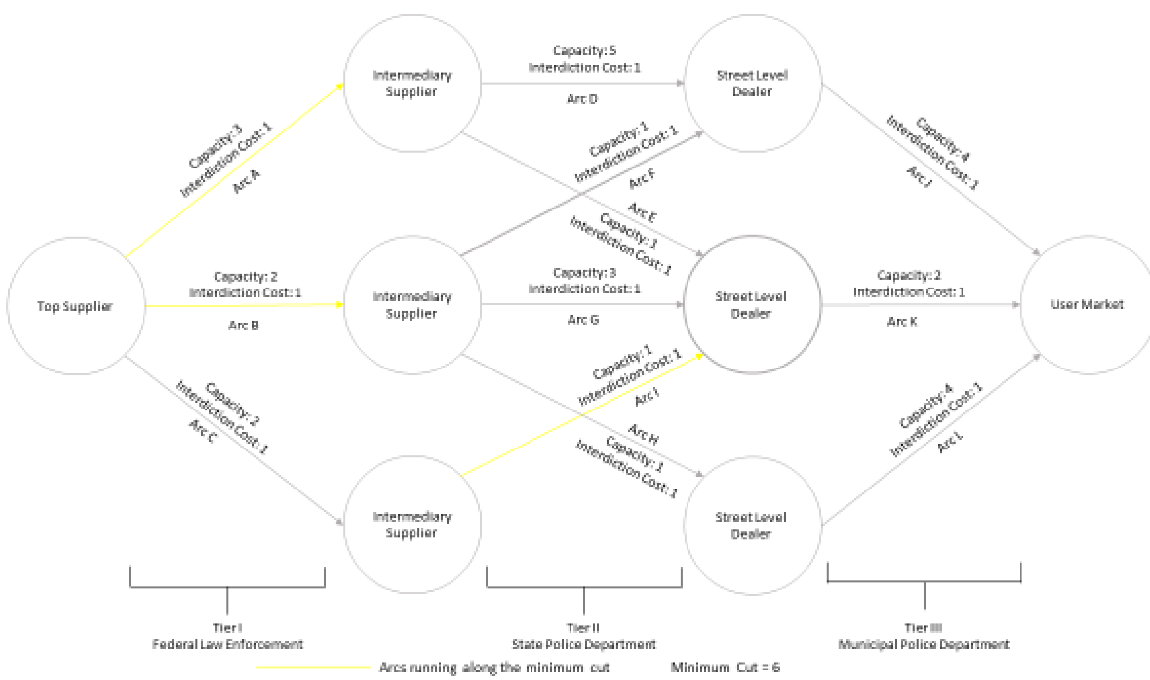

FIGURE 4.1: INTACT CITY LEVEL NARCOTICS NETWORK

The narcotics flow through the network is directed from the top supplier towards the user market. The flow follows a pattern such that Arc A will push 3 units of narcotics to its associated end node (intermediary supplier). When the narcotics reach the intermediary supplier, the quantity will be distributed along Arc D and Arc E, and so on throughout the network. Figure 4.1 details this network's shape and attributes, including the arcs that currently make up the network's minimum cut, indicated by the color yellow.

4.1 Uncoordinated Interdiction

Consider the narcotics network in Figure 4.2 from the perspective of the three agencies: the federal agency, state law enforcement and municipal law enforcement. These agencies work independently from one another and do not share interdiction strategies. Each of these agencies has the ability to interdict within their assigned tier and has enough resources to make one interdiction – i.e., remove one arc from the network. Operating blind to the other agencies' strategies, the federal agency breaks Arc A. In the next two tiers, the state police break Arc D and the municipal police break Arc J, unaware that flow has been cutoff to Arc D's intermediary supplier.

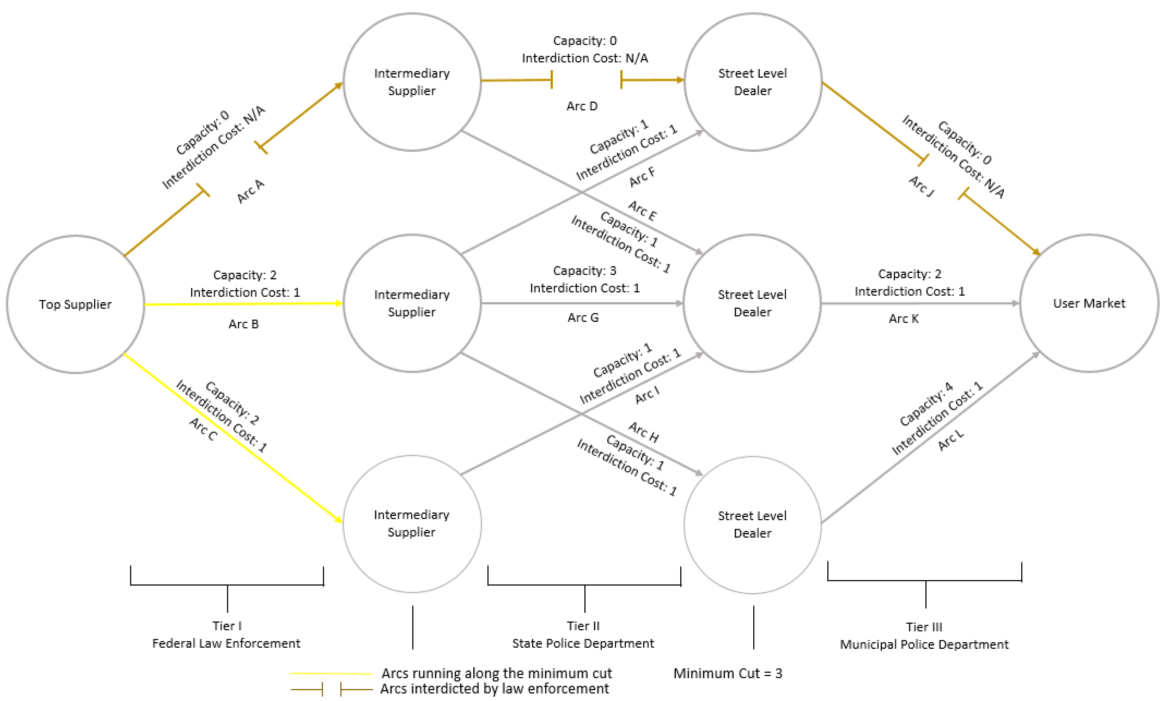

FIGURE 4.2: DISRUPTED CITY LEVEL NARCOTICS NETWORK – UNCOORDINATED SOLUTION

In all cases, the agency disrupts the arc that eliminates the most flow through their portion of the network without understanding the interdiction decisions implemented elsewhere. The minimum cut now runs across arcs B and C with a value of 3. The interdictions work to provide the agencies with a more optimal value, however they do so in an inefficient way relative to resource use.

4.2 Coordinated Interdiction

Now consider the same narcotics network from the perspective of a joint task force comprised of the federal agency, state law enforcement and municipal law enforcement. Each of these agencies has the ability to interdict within their assigned tier, however, the joint task force can only allocate enough resources for two interdictions. In this case, the optimal solution would be to break arcs H and J, bringing the minimum cut from a value of 6 to a value of 2.

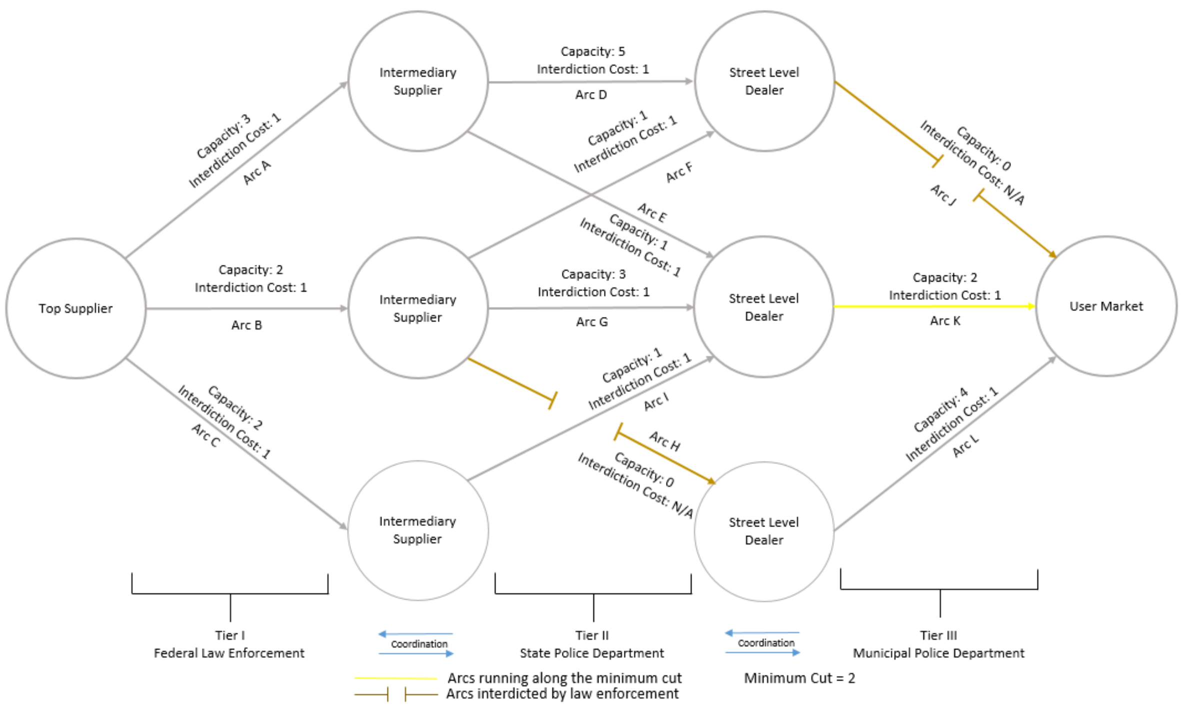

FIGURE 4.3: DISRUPTED CITY LEVEL NARCOTICS NETWORK – COORDINATED SOLUTION

Regardless of only providing the resources for two interdictions between the three agencies, the joint task force is able to develop a more effective strategy through information-sharing within the coordination decision-making environment. The decisions are laid out visually in Figure 4.3.

4.3 City Level Network Analysis and Results

Based upon this three tier network, we create larger instances with up to forty intermediate suppliers and dealers. We then test the coordinated and uncoordinated environments with different budget levels (3, 6, and 9) where each tier can interdict the same number of arcs (so 1, 2, and 3). This ensures the model can handle a robust array of settings, given that we aim to analyze several groupings of coordination under various budget levels. Upon outputting the results, the operability of the computer model was validated. Additionally, preliminary insights into the value of coordination were obtained. The city level narcotics network operated on a small enough level that the value of coordination proved to be extremely effective in disrupting a large level of distribution operations. The chart in Figure 4.4 displays the percentage decrease in the maximum flow of the coordinated decision-making environment as it compares to the percentage decrease in maximum flow of the uncoordinated decision-making environment.

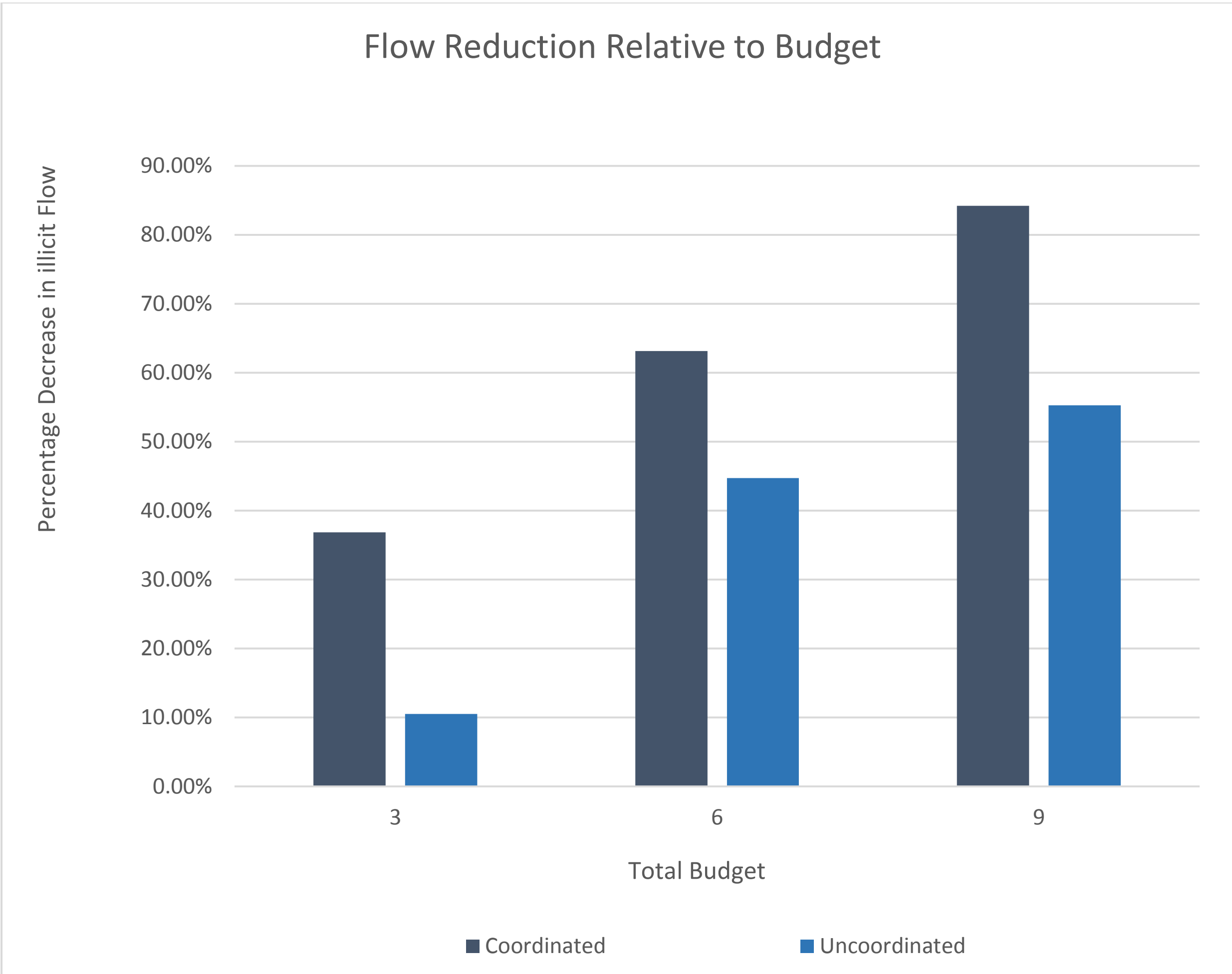

FIGURE 4.4: FLOW REDUCTION RELATIVE TO BUDGET

5. MODELING THE TRANSNATIONAL HEROIN NETWORK

The heroin network was modeled from reporting supplied by the Obama White House, the Drug Enforcement Administration, and U.S. Customs and Border Patrol. Five tiers of the network were established. These five tiers connect six levels of nodes that represent the geographic regions involved in the production, distribution, and consumption of heroin. From start to end of the network respectively, the six geographic regions are:

- Central and South American grow regions,
- The U.S. southern border
- Major U.S. regions
- U.S. states
- U.S. cities (or small regional areas)
- Smaller areas (territories) within each city

The node count for the first node level is set at 11, as this is the number of grow regions located throughout Columbia and Mexico (DEA Strategic Intelligence Section 2015). For the second level the node count is set at 85. This number is related to the number of border patrol stations spanning the U.S. southern border. In total, there are 84 stations. Assuming that traffickers can enter the country anywhere outside of these stations, an estimate of 85 geographic points of entry were located along the border (note that if the smugglers were to use legal checkpoints in their routes, we could model them within these 85 points of entry by expanding the definition of these nodes). In the third level of nodes, it was determined that the nine drug organizations involved in the network operate in 6 major U.S. regions across the nation (DEA

Portions of this section are to appear in John R. Wilt and Thomas C. Sharkey (2019). Measuring the Impact of Coordination in Disrupting Illicit Trafficking Networks. *2019 IISE Annual Conference*.

Strategic Intelligence Section 2015). The fourth level of nodes was set at 48, representing the 48 continental Unites States, all of which experience some level of heroin use. The fifth level of nodes was set at 96, under the estimation that these organizations have a major influence in roughly two cities (or regions) per state. Furthermore, level six was set at 192 nodes to model the division of drug distribution by gang or organization within cities (or regions). Thus, each city (regions) was broken down into two territories.

The arcs connecting these six levels of nodes represent the transportation pathways that traffickers use to smuggle heroin. The number of arcs in a given tier is defined as the density of the tier. The first tier, connecting the grow regions to the U.S. border was set at a base level of 100 arcs. This number is representative of traffickers sending couriers across roughly 100 routes aiming for the 85 sections of the border. Traffickers likely know that a portion of their goods will be seized by law enforcement, so they plan contingency couriers. The arcs in the second tier, which move product across the border to six major U.S. regions also consists of 100 arcs at the base level. This density was set to represent the 85 passageways across the border by land, with an additional 15 to account for alternative but less common modes of transportation, such as by air or sea. The base level for the third tier, which connects U.S. regions with states, was set at 96. This number is used as an estimation of the number of accessible sections of interstate in each region. The fourth tier was set at a density of 573 arcs. This number is estimated from the number of highways running through each state that could be possibly used to traffic heroin within U.S. states to cities. The final tier density was set at 182, representing the direct distribution of heroin to major cities to two segregated territories within these cities.

These density estimations are considered the most realistic for the transnational heroin network, however, two additional density levels were constructed for analysis in order to observe the interaction of the task force model as the complexity of the network varied. The density levels for Tier 1 (grow points to border crossings), Tier 2 (border crossings to regional distribution areas), Tier 3 (regional distribution to state distribution), Tier 4 (state distribution to city/region), and Tier 5 (city distribution to territory distribution) respectively were set as follows:

- Low: 85, 85, 48, 96, 182
- Base: 100, 100, 96, 573, 182
- High: 115, 115, 144, 1050, 182

At each level, this network can push anywhere between 9.2 to 19.8 metric tons of heroin. For each instance of this network generated, the capacity of each arc was randomly assigned within a range proportional to its tier's density. Additionally, the cost of the interdiction of each arc was randomly assigned within a range related to its tier. Up the supply chain, the cost of interdiction tends to be increasingly more expensive. This models the concept that, for example, a move that disrupts arcs out of a grow region will require operations overseas which will likely need a greater level of resource allocation than a municipal or state level narcotics bust. In terms of interdictions, the "international agency" can disrupt Tier 1 (and could model military and/or intelligence operations) arcs, border patrol would disrupt Tier 2 arcs, federal law enforcement would disrupt Tier 3 arcs, state law enforcement would disrupt Tier 4 arcs, and municipal law enforcement would disrupt Tier 5 arcs. A depiction of the general shape of a potential instance of the transnational heroin network is shown in figure 5.1.

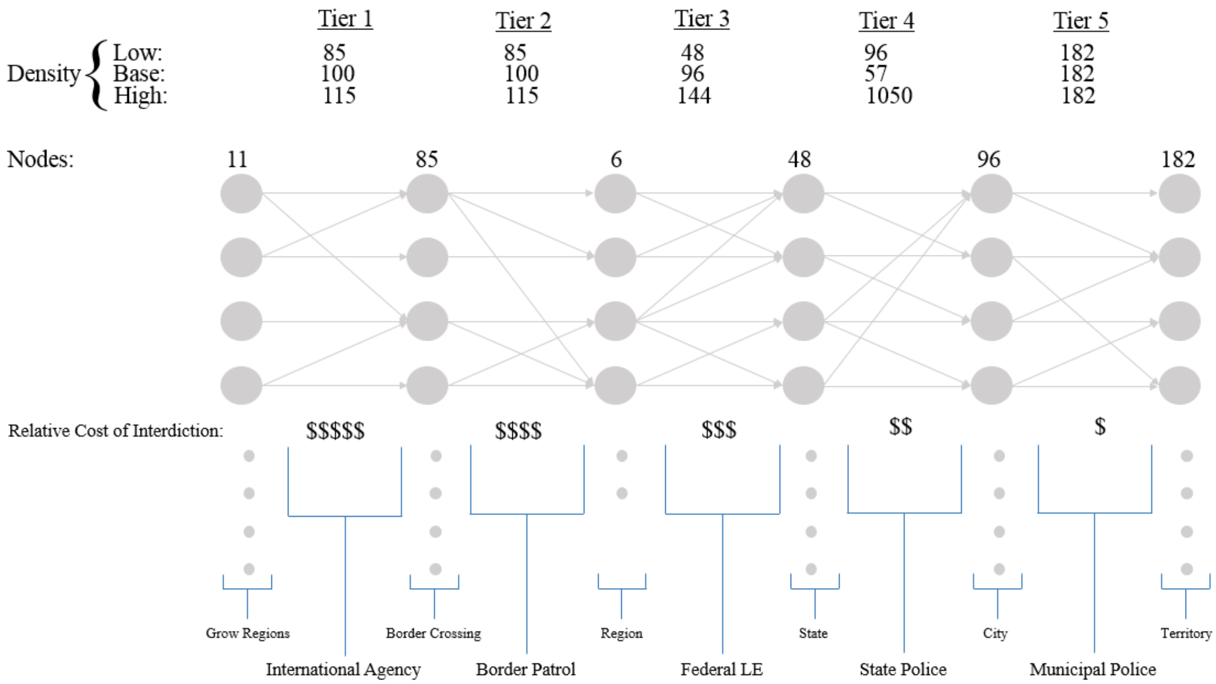

FIGURE 5.1: TRANSNATIONAL HEROIN NETWORK DEPICTION

6. QUANTITATIVE ANALYSIS TO UNDERSTAND THE IMPACT OF COOPERATION BETWEEN AGENCIES IN INTERDICTING TRANSNATIONAL ILLEGAL DRUG SUPPLY CHAINS

Based upon the network described in Section 2, we analyze six different levels of coordination between the intelligence and law enforcement agencies. These six levels are:

- All agencies work independently from one another (which we view as the baseline)
- All agencies coordinate their efforts (which may be impractical across a transnational illicit supply chain but represents the "best case" improvement)
- All the international interdicting agency cooperates with border patrol (thus the Tier 1 and 2 interdictors cooperate)
- Border patrol cooperates with the federal law enforcement agency (thus the Tier 2 and 3 interdictors cooperate)
- Federal law enforcement cooperates with state and local agencies (thus the Tier 3, 4, and 5 interdictors cooperate)
- State and local agencies cooperate with one another (thus the Tier 4 and 5 interdictors cooperate).

We note that we examine each of these coordinated environments independently from one another (e.g., we do not consider environment (3) and (6) simultaneously) but this could be an important area of future analysis. Further note that the state and local resources are planned across all cities/territories and could thus be viewed as the allocation of federal funds to various

Portions of this section are to appear in John R. Wilt and Thomas C. Sharkey (2019). Measuring the Impact of Coordination in Disrupting Illicit Trafficking Networks. *2019 IISE Annual Conference*.

state and local police efforts. Note that each interdicting agency was required to interdict within its tier, constrained by its specific budget.

In testing the performance of these coordinated environments, five different networks were generated at three different density levels. We considered two different levels of budget, 2.5% and 5%, where each interdicting agency was given either 2.5% or 5% of the total budget required to interdict every arc in their tier. We test each of these budget levels across the three different density levels discussed in Section 2. Tables 6.1 -6.3 (the raw data concerning flow levels can be found in the Appendix) provide the percentage improvement from various coordination environments from the baseline situation of all agencies working independently from one another for the high arc density, base arc density, and low arc density situations, respectively. This improvement was calculated as one hundred percent times the difference in the maximum flow (minimum cut) value between the baseline environment and the coordinated environment divided by the maximum flow (minimum cut) in the baseline environment.

Table 6.1: High Density Percentage Improvement by Task Force

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	1.88%	1.81%	0.00%	2.52%	2.95%	7.20%	1.88%	1.81%	0.00%	0.00%	2.95%	12.16%
Network II	2.11%	4.26%	1.21%	3.98%	4.65%	10.51%	2.11%	4.26%	0.00%	0.00%	4.65%	12.11%
Network III	0.00%	3.30%	1.86%	6.68%	0.44%	8.18%	0.00%	3.30%	0.00%	0.00%	6.02%	14.94%
Network IV	3.03%	4.50%	0.38%	0.00%	4.94%	9.32%	3.03%	4.50%	0.00%	0.00%	4.94%	14.18%
Network V	0.95%	3.04%	1.36%	2.71%	3.55%	9.37%	0.95%	3.04%	0.00%	0.00%	3.55%	9.80%
Average	1.59%	3.38%	0.96%	3.18%	3.31%	8.92%	1.59%	3.38%	0.00%	0.00%	4.42%	12.64%

6.2: Base Density Percentage Improvement by Task force

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	7.74%	8.35%	7.56%	8.78%	9.60%	14.26%	7.74%	8.35%	0.00%	0.00%	10.57%	23.71%
Network II	2.75%	6.13%	0.00%	0.00%	3.85%	8.70%	2.75%	6.13%	0.00%	0.00%	3.85%	14.79%
Network III	2.99%	4.65%	2.99%	2.28%	4.15%	9.67%	2.99%	4.65%	0.00%	0.00%	4.15%	16.29%
Network IV	2.79%	5.35%	0.75%	2.35%	4.30%	11.17%	2.79%	4.63%	0.00%	0.00%	4.30%	15.37%
Network V	1.54%	1.82%	0.82%	0.43%	2.95%	7.57%	1.54%	1.82%	0.00%	0.00%	2.95%	12.68%
Average	3.56%	5.26%	2.42%	2.77%	4.97%	10.27%	3.56%	5.12%	0.00%	0.00%	5.16%	16.57%

Low Density Percentage Improvement by Task Force

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	0.55%	5.59%	0.65%	5.59%	3.21%	9.00%	0.55%	5.59%	0.00%	0.00%	9.87%	23.08%
Network II	1.87%	2.51%	0.00%	0.00%	3.29%	8.36%	1.87%	2.51%	0.00%	0.00%	10.16%	20.72%
Network III	1.23%	4.56%	0.34%	2.17%	1.36%	9.06%	1.23%	4.56%	0.00%	0.00%	10.34%	21.52%
Network IV	3.66%	4.77%	0.67%	4.71%	3.37%	8.26%	2.37%	4.77%	0.00%	0.00%	11.63%	22.82%
Network V	1.13%	4.68%	1.74%	6.13%	3.08%	8.51%	1.13%	4.68%	0.00%	0.00%	10.66%	23.21%
Average	1.69%	4.42%	0.68%	3.72%	2.86%	8.64%	1.43%	4.42%	0.00%	0.00%	10.53%	22.27%

There are several interesting conclusions to draw from this analysis. The first observation is that the most consistently impactful cooperation on increasing the effectiveness of the interdiction efforts results from federal, state, and municipal coordinating their efforts across multiple tiers. An initial explanation of this observation is that this is the only environment where three interdictors are working together; however, the addition of the federal agency in the cooperation more than doubles the improvement in 18 out of 30 instances and, on average, is 2.49 times more impactful than just state and municipal working together. This means that we do not see a simple linear return on increasing the number of cooperative agencies. Therefore, it is likely quite impactful for federal agencies to coordinate their efforts with those responsible for funding interdiction resources at the state and local levels.

The second observation is that full coordination between all agencies is especially important as the network becomes less dense in terms of the number of arcs connecting its various tiers (for the 5% budget, we see 12.64%, 16.57%, and 22.27% improvements for the high, base, and low environments). This is intuitive in the sense that for less dense networks, the number of arc-disjoint paths becomes smaller and, therefore, there is more likely duplicative disruption efforts on the same path by multiple agencies without coordination. With coordination, it becomes easier to distribute the responsibilities of disrupting flow on a certain path to a particular interdicting agency. It would be of interest to know if improvements could be made in the uncoordinated environments by simply sharing information about planned interdictions rather than fully coordinating efforts to remove this duplicative effect.

The third observation is that the importance of a particular coordinated environment increases more than twofold when you increase the budget twofold when both budgets are relatively small (2.5% and 5%). This is an interesting observation since it points to the fact that the increase in budget should not only focus on increasing the interdiction budgets themselves but also increasing the resources necessary for the different intelligence and law enforcement agencies to coordinate with one another to disrupt the transnational illicit supply chains in order to take advantage of this additional impact from coordination.

In summary, there are key insights drawn from these results. The first addresses the most effective coordination grouping in disrupting the trafficking supply chain, which consists of federal, state and municipal law enforcement working in cooperation with one another. The second addresses the role that coordination plays in terms of the density of the network, as we observe that coordination between all agencies is more important when dealing with lower density networks. The third addresses the budget impact on coordinated efforts, as we observe the importance of coordinated efforts increase more than twofold when the budget is increase by twofold given a relatively small budget.

7. HUMAN TRAFFICKING INTERDICTION IMPLICATIONS

Given that we have not established a precise and detailed network for the human trafficking supply chain, it is difficult to directly apply the results gleaned from the transnational heroin analysis to human trafficking interdiction strategies. For example, within the heroin network we know that product seized will be held or destroyed by the interdicting agencies, essentially putting the supply out of play. In cases of human trafficking, however, we need to understand the process by which trafficking survivors re-enter society after interdictions have been implemented within the trafficking network. Upon entering back into the world as a freed individual, there is the potential for a victim of human trafficking to be tracked and once again seized by traffickers. Similarly, as pointed out by Busch-Armendariz, Nsonwu, & Heffron (2009), a large number of victims who are minors will likely go unclaimed. This consideration calls for the involvement of not only agencies capable of interdiction, but also agencies capable of providing safety, care and shelter to victims. The involvement of these agencies is essential, and therefore, we see that both the human trafficking network taking on a much different "general shape" than the heroin network detailed in Section 2 (e.g., there are multiple processes by which victims enter the trafficking network as opposed to a single way heroin is produced) and that interdiction strategies may have much different impacts (e.g., .there is a critical need to support survivors once interdictions take place in the human trafficking network).

While we cannot draw finer connections between the two problems, we are able to consider the broader implications the transnational heroin results provide. One observation that has potential applications to the human trafficking network is that, as a general rule, coordination between agencies is effective, especially at the lower-levels of the trafficking network. This calls for a higher level of interoperability among agencies that would otherwise not normally work together, e.g. a U.S. embassy, U.S. Citizenship and Immigration Services (USCIS) U.S. and Occupational Safety and Health Administration (OSHA).

A second observation is that not all coordination groupings or “task forces” yield equal “coordinated” results. In other words, simply because coordination exists between some agencies does not mean that it exists between the optimal agencies. Finding the right configuration of the grouping or “task force” is extremely important. This has observation has profound insights into human trafficking interdiction, as many of the agencies responsible for victim care are under very tight budgetary resources. Given these considerations, identifying which other agencies a particular organization should be coordinating with is important since it will allow for a proper allocation of time. Further, without careful coordination between certain agencies, survivors may enter conditions where they have a higher likelihood of re-victimization. Consequentially, it would be ideal to create groupings based on their potential impact on moving towards the central optimal solution, rather than involving all potential agencies involved.

8. CONCLUSION

An optimization model and decision making frameworks were developed to assess the impact of coordination between various law enforcement and intelligence agencies on disrupting large scale, transnational heroin trafficking networks. The legitimacy of the model was first tested using a small scale, city level narcotics network consisting of three functional tiers. For this network, the model was tested at three different budget settings: 3, 6 and 9 for both the coordinated and uncoordinated decision-making environment. In this theoretical case, a federal agency, state police and municipal police were responsible for interdiction. Following this preliminary test, a realistic transnational heroin network was modeled. Five discrete instances of this network were created at four different density levels. For each of these networks, interdictions were carried out with six different groupings or "task force" configurations at two different budget levels, yielding a total of 240 data points. Subsequently, these results were analyzed to determine that coordination between interdiction agencies has significant value. Broader conclusions drawn from these results were expanded to human trafficking networks.

There is a great deal of potential for future expansion and application of this work. Future work could encompass additional coordination environments, such as a budget-sharing environment, in which agencies are not only able to coordinate their decision-making but also are able to allocate resources to any tier they are in coordination with. An alternative coordination environment could be an information-sharing environment. In this environment, we would not see explicit groupings or "task forces" but rather control the flow of information between agencies. In doing so, we would be able to decentralize the interdiction effort to some extent while potentially yielding comparable results. Additionally, there is work to be done in modeling the human trafficking supply chain but that work must address the nuances of human trafficking and, most importantly, understand the consequences on the victims/survivors of any implemented interdiction actions.

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10. APPENDICES

10.1 Heroin Flow Following Interdiction in Ounces

10.1.1 High Density Network Maximum Flow Following Interdiction by Ounce

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	343745	307826	350324	305596	339988	290939	343745	307826	350324	313507	339988	275396
Network II	341468	297069	344582	297959	332599	277703	341468	297069	348812	310301	332578	272714
Network III	339524	298118	333222	287707	338045	283079	339524	298118	339524	308305	319093	262248
Network IV	345747	297105	355180	311747	338917	282113	345747	297105	356547	311099	338917	266972
Network V	356220	309504	354741	310572	346872	289322	356220	309504	359631	319222	346881	287947

10.1.2 Base Density Network Maximum Flow Following Interdiction by Ounce

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	322241	278429	322839	277130	315739	260494	322241	278429	349257	303801	312342	231783
Network II	319589	271407	329905	289593	315964	263984	319589	271407	328610	289127	315964	246356
Network III	287819	332539	294960	328551	272648	332539	287819	342792	301841	328551	252680	388360
Network IV	288686	342077	297847	329843	270931	335048	290883	344674	305005	329843	258120	395955
Network V	343788	299564	346303	303823	338898	282029	343788	299564	349182	305120	338898	266443

10.1.3 Low Density Network Maximum Flow Following Interdiction by Ounce

	International Working with Border Patrol		*Border Patrol Working with Federal*		*Federal Working with State and Municipal*		*State Working with Municipal*		*Agencies Work Independently*		*All Agencies Work Together*	
Budget	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%	2.5%	5%
Network I	338005	289863	337651	289863	328961	279383	338005	289863	339864	307030	306336	236153
Network II	343706	302403	343706	300723	338733	284278	343706	302403	350272	310199	314694	245914
Network III	291542	345216	298862	341682	277797	342131	291542	346404	305482	310588	239736	422621
Network IV	292999	348146	293155	338699	282245	342212	292999	350509	307660	309745	237438	414592
Network V	345619	297166	343489	292633	338796	285225	345619	297166	349569	311742	312295	239397