# Spatial Optimization from a Student Perspective: Modeling Optimal Interdiction Strategies for NSF Funded Research

THE UNIVERSITY OF ALABAMA®

Laboratory for Location Science

Ashleigh N. Price, anprice5@crimson.ua.edu

## Introduction

Current Federal drug-control policy aims to reduce the flow of narcotics into the United States, in part, by intercepting cocaine shipments in Central America. Despite longstanding US presence, however, the volume and frequency of illicit trafficking through the region has continued to rise and government-led interdiction forces intercept fewer than 6% of known trafficking events. Recent research has shown that interdiction contributes to the spatial fragmentation and proliferation of existing narco-trafficking networks and the ensuing propagation of collateral damages including violence, land seizures, and environmental degradation. Furthermore, maritime, airborne, and ground-based counterdrug operations are subject to temporally dynamic availability and demand, necessitating the development of alternative interdiction strategies. This project presents two new models built on the established Maximal Covering Location Problem (MCLP): Maximal Covering for Interdiction (MCI) and Maximal Covering for Interdiction of Cartels (MCIC). These models identify the optimal interdiction – 'force package' - locations given known drug flows and by differentiating among the illicit transit routes used by various drug trafficking organizations. These models were tested in a realistic interdiction scenario within the Illicit Supply Network (ISN) geography of Central America. The results demonstrate that location covering models can inform spatial decision making by counter-drug organizations by supporting the development of alternative interdiction strategies and improving the outcome-effectiveness of interdiction operations in the transit zone.

## Data

A dataset representing the Illicit Supply Network (ISN) from South America through Central America to Mexico (and ultimately the US) has been employed. The ISN consists of 156 nodes representing potential cocaine transshipment locations where interdiction can take place. These potential force package locations are connected with a set of 1,004 links representing the generalized connections among nodes. Each link has a 'flow' value representing the amount of illicit goods trafficked along that link. Cocaine shipments in transit along a link are intercepted when a force package is located at the end node of that link. Therefore, the facility locations able to provide coverage to each demand link consist of the end node of that link. That node may be the end node of multiple links, in which case each of those links can be covered with the same force package. For example, in the hypothetical network shown in Figure 1, interdicting at node 4 would capture the flow along links $a_{14}$ and $a_{24}$, while interdiction at node three captures flow along link $a_{23}$.

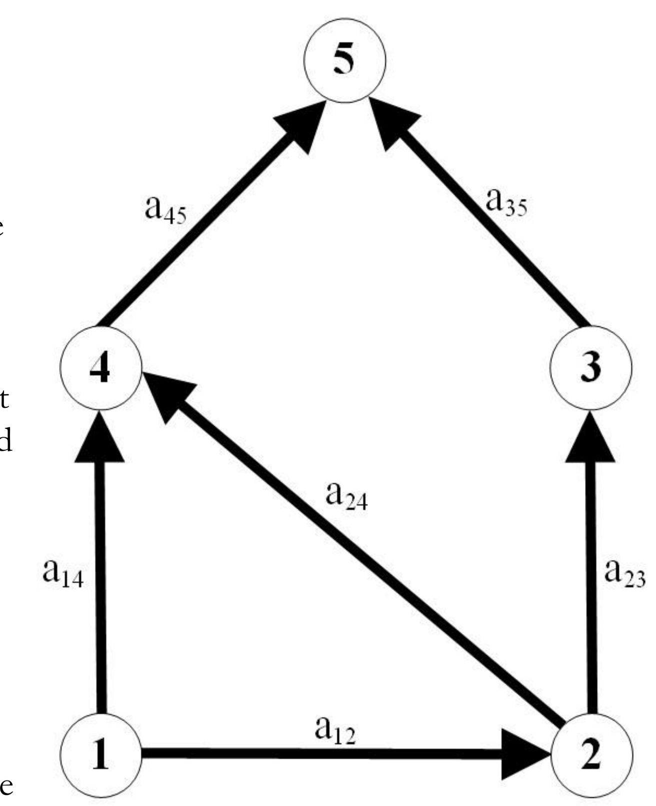


**Figure 1: Hypothetical ISN.**

For this analysis, the values assigned to each link are adapted from the Consolidated Counterdrug Database (CCDB), a data repository maintained by the Joint Interagency Task Force-South (JIATF-S) to store interagency data on cocaine flow through the transit zone ((Magliocca et al. 2019; McSweeney 2020). The flow values are the CCDB 2018 estimates of cocaine movements and each link is assigned a value based on the country encompassing the end node of that link. Figure 2 (below) shows the study area and an example subset of end nodes used in the analysis.

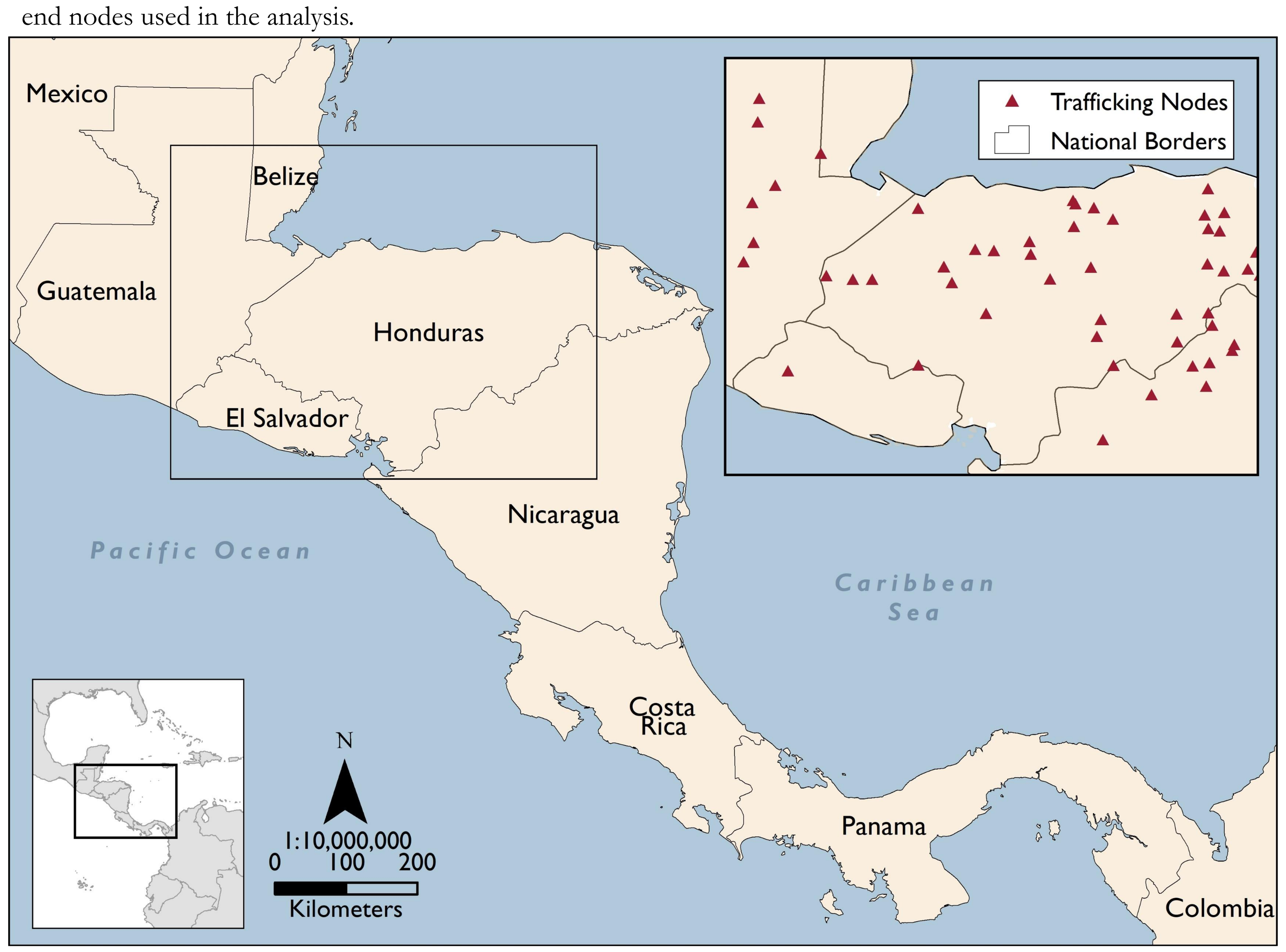


**Figure 1: Central America. Example narco-trafficking nodes/potential force package locations shown in inset.**

## Methods

The Maximal Covering Location Problem (MCLP) formulated by (Church and Revelle 1974) finds the optimal facility locations for maximizing coverage based a limited number of facilities or other resource constraints. The extant literature, however, has not addressed expanding the MCLP to support spatial decision making by counter-drug organizations. The methods for this project consist of formulations of two interdiction models based on maximizing the disruption to narcotrafficking operations and solving those models on a realistic illicit suppluy network with a range of plausible data values. Maximal covering models can be applied to the problem of locating interdiction operations with the following formulations:

### Maximal Covering for Interdiction (MCI)

Maximize

$$\sum_{i \in I} a_i y_i \quad (1)$$

Subject To:

$$\sum_{j \in J} x_j = P \quad (2)$$

$$x_{e_i} \geq y_i \quad \text{for all} \quad i \in I \quad (3)$$

$$x_j = (0,1) \quad \text{for all} \quad j \in J \quad (4)$$

$$y_i = (0,1) \quad \text{for all} \quad i \in I \quad (5)$$

Where:

- $I, i$ = the set and index of links where illicit goods are trafficked
- $J, j$ = the set and index of end nodes (potential facilities/interdiction locations)
- $x_j$ = 1 if interdiction at node j, and 0 otherwise
- $y_i$ = 1 if flow i is covered by interdicting at an end node, and 0 otherwise
- $x_{e_i}$ = special case of $x_j$ where $e_i$ is the end node j of link i covers flow from link i
- $a_i$ = flow for each link i
- $P$ = number of interdiction/facilities/force packages to be located

The classic MCLP can be cast in the context of interdiction, and the model is here termed the Maximal Covering for Interdiction (MCI) model. In this formulation, the objective (1) is to cover as many demands for interdiction services (links where illicit goods are trafficked) as possible. These links are weighted by the amount of illicit goods that is known or estimated to be present on the links. Constraint (2) ensures that only the user specified number of interdiction facilities (sometimes referred to by interdiction agencies as "force packages") *P* are located. Constraint (3) is known as the covering constraint and serves to ensure that a demand *i* can only be considered covered ($y_i = 1$) if a force package is located at the end node $e_i$ of that link *i*. Constraints (4) and (5) require that only integer values are included in the solution, meaning a single force package cannot be partially (fractionally) assigned to a location, and similarly demands cannot be partially covered.

### Maximal Covering for Interdiction of Cartels (MCIC)

Maximize

$$\sum_{i \in I} \sum_{c \in C} a_{ic} y_{ic} \quad (6)$$

Subject To:

$$x_{e_i c} \geq y_{ic} \quad \text{for all} \quad i, c \quad (7)$$

$$\sum_{j \in J} x_{jc} = P_c \quad (8)$$

$$\sum_{j \in J} \sum_{c} x_{jc} = P \quad (9)$$

$$x_{jc} = (0,1) \quad \text{for all} \quad j \in J \quad (10)$$

$$y_{ic} = (0,1) \quad \text{for all} \quad i \in I \quad (11)$$

Where:

- $x_{jc}$ = 1 if interdiction targets cartel *c* at node *j*, and 0 otherwise
- $y_{ic}$ = 1 if flow *i* attributed to cartel *c* is covered by interdicting at an end node, and 0 otherwise
- $e_i c$ = the end node *j* that covers flow from link *i* attributed to cartel *c*
- $a_{ic}$ = expected flow for each link *i* attributed to cartel *c*
- $P_c$ = number of force packages targeting cartel *c*
- $x_{Pc}$ = minimum number of force packages targeting cartel *c*

The rationale for the MCIC is that interdiction forces are – at times – required to direct their actions not only at the largest flow of illicit goods, but for various reasons, they may need to apply interdiction force across a set of illicit suppliers. Generally, drug-trafficking organizations, simply referred to here as *cartels,* control a geographic area, and exclude the operations of other cartels in those areas. If there is value in maintaining continuous interdiction operations against all cartels, then the model should ensure that at least one force package is allocated to each cartel. Similarly, if a certain level of interdiction is required against a particular cartel, then the model should enforce this minimum required allocation of force packages. For this latter case we posit a set of values *Pc* designating the specific number of force packages to be allocated to cartel *c*. The decision variables *xjc* and *yic* now indicate which cartel is targeted at node *j* and which cartel's flow is interdicted on link *i*. In the case of regional drug smuggling there can be multiple drug cartels that operate independently. The dataset used here represents a generalized view. At this scale, there can be more than one cartel operating at each node, meaning the model should have the capability to locate more than one force package at the same node. It should also be noted that the models presented here are free from context or scale, and thus translate to other illicit network geographies.

## Results

Due to various limitations and constraints, the availability of, and demand for, counter drug forces in Central America can change over time. Alternative policing activities, routine repair and maintenance, and the discovery of new intelligence can all necessitate the reduction or relocation of interdiction assets. The MCI was first tested on the ISN dataset for a range of values for P representing the varying number of force packages available at different times. Figure 3 shows the resulting force package locations and the percent coverage.

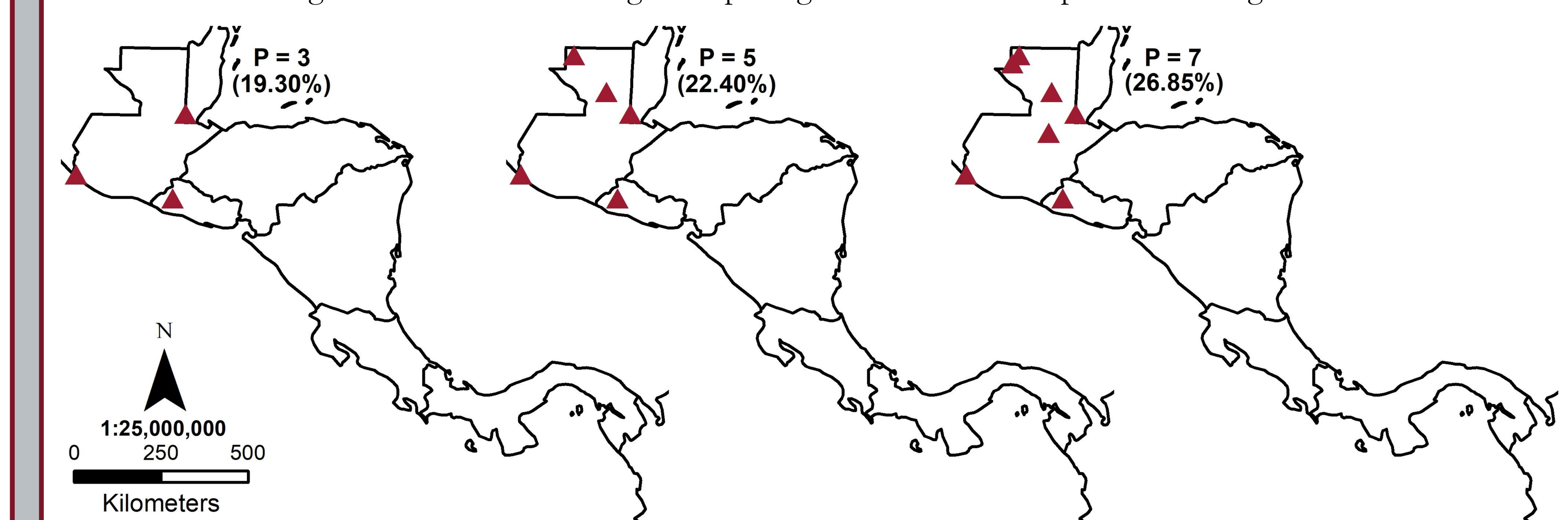


**Figure 3: MCI Force Package Locations. Percent coverage shown in parentheses.**

The MCIC was tested on the ISN dataset with goal of targeting different cartels. Each node in the dataset was randomly assigned to at least one of three hypothetical cartels and the flow along each link was divided among the DTOs operating at the end node of those links. The MCIC was solved using a Pc value of 3 for each cartel and the resulting force package locations and percent coverage are shown in figure 4.

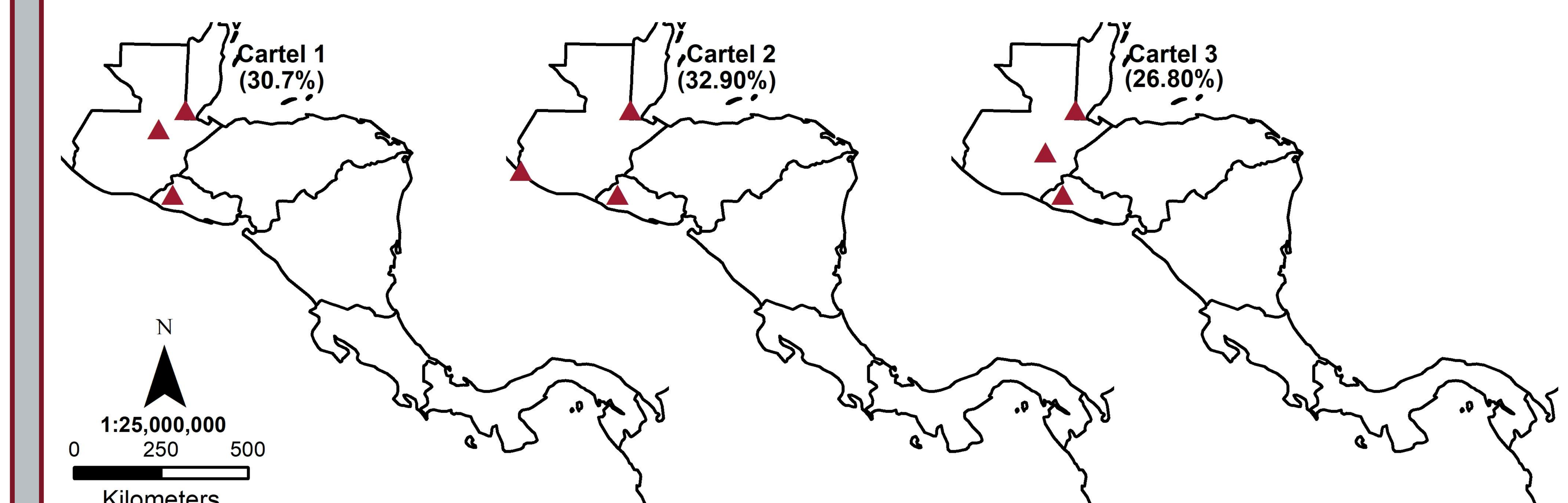


**Figure 4: MCIC Force Package Locations. Percent coverage for each cartel is shown in parentheses.**

## Conclusion

Counter-drug operations in Central America are underway on an ongoing basis and the results of that interdiction fall short of the goals that counter-narcotics forces set for themselves. In fact, US led counter-drug operations in the western hemisphere intercept fewer than 10% of the known volume of cocaine in the transit zone (McSweeney, 2020). This project presented two new covering model formulations in support of realistic, alternative interdiction strategies: Maximal Covering for Interdiction (MCI) and Maximal Covering for Interdiction of Cartels. These models were tested using known cocaine trafficking events from the Consolidated Counterdrug database (CCDB) and a novel dataset representing the illicit supply network (ISN) through Central America. The results of the MCI allow for comparing interdiction outcomes for varying numbers of available force packages using the location and volume of known cocaine trafficking events. The MCIC results illustrate the flexibility in designing alternative interdiction scenarios, including targeting multiple cartels or jurisdictional limits, and demonstrate the utility of extending location covering models to government-led interdiction efforts.

## References


Bagley, B. (2013). The evolution of drug trafficking and organized crime in Latin America. *Sociologia, Problemas e Praticas*, *71*(April 2019), 99–123. https://doi.org/10.7458/SPP2013712333

Church, R. L., & Revelle, C. (1972). The Maximal Covering Location Problem. *Papers of the Regional Science Association*, *32*, 101–113.

Magliocca, N. R., McSweeney, K., Sesnie, S. E., Tellman, E., Devine, J. A. J. A., Nielsen, E. A. E. A., … Wrathall, D. J. D. J. (2019). Modeling cocaine traffickers and counterdrug interdiction forces as a complex adaptive system. *Proceedings of the National Academy of Sciences*, *116*(16), 7784–7792. https://doi.org/10.1073/pnas.1812459116

Mcsweeney, K. (2020). Reliable drug war data : The Consolidated Counterdrug Database and cocaine interdiction in the " Transit Zone ." *International Journal of Drug Policy*, *80*, 102719 https://doi.org/10.1016/j.drugpo.2020.102719


ACKNOWLEDGMENTS. This work was supported by funding received from National Science Foundation Early-Concept Grants for Exploratory Research Project ISN: Anticipatory Interdiction in Narco-Trafficking Networks 1837698.