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Mexico's drug networks: Modeling the smuggling routes towards the United States

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ABSTRACT

Drug smuggling routes are chosen to maximize profit while minimizing costs. Routes with the least drug transportation costs and the lowest risk for drug confiscation and gang fight are most preferred. This study attempts to predict the ground trafficking corridors for transporting marijuana and opium derivatives from Mexico to the United States border. The cost surface, representing impedance to transport illicit drugs, is modeled by considering physical, socio-demographic, and drug violence factors. The impedance is then transferred to the road network to represent the cost for moving drugs along the roads, which becomes the main input for network analysis. The results from the routes simulation confirm largely the known territory divisions and the drug trafficking routes of the major Mexican drug organizations. The findings help us understand the development of drug trafficking routes in Mexico, which can potentially enhance our capability to predict the dynamics of drug smuggling routes.

Introduction

Mexico has been a major producer of illegal drugs for more than a century. Over the last few decades, the country's production has steadily increased and diversified, so much so that Mexico now has become the main supplier of illicit narcotics to the United States (BINLEA, 2009, 2010). The drug smuggling business in Mexico has largely been controlled by a few local groups that dominate the entire chain of production: cultivation, distribution, and commercialization. Traditionally, the areas along Mexico's northern border have been most sought-after by drug gangs when looking to establish their headquarters and dominate lucrative smuggling corridors for moving narcotics into the United States (Astorga, 2005) (See Fig. 1). The networks of roads and highways, and other traditional hubs of infrastructure – such as maritime ports and airports – are frequently used to move drugs north, shaping the patterns of drug violence (NDIC, 2011).

However, the introduction of cocaine and synthetic drugs in Mexico has led to the rise of a rash of new and ruthless drug gangs, which have begun battling traditional Mexican cartels for a share of the smuggling business (Medel & Thoumi, 2014). Moreover, the collapse of Mexican state-sponsored protection rackets for drug trafficking in the 1990s and early 2000s (Astorga, 2005; Snyder & Duran-Martinez, 2009) has fermented the breaking-down of the balance between historically entrenched and powerful drug organizations. New competitors for the drug business started emerging and redefining the landscape of drug activities. The fight for drug business and control of key smuggling routes to the United States generated a huge spike in drug violence, claiming more than 50,000 lives between 2007 and 2011 (Cave, 2012).

Many drug violence studies in Mexico have centered on the causes and patterns of it (Beittel, 2010; Friman, 2009; Shirk, 2010; Snyder & Duran-Martinez, 2009). Others attempted to understand the history of drug gangs and smuggling (Astorga, 2003, 2005; Grillo, 2011). Most research on drug trafficking in Mexico examined the policy implications for the U.S.–Mexico relationship (Andreas, 2012; Astorga & Shirk, 2010; Tullis, 1995). Very few have focused on the geographical routes that are used for drug smuggling. To the authors' knowledge, Dell's (2011) study on Mexico's drug trafficking networks is the only such investigation. The study found that political-affiliation shifts in the administration of different municipalities had an effect on controlling drug violence and diverging drug smuggling to alternative routes.

The study reported in this paper aims at predicting the smuggling routes used by the Mexican traffickers to move marijuana and opium poppy derivatives from Mexico to the United States. Because drug trafficking calls for strategic business operation, kingpins act

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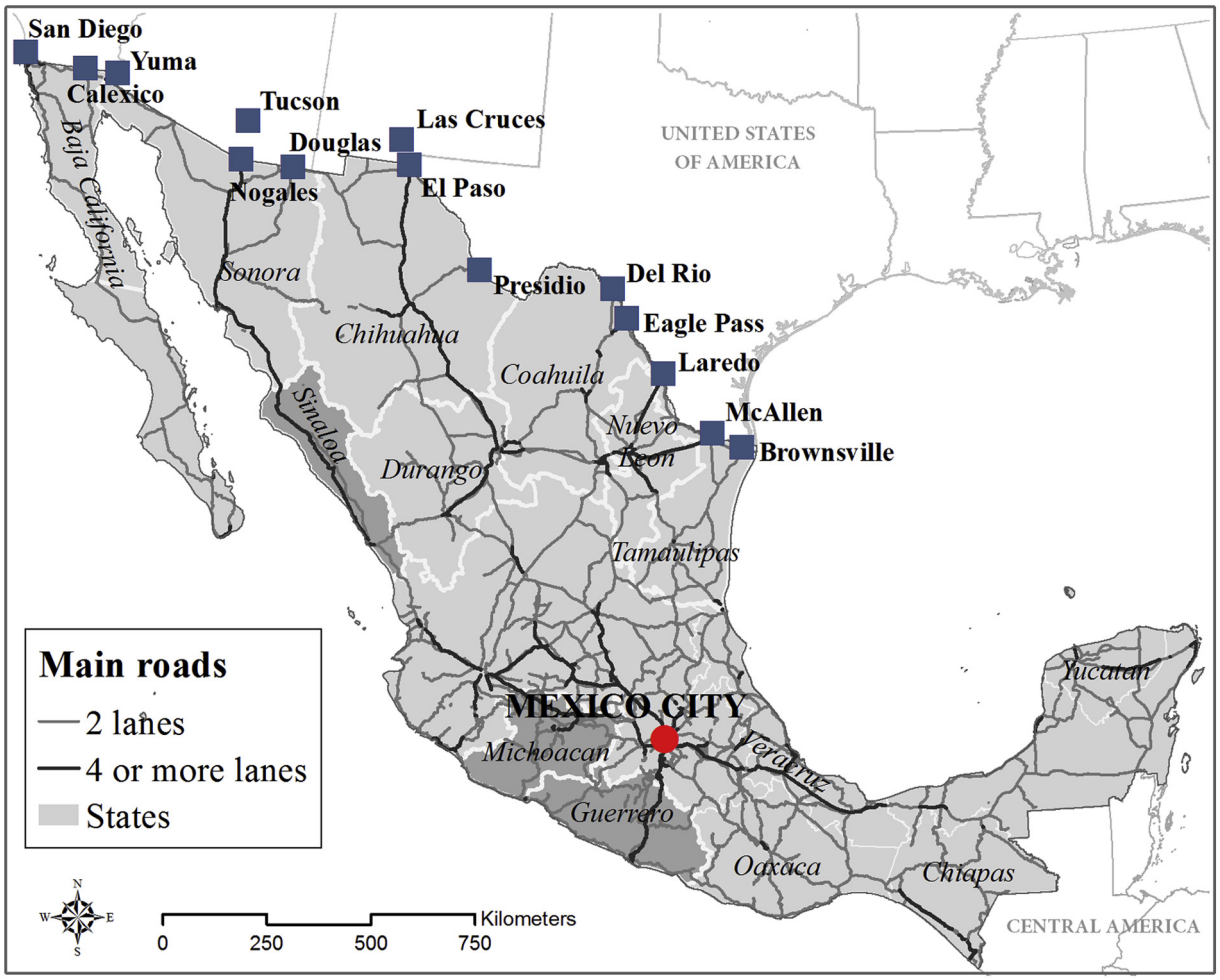

Fig. 1. Study area: Mexico road network.

in a very rational manner, seeking to maximize their returns while minimizing costs and risks. By accounting for the restrictions and costs for transporting drugs, this study estimates the possible drug trafficking routes that connect the Mexican drug production areas to the American cities along the U.S.–Mexico border. Restrictions to traverse include both social and political aspects, such as effective law enforcement, presence of local policy regimes less tolerant to drug smuggling, and elevated risks for drug-related killing and drug confiscation. The least-cost routes for drug trafficking are simulated for the years 2007–2010. A quality prediction of the drug trafficking routes is essential for effective allocation of resources and for necessary implementation of regional policies and practices in order to crack down drug smuggling and drug violence. The study contributes to understanding the dynamics of drug trafficking routes in Mexico.

Related literature on Mexico drug crime and criminology theories

According to the U.S. National Drug Threat Assessment (NDIC, 2011), most of the cocaine, heroin, foreign-produced marijuana, and foreign-produced methamphetamine available on American soil are moved into the U.S. through the land border along Arizona, California, New Mexico, and Texas. Different drug shipment methods are employed, ranging from small amounts that can be transported by car, SUV or pickup truck, to loads of one ton or more that are packed into commercial and non-commercial vehicles. Smugglers are believed to have a certain set of preferred routes for moving the different types of drugs. According to the NDIC (2011), seizures at and between the points of entry in Arizona represent roughly half of the marijuana confiscated at the border; the Rio Grande Valley in South Texas is another primary crossing point for the drug; heroin is smuggled across the border most frequently into California.

Most of the existing studies on Mexico drug offenses examined the causes, patterns, and history of drug violence (e.g. Astorga, 2003, 2005; Beittel, 2010; Friman, 2009; Grillo, 2011; Shirk, 2010; Snyder & Duran-Martinez, 2009). Among the small numbers of studies that discussed the topic of drug smuggling, the attention was on the possible policy implications on the U.S.–Mexico relationship (e.g. Andreas, 2012; Astorga & Shirk, 2010; Tullis, 1995). The only study known to the authors of this paper that analyzed the selection of drug smuggling routes connecting Mexico to the U.S. was conducted by Dell (2011). In this investigation, Dell pointed out that political changes in the municipal administration have an impact on the levels of violence linked to drug smuggling while also have the effect of deviating drug routes toward other regions.

According to crime theories, criminals do not make random movements, neither do crimes occur randomly at places. Rational choice theory (Clarke & Cornish, 1985) believes that an offender makes spatial decisions on offenses to maximize the potential benefit from committing crime and minimize the possible risk. An

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offender therefore tends to follow the principle of least effort (Zipf, 1949). In the case of drug smuggling, the smugglers will use the shortest and least-cost route that carries the least risk for confiscation and for drug fighting with other cartels. The smugglers' seeking balance between maximum profit and minimum risk is explained as a dual-role of drug smugglers by foraging theory (Felson, 2014; Johnson, 2014). On the one hand, the smugglers are actively considering and evaluating new opportunities for smuggling routes; on the other hand, they are preys who try to sneak around avoiding being captured by police or killed by other cartels. Dell's (2011) findings on how the Mexican drug traffickers decide on smuggling routes provide direct empirical support to the application of these theories.

Environmental criminology (Brantingham & Brantingham, 1991) and crime pattern theory (Brantingham & Brantingham, 1993, 1995) examine crime activity by accounting for the impacts of environmental and contextual factors. Environmental criminology studies crime by relating to place and examining how offender's activities are influenced by spatial factors. Crime pattern theory furthers the investigation of how spatial factors may shape offenses by examining how an offender interact with the environment through the nodes and paths along his/her spatial activity routines. Applying to the selection of drug smuggling routes, these criminology theories clearly point to the important role of the various environmental factors. Some of these factors may inhibit the use of a route for drug trafficking while others may encourage it.

The selection of drug trafficking routes by the Mexican drug cartels is believed to be guided by the principle of maximizing profit while minimizing cost and risk. The selection of a particular road or road segment is directly related to how closely the environmental factors along that road may allow the traffickers to follow their route selection principle. The general patterns of the drug smuggling routes are determined on the large scale by the structure of road and highway networks in Mexico, the control of strategic drug production areas by different cartels, and the points of entry along the U.S.–Mexico border. The shortest path connecting a production area with a U.S. border city is generally preferred at this level. However, other context factors must be considered for a particular route selection. As part of their foraging activities in their awareness space (Felson, 2014; Johnson, 2014), smugglers will also consider the costs of transporting along a road as determined by factors other than the physical distance. Some of these variables are the availability of protection from the natural environment (e.g. remote areas with few people, forest or woods of high trees), the level of tolerance to drug activities (e.g. police resources, political affiliation), and the potential profit that can be perceived from the past and other cartel's experience. It must be noted that the changes in policies and practices to combat drug offense in the beginning of 2000s has translated into changes in environmental and contextual factors, which affect drug trafficking patterns. Certain geographic factors that previously were not central for trafficking, such as the spatial distribution of police forces or the land-cover type, became vital. Furthermore, past drug-related violence may have a dual-effect on selecting smuggling routes. On the one hand, clashes among rival drug organizations can indicate especially lucrative transporting routes that are worth fighting for (Friman, 2009). On the other hand, violence can be bad for business, and drug organizations may try to avoid the related routes or establish new alliances (Friman, 2009). However, considering that the public attention and police resources tend to be steered nowadays towards the areas showing drug violence issues, the risk of transporting drug through these areas often out-weights the potential benefit. These areas are more likely to be dropped from drug cartels' grid of possible smuggling routes.

The empirical analyses of this study are designed to account for the many environmental and contextual factors that may work together to shape the selection of drug smuggling routes by the Mexican cartels. By extending Dell's (2011) congestion costs for drug trafficking to include a more broadly defined friction cost, this study includes both physical and socio-demographic aspects that drug smugglers must overcome to move drug across Mexico and into the U.S. In addition to distance, the cost to traverse a path depends on the quality of roads, population density, land use cover type, and poverty in the areas along the roads. A low population density and the existence of forest land cover enable drug offenders to remain relatively hidden, high-quality of roads allow them to move faster when required, and high poverty levels make it easier to buy people's silence on drug operation (Medel & Lu, 2014). Moreover, both drug violence and recent confiscations of drugs are considered as risk measurements for transporting drugs (Gutfraind, Hagberg, & Pan, 2009), and thus count towards costs along the roads for drug smuggling.

Data and methods

Data and sources

Physical, socio-demographic, and drug violence data are used to construct a cost surface, which is further used to estimate the friction cost for transporting drugs along the roads in Mexico. Because it is illegal, drug smuggling is closely influenced by probability of police presence, opportunities for hiding from the public, the possibility of crackdowns by authorities, and chances of territorial battles with other gangs. These variables, together with the regular variables for transportation cost, define the friction cost for moving drugs.

The physical factors that were considered when modeling drug trafficking impedances include the capacity of road (measured by number of lanes) and the type of transportation networks (i.e. federal-administered versus private-maintained, and state-controlled versus unknown or other types). Another category of physical data is the land cover data, which is used to estimate the availability of hiding places from the general population and law enforcement agencies. All these data were obtained from Mexico's National Institute of Statistics and Geography (INEGI).

The socio-demographic variables considered in this study include population size, poverty level, and police presence. The population data and the statistics on police presence for year 2005, both at municipality level, were downloaded from the INEGI website. Data on poverty was obtained from Mexico's Secretary of Social Development (SEDESOL) at municipality level.

The drug and drug-related violence data include the number of drug-related killings and that of drug confiscations and are used to measure the potential costs for drug trafficking. The data on drug-related killings for the years 2007–2010 were extracted from a database released by Mexico's Presidency in 2011. Data on drug confiscations for the years 2006–2010 was obtained from the Secretary of Defense (SEDENA) of Mexico via a transparency law as an open-records request. Both datasets were reported on municipality level. Table 1 provides a summary of the three groups of datasets, their sources, and their reporting level.

Modeling the impedances for drug trafficking

A friction surface (or cost surface) is a raster surface that defines the cost or amount of impedances while traversing each cell on the surface. This study models the overall impedance for drug trafficking across any place in Mexico as a combination of costs from several aspects, each can be represented by an individual surface.

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Table 1
Variables included to define drug trafficking cost.

Variables		Data format	Data source	Spatial reporting unit	Time reporting period	Weights
Physical	Land Cover	Polygon	INEGI	Municipality	2000	5
	Road network	Polyline	INEGI	Split at municipality	2000	15
Socio-Political	Population	Table	INEGI	Municipality	2005	5
	Police presence	Table	INEGI	Municipality	2005	10
	Poverty	Polygon	SEDESOL	Municipality	2005	5
Drug violence	Drug-related killings	Table	Mexico's Presidency	Municipality	2007–10	20
	Drug confiscations	Table	SEDENA	Municipality	2006–10	40

The accuracy of a friction cost is related to both the quality of the data that describe the different factors and how these factors are combined following a weighting scheme. Multi-Criteria Evaluation (MCE) are commonly performed to generate an integrated cost by incorporating techniques such as Analytic Hierarchy Process (AHP) or Weighted Linear Combination (WLC) (Herrera-Seara, Aznar Dols, Zamorano & Alameda-Hernandez, 2010; Makropoulos & Butler, 2006). Due to the lack of information regarding how drug traffickers assess the various factors to select particular routes, the researchers of this paper decided the weights for the three groups of factors by considering two fundamental aspects. These are related to the common knowledge on the unique facets for drug trafficking as compared to general transportation cost, and the findings in literature and news reports on how drug trafficking activities may have responded to the dynamics of social, political, and drug fighting dynamics. Table 1 reports the weights for the three groups and a total of seven factors that were used for simulating the drug smuggling routes.

This cost surface was built using ArcGIS 10.1. Separate cost surfaces for the different variables were first built and then combined into an overall cost surface for drug trafficking. Population, police presence, amount of drug-related killings, and drug confiscations were reported on municipality level, and were transformed into density for each municipality in Mexico. The road network was summarized to municipality level by adding up all road segments, measured in kilometers, inside each municipality. The layers were further converted to raster format with cell-size of 1000-m. Each of these cost layers were then reclassified into 7 categories for its cells indicating the cost for trafficking drugs. A score of 7 represent the most costly cells and thus the least desirable by the smugglers. The land cover data was converted to raster first. The original 17 classes of land cover were collapsed to 7 (excluding No Data) to reflect the potential to provide hiding places for drug smugglers. The highest values represent the least desirable categories as hiding places, therefore the highest cost for drug trafficking. Forest and jungle were at the top of the list, receiving a value of 1. Mixed land use involving jungle, forest or grasslands received an intermediate score. Water bodies, agricultural uses and urban areas were assigned the highest score, as they tend to be relatively open and accessible to general population and police and thus least desirable for hiding.

The raster layers obtained after pre-processing physical and socio-demographic variables, except the drug-related killings and drug confiscations, were overlaid using the weighting scale described in Table 1. To generate a combined cost surface for drug trafficking, the above output is further combined with the cost layers of drug-related killings and drug confiscations after a time lag is applied. The perceived risk or cost related to these two layers has a time delay, meaning that a smuggler will judge the potential costs based on the drug-related violence and seizures that already occurred. Therefore, the cost surfaces from drug-killings and drug-confiscation data should be modeled as impacting the selection of smuggling routes at a later time. In this study, the cost layers of these two factors for a particular year were used as weights for the next year's routes.

A drug trafficker's loss derived from interdiction is related to the types of drug and the stages of them in the process of drug production. The cost layer for drug confiscation in this study further reflected this issue. Accordingly, drug seizures were classified for each type of drug (i.e. marijuana and opium poppy being the two types produced domestically in Mexico) and the stage of their processing. For example, in the case of marijuana, the drug confiscations were divided into subcategories for marijuana seeds, plants of marijuana, and marijuana leaves packed (what is commonly known as a brick). Opium, meanwhile, was further classified as opium gum, heroin, and opium poppy seeds. Additionally, data on methamphetamine and cocaine confiscations were used because they are also powerful indicators of smuggling routes used by drug organizations. All the different drug categories were given weights according to their level of processing to becoming finished drugs ready for sale. Drugs in the final stages were given more weight, such as cocaine, heroin or packed marijuana, while drugs in early stages of production, such as seeds of opium poppy or marijuana, were assigned less importance.

Assigning cost to road network and conducting network analysis

The overall cost surface was used to assign impedance for drug smuggling to the road segments. A shortest path analysis was then conducted using Dijkstra's (1959) algorithm. This cost value for each municipality was assigned to the roads in that municipality by making a summarized spatial join of the road layer and the municipality polygon friction surface. Hence, the roads in each municipality acquired a quantification of the friction for smuggling drugs along them. The network analysis was then done using the friction cost as traveling impedance, higher friction or impedance value indicating more expensive for drug smugglers to transverse.

For the shortest path analysis along the Mexico road network, the well-known drug production zones were designated as the origins, and the destinations were set to be the main ports of entry the U.S.–Mexico border. Marijuana and opium poppy routes were modeled together for this study. The closest facility function in ArcGIS Network Analyst was used to predict the drug smuggling routes from each Mexican production region to the closest U.S. border city.[1] The prediction of drug trafficking for 2007 did not include drug killings as a factor since the drug-related murders data for year 2006 were not available. Note that the shortest path prediction for 2008 is worth special attention based on two

[1] Originally, the researchers considered pairing the drug production zones and the destinations that are controlled by the sane gangs using the knowledge from academic literature and government and newspaper reports to guide the shortest path analysis. But the outcomes from the simulations without pairing origins and destinations showed that the highest ranked drug trafficking routes in fact coincide with the ones depicted by the academic and journalistic reports, as discussed in the Results section of this paper.

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Table 2
Joint operations against drug trafficking.

Crackdowns	Date	Area	Changes/Date	Changes/Description	Violence peaks
Chihuahua	Mar-08	Opt. Chihuahua	Feb-09, Mar-10	Federal police	4Q-2008, 3Q-2009
Sinaloa	May-08	Culiacan-Navolato	Jul-08	Mazatlan, Salvador Alvarado	2Q-2008, 4Q-2009
Tamaulipas	Feb-07	Opt. Tamaulipas			4Q-2008, 1Q & 2Q 2010
Nuevo Leon	Feb-07	Opt. Nuevo Leon			3Q & 4Q-2008, 1Q & 2Q-2010
Baja California	Feb-07	Opt. Tijuana	Apr-07	Reinforcement	4Q-2008, 2Q-2010
Michoacan	Dec-06	Opt. Michoacan	Jul-09	Reinforcement Morelia, Uruapan, Lazaro Cardenas	2Q-2008, 1Q & 2Q-2010

considerations. First, the prediction is made using 2007 drug violence data, which is considered as an integral aspect for drug trafficking impedance in this study. Second, the years of 2007–2008 were a peak period when the Mexican federal government conducted a series of crackdown operations against drug activities (See Table 2). This should be a typical time when the gangs were actively seeking alternative trafficking routes or redefining the traditional routes.

It is important to note that the modeling of drug smuggling routes using the least expensive path is based upon some assumptions. These include:

- The majority of drug smuggling from Mexico into the U.S. is done via ground transportation;
- Drug organizations make rational-scale decisions when selecting routes for drug smuggling;
- Killings are seen as a cost for drug smuggling by drug organizations;
- The destination of Mexican drug smuggling is the U.S., not the local market in Mexico.

Results and discussion

Seeking the least expensive path appears to be a major factor in explaining the drug smuggling patterns in Mexico and the strategic location of drug syndicates' headquarters. The predicted patterns of shortest drug smuggling routes showed exciting results. The routes that ranked the highest for the drug production states in Mexico all connect to the same primary entry points to the U.S. as identified by the National Drug Intelligence Center (NDIC) in their National Drug Threat Assessment for the years simulated by this study (NDIC, 2008, 2009, 2010, 2011). This is especially true for those states that are bulk production zones for marijuana and opium poppy, i.e. the States of Sinaloa, Guerrero, and Michoacan, all on Mexico's Pacific coast.

The simulation for 2007 showed Guerrero exporting the bulk of its marijuana and opium poppy derivatives via the U.S. entry points

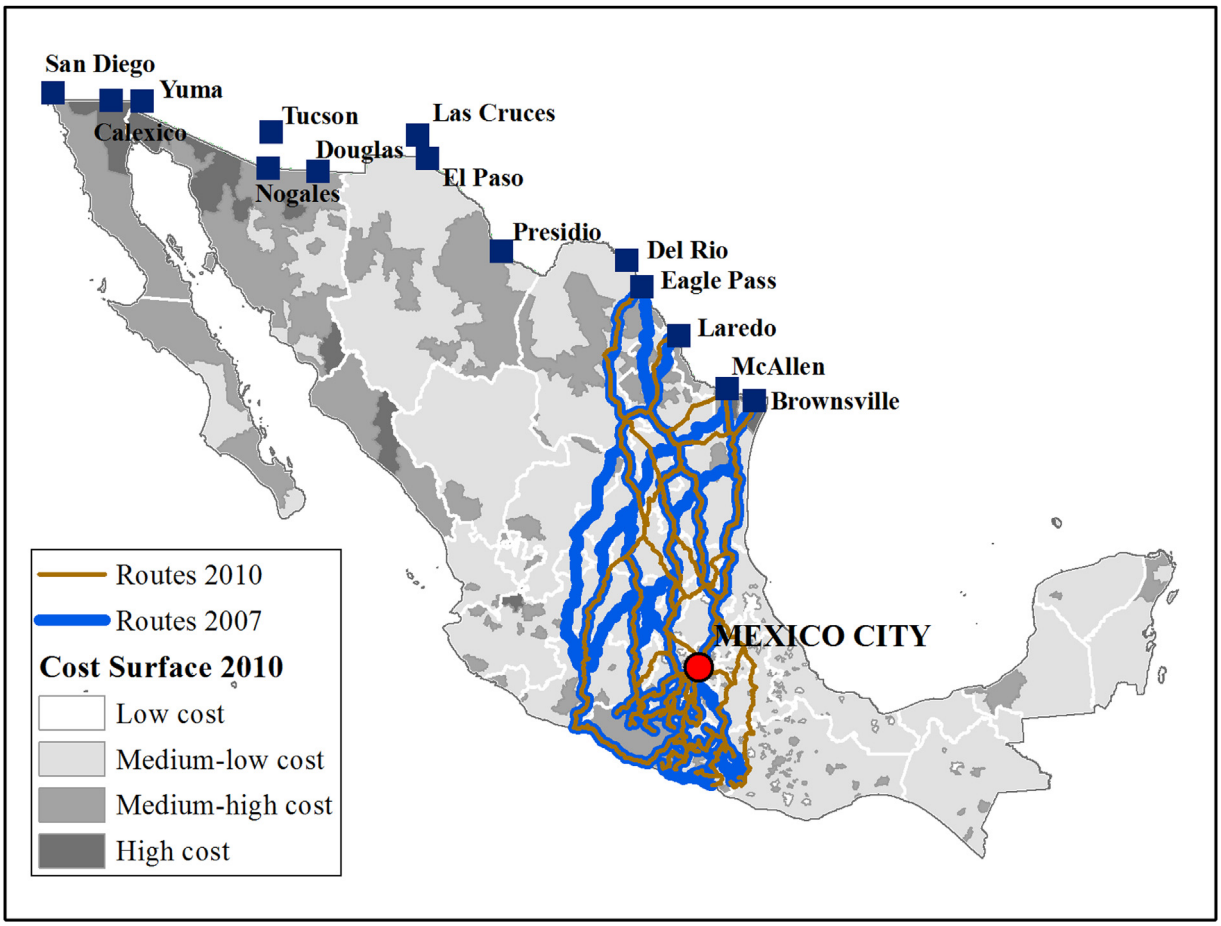

Fig. 2. Guerrero main predicted smuggling routes 2007 and 2010.

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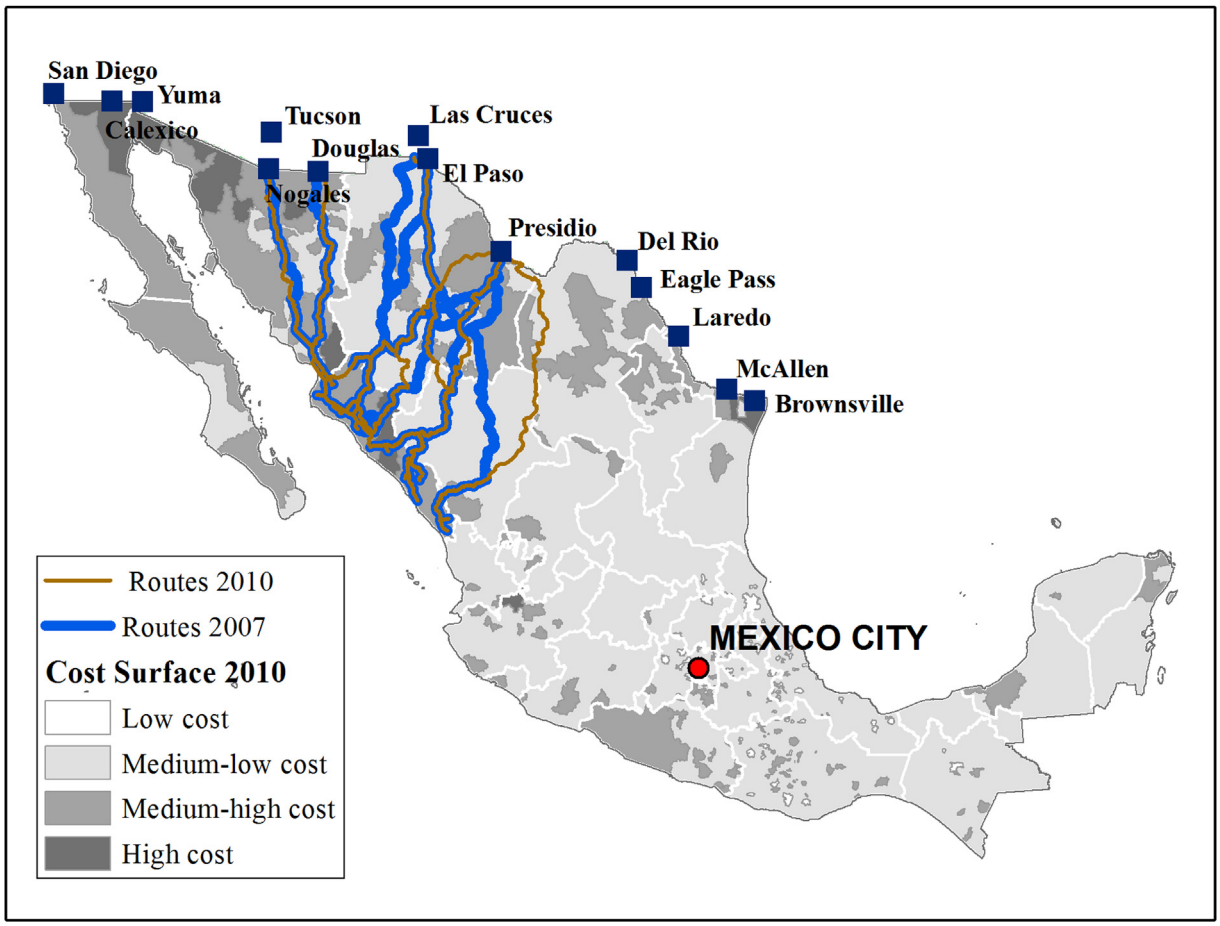

Fig. 3. Sinaloa main predicted smuggling routes 2007 and 2010.

of Brownsville, McAllen and Laredo, Texas, although other routes used connect to El Paso, Texas, and Nogales and Douglas, Arizona (Fig. 2). Production of drugs in Guerrero state has been traditionally controlled by the Sinaloa Cartel, lately referred to as the Pacifico organization by Mexican officials. In the late 2000s, however, that gang's control of the region was challenged by the South Pacific Organization, a remnant of the Beltran Leyva smuggling syndicate, which split from the Sinaloa Cartel in 2008 and was headquartered in the state of Morelos, close to Mexico City (InSight Crime, 2014). But in the years following 2009, that area was even more heavily disputed, first by the Gulf Cartel, and later by the Zetas (Castillo, 2013). The Gulf Cartel has its headquarters in Tamaulipas, and the Zetas used to be the group's enforcers until they split and formed their own rival drug gang in 2010 (Wells, 2013).

The prediction for 2010 shows changes in the routes, diverting smuggling corridors from some of the previously established routes due to the increased cost of traversing them, particularly in regions with increased violence (such as Morelos state) or more-frequent drug confiscations (such as along the border between Coahuila and Nuevo Leon states). While doing so, violence is increasing along the new routes (See Fig. 2).

In the case of Sinaloa, the highest ranked routes run directly to Nogales and Douglas in Arizona, and to Presidio and El Paso in Texas. This is the area for which the Sinaloa Cartel has battled with the Juarez Cartel for years, and the area hosts its headquarters in Ciudad Juarez, across the border from El Paso (Wells, 2013) (See Fig. 3). But the simulation for year 2010 revealed diverging of smuggling routes to avoid some roads throughout Chihuahua and Durango states, resulted from the changes in friction grid for moving illicit drugs. It is important to note that during this time, crime shift to the same areas that the drug smuggling routes moved into (See also Fig. 3).

The analyses also showed that the highest ranked routes for drugs smuggled from Michoacan state, in the Mexican Pacific coast, point to Texas. More specifically, toward the cities of Laredo, McAllen and Brownsville, a territory that was controlled by the Gulf Cartel in 2007, but which has been the site of a power struggle between the Gulf Cartel and the Zetas recently (El Nuevo mapa, 2012). Michoacan state has been the subject of territorial battles between the alliance of Familia Michoacana (LFM) and the Gulf Cartel organizations and the Sinaloa Cartel until 2006, and more recently, between the Knight Templars (a remnant of the LFM) and the Zetas (the Gulf Cartel's former allies) (El Nuevo mapa, 2012). Even though the least expensive route for drug trafficking heads straight to the southeast corner of Texas (i.e. Brownsville), in reality, the Knights Templar group's current alliance with the Sinaloa organization has shifted the routes towards the territories controlled by the Sinaloa syndicate (Langner, 2013). The routes prediction for 2010 reveals some shifts to avoid crossing between Zacatecas, Coahuila and Nuevo Leon toward the U.S. border, but also throughout some areas in Tamaulipas. The routes tend to follow more direct paths out of Michoacan state, possibly resulting from an attempt to avoid the increasing violence due to territorial battles with the Zetas (See Fig. 4).

Geographical factors shape the drug crime landscape in Mexico also through influencing the formation of alliances and the

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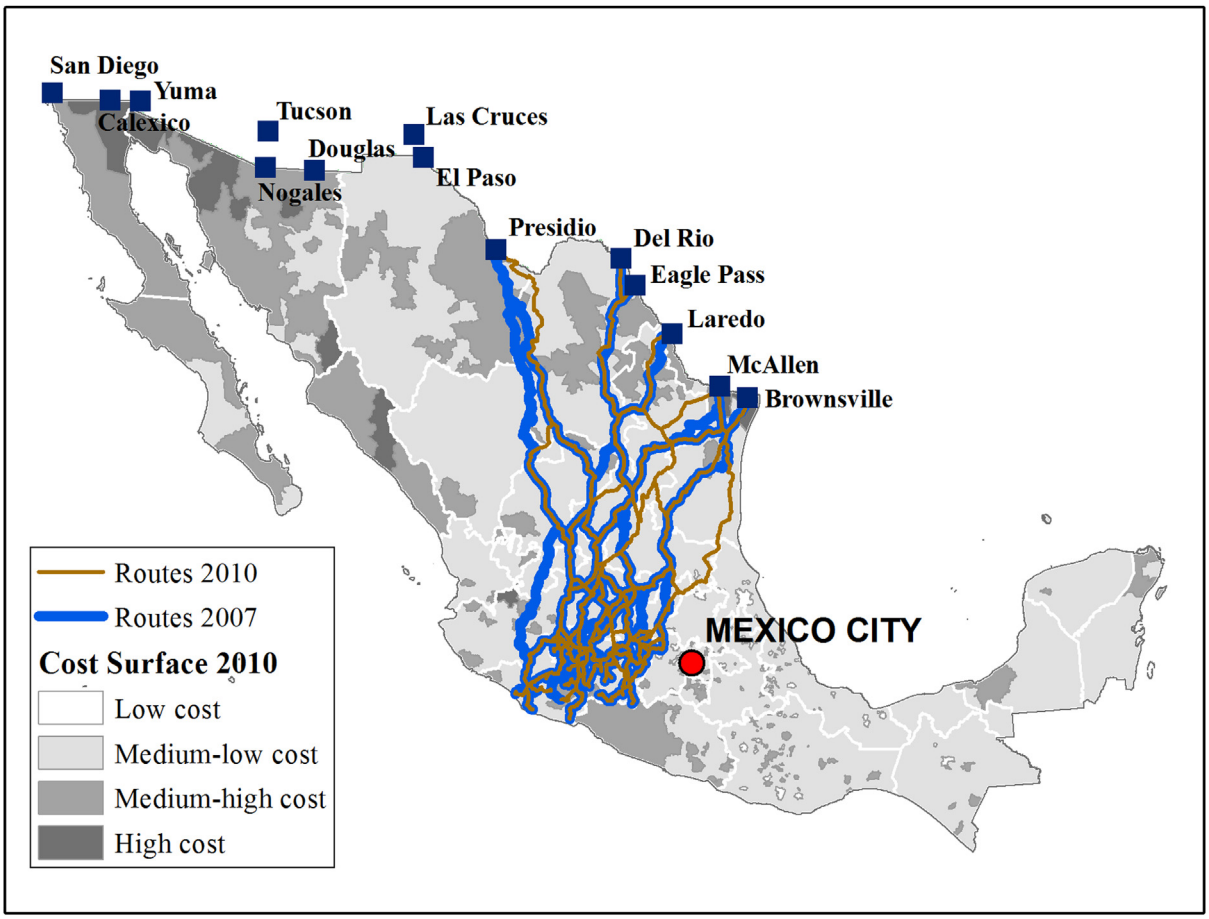

Fig. 4. Michoacan main predicted smuggling routes 2007 and 2010.

emergence of disputes between gangs. The more traditional drug cartels have always had their drug trafficking routes moving along the Pacific coast and the interior regions bordering the production areas via Chihuahua and Durango. The improvement of ground communication and the sheer volume growth in Mexico–U.S. trading after the signing of North America Free Trade Agreement (NAFTA) facilitated the emergence of a new drug syndicate, the Gulf cartel, in the region south to Texas (Astorga, 2005). The Gulf area had the easiest access to the newly revamped entry ports connecting the Mexican and American cities of Nuevo Laredo and Laredo, Reynosa and McAllen, and Matamoros and Brownsville. But the drug syndicate newly established there did not have production areas directly under its control. It was in the late 1990s that cultivation of marijuana and opium poppy in the states of Veracruz and Tamaulipas started spiking (Mexico Secretary of Defense, personal communication, July 26, 2011). The previously least-cost drug smuggling routes from Guerrero and Michoacan to the U.S. via the Gulf Cartel's routes and territory seeded the ground for territorial battles between the Gulf and the Sinaloa organizations.

Conclusions

Drug smuggling is a rational business, and the routes are selected to maximize profits and minimize costs. There are strategic reasons for the cartels to have their headquarters in specific cities by the border to control the territories they continue to hold onto and fight for. They look for the shortest path with least-cost, to move their illicit products from production zones to the main market, the United States. During this process, drug organizations attempt to avoid “plazas calientes” (hot spots) and areas where drug shipments were previously confiscated in large quantities by the authorities. But they also, as is frequently seen in the business world, form alliances, undergo mergers, and even stage “hostile takeovers” that can completely alter the way drug networks are routed. Taking advantage of geographic conditions and pre-existing networks of drug trafficking routes and other transportation infrastructure, different drug turfs are, to a great extent, based on the dispute of strategic links (edges) that connect key areas on the route to the U.S. This may very likely bring unintended consequences to the municipalities where these links are located, which usually means they bear the brunt in terms of the related violence unleashed.

This study made one of the earliest steps to predict the drug smuggling routes from the major production zones in Mexico to the land port entries to the U.S. The fact that the predicted smuggling routes echo so closely the known connections between the well-known marijuana and opium producing states in Mexico and the main ports along the U.S. border indicates that the variables that were considered for the route prediction in the study have a good grasp of the factors that play important roles in the cartel's route selection. This is undoubtedly an important step toward understanding the drug smuggling route selection by drug cartels and the reasons for cartels battling to control certain areas.

This study, however, is not free from limitations. First, the drug smuggling routes prediction did not give different drugs individual treatment. Different drugs may have unique route selection considerations due to their particular properties. However, drug-specific route analyses must be built upon more detailed data

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about their production, trafficking, and control by the different cartels in the different regions and along the different roads, which are beyond what is available for this study. Second, the analyses reported here are focused exclusively on smuggling routes on land. Some drugs are known to be smuggled to the United States by air or sea, especially in the case of heroin. Lastly, the impact of drug-related violence on route selection is more complicated than the assumption for this study. The drug-killings data is only a rough indicator for drug violence and cartel battling.

References

Andreas, P. (2012). *Border games: Policing the US–Mexico Divide*. Ithaca, NY: Cornell University Press.

Astorga, L. (2003). *Drogas sin fronteras. Los expedientes de una guerra permanente*. México: Grijalbo.

Astorga, L. (2005). *El siglo de las drogas: el narcotráfico, del Porfiriato al nuevo milenio*. México City: Plaza y Janés.

Astorga, L., & Shirk, D. A. (2010). *Drug trafficking organizations and counter-drug strategies in the US–Mexican context. Mexico and the United States: Confronting the Twenty-First Century*. USMEX WP 10–0, Center for U.S.-Mexican Studies, School of International Relations and Pacific Studies, University of California, San Diego (USMEX), El Colegio de la Frontera Norte (Tijuana), Woodrow Wilson International Center for Scholars, El Colegio de Mexico.

Beittel, J. S. (2010). *Mexico's drug-related violence*. DIANE Publishing.

Brantingham, P. J., & Brantingham, P. L. (1991). *Environmental criminology*. Prospect Heights, IL: Waveland Press.

Brantingham, P. L., & Brantingham, P. J. (1993). Environment, routine and situation: toward a pattern theory of crime. *Advances in Criminological Theory, 5*, 259–294.

Brantingham, P., & Brantingham, P. (1995). Criminality of place: crime generators and crime attractors. *European Journal of Criminal Policy and Research, 3*, 5–26.

Bureau of International Narcotics and Law Enforcement Affairs (BINLEA), U.S. Department of States. (2009). International Narcotics Control Strategy Report (INCSR). In *Drug and chemical control* (Vol. 1). http://www.state.gov/j/inl/rls/nrcrpt/2009/vol1/index.htm Accessed 10.01.14.

Bureau of International Narcotics and Law Enforcement Affairs (BINLEA), U.S. Department of States. (2010). International Narcotics Control Strategy Report (INCSR). In *Drug and chemical control* (Vol. 1). http://www.state.gov/j/inl/rls/nrcrpt/2010/vol1/index.htm Accessed 10.01.14.

Castillo, G. (2013, August 11). *Domina Cartel de Sinaloa la ruta verde*. La Jornada. Retrieved from http://www.jornada.unam.mx/2013/08/11/politica/002n1pol.

Cave, D. (2012, January 11). *Mexico updates death toll in Drug War to 47,515, but critics dispute the data*. The New York Times. http://www.nytimes.com/2012/01/12/world/americas/mexico-updates-drug-war-death-toll-but-critics-dispute-data.html?module=Search&mabReward=relbias%3Ar&_r=0.

Clarke, R. V., & Cornish, D. B. (1985). Modeling offenders' decisions: a framework for research and policy. *Crime and Justice, 6*, 147–185.

Dell, M. (2011). *Trafficking networks and the Mexican Drug War*. Technical report, MIT.

Dijkstra, E. W. (1959). A note on two problems in connexion with graphs. *Numerische Mathematik, 1*, 269–271.

El Nuevo mapa del narcotráfico en México.(2012). http://www.bbc.co.uk/mundo/noticias/2012/10/121010_mexico_mapa_guerra_narco_carteles_jp.shtml Accessed 30.04.14.

Felson, M. (2014). Eight crime foraging contingencies – Comment on Johnson's review. *Legal and Criminological Psychology, 19*(2), 215–217.

Friman, H. R. (2009). Drug markets and the selective use of violence. *Crime, Law and Social Change, 52*(3), 285–295.

Grillo, I. (2011). *El narco: The bloody rise of Mexican drug cartels*. London, England: Bloomsbury Publishing.

Gutfraind, A., Hagberg, A., & Pan, F. (2009). Optimal interdiction of unreactive Markovian evaders. In *Integration of AI and OR techniques in constraint programming for combinatorial optimization problems* (pp. 102–116). Heidelberg: Springer Berlin.

Herrera-Seara, M. A., Aznar Dols, F., Zamorano, M., & Alameda-Hernandez, E. (2010, March). *Optimal location of a biomass power plant in the province of Granada analyzed by multi-criteria evaluation using appropriate geographic information system according to the analytic hierarchy process*. Paper presented at the International Conference on Renewable Energies and Power Quality (ICREPQ'10), Granada, Spain.

In SightCrime, Beltran Leyva Organization Profile 2014, http://www.insightcrime.org/mexico-organized-crime-news/beltran-leyva-organization-profile, Accessed 11.13.14.

Johnson, S. D. (2014). How do offenders choose where to offend? Perspectives from animal foraging. *Legal and Criminological Psychology, 19*(2), 193–210.

Langner, A. (2013, April 14). *Nuevas alianzas de carteles*. El economista. http://eleconomista.com.mx/sociedad/2013/04/14/tamaulipas-nuevas-alianzas-carteles Accessed 30.10.14.

Makropoulos, C. K., & Butler, D. (2006). Spatial ordered weighted averaging: incorporating spatially variable attitude towards risk in spatial multi-criteria decision-making. *Environmental Modeling & Software, 21*, 69–84.

Medel, M., & Lu, Y. (2014). Predicting illegal cultivation in Mexico: an examination of the environmental and human factors. *Cartography and Geographic Information Science*. http://dx.doi.org/10.1080/15230406.2014.985716.

Medel, M., & Thoumi, F. (2014). Mexican drug "Cartels." In Paoli Letizia (Ed.), *Oxford handbook on organized crime* (pp. 196–218) NY: Oxford University Press.

National Drug Intelligence Center (NDIC), U.S. Department of Justice. (2008). *National Drug Threat Assessment*. http://www.justice.gov/archive/ndic/pubs25/25921/25921p.pdf Accessed 10.01.14.

National Drug Intelligence Center (NDIC), U.S. Department of Justice. (2009). *National Drug Threat Assessment*. http://www.justice.gov/archive/ndic/pubs31/31379/31379p.pdf Accessed 10.01.14.

National Drug Intelligence Center (NDIC), U.S. Department of Justice. (2010). *National Drug Threat Assessment*. http://www.justice.gov/archive/ndic/pubs38/38661/38661p.pdf Accessed 10.01.14.

National Drug Intelligence Center (NDIC), U.S. Department of Justice. (2011). *National Drug Threat Assessment*. http://www.justice.gov/archive/ndic/pubs44/44849/44849p.pdf Accessed 10.01.14.

Shirk, D. A. (2010). Drug violence in Mexico: data and analysis from 2001–2009. *Trends in Organized Crime, 13*(2–3), 167–174.

Snyder, R., & Duran-Martinez, A. (2009). Does illegality breed violence? Drug trafficking and state-sponsored protection rackets. *Crime, Law and Social Change, 52*(3), 253–273.

Tullis, F. L. (1995). *Unintended consequences: Illegal drugs and drug policies in nine countries*. Boulder, CO: L. Rienner Publishers.

Wells, M. (2013, November 4). *Mexico–US border shootouts: Surge of Zetas-Gulf battle? InSight crime*. Retrieved from http://www.insightcrime.org/news-briefs/shootouts-in-mexican-border-city-kill-13.

Zipf, G. (1949). *Human behavior and the principle of least effort*. Cambridge, MA: Addison–Wesley.

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