A Network Flow Model of the Complex Illicit Trafficking Network Operating in the El Paso-Juarez Area

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Authors' Notes: 2LT Armando Penã has a bachelor's degree with honors in system engineering from the United States Military Academy. He is currently serving as an Army Aviation Officer. LTC Elizabeth Schott holds a PhD in Industrial Engineering and has over 20 years service in the Army as both a Quartermaster Officer and an Operations Research Systems Analyst. She is currently serving as an Academy Professor in the Department of Systems Engineering at the United States Military Academy.

Abstract: In 2013, El Paso, TX, was selected for the third time in a row by the Congressional Quarterly Press as the number one safest city with a population over 500,000 people (Borunda, 2013). Just across its border though, sits Ciudad Juarez, considered one of the most dangerous cities in the world. There is a unique social ecosystem between the two cities, a product of many years of shared history and traditions. The El Paso-Juarez area also happens to be one of the most valuable plazas for the Mexican Drug Cartels. According to BBC Mundo, the Sinaloa Cartel has won the El Paso-Juarez territory over the Juarez Cartel and the Zetas (Najar, 2012). Consequently, now that the territory is dominated by one cartel, drug trafficking through the area will likely increase and smuggling through border crossing check points will continue to be more prevalent. The purpose of this research effort is to assist the Border Patrol in allocating its resources towards improved interdiction of illicit trafficking. Whether it is manpower, money, technology, or any other resource, the Border Patrol desires to efficiently allocate to maximize interdiction. This analysis is intended to suggest a tool that will assist in allocating resources and aid the extremely important effort to maintain El Paso, TX, as the safest city in the U.S. by keeping drugs away from the streets. This research presents a network flow model of the complex illicit trafficking network operating in the El Paso-Juarez area, and provides insight that will aid such agencies as the Border Patrol in allocating its resources.

Keywords: Illicit Trafficking, El Paso, Juarez, Border Patrol, Network Flow, Drugs

1. Modeling El Paso-Juarez Illicit Drug Networks

1.1 Background and Introduction

"El Paso welcomes you to the safest city in America," a recorded voice tells travelers arriving at the city's airport. With a rate of 1.9 homicides per 100,000 residents in 2010, the city of Texas' western extremity ranked number one that year, and again in 2011 and currently in 2013, as the safest of all U.S. cities with a population over 500,000, according to a study by Congressional Quarterly Press (Washington Office of Latin America, 2011). Whether measured in the $18 billion spent annually on border security, the 22,000 National Guard soldiers, the record number of criminal deportations in the past four years, or the record-low immigrant apprehensions this past year, the fact is that the border has never been safer (Manning, 2013). However, Mexican cartels are in state of war to control such crossings as this, and the fact is that drugs are flowing constantly through Juarez into El Paso and into the rest of the U.S..

On the other side of the border, the battle in Juarez, Mexico, over the control of drug trafficking into El Paso began in 2008. The Juarez Cartel, Beltran-Leyva Organization, and remnants of the Gulf Cartel (including Los Zetas) have been battling against the Joaquin Guzman-Loera (El Chapo), Ismael Zambada-Garcia, Juan Jose Esparragosa-Moreno, and Ignacio Coronel-Villarreal Organizations for control of drug trafficking in the Plaza (High Intensity Drug Trafficing Area Program, 2009). Since then, conflict has spread across much of Mexico's north, as various cartels, street gangs, local police, and Mexican Army units battle for legitimate authority. The 2010 homicide rate was well over 200 per 100,000 residents. More than 9,000 people have been murdered in Juarez since 2009 (Washington Office of Latin America, 2011). As a former Juarez resident, before 2008, I was able to go out with my friends at night, play at any park, walk anywhere, and visit other people in

neighborhoods that we did not know. After 2008, the night life disappeared. Shootings at restaurants, bars, parks, hospitals, schools, and any other place you can imagine made our houses the only safe place.

While the recent war among various gangs and drug cartels in Mexico has made Juarez, Mexico, one of the world's most dangerous cities, El Paso, Texas remains calm, even eerily prosperous. Still, some three million people are linked at this border, by ties of blood and commerce, and its fluid social ecosystem still retains something unique and emblematic and perhaps, worth saving. The fluid social ecosystem is based in tradition, family, and uniqueness. Most people living in Juarez have family and close friends on the other side of the border. The close relationship between the two border towns is being deteriorated by the violence as the drug cartels battle to control illicit drug trafficking through the area.

1.2 Purpose

The purpose of this effort is to conduct a detailed modeling investigation into the illicit drug trafficking network in the El Paso-Juarez border area based on a holistic system analysis. Our goal is to develop a viable model that can be used by the Border Patrol in the area of El Paso, Texas, to better allocate their resources, so people like me and other El Paso residents are able to feel more secure and assured that the drugs flowing in Juarez, Mexico, stay away from our streets, and more importantly, from our people. Through extensive research, analysis, and system engineering problem solving, we propose a simplified network flow model that estimates drug flow by mode of transport through ports of entry (POE) in El Paso, TX. These results can provide insights to allocating Border Patrol resources.

2. Research

2.1 Federal Strategy Against Drugs

Illicit drug use in America contributed to an estimated $193 billion in crime, health, and loss of productivity costs in 2007, the year for which the most recent estimate is available. The 2012 National Drug Control Strategy serves as the nation's blueprint for reducing drug use and its consequences. Since 2009, the Federal Government has spent more than $31 billion on drug control, including $9.4 billion in fiscal year 2012 for U.S. Law Enforcement and Incarceration and $3.6 billion for Interdiction. Figure 1 compares federal drug control spending (Office of National Drug Control Policy, 2012).

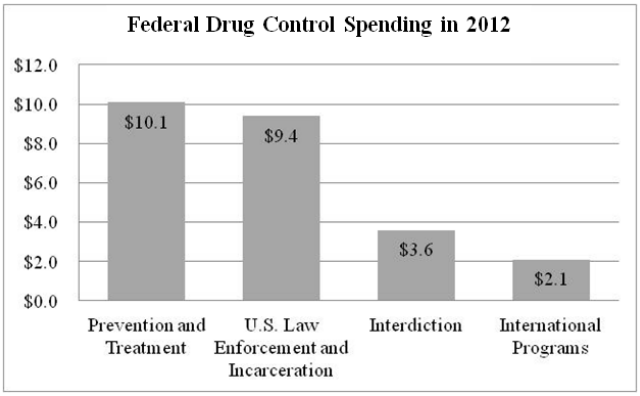


Figure 1. Federal Drug Control Spending in 2012.

2.2 The West Texas High Intensity Drug Trafficking Area (HIDTA)

The West Texas HIDTA is displayed in Figure 2. The West Texas HIDTA encompasses El Paso and overall includes 10 counties in West Texas that lie along a 520-mile section of the U.S.–Mexico border. El Paso POE are extensively used by traffickers to smuggle drug shipments into the HIDTA region. Cocaine availability decreased in the West Texas HIDTA region from 2009 to 2010; however, recent seizures at El Paso POE and law enforcement reporting in early 2011 indicate that the Sinaloa Cartel's greater prominence in the El Paso-Juarez Plaza may be increasing the flow of cocaine into the region. Also, methamphetamine availability is increasing at the border, and the abuse is increasing in the El Paso area as local young adults who previously traveled to Juarez to abuse the drug are moving to El Paso.

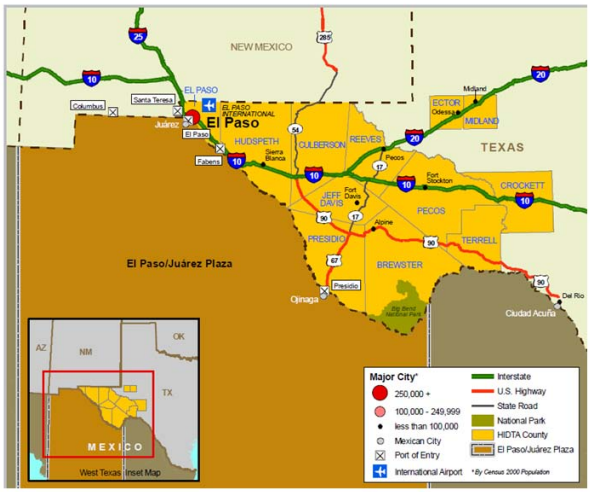


Figure 2. West Texas High Intensity Drug Trafficking Area.

Traffickers use private and commercial vehicles and couriers on foot to transport drug shipments into the U.S.. The following are some examples of seizures that demonstrate the methods that traffickers use to conceal and transport illicit drugs into the HIDTA region: 120 kg of marijuana concealed in the fuel tanks of a tractor-trailer at the Zaragoza POE seized in December 2008; 2.7 kg of marijuana that was packaged in bundles and taped to the legs and midsection of a pedestrian seized at the El Paso del Norte POE in October 2008. These examples are utilized to model illicit trafficking methods of transportation and their capacities (High Intensity Drug Trafficing Area Program, 2009).

2.3 El Paso-Juarez Economic Relationship

In addition to the unique social ecosystem between El Paso and Juarez, there is a very strong economic relationship. These are some of the most important facts about this relationship: 14,000 direct jobs and 30,000 indirect jobs in El Paso are related to the maquiladora activity in Juarez (a maquiladora is a factory in Mexico run by a foreign country and exporting its products to the country of that company); 54.5% of El Paso retailers have stated that at least half of their sales are to Mexican nationals; 18% of all trade between Mexico and the United States passed through this border; an estimated 3,800 retail jobs are created by Mexican nationals spending in El Paso; 3,400-9,000 managers, engineers, executives live in El Paso and work in Juarez; and $15.7 million of 2008's general fund budget comes from the El Paso area and includes bridge revenues and sales taxes from Mexican nationals (Herrera-Flanigan, Gee, Twinchek, & O'Connor, 2008). Therefore, drug related violence in Juarez directly affects El Paso's economy.

2.4 Border Patrol

Customs and Border Protection (CBP) is one of the Department of Homeland Security's largest and most complex components, with a priority of keeping terrorists and their weapons out of the U.S. It also has a responsibility for securing the border and facilitating lawful international trade and travel while enforcing hundreds of U.S. laws and regulations, including immigration and drug laws (CBP, 2013).

Today, the El Paso Sector, Figure 3, is one of nine Border Patrol Sectors that run along the Southwest Border of the U.S. with Mexico. The sector is comprised of eleven stations and covers the geographical region of the entire state of New Mexico and two counties within far west Texas. The El Paso Sector employs approximately 2,400 Border Patrol agents, six permanent vehicle checkpoints and patrols 268 miles of international border encompassing 125,500 square miles (CBP, 2013).

Figure 3. El Paso CBP Sector.

El Paso Sector is understaffed according to interviews by the Washington Office for Latin Americans (WOLA). In 1993, there were 3,444 Border Patrol agents stationed along the entire U.S.-Mexico border, 608 of them in the El Paso Sector. By 2011 there were 18,506 Border Patrol agents along the border, 2,738 of them in the El Paso Sector. Although El Paso has seen growth in numbers, this growth has been under proportion to other sectors contributing to El Paso ranking only seventh in apprehensions (Washington Office of Latin America, 2011).

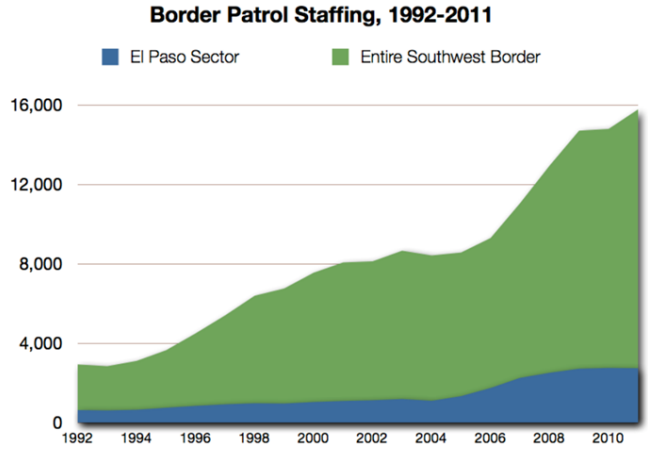


Figure 4. Border Patrol Staffing, 1992-2011.

As we can see in Figure 4, the proportion of personnel working in the El Paso Sector has decreased over the years compared to other sectors. Proper allocation of personnel can better reduce the drug trafficking coming into the United States. The scope of this project initially focuses only on the El Paso-Juarez border within the El Paso Sector.

2.5 Ports of Entry (POE)

The El Paso-Juarez region's international border crossings are a system of regional, statewide, and national significance. They facilitate billions of dollars of trade, providing access to schools and businesses, and contributing to a shared regional culture and lifestyle. Most drugs pass right under border guards' noses, smuggled in some of the tens of thousands of cars and trucks that pass daily through these official POE. Historical data in Tables 1 through Table 5 captures the volume of trucks, buses, privately-owned vehicles (POV), and pedestrians moving through the POE from Juarez to El Paso by bridge and by month for 2011 (U.S. Customs Service and Border Protection, 2012).

Table 1: Paso Del Norte Point of Entry.

PASO DEL NORTE POINT OF ENTRY				
Month	**Trucks**	**Buses**	**POV**	**Pedestrians**
January	-	765	197,558	342,956
February	-	608	16,172	65,899
March	-	833	187,012	344,003
April	-	931	175,823	335,208
May	-	835	181,817	322,527
June	-	871	180,272	214,729
July	-	1,198	189,607	343,103
August	-	1,078	195,533	358,277
September	-	1,274	185,813	332,959
October	-	1,159	187,271	338,075
November	-	1,141	162,102	327,991
December	-	1,042	164,459	353,926
Total	-	11,735	2,023,439	3,779,653

Table 2: Stanton Port of Entry.

STANTON PORT OF ENTRY (DEDICATED LINE)				
Month	**Trucks**	**Buses**	**POV**	**Pedestrians**
January	-	-	71,319	-
February	-	-	85,281	-
March	-	-	104,659	-
April	-	-	103,935	-
May	-	-	104,288	-
June	-	-	92,685	-
July	-	-	85,856	-
August	-	-	98,548	-
September	-	-	58,541	-
October	-	-	107,189	-
November	-	-	100,306	-
December	-	-	94,423	-
Total	-	-	1,107,030	-

Table 3: Bridge of the Americas Port of Entry.

BRIDGE OF THE AMERICAS PORT OF ENTRY				
Month	**Trucks**	**Buses**	**POV**	**Pedestrians**
January	25,073	1,226	288,841	75,303
February	23,886	1,016	248,312	65,899
March	30,762	1,150	278,139	85,495
April	27,722	1,142	269,942	86,453
May	29,627	1,068	267,122	84,246
June	30,637	1,063	259,242	77,649
July	28,019	895	277,190	83,335
August	31,530	817	293,194	78,499
September	29,577	773	278,654	79,590
October	29,171	816	278,228	83,770
November	27,112	822	251,625	85,239
December	24,493	894	277,687	89,939
Total	337,609	11,682	3,268,176	975,417

Table 4: Zaragoza Port of Entry.

ZARAGOZA (YSLETA) PORT OF ENTRY				
Month	**Trucks**	**Buses**	**POV**	**Pedestrians**
January	30,049	1	149,810	96,304
February	28,747	-	135,546	84,015
March	36,468	-	157,379	104,043
April	32,722	-	149,874	112,891
May	33,177	-	148,653	103,426
June	33,490	-	150,577	97,383
July	29,198	-	159,750	105,604
August	33,471	2	168,381	98,186
September	32,538	-	158,734	95,558
October	31,895	-	163,283	96,801
November	30,473	-	154,728	95,786
December	27,280	-	160,324	102,506
Total	379,508	3	1,857,039	1,192,503

Table 5: Santa Teresa, NM, Point of Entry.

SANTA TERESA, NM, POINT OF ENTRY				
Month	**Trucks**	**Buses**	**POV**	**Pedestrians**
January	6,394	17	37,474	7,900
February	5,224	8	30,677	5,825
March	6,773	31	34,616	8,584
April	5,949	74	35,005	15,913
May	6,097	12	32,935	8,392
June	6,465	18	33,111	9,223
July	5,994	30	35,628	18,727
August	5,732	20	32,436	10,488
September	5,775	23	30,176	7,224
October	6,145	16	33,160	6,338
November	6,172	33	36,273	7,807
December	5,446	33	37,123	14,392
Total	72,166	315	408,614	120,813

This data will be used to estimate the capacity of each POE that will be used in our model. For example, in January at the Paso Del Norte POE, there were 197,558 POVs and 342,956 Pedestrians crossing. Additionally, drug seizure data is also available in order to estimate the amount of drugs that are transported across the border. Border Patrol seized 27,482 kg (kg) of illegal drugs at El Paso area POE in fiscal year 2010. Although seizure amounts are broken down into various drug types (marijuana, cocaine, heroin, and methamphetamine), we will model drugs as a whole, estimating the annual combined supply of drugs the Sinaloa Cartel has to ship (High Intensity Drug Trafficing Area Program, 2009).

2.6 New Drug Cartels Territory

In 2006, when President Felipe Calderon took office, there were four main cartels in Mexico: Sinaloa Cartel, Juarez Cartel, Gulf Cartel and Familia Michoacana. The recent declared war between the government and the drug cartels, and the internal battles between the main cartels for the control of the main routes and markets of illicit drugs, created several divisions among the main cartels and even new organizations. According to specialists and federal agencies, there are at least seven powerful cartels and at least 20 local groups. However, there are only two groups that control 80% of the drugs: the Sinaloa Cartel and the Zetas. The Sinaloa Cartel has recently won the battle over Juarez, where “El Chapo” controls all the traffic in Chihuahua and Durango, Mexico. In 2012, BBC Mundo launched a new map of the main drug cartels in Mexico, where we can see how the Sinaloa Cartel has taken over the El Paso-Juarez area (Najar, 2012).

Figure 5. Territories of the Main Mexican Drug Cartel.

With this information we assume our supply source is only one cartel rather than having multiple cartels supplying the drugs into the United States.

2.7 Methods of Crossing Illegal Drugs

Most drugs cross into the U.S. through the main POE in trucks and POVs. Pedestrians also cross drugs by hiding them in their boots, jackets, pockets, or other creative ways. Ultra light aircraft and tunnels are also used.

Mexican organized crime groups use ultra-light aircraft to drop marijuana bundles in fields and desert scrub across the U.S. border. The incursions are hard to detect and are on the upswing. The pilots release 250 pound (110 kilogram) payloads that land on the American territory (Marosi, 2011). We will use the capacity of the ultra-light aircrafts in our model.

Drug-smuggling tunnels are very rare in El Paso. However, in June 2010, Border Patrol discovered a tunnel used by traffickers stretching 130 feet under the concrete-lined Rio Grande. Though small, dark and unventilated, the tunnel allowed people to crawl from Mexico to the U.S. The Border Patrol found 90 kg of marijuana inside the tunnel and arrested a 17-year-old from Mexico (Hinojosa, 2010). Consequently, our model will use five methods of transportation to include trucks, POV, and pedestrians through the main POE, and ultra-light aircraft and tunnels through the wilderness area in the Anapra vicinity.

3. Problem Statement

In order to frame the situation in the El Paso-Juarez border, a thoughtful analysis of the above information was necessary to have a better understanding of the dynamics of the two cities. Both cities are completely different regarding the violence in each one, but at the same time they share a unique social ecosystem and a very strong economic relationship that makes both cities dependent on each other. Since the violence in Juarez is out of control, it is important that such violence does not spill over in to El Paso. One of the roots of such violence is illegal drug trafficking. Therefore, if we are able to develop a model that provides insights to the Border Patrol in allocating resources in the El Paso area, we can mitigate the negative effects of drug trafficking and contribute something to keeping the ties between Juarez and El Paso. Keeping in mind the needs and the desires of both cities, we developed the following problem statement:

Develop a *practical model* that can be incorporated into the tools and techniques of the Border Patrol, El Paso area, and *offer insights* into the allocation of resources to the different Ports of Entry to affect illicit trafficking.

Understanding the complexity of illicit drug trafficking, we made a conscious decision to narrow our focus to the El Paso-Juarez area, and not the El Paso Sector defined by CBP as the eleven regions discussed previously. Being able to narrow our area of focus is intended to provide better localized results that will help people in charge of this area.

4. Approaches Considered

4.1 Network Flow

Network flow models have a wide range of applicability to real world problems. They are usually used in airlines, transportation companies, distribution centers, and many other scenarios where something needs to be sent or transported from a source to a destination using a certain transport method. Flow is associated with the network, entering and leaving at the nodes and passing through the arcs. Flow is conserved at each node, implying that the total flow entering a node, either from arcs or external supplies, must be equal the total leaving the node, either to arcs or to the external demands. The arc flows are decision variables for the network flow programming model. The flow is limited in an arc by the lower and upper bounds on flow. Sometimes the term capacity refers to the upper bound on flow. Such limiting attributes are very important for the formulation of our network flow model (Chinneck, 2001). Network flow modeling provides a useful approach to our problem as we can represent the illicit drug smuggling network. We label the Sinaloa Cartel as the supplier, their methods of transportation through routes or POE as the arcs or routes, and the U.S. as the demand.

4.2 Network Science

According to Ted G. Lewis, a Professor of Computer Science at the Naval Postgraduate School and author of *Network Science: Theory and Practice*, network science can be defined in numerous ways. The National Research Council defines network science as an "organized knowledge of networks based on their study using the scientific method" (Lewis, 2009). In other words, it is the knowledge and use of networks to better understand a culture, organization, or flow of information and material. Lewis says there are two key ingredients of network science: "(1) it is the study of the structure of a collection of nodes and links that represent something real, and (2) it is the study of dynamic behavior of the aggregation of nodes and links" (Lewis, 2009). Nodes in a network can be defined as many different things to include information centers and specific humans, individuals with knowledge in a subject area, taxes, government spending, or even consumers or employment. Further efforts could be made in the future to use network science in order to improve our model.

4.3 Case Studies

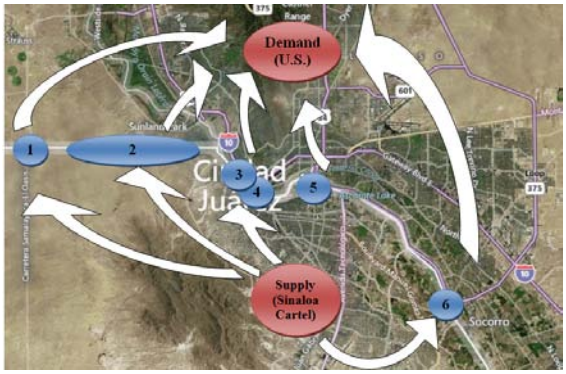
A case study is a detailed investigation of a single individual or group. A case study can be qualitative or quantitative in nature, and often combines elements of both. The defining feature of a case study is a holistic approach, which aims to capture all the details of a particular individual or group. We could also use the results from comparison of various case studies to help the Border Patrol in the El Paso area to allocate its resources better in order to stop the constant smuggling of drugs in such area (National Center for Technology Innovation, 2013).

The border of San Diego and Tijuana is an example where a case study could potentially be very helpful. There is a similitude between the two borders such as the unique relationship between the two cities, but most importantly the struggle of the Border Patrol to stop the drug trafficking. Therefore, we could utilize data and measures from the San Diego-Tijuana border in order to benefit our effort in El Paso area.

5. Network Flow Model

5.1 Defining the Network

Based on research, we were able to create a practical model that helps identify the main crossing points for the drugs. Figure 6 shows the network outline of our model. We identify the source or supply node of our network as being the Sinaloa Cartel in Juarez and the destination or demand node as the U.S. We identify six different routes or arcs representing the main crossing points used by the Sinaloa Cartel to illegally cross the drugs.



Supply (Sinaloa Cartel)

i(1) = Santa Teresa, NM, POE
i(2) = Anapra Vicinity
i(3) = Paso del Norte POE
i(4) = Stanton POE
i(5) = Americas POE
i(6) = Zaragoza POE

Demand (U.S.)

Figure 6. Network Outline.

Each route has different methods that can be used to transport drugs and the maximum capacity for each route by method is modeled as the largest month of the year. For example, in the Paso del Norte POE (route 3) the maximum number of pedestrians that crossed in 2011 is 358,277 in December, which gives the upper bound for the pedestrians in route 3. We modeled the max capacity of each of the methods by month for each routes this way. Figure 7 shows the capacities at each route per method of transportation.

CAPACITIES PER NODE PER METHOD OF TRANSPORTATION (IN UNITS)											
		Trucks		POVs		Pedestrians		Ultra-light Aircraft		Tunnels	
Nodes	Name	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Source	Sinaloa Cartel	0	∞	0	∞	0	∞	0	∞	0	∞
1	Santa Teresa, NM, POE	0	6,773	0	37,474	0	18,727	0	0	0	0
2	Anapra vicinity	0	36,468	0	0	0	0	0	5	0	2
3	Paso del Norte POE	0	0	0	197,558	0	358,277	0	0	0	0
4	Stanton POE	0	0	0	107,189	0	0	0	0	0	0
5	Americas POE	0	31,530	0	293,194	0	89,939	0	0	0	0
6	Zaragoza POE	0	36,468	0	168,381	0	112,891	0	0	0	0
Demand	United States	0	∞	0	∞	0	∞	0	∞	0	∞

Figure 7: Capacities at Each Node per Method of Transportation.

We define what methods of transportation are feasible to go through each route. For example, in node one (Santa Teresa, NM, POE), it is extremely hard to have a tunnel right underneath the bridge or to have ultra-light aircraft flying over the POE. Therefore, the methods of transportation for route one is limited to trucks, POVs, and pedestrians. Similarly, in route two (Anapra Vicinity) there is not a single road that allows pedestrians or POVs to enter the United States. Cartels rely in ultra-light aircraft, tunnels, and trucks to smuggle drugs in this vicinity. Additionally, the amount of drugs that each method of transportation is available to carry is defined by our previous research. The five methods modeled include Trucks, POVs, Pedestrians, Ultra-light Aircraft, and Tunnels. Each method is modeled as having an average capacity as follows: A = Trucks (120 kg per truck); B = POVs (30 kg per POV); C = Pedestrians (3 kg per person); D = Ultra-light aircraft (110 kg per aircraft); E = Tunnels (90 kg per trip). Some methods are not employed on some routes. Methods of transportation for each route are as follows: *i(1)* = A, B, C; *i(2)* = A, D, E; *i(3)*= B, C; *i(4)*= B; *i(5)* = A, B, C; *i(6)* = A, B, C. See Figure 8.

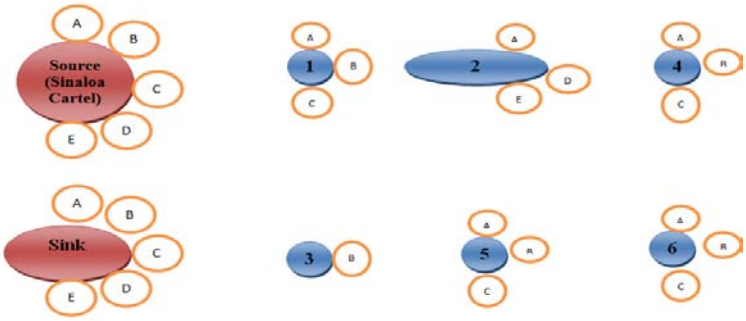


Figure 8: Different Methods of Transportation per Node.

Once we identified all the routes, methods of transportation, and the capacities for each, we developed the linear programming of our network flow.

5.2 Decision Variables

The decision variables will change in order to maximize the objective function. In this model, the decision variables are the amount of drugs the cartels are able to smuggle through each route organized by method of transportation and month. The total amount of drugs at each route is a sum of the drugs smuggled by each method of transportation used and the month of the shipment. They are represented by each leg, or arc, in the maximization flow network.

X_{ijk} = Amount of drugs in Kilos sent through route *i* by method of transportation *j* during month *k*

Figure 9 is a representation of the network where each arc is a decision variable. It only shows one arc for each route for simplicity.

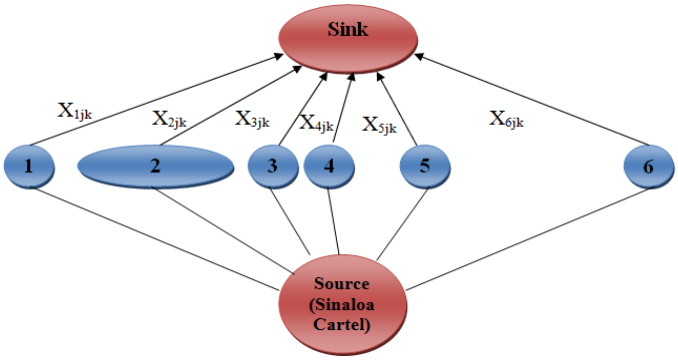


Figure 9. Network Flow Model.

The costs along these arcs are usually modeled as a function of actual cost in dollars. However, it is very difficult to gather accurate information regarding the costs that cartels spend transporting the drugs. Instead we model cost as *gain* (in percentage). For example, the cartels have a higher risk of losing their drugs if inspections at the POE are stricter, which could be represented with a lower *gain* percentage. If inspections are quick and not enforced, there is a lower percentage of getting caught, which is represented with a higher *gain* percentage. For example, if we analyze the data, February seems to have very low traffic in the official POE. Low traffic volume allows the CPB agents to have more meticulous inspections. The cartels have a higher risk to get caught and a lower *gain* value. During Christmas time, there are a lot of people traveling in and out the U.S. Border Patrol agents are required to keep inspection times to a minimum since people trying to cross to the U.S. may take up to three hours waiting in line to get inspected. Then, there is a lower risk to get caught and a higher *gain* value.

200 metric tons of drugs were seized from the 378 metric tons estimated to have been shipped to the U.S. from South America in 2009 (United Nations Office on Drugs and Crime, 2011). We use this approximation of 53% loss in

seizures to model the *gain* value in our formulation.

We assumed that each POE will reach a maximum *gain* value of 100% when it is at its maximum capacity (busiest), and a *gain* value of 47% when it is at its lowest capacity (slowest). Any capacity between the lowest and maximum capacity will be calculated with a linear relationship between those two values. Table 6 is an example of the *gain* value at the Americas POE (route 5).

Table 6: Americas Point of Entry (Gain-Value).

AMERICAS POINT OF ENTRY (GAIN-VALUE)								
Month	**Trucks**	**Gain**	**Month**	**POV**	**Gain**	**Month**	**Pedestrians**	**Gain**
February	23,886	47.00%	February	248,312	47.00%	February	65,899	47.00%
December	24,493	50.39%	November	251,625	53.72%	January	75,303	67.38%
January	25,073	54.39%	June	259,242	62.86%	June	77,649	72.54%
November	27,112	68.46%	May	267,122	72.32%	August	78,499	74.41%
April	27,722	72.67%	April	269,942	75.70%	September	79,590	76.81%
July	28,019	74.72%	July	277,190	84.40%	July	83,335	85.05%
October	29,171	82.67%	December	277,687	84.99%	October	83,770	86.01%
September	29,577	85.47%	March	278,139	85.54%	May	84,246	87.06%
May	29,627	85.82%	October	278,228	85.64%	November	85,239	89.24%
June	30,637	92.79%	September	278,654	86.15%	March	85,495	89.80%
March	30,762	93.65%	January	288,841	98.38%	April	86,453	91.91%
August	31,530	100.00%	August	293,194	100.00%	December	89,939	100.00%

At the Americas POE (route 5), February had the fewest number of trucks, POVs and Pedestrians through the route during the year. It is assumed that the Border Patrol is able to be more meticulous with inspections during the slower months leading to a higher likelihood of interdiction, and in turn less *gain* for the traffickers. The *gain* assumed is only 47% for each of these methods in February. The busiest month for Trucks and POVs is August resulting in a 100% *gain* and the busiest month for Pedestrians is December resulting in a 100% *gain*. Each other month's *gain* is derived based on the relative monthly volume of traffic by method. This process is applied to every month and method of transportation at every route.

5.3 Objective Function and Constraints

The objective of the network flow is seen through the cartel point of view. One way for the Border Patrol to optimize its allocation of its resources, whether it is money, manpower, or any other resource, is to be able to anticipate the cartel's move. It is more convenient to create a model that mirrors the cartel's rational course of action, which is to maximize its revenue. Therefore, our model will maximize the amount of drugs being smuggled into the U.S. The principle equation of our network flow model follows.

$$max: \sum_{i=1}^{6}\sum_{j=1}^{5}\sum_{k=1}^{12} g_{ijk} * x_{ijk} \qquad (1)$$

$$Limit_{ik}$$

In equation (1), g is the *gain* value and x is the amount of drugs being transported to the U.S. in kilograms by each route, method of transportation, and by month. We will utilize the maximized decision variables from each route for the analysis. For example, once we run the network flow model in a linear program, we will be able to see the amount of drugs being smuggled at each node per method of transportation per month. We can use that information to compare it with the optimized amount from all other nodes and see where and when the drugs are being shipped. We can compare the data from each route to see where it may make sense to allocate more resources each month.

An important assumption is the initial amount of drugs the Sinaloa Cartel is trying to ship. As discussed previously, the World Drug Report 2011, 53% of the total drugs is seized. If the Border Patrol was able to seize 27,482 kg in fiscal year 2010, we can assume that the initial amount of drugs that the cartels have to cross to the U.S. is 51,853 kg. Since we don't

know the actual route(s), month(s), and method(s) of transportation the Sinaloa Cartel used to smuggle the 24,371 kgs successfully into the U.S., we assume that the cartels equally distribute the drugs per month and per route in order to keep up with the demand in all areas of El Paso. Consequently, we used the amount 339 kg per route per month.

These are the final constraints:

$$x_{ijk} \leq Capacity_{ijk} \tag{2}$$

$$\sum_{j=1}^{5} x_{ijk} \leq Limit_{ik} \tag{3}$$

$$x_{ijk} = d_j * Xunits_{ijk} \tag{4}$$

Equation (2) regulates that the amount of drugs crossed through each route is not greater than the capacity of each route. Equation (3) limits the amount of drugs transported due to the initial supply of the cartel, and equation (4) converts every unit of transportation into amount of drugs the cartel smuggles in kilograms depending on the capacity of each method of transportation (d).

5.4 Method for Solving

Although this initial network flow model is simplified with only two nodes and can be solved in Microsoft Excel, we chose CPLEX. IBM ILOG CPLEX is a high-performance mathematical programming solver for linear programming. Its technology enables decision optimization for improving efficiency, reducing costs, and increasing profitability (IBM, 2013). CPLEX gives the opportunity to easily adjust the decision variables, objective function, and constraints to make changes to the model. This software can be used in the way ahead by adding many more constraints and decision variables since IBM ILOG CPLEX Optimizer has solved problems with millions of constraints and variables (IBM, 2013). With the intent to expand the network flow structure in future work, we used CPLEX as the method for solving this optimization problem.

5.5 Results

We set up the linear program to have the optimal solution output both amount of drugs in kilograms crossed into the U.S. and the units of each specific method of transportation being utilized to cross the drugs. Analyzing the output associated with our decision variables (X_{ijk} = Amount of drugs in Kilos sent through route *i* by method of transportation *j* during month *k)*, can provide insights into the likely methods of transportation used each month at each route which in turn can aid the Border Patrol to focus their inspections in either the truck line, POV line, or the pedestrian line at a given POE. For example, Figure 10 shows example output results.

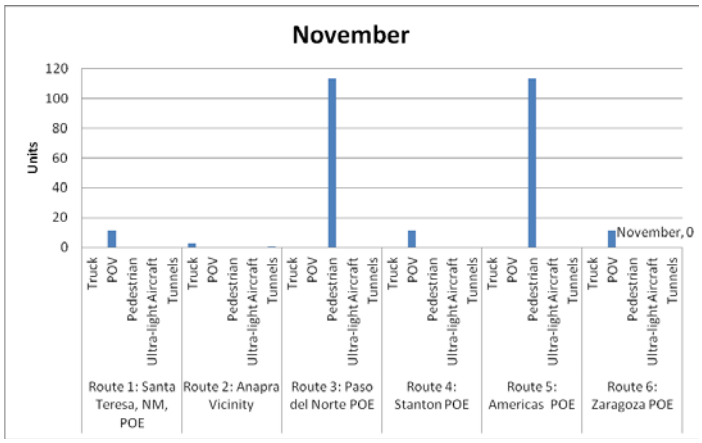


Figure 10. Total Units Utilized in November.

Output results for November suggest that at routes 1, 4, and 6, CPB should focus their inspections more in the POV line. They should have extra manpower, sniffing dogs, or other resources available in those POV lines. Route 2 will experience some activity in the truck line and there is the possibility of a run through a tunnel in the Anapra vicinity. Routes 3 and 5 will have more activity in the pedestrian line of those two POE. Our model will provide the Border Patrol with viable insights to narrow their inspection efforts and allocation of resources on a specific method of transportation.

6. Conclusion and Way Forward

Network flow modeling has the potential to be a useful approach in allocating resources to combat illicit trafficking. This effort addresses a simplified network flow model in which the results are intended to provide Border Patrol agents insights into likely methods of transporting drugs through six primary transportation routes from Juarez into El Paso. We can compare and contrast every method of transportation at every route each month to see where they need extra manpower or other resources to better interdict drugs. This will allow the Border Patrol to successfully allocate their resources to fight against the Sinaloa Cartel.

This approach can be expanded and adjusted for more robust data or different areas. Our next step in this effort is to continue incorporating more robust data and assumptions into our model for more accurate findings. We can forecast that the Sinaloa Cartel will continue to take over the Juarez Plaza, while analyzing their methods of transportation and their rationale used to decide where and when to ship their drugs into the U.S. Improving the *gain* value used in this model is essential for further and more accurate results. This might include more research about what risks the Sinaloa takes into consideration before shipping a load. Do they care if they lose a couple of kilos? Do they really have unlimited resources? All of these questions are crucial to develop a more accurate *gain* value. In addition, this model only applies to the El Paso-Juarez border; however, with further research, it can be developed to model the entire El Paso Sector and one day to the entire Mexican border. Despite the limitations, we are confident that this practical model provides useful insights to the Border Patrol, El Paso area, to better allocate their resources.

7. References

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Washington Office of Latin America. (2011, December 20). *An Uneasy Coexistence: Security and Migration Along the El Paso-Ciudad Juarez Border.* Retrieved from WOLA: Officina de los Derechos Humanos, la Democracia y la Justicia Social: http://www.wola.org/es/node/2894

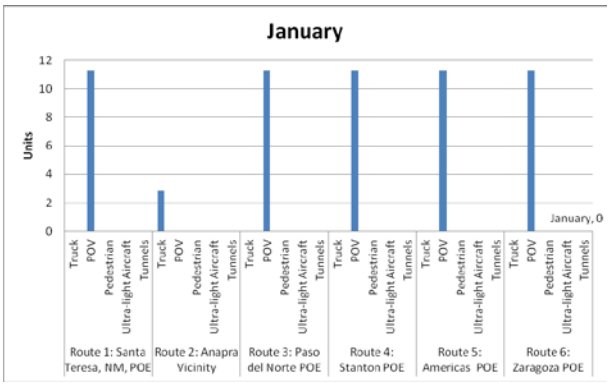
APPENDIX A
IBM ILOG CPLEX Optimizer Code

```
/*********************************************
 * OPL 12.5 Data
 * Author: x38858
 * Creation Date: Apr 19, 2013 at 1:50:36 PM
 *********************************************/
r= 6;
t= 5;
m= 12;

d=[120 30 3 110 90];

gain=[

  [[0.8693  0.4700  1.0000  0.7172  0.7678  0.8936  0.7325  0.6429  0.6577  0.7842  0.7934  0.5451]
        [1.0000  0.5179  0.8055  0.8339  0.6828  0.6956  0.8793  0.6463  0.4700  0.6992  0.9264  0.9885]
        [0.5546  0.4700  0.5827  0.8832  0.5748  0.6089  1.0000  0.6607  0.5269  0.4906  0.5508  0.8208]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]]


  [[0.6429  1.0000  0.4700  0.7842  0.7325  0.5451  0.7678  0.8693  0.7934  0.7172  0.6577  0.8936]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.4700  0.9885  0.6992  0.6956  0.8793  0.8339  0.6828  0.9264  1.0000  0.8055  0.6463  0.5179]
        [0.6089  1.0000  0.5748  0.4906  0.5827  0.5546  0.4700  0.5508  0.8208  0.8832  0.6607  0.5269]]


  [[0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [1.0000  0.4700  0.9623  0.9299  0.9473  0.9428  0.9699  0.9870  0.9589  0.9631  0.8901  0.8969]
        [0.9665  0.4700  0.9685  0.9510  0.9256  0.7100  0.9667  1.0000  0.9465  0.9567  0.9365  0.9884]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]]

  [[0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.4700  0.7703  0.9835  0.9755  0.9794  0.8518  0.7766  0.9162  0.6167  1.0000  0.9356  0.8709]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]]

  [[0.5439  0.4700  0.9365  0.7267  0.8582  0.9279  0.7472  1.0000  0.8547  0.8267  0.6846  0.5039]
        [0.9838  0.4700  0.8554  0.7570  0.7232  0.6286  0.8440  1.0000  0.8615  0.8564  0.5372  0.8499]
        [0.6738  0.4700  0.8980  0.9191  0.8706  0.7254  0.8505  0.7441  0.7681  0.8601  0.8924  1.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]]

  [[0.6392  0.5637  1.0000  0.7943  0.8207  0.8388  0.5899  0.8377  0.7836  0.7463  0.6638  0.4700]
        [0.6791  0.4700  0.8002  0.6801  0.6605  0.6913  0.8381  1.0000  0.8218  0.8946  0.7577  0.8473]
        [0.6615  0.4700  0.8008  1.0000  0.7897  0.6809  0.8289  0.6953  0.6480  0.6704  0.6521  0.7731]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]
        [0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000  0.0000]]
```

```
        ];
                /*GAIN is composed of six matrices. Each matrix represents a route.
                Each matrix is composed of 12 cols and 5 rows. Each column
                represents a month, and each row represents a method of transportation.
                It goes in this order: truck, POV, Pedestrians, Ultra-light
                Aircraft and Tunnels.*/

capacity=[
  [[ 6773  6773  6773  6773  6773  6773  6773  6773  6773  6773  6773  6773]
        [37474 37474 37474 37474 37474 37474 37474 37474 37474 37474 37474 37474]
        [18727 18727 18727 18727 18727 18727 18727 18727 18727 18727 18727 18727]
        [   0    0    0    0    0    0    0    0    0    0    0    0]
        [   0    0    0    0    0    0    0    0    0    0    0    0]]

  [[36468 36468 36468 36468 36468 36468 36468 36468 36468 36468 36468 36468]
        [   0    0    0    0    0    0    0    0    0    0    0    0]
        [   0    0    0    0    0    0    0    0    0    0    0    0]
        [   5    5    5    5    5    5    5    5    5    5    5    5]
        [   2    2    2    2    2    2    2    2    2    2    2    2]]

  [[    0     0     0     0     0     0     0     0     0     0     0     0]
        [197558 197558 197558 197558 197558 197558 197558 197558 197558 197558 197558 197558]
        [358277 358277 358277 358277 358277 358277 358277 358277 358277 358277 358277 358277]
        [    0     0     0     0     0     0     0     0     0     0     0     0]
        [    0     0     0     0     0     0     0     0     0     0     0     0]]

  [[     0      0      0      0      0      0      0      0      0      0      0      0]
        [ 107189  107189  107189  107189  107189  107189  107189  107189  107189  107189  107189  107189]
        [     0      0      0      0      0      0      0      0      0      0      0      0]
        [     0      0      0      0      0      0      0      0      0      0      0      0]
        [     0      0      0      0      0      0      0      0      0      0      0      0]]

  [[ 31530  31530  31530  31530  31530  31530  31530  31530  31530  31530  31530  31530]
        [293194 293194 293194 293194 293194 293194 293194 293194 293194 293194 293194 293194]
        [ 89939  89939  89939  89939  89939  89939  89939  89939  89939  89939  89939  89939]
        [    0     0     0     0     0     0     0     0     0     0     0     0]
        [    0     0     0     0     0     0     0     0     0     0     0     0]]

  [[ 36468  36468  36468  36468  36468  36468  36468  36468  36468  36468  36468  36468]
        [ 168381  168381  168381  168381  168381  168381  168381  168381  168381  168381  168381  168381]
        [ 112891  112891  112891  112891  112891  112891  112891  112891  112891  112891  112891  112891]
        [     0      0      0      0      0      0      0      0      0      0      0      0]
        [     0      0      0      0      0      0      0      0      0      0      0      0]]

];

                        /*CAPACITY is composed of six matricies. Each matrix represents a route.
                        Each matrix is composed of 12 cols and 5 rows. Each column
                        represents a month, and each row represents a method of transportation.
                        It goes in this order: truck, POV, Pedestrians, Ultra-light
                        Aircraft and Tunnels.*/

limit=[
            [339 339 339 339 339 339 339 339 339 339 339 339]
            [339 339 339 339 339 339 339 339 339 339 339 339]
```

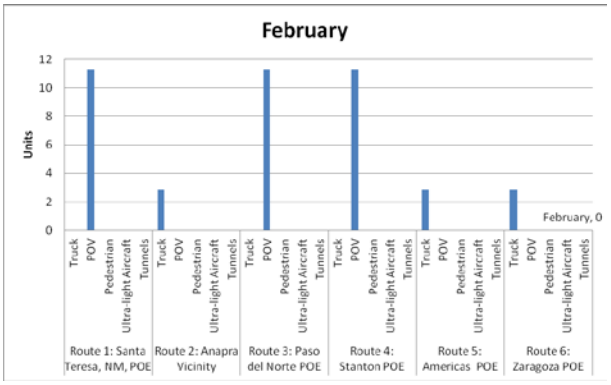
```
[339 339 339 339 339 339 339 339 339 339 339 339]
[339 339 339 339 339 339 339 339 339 339 339 339]
[339 339 339 339 339 339 339 339 339 339 339 339]
[339 339 339 339 339 339 339 339 339 339 339 339]

];
                /*LIMIT is composed of one matrix. This matrix is composed of 12 cols
                and 6 rows. Each column represents a month, and each row represents
                a route.*/

/*********************************************
 * OPL 12.5 Model
 * Author: x38858
 * Creation Date: Apr 19, 2013 at 1:50:36 PM
 *********************************************/

 int r = ...;
 int t = ...;
 int m = ...;

 range route = 1..r;
 range transpo = 1..t;
 range month = 1..m;

 float gain[route][transpo][month]= ...; /*how much the cartels are going to be able to cross*/
 float capacity[route][transpo][month]= ...; /*capacities of each point of entry*/
 float limit [route][month]= ...;

 float d [transpo]= ...;/* converts unit for mode of transport to kilograms */

 dvar float+ x[route][transpo][month];/* weight in kilos */
 dvar float+ xunits[route][transpo][month]; /* number of units */

maximize sum(i in route) sum(j in transpo) sum(k in month) gain[i,j,k]*x[i,j,k];

subject to {
   forall (i in route) forall (j in transpo) forall (k in month) x[i,j,k] ==d[j]*xunits[i,j,k];
   /*This formula converts every unit of transportation into amount of drugs the cartel smuggles.
   The unit is Kilograms.*/

        forall (i in route) forall (j in transpo) forall (k in month) x[i,j,k]<= capacity[i,j,k];
        /*This constraint regulates that the amount of drugs crossed through each port of entry is not
        greater than the capacity of each port of entry*/

        forall (i in route) forall (k in month) sum (j in transpo) x[i,j,k]<= limit[i,k];
        /*This constrait limits the amount of drugs transported due to the initial supply of the cartel*/

            }
```

APPENDIX B
Results of the Total Units of Methods of Transportation Utilized by the Drug Cartel per Month



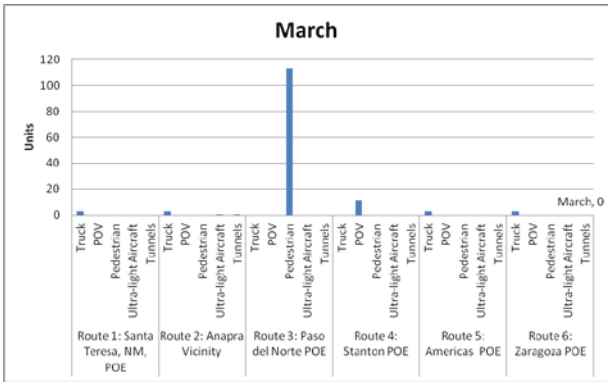
Total Units Utilized in January

Every POE, with the exception of Route 2, will experience illicit activity through the POV lane. CBP needs to allocate more resources such as sniffing dogs, manpower, metal detectors, better x-ray machines, and more carefully inspections in order to seize the illegal contraband. There is also truck activity through the Anapra vicinity.



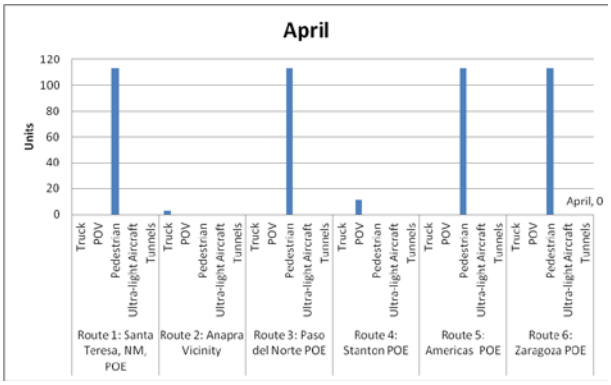
Total Units Utilized in February

In February there is going to be POV activity in routes 1, 3, and 4 and truck activity in the Anapra vicinity and routes 5 and 6. Since there is not illegal pedestrian activity during this month, CBP can close few lines and allocate the extra manpower in the POV lane.



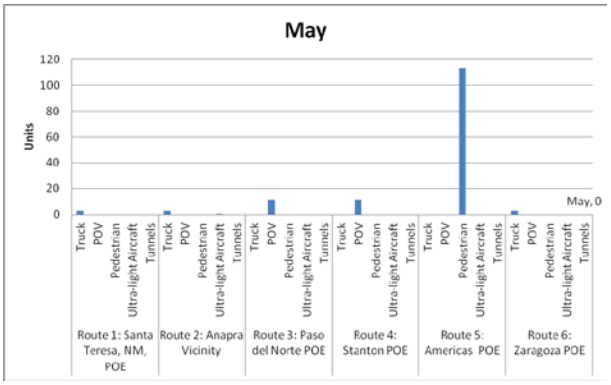
Total Units Utilized in March

In March, El Paso del Norte POE seems to have a lot of activity in the pedestrian line. CBP and Border Patrol agents need to allocate more resources such as manpower, sniffing dogs, or even an extra x-ray machine to check every pedestrian trying to cross the border. There is also going to be some activity in the truck line in routes 1, 2, 4, and 6, and some activity in the POV lines in routes 1 and 4. We can also see that the cartels might use some ultra-light aircraft and a couple of runs through the tunnels for the first time in the year.



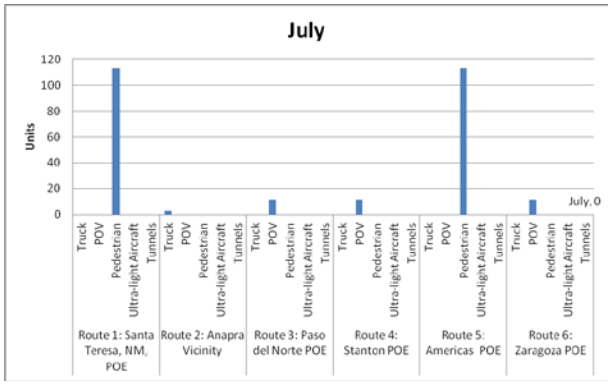
Total Units Utilized in April

In April there is an increment in illegal activity in the pedestrian lines in routes 1, 3, 5, and 6. Once again, the CBP and the Border Patrol agents need to spend extra time inspecting pedestrians at those POE.



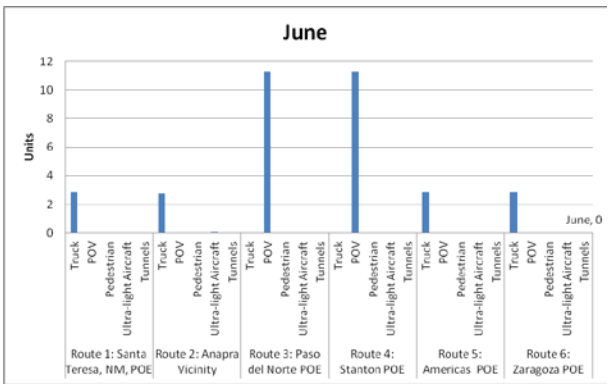
Total Units Utilized in May

In May, the pedestrian line in the Americas POE is going to be targeted by the cartel as their main crossing point. In this month, the truck and POV activity is split throughout each POE. In addition, there might be an ultra-light aircraft crossing attempt in the Anapra Vicinity.



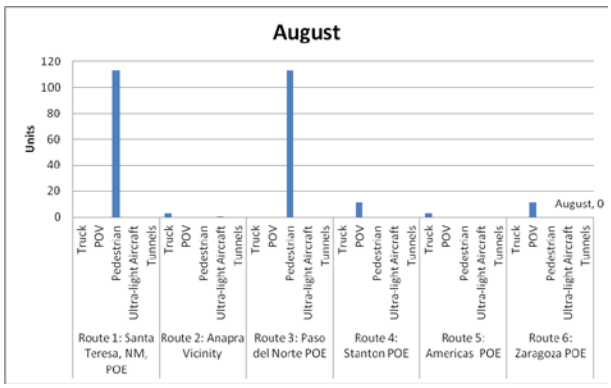
Total Units Utilized in July

In July, route 1 and route 6 has a large activity in pedestrian utilization. The CBP and Border Patrol agents need to be ready to inspect meticulosly the people trying to cross the border, even people with student visas, special worker visas, temporary permits, and any other case of forms of entry. Trucks are only being utilized in route 2. Therefore, they can use the resources allocated for the truck lines on inspecting POV on the other POE.



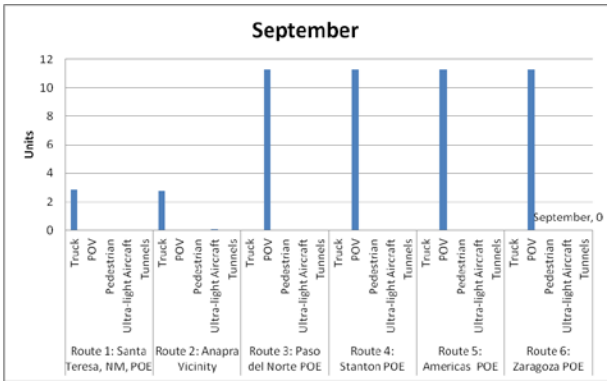
Total Units Utilized in June

In June, the cartels will shift from pedestrians to trucks and POVs as their method of transportation. There is an increase in the POV lines in routes 3 and 4. There is also going to be a lot of activity in the Anapra vicinity with trucks and ultra-light aircraft.



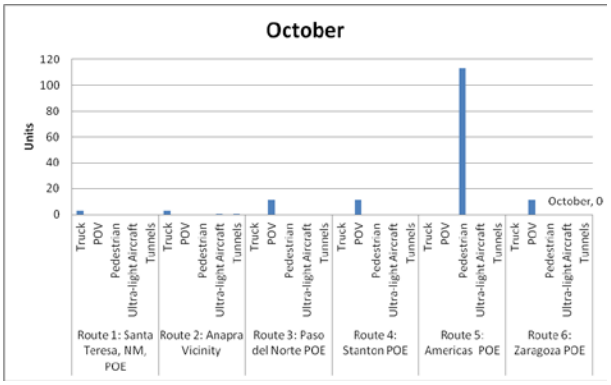
Total Units Utilized in August

August continues to show a large activity in the pedestrian line of the Santa Teresa, NM, POE, but this time the pedestrian activity shifted from route 5 to route 3. There is also POV activity in routes 4 and 6. In the Anapra vicinity, the cartels will not utlize the tunnel, instead they will use ultra-light aircraft and trucks to cross the dessert.



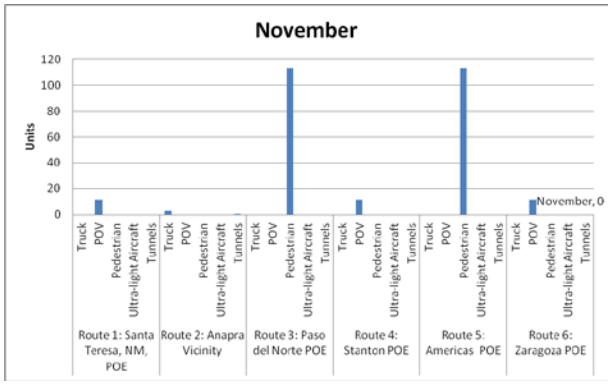
Total Units Utilized in September

During September, the pedestrian shows no activity on any route. The Anapra vicinity will have activity trucks, and ultra-light aircraft, while routes 3, 4, 5, and 6 will experience POV activity. Although there is going to be an even amount of activity in the last 4 routes, changes within their own POE can be made in order to better allocate manpower and other resources to have better results seizing illegal drugs.



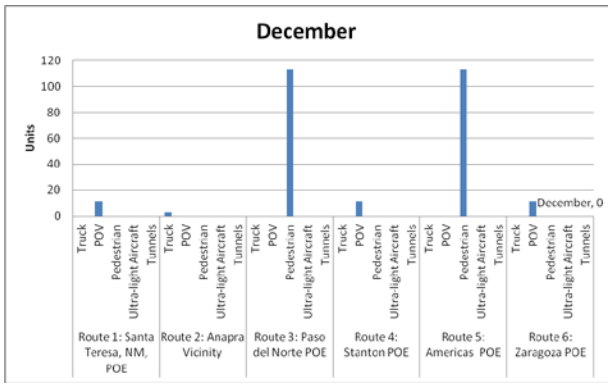
Total Units Utilized in October

In October, there is an increase in the pedestrian activity in route 5. There is also going to be activity in the Anapra vicinity with few ultra-light aircraft and tunnel runs (for the second time in the year) in addition to trucks in the same area. This seem to be the month where every CBP and Border Patrol agents should be working overtime. They could possibly ask for reinforcement from other areas.



Total Units Utilized in November

In November, route 1, 4, and 6 should focus their inspection in the POV line. They should have extra manpower, sniffing dogs, or other resources available in those POV lines. Route 2 will experience some activity in the truck's line and there is the possibility of a run through a tunnel in the Anapra vicinity. Routes 3 and 5 will have more activity in the pedestrian line of those two POE.



Total Units Utilized in December

Finally, December is very similar to November. However, since tunnel activity is not forecasted in this month, extra personnel should reinforce the pedestrian lines at the El Paso del Norte and Zaragoza POEs, since many people will be utilizing those routes to cross into the United States to celebrate the festivities.