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Analyzing Maritime Transportation of Illegal Drugs from South America Final Report

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Abstract

This report addresses two objectives: (1) estimating the steady-state presence of drug-trafficking vessels at sea originating from South America, (2) analyzing how Drug Trafficking Organizations (DTOs) may alter the flow of drug shipments at sea in response to actions taken by the US Southern Command (USSOUTHCOM). This information will provide insight to USSOUTHCOM about the effect of force allocation on the outcome of counter-drug operations.

Keywords: drug smuggling, game theory

1 Introduction

One of USSOUTHCOM's primary missions is to disrupt the flow of drugs from Central and South America to the United States via the southern approaches. Drug Trafficking Organizations (DTOs) use both maritime and air conveyances and use a variety of vessel types to transport the drugs. Examples of maritime means of transportation include go-fast boats, pangas, fishing vessels, and self-propelled semi-submersibles (SPSS). USSOUTHCOM's area of operation (AO) covers over 42 million square miles and it has limited search and interdiction assets to effectively support the mission. The organization in charge of detecting and interdicting this flow of illegal drugs is the Joint Interagency Task Force South (JIATF-S). JIATF-S is a US-government interagency that collaborates with law-enforcement agencies from other countries in Central America.

Notwithstanding possible lead-times in the drugs supply chain, a reasonable estimate for the non-intercepted flow of cocaine from South America to the US in a given time period is the estimated total consumption of cocaine during that time in the US. If the total consumption is X, and there are no other significant sources of cocaine shipped to the US, then the total flow of cocaine to the US in that period is X too. Estimates of drug consumption are given in [10, 14, 15, 12, 13, 2, 16, 19].

We must take care with this approach however. First, the purity of cocaine decreases as it moves through the supply chain down to the consumers. Second, nearly all the cocaine exported from South America flows through USSOUTHCOM's AO, and thus we cannot merely focus on US consumption.

The main question we address in this report relates to the interdiction efforts of JIATF-S: how many cocaine-carrying vessels of a certain type are afloat in the AO at any given time? The number of vessels at any given time is affected by the number and capacity of the vessels, production and processing schedules of cocaine at the sources in South America, weather, and possibly seasonality in demand for cocaine. The number of vessels and their spatial distribution in the AO are also affected by the actions of the interdicting force - JIATF-S. The latter lends itself to a game-theoretic situation.

This report is divided into two parts. Section 2 aims at estimating the DTO traffic at sea by focusing on the maritime transportation section of the DTO supply chain. Here we take an aggregate approach by considering both production and consumption data to constitute the base for estimating total DTO traffic in the maritime AO (Caribbean and Pacific). In particular, we ignore possible responses of the DTOs to interdiction efforts. In Section 3 we assume that the drug trafficking organization (DTO) is strategic, and it reacts to observable interdiction actions by JIATF-S. Here we will develop a new game-theoretic model.

2 DTO Traffic Estimate

As mentioned in the Introduction, the objective here is to answer the following question: how many drug-carrying DTO vessels of a certain type are afloat in the AO at any given time? The challenge is to estimate an unobservable parameter (undetected vessels) based on limited available data and production and consumption estimates.

A DTO vessel can be classified under one of three broad categories: interdicted, known but not interdicted, and unknown. An issue about the "known but not interdicted" category is whether the agency that knows about the vessel (e.g., FBI, CIA, DEA, local law enforcement, partner nations, etc.) passes that information along so that it appears in appropriate databases. The primary challenge, however, lies with estimating the unknown category. The Consolidated Counterdrug Database (CCDB) tracks some of these shipments and labels them as either confirmed (seizures), substantiated, or suspect [10]. The suspect category may be a rough proxy for some of the unknown traffic flow, however some of the events in the suspect category may include drug shipments that do not actually exist. See section 7.1.3.3 in [10] for a more in-depth discussion of the uncertainty associated with using the data in the CCDB. Rather than work directly with the data in the CCDB and attempt to correct for possible under and over counting, we start our analysis at a more aggregate level and consider production and consumption data. We will first construct an estimate of the cocaine departing Colombia via maritime conveyances. We will then use information on routes and vessels used by DTOs to estimate the number of vessels transiting the AO at any given time.

We limit ourselves to data from the unclassified realm. Much more detailed classified data exists in the CCDB and other sources. We could perform a similar classified analysis using data from those sources. We focus our attention on four types of vessels and three smuggling corridors. We consider go-fasts, SPSS, fishing vessels, and pangas. The corridors are the eastern Pacific (EastPac), the western Caribbean (WCarib) consisting of routes arriving in Central America, and the eastern Caribbean (ECarib) consisting of routes heading toward Caribbean islands such as Jamaica, Hispaniola, and Puerto Rico. We use these specific corridors because we have data about these three corridors. If more detailed route information exists (e.g., information about specific departure and arrival zones along each corridor), we could enhance our analysis to account for this level of detail. Our main result is that we expect about 57 shipments launched per month across all corridors and vessel-types and at any particular time about 2.5 drug-smuggling vessels on the water across all corridors and vessels. To compute these quantities we estimate the following inputs.

1. Amount of export quality cocaine leaving South American each year.
2. Fraction of exported cocaine that transits via maritime conveyances in the AO.
3. Fraction of cocaine that traverses along each of the three corridors.
4. Average distance traveled by smugglers along maritime routes for each of the three corridors.
5. Fraction of cocaine carried on each of the four types of vessels.
6. Velocity of each of the four vessel-types.
7. Drug-capacity of each of the four vessel-types.
8. Average time to traverse each corridor by vessel-type.

We present our baseline estimates for each of these quantities in the following tables. There is a great deal of uncertainty associated with these estimates. The details behind the estimates appear in Section 2.1, and we perform sensitivity analysis in Section 2.2.

Cocaine leaving South America each year	850 metric tons
Fraction of cocaine transported via water	0.9

Table 1: General parameters

	EastPac	WCarib	ECarib
Average distance of route along corridor	750nm	680nm	500nm
Fraction of flow along corridor	0.59	0.33	0.08

Table 2: Corridor parameters

	Go-fast	SPSS	Fishing	Panga
Velocity	25kts	10kts	15kts	20kts
Capacity	1 metric ton	5 metric tons	1 metric ton	0.5 metric tons
Fraction of flow using vessel-type	0.74	0.18	0.03	0.05

Table 3: Vessel parameters

	EastPac	WCarib	ECarib
Go-fast	0.38	0.28	0.08
SPSS	0.15	0.03	0.00
Fishing	0.01	0.02	0.00
Panga	0.05	0.00	0.00

Table 4: Bivariate distribution for cocaine flow by corridor and vessel-type

850 metric tons of export quality cocaine flow out of South America each year. Approximately 0.1 of the cocaine transits via air, and we assume the remaining 0.9 transits via the water in the AO. Even the drugs that eventually transit to Europe via air, usually travel to an intermediate point first in Central America or the Caribbean [19]. Thus, 765 metric tons traverse the water each year, and multiplying this number by the distribution in Table 4 provides the amount of cocaine that flows on each corridor/vessel-type combination. To determine how many shipments are made each year, we divide the amount of drugs by the average capacity per vessel from Table 3. For example 112 metric tons (765×0.15) flow along the EastPac each year in SPSS. Since each SPSS carries 5 metric tons, that equates to approximately 22 SPSS transits in the EastPac per year, or slightly less than 2 per month. Performing similar calculations yields the following table

	EastPac	WCarib	ECarib	
Go-fast	24.4	17.9	5.0	47.3
SPSS	1.9	0.4	0.0	2.3
Fishing	0.7	1.4	0.0	2.1
Panga	5.7	0.0	0.0	5.7
	32.7	19.8	5.0	57.4

Table 5: Average number of shipments initiated along each corridor per month

We also compute the average number of vessels in the AO at any given time. The longer it takes to traverse a route, the more vessels we expect to see on the water. We require the average traversal time along each route by each vessel-type, but unfortunately we could not find this information in the unclassified domain. Instead we rely on the velocities in Table 3 and the distances in Table 2 for our calculation. For example a go-fast traveling 25kts will traverse the average 750nm EastPac route in 30 hours. From Table 5 0.033 go-fasts are initiated every hour ($\frac{24.4}{30*24}$) along the EastPac, and thus we would expect about 1.0 go-fasts (0.033×30) along the EastPac corridor at any given time. Similar calculations produce Table 6

	EastPac	WCarib	ECarib	
Go-fast	1.00	0.67	0.14	1.81
SPSS	0.19	0.04	0.00	0.23
Fishing	0.05	0.09	0.00	0.14
Panga	0.29	0.00	0.00	0.29
	1.54	0.80	0.14	2.47

Table 6: Average number of vessels along each corridor at any given time

2.1 Parameter Estimates

We now provide the sources and logic behind the estimates in Tables 1–4. To reiterate: we only use unclassified sources. As there is significant uncertainty surrounding many of the estimates, we perform sensitivity analysis in Section 2.2 to provide a range for the results in Tables 5 and 6.

2.1.1 Export Quality Cocaine Leaving South America

There are many estimates of cocaine consumption, seizures, production, and transportation throughout the world. As our focus is on the detection and interdiction efforts of JIATF-S, we need to know or estimate the flow of cocaine that leaves South America via maritime means of transportation. Some of the cocaine heading to Asia, Africa, and Europe may not transit through the AO, but we did not find any concrete information about what fraction of the non-Americas flow avoids the AO. Thus, for our estimates we assume a "best case" scenario where all cocaine that transits via maritime means will pass through the JIATF-S AO.

Estimates of the flow out of South America do exist, but there are many variations. We do not include consumption or seizures within South America before it is exported. We also must take care to remain consistent with purity level. Data in reports can be listed as 100% pure, export purity, wholesale purity, or retail purity. We desire to use export quality because cocaine transits out of South America at this purity level. Sometimes sources list flow "toward the United States." We want to consider all cocaine leaving South America, and the label "toward the United States" is ambiguous and can be interpreted in several ways.

In Table 7 we list the best estimates we could find and the corresponding sources. These sources consider production, consumption, and trafficking data to derive their estimates. We use 850 metric tons as our baseline estimate in Table 1 as this corresponds to the most recent number in 2012. We have two estimates form 2012, both from the same source. The higher estimate is based on production and trafficking information, whereas the smaller number derives from consumption data. We choose the larger number as our baseline. The flow and consumption of cocaine has decreased significantly in the first decade of the 21st century. If these trends continue, the estimate for the current flow in 2015/2016 might be much lower that what appears in Table 7.

Estimate	Year	Source
1025	2006	Figure FW.4 of [14]
572	2008	Figure 1 of [14]
491–1303	2008	Figure 1 of [14]
788	2009	Page 21 of [19]
709	2010	Figure 1 of [15]
833	2010	Figure 1 of [12]
633	2012	Figure 1 of [13]
849	2012	Figure 1 of [13]

Table 7: Yearly export quality metric tons exported from South America

As a sanity check, we derive the export estimate by starting with US consumption. In 2010 the US consumed 150 metric tons of pure cocaine (see Table S.3 in [10]). The United States consumes 0.35 of the cocaine in the world [19, 15, 13] (see Table 14). Worldwide seizures range between 400-700 metric tons [14, 15, 12, 13, 19] (see Table 15). As only one source lists the seizure amount in 100% purity, we use 650 metric tons from [19]. This puts the global production at 1080 metric tons, 430 of which was consumed. This 1080 is close to the 1100 value stated on page 119 of [19]. 20% of consumption occurs in South America (see Fig 85 of [19]), which leaves approximately 340 pure metric tons exported for consumption. 60% of seizures occur in South America (see Fig 83 of [19]). Consequently, 260 of the 650 metric tons seized worldwide first leave South America. Putting the pieces together produces 600 metric tons (340 consumed plus 260 seized) of pure cocaine exported from South America. Export purity is roughly 0.75 [14, 15, 12] (see Table 17), which produces a final estimate of 800 metric tons of export quality cocaine leaving South America. This estimate is consistent with the direct estimates listed in Table 7.

2.1.2 Fraction of Drugs via Maritime Conveyances

Our goal is to estimate the number of drug-smuggling maritime vessels, and thus we discard the cocaine transported via air. The estimates in Table 8 correspond to the flow to North and Central America. We use these number as our default for all cocaine flowing out of South America because most of the non-Americas cocaine travels via maritime means [12, 13, 19]. Even if the cocaine is flown across the Atlantic, often it is first shipped to an intermediate destination in Central America or the Caribbean [19]. We choose 0.9 as our baseline in Table 1 as it corresponds to the most recent data in 2012. Classified data should exist to generate a more precise estimate for this value.

Estimate	Year	Source
0.9	2009	Figure 4 of [14]
0.86	2010	Figure 3 of [15]
0.8	2011	Page 13 of [22]
0.87	2011	Page 5 of [12]
0.91	2012	Figure 2 of [13]

Table 8: Fraction of cocaine that leaves Colombia via maritime routes

2.1.3 Drug Corridors

The *Cocaine Smuggling* reports found in [14, 15, 12, 13] present three primary corridors of smuggling: the eastern Pacific, the western Caribbean, and the eastern Caribbean. As Table 9 shows, the distribution changes by a non-trivial amount from year-to-year. This occurs as the DTOs adjust to interdiction efforts. We use the 2012 estimate as our baseline for Tables 2 and 4. We assume all flow in the AO follows this distribution. It is likely the flow heading to Central and North America differs from that heading to Europe. We consider such a scenario in Section 2.2.2.

EastPac	WCarib	EastCarib	Year	Source
0.72	0.25	0.03	2009	Figure 4 of [14]
0.61	0.34	0.05	2010	Figure 3 of [15]
0.53	0.42	0.05	2011	Page 4 of [12]
0.59	0.33	0.08	2012	Figure 2 of [13]

Table 9: Distribution of Cocaine Flow Along Different Corridors

Figure 4 of [15], Figure 5 of [12], and Figure 4 of [13] provide more detailed information about the flow of cocaine across various routes in each corridor. This allows us to generate an estimate for the distance a smuggler travels along each route. In Table 10, we present information on various routes derived from Figure 4 of [13]. Each route begins in Colombia and ends in the country in the `Route` column. Figure 4 of [13] provides an estimate for the amount of drugs transported along the route for 2012, which we replicate in Table 10. We compute the distance along each route using standard mapping procedures. Taking a weighted average, by drugs transported, of the distances along each route of a given corridor produces the estimates in Table 2

Corridor	Route	Drugs Transported	Estimated Route Distance
EastPac	Panama	82mt	350nm
EastPac	Costa Rica	59mt	700nm
EastPac	Guatemala	22mt	1000nm
EastPac	Mexico	55mt	1300nm
WCarib	Panama	22mt	350nm
WCarib	Nicaragua	25mt	550nm
WCarib	Honduras	69mt	800nm
WCarib	Mexico	7mt	1000nm
ECarib	Hispaniola	68mt	500nm

Table 10: Characteristics of cocaine flow along different routes in 2012. Derived from Figure 4 of [13]

2.1.4 Vessel-Type

The *Cocaine Smuggling* documents [14, 15, 12, 13] also provide a breakdown of types of vessels used by the DTOs along the three corridors. We focus on go-fast, SPSS, fishing vessels, and pangas. The distribution for four years appears in Table 11, which illustrates the preference for go-fast vessels. We use the 2012 values as our base-case in Tables 3 and 4. Trans-Atlantic flow often transits on container ships [12, 13, 19]. Thus our analysis may overstate the flow on the smaller vessels in the AO.

go-fast	SPSS	Fishing	Panga	Year	Source
0.57	0.26	0.16	0.00	2009	Figure 4 of [14]
0.72	0.12	0.05	0.10	2010	Figure 3 of [15]
0.63	0.24	0.08	0.04	2011	Page 5 of [12]
0.74	0.18	0.03	0.05	2012	Figure 2 of [13]

Table 11: Distribution of cocaine flow by vessel-type

2.1.5 Capacity

There is very little concrete unclassified information on the capacity of drug-smuggling vessels. Various reports list possible capacities [12, 13, 20], but there is no systematic study of the average load. We augment these reports with news accounts of interdiction events (see for example: [5, 6, 1]). In Table 12 we present several estimates from various sources for the four vessel types. The baseline values in Table 3 are representative of the estimates in Table 12. The exception is the fishing vessel category. With so little information, we use the same capacity as a go-fast for the baseline estimate. Classified information should record information about the loads of specific shipments. This information would be very useful to provide a much more accurate estimate of the capacities.

Type	Estimate	Source
Go-fast	0.5	[17]
Go-fast	0.5-0.75	[1]
Go-fast	0.5-1	[6]
Go-fast	0.5-2	[7]
Go-fast	1-2	[5]
Go-fast	1.5	[4]
Go-fast	2	[12, 13, 3]
SPSS	5-10	[20]
SPSS	6	[8]
Fishing vessel	2.4	[9]
Panga	0.3	[15]
Panga	0.75	[11]

Table 12: Cocaine capacity for various types of vessels in metric tons

2.1.6 Velocity

As with capacity, very little information exists in the open literature about the velocities of drug-smuggling vessels during transit. There are reports that list maximum speed or average speed of a particular vessel. However, just because a go-fast can travel comfortably at 25kts in most sea-states, does not mean it will do so constantly over the entire duration of the trip. There are reports that smugglers will idle for periods to thwart detection [18, 6]. As an example, the smugglers may stop during the day and cover the vessel with a blue tarp to limit visual detection capabilities. In this case the average velocity may be half the standard cruising velocity of the vessel. This will have a significant impact on the results. As there is so much uncertainty with the velocity, we perform additional sensitivity analysis for this estimate in Section 2.2.1. We do not need the velocity to perform our analysis; we need the average transit time for each vessel-type along each corridor. We could not find any reliable estimates for this in the open literature. If classified information exists on transit times, we can use that information directly rather than having to rely on velocities.

Type	Estimate	Source
Go-fast	50	[7]
Go-fast	50	[18]
Go-fast	25	[13]
SPSS	10	[21]
SPSS	13	[8]

Table 13: Velocity for various types of vessels in knots

2.1.7 Other Parameters

In this section we list other parameters that may be useful in performing additional analysis. Table 14 lists the fraction of cocaine consumed by the United States. We use this parameter in Section 2.1.1 to estimate the amount of cocaine exported from South America, starting with US consumption.

Estimate	Year	Source
0.36	2009	Page 16 of [19]
0.4	2009	Figure 8 of [13]
0.37	2010	Figure 8 of [13]
0.46	2010	Figure 8 of [15]
0.34	2011	Figure 8 of [13]
0.32	2012	Figure 8 of [13]

Table 14: Fraction of cocaine consumed by the United States

To generate the consumption estimate in Section 2.1.1 requires knowledge of the amount of cocaine seized or lost throughout the world. Table 15 provides several estimates.

Estimate	Year	Source
650	2009	Page 119 of [19]
540	2009	Figure 6 of [14]
450	2010	Figure 7 of [15]
425	2011	Figure 9 of [12]
450	2012	Figure 10 of [13]

Table 15: Worldwide losses and seizures of cocaine in metric tons

In Table 16 we list the fraction of flow heading to North and Central America. The remaining cocaine ends up in Europe, Africa, Asia, or Australia. In the base-case scenario we assume that the cocaine flow that eventually lands outside the Americas still follows the corridors defined in Section 2.1.3 in the initial phases of the transit while in the AO. In Section 2.2.2 we modify this assumption.

Estimate	Year	Source
0.57	2009	Page 119 of [19]
0.7	2011	Figure 7 of [13]
0.58	2012	Figure 7 of [13]

Table 16: Fraction of cocaine flow to North and Central America

Finally in Table 17 we list the export purity of cocaine. Several reports state values in units of 100% purity, and thus we use the values in Table 17 to generate the equivalent export purity.

Estimate	Year	Source
0.76	2008	Page 1 of [14]
0.76	2010	Page 9 of [15]
0.73	2011	Page 6 of [12]

Table 17: Export purity of cocaine leaving South America

2.2 Sensitivity Analysis

As discussed in Section 2.1, there is a great deal of uncertainty in the baseline estimates provided in Tables 1–4. In this section we perform sensitivity analysis to provide a range of plausible values for the number of smuggling vessels as we vary the parameter estimates. We also developed a simple Excel file that allows a user to enter in his own estimates for the values in Tables 1–4 to generate the corresponding information displayed in Tables 5 and 6. We will send this Excel file to any interested party.

Some sensitivity analysis is very straightforward. For example any change in our baseline of 850 metric tons flowing out of South America will produce a proportional change in Tables 5 and 6. For example, the first decade of the 21st century saw a sharp decrease in the consumption and flow of cocaine [10, 13, 16]. If the current 2015 value is, for example, 20% less than the 2012 estimate we use in Table 1, then the values in Tables 5 and 6 will also decrease by 20%, producing an average of 46 shipments initiated per month. A decade ago, some sources estimated the flow of cocaine at nearly 1200 metric tons [10, 14]. Using this estimate would increase the values in Tables 5 and 6 by 41%, producing an average of 80 shipments initiated per month, which translates into an average of 34.4, 25.3 and 7.1 go-fast boats at any given moment in the EastPac, ECarib and WCarib, respectively, when we consider base-case velocities and capacities. The same logic applies for the fraction of drugs that transit via maritime conveyances. If we use the 0.8 estimate from Table 8, then the results in Tables 5 and 6 will decrease by 11%.

The results are most sensitive to the velocity and drug capacity of the vessels. There is a large range for these values, and these differences lead to much more significant changes in our results than those described in the previous paragraph. We focus on the the velocity and capacity in Section 2.2.1 and examine modifications to the bivariate distribution in Table 4 in Section 2.2.2

2.2.1 Capacity and Velocity

As described in Section 2.1.5, the capacities of the vessels may be up to twice as large as the baseline values in Table 3. If this extreme occurs for all vessel-types, half as many vessels would be out on the water and the values in Tables 5 and 6 will decrease by 50%. On the other extreme, many news report list a load of only a few hundred kilograms. If the average capacity is in fact that low for the non-SPSS vessels, then that would decrease the average capacity by a factor between 2-5 and would significantly increase the amount of vessels on the water. There would be well over 100 shipments initiated per month in this low-capacity scenario.

There is also a large amount of uncertainty regarding velocity. As discussed in Section 2.1.6, all four vessels are capable of faster speeds than those reported in Table 3. However, it is more likely that the average speed over the entire transit will be less than the values in Table 3, as the smugglers may stop for rest or tactical reasons. In this case the average velocity may be much smaller, perhaps reduced by half. Such a situation would double the number of vessels in Table 6. Velocity does not impact number of shipments initiated, so the values in Tables 5 will remain unchanged.

For concreteness we now look at high and low capacity and velocity combinations to provide a range of feasible values for Tables 5 and 6.

	Go-fast	SPSS	Fishing	Panga
Low Capacity	0.5 metric tons	2 metric tons	0.5 metric ton	0.3 metric tons
High Capacity	2 metric tons	10 metric tons	2 metric tons	1 metric ton
Low Velocity	10kts	5kts	10kts	10kts
High Velocity	40kts	15kts	25kts	30kts

Table 18: High and Low values for Capacity and Velocity

The combination of high capacity and high velocity translates to fewer vessels on the water. If we use the high/high combination in Table 18, we generate the following numbers

	EastPac	WCarib	ECarib	
Go-fast	12.2	9.0	2.5	23.6
SPSS	0.9	0.2	0.0	1.1
Fishing	0.4	0.7	0.0	2.1
Panga	2.9	0.0	0.0	2.9
	16.3	9.9	2.5	28.7

Table 19: Increased Capacity and Velocity: Average number of shipments initiated along each corridor per month

	EastPac	WCarib	ECarib	
Go-fast	0.31	0.21	0.04	0.56
SPSS	0.06	0.01	0.00	0.08
Fishing	0.01	0.03	0.00	0.04
Panga	0.10	0.00	0.00	0.10
	0.49	0.08	0.04	0.78

Table 20: Increased Capacity and Velocity: Average number of vessels along each corridor at any given time

The combination of low velocity and low capacity generates many more vessels on the water. If we use the low/low combination in Table 18, we generate the following results

	EastPac	WCarib	ECarib	
Go-fast	48.7	35.9	10.0	94.6
SPSS	4.7	1.1	0.0	5.7
Fishing	1.4	2.9	0.0	4.3
Panga	10.0	0.0	0.0	10.0
	64.3	39.8	10.0	114.1

Table 21: Decreased Capacity and Velocity: Average number of shipments initiated along each corridor per month

	EastPac	WCarib	ECarib	
Go-fast	5.00	3.34	0.69	9.03
SPSS	0.96	0.20	0.00	1.16
Fishing	0.15	0.27	0.00	0.42
Panga	0.98	0.00	0.00	0.98
	7.09	3.80	0.69	11.58

Table 22: Decreased Capacity and Velocity: Average number of vessels along each corridor at any given time

It is doubtful that the average vessel has both velocity and capacity near the high-end of the uncertainty range to generate Table 19 and Table 20. However, with evidence of smaller loads and the possibility that smugglers may purposefully slow or stop during portions of the journey, the values presented in Table 21 and Table 22 are plausible. Thus it is possible that over 100 shipments initiate every month, and that at any given time there are over 10 smuggling vessels on the water.

2.2.2 Corridor/Vessel-type Distribution

We now alter the bivariate distribution Table 4 to consider two different flow scenarios. In the first scenario, the cocaine that eventually ends up outside the Americas only traverses through the Caribbean. In the second scenario, we assume the data to generate Table 4 (Figure 2 of [13]) relates to transit-events not kilograms of cocaine. In this case, the total flow of cocaine carried by SPSS must increase because those vessels carry more per transit than the other vessels.

The deviations from the baseline results in Tables 5 and 6 are minimal when considering these two scenarios. First we assume that 0.65 of the cocaine flows to Central and North America and the remaining 0.35 heads to Europe. Estimates of the flow to Central and North America range from 0.55-0.7 (see Table 16). We assume the flow heading to Central and North America follows the distribution in Table 4. The 0.35 of drugs that transit to Europe have the (re-normalized) distribution given by the last two columns of Table 4; in this scenario no drugs marked for Europe flow through the EastPac. The total number of shipments initiated per month increases slightly over the baseline to 58.1, whereas the steady-state number on the water decreases slightly to 2.4. Obviously more of the flow is concentrated in the Caribbean. This scenario also results in more go-fast and fishing vessels and fewer pangas and SPSS.

If we view Table 4 as representing the distribution of smuggling transits rather than kilograms cocaine, we must compute the joint distribution of cocaine flow by weighting each row by capacity. When we do this, the fraction of cocaine transported via SPSS increases significantly to 0.53 and the fraction transported by go-fast decreases to 0.43. With a much higher prevalence of high-capacity SPSS, the number of vessels decreases to 38 shipments per month with 1.9 on the water at any given time.

Even with fairly substantial changes to the distribution in Table 4, the results do not change as much as they do from changing the capacity and velocity in Section 2.2.1. Efforts should be made to pin down the estimates for velocity and capacity to improve the precision in the final results.

3 Strategic DTO

In this section we move away from the descriptive mode presented in Section 2, in the form of DTO traffic estimation, and move to a prescriptive mode were we consider game-theoretic implications. Here we assume that the DTO and the interdictor (JIATF-S) are strategic and attempt to optimize their objectives.

We assume a one-on-one situation where a single DTO vessel is to be intercepted by a single government interceptor (for brevity, henceforth we refer to *vessel* and *interceptor,* respectively). The model can be extended to many-on-many scenario. There are $i = 1, \dots, I$ routes that the vessel may select. The vessel is sent through route i with probability p_i. The interceptor selects patrol route i with probability q_i and intercepts with probability c_i any vessel that traverses the same route. The values of c_i capture the characteristics of the vesssel, and physical characteristics of route i (distance, weather, etc). The probabilities p_i and q_i, $1, \ldots, I$, are the decision variables for the vessel and the interceptor, respectively, and $\sum_{i=1}^{I} p_i = \sum_{i=1}^{I} q_i = 1$.

The DTO wishes to maximize expected profit, which is the difference between expected revenue and cost. The revenue over route i equals the sale price of the drugs at the destination (assumed to be constant and equal to s) times the probability of reaching the destination port; that is $s(1 - q_i + (1 - c_i)q_i) = s(1 - c_i q_i)$.

The government and DTO have information about past interceptions and therefore both know the values of $c_i,\ 1, \ldots, I$. We assume the worst-case scenario for the interceptor in that the DTO knows q_i when launching the vessel. We model the situation as a two-stage game in which the government hedges against the worse case scenario. That is, the interceptor minimizes the maximum (over the p_i's) expected profit generated by the vessel. That is,

$$\min_{q_1,\ldots,q_I} \max_{p_1,\ldots,p_I} s \sum_{i=1}^{I} p_i(1 - c_i q_i).$$

Clearly, the DTO's set $p_i = 1$ along the route i with largest $1 - c_i q_i$. Hence, the interceptor has to equalize the DTO's expected profit over all routes. That is, the solution for the interceptor satisfies $1 - c_i q_i = k$, where the constant k is set so that the q_i's add up to one. The solution is easily seen to be $k = 1 - 1/\sum_{i=1}^{I} c_i^{-1}$, and $q_i^* = c_i^{-1}/\sum_{j=1}^{I} c_j^{-1}$. Since the solution is independent of the p_i's it follows that no matter what route the vessel selects the expected profit for the DTO will be $s(1 - 1/\sum_{j=1}^{I} c_j^{-1})$. We see, for example, that when $c_i \to 0$ for all i, the expected profit approaches s. At the other extreme, when $c_i = 1$, the expected profit equals $s(1 - 1/I)$, which is s times the probability the DTO and government vessels do not choose the same route.

So far we have assumed a sequential game, where the interceptor chooses q_i and the vessel observes these values but obviously not the actual deployment of the interceptor. The vessel responds by choosing p_i (essentially, choosing a route). In typical Stackleberg fashion the interceptor equalizes the cost across routes to make the vessel indifferent which route to choose. We can also consider a simultaneous game, which would produce a mixed strategy. In the simultaneous setting, each player chooses one route. For example the payoff matrix would be the following for a three route scenario.

	Route 1	Route 2	Route 3
Route 1	$s(1 - c_1)$	s	s
Route 2	s	$s(1 - c_2)$	s
Route 3	s	s	$s(1 - c_3)$

Table 23: The row player is the DTO who wants to maximize expected profit and the column player is the government who wants to minimize expected profit

The solution is the same as the one corresponding to the sequential game:

$$p_1 = q_1 = \frac{1/c_1}{1/c_1 + 1/c_2 + 1/c_3}, \quad p_2 = q_2 = \frac{1/c_2}{1/c_1 + 1/c_2 + 1/c_3}, \quad p_3 = q_3 = \frac{1/c_3}{1/c_1 + 1/c_2 + 1/c_3},$$

in the case where the are 3 possible routes. For I routes, the solution is $p_i^* = q_i^* = c_i^{-1} / \sum_{j=1}^{I} c_j^{-1}$

If c_1 is large relative to c_2 and c_3, which means that the interceptor is more effective on route 1 then on routes 2 and 3, then the vessel, knowing that, will try to avoid this route. The interceptor deduces this, and thus patrols this route with a low probability. Following this argument, if c_1 is quite small relative to c_2 and c_3, than both the vessel and the interceptor will visit route 1 with high probability. The expected profit using the optimal strategy is the same as in the sequential game:

$$s\left(1 - \frac{1}{\sum_{j=1}^{I} c_j^{-1}}\right).$$

We conclude that the sequential and simultaneous formulations give essentially the same result. The benefit of the sequential game is that it naturally leads to a greedy solution that can be extended (e.g., the investment situation described below). The simultaneous game has the nice property that the vessel has one unique mixed strategy, as opposed to being indifferent among all strategies in the sequential game.

3.1 Extensions

The game can be extended by making the c_i's a function of effort, say money. More precisely, suppose that for each route $c_i(\cdot) \in [0, 1]$ is a continuously differentiable, convex, decreasing function of the interdiction *investment* x_i made by the DTO along route i. Then the problem faced by the interceptor is to maximize $s(1 - 1/\sum_{j=1}^{I} c_j(x_j)^{-1})$, which is the same as

$$\max_{x_1,\ldots,x_i} \sum_{i=1}^{I} 1/c_i(x_i)$$

subject to

$$\sum_{i=1}^{I} x_i \leq x, \text{ and } x_i \geq 0.$$

It can be seen that a greedy policy is optimal here, allocating each extra dollar to the route with the largest bang-for-the-buck.

We next consider an asymmetric information setting. The DTO knows how many shipments were made and how many were interdicted on a patrolled route. We assume the DTO can determine, perhaps after-the-fact, whether a route is patrolled. The interceptor also has an exact tabulation of the number of interdictions, but only imperfect knowledge of the number of shipments. Thus the DTO knows the true value of c_i, but the interceptor has an imperfect estimate $\tilde{c}_i$. The interceptor solves the original problem with $\tilde{c}_i$ and thus $q_i^* = \tilde{c}_i^{-1} / \sum_{j=1}^{I} \tilde{c}_j^{-1}$. The DTO is no longer indifferent among the routes; the vessel chooses the route that maximizes $1 - c_i q_i^*$. This corresponds to the route that minimizes $c_i/\tilde{c}_i$. Large values of $c_i/\tilde{c}_i$ correspond to routes where the interceptor thinks it can easily interdict the vessel, but it is actually difficult to do so. We do not need to assume that the vessel has knowledge of the interceptor's erroneous $\tilde{c}_i$. We only require that the vessel can gain knowledge of the interceptor's mixed strategy q_i^*.

As a final extension, we consider the case where the government operates more than one interceptor. More precisely, suppose the government *looks* along route i and detects any vessel in it with probability c_i. If the looks along each route are independent of each other and the government allocates ℓ_i looks at route i, then the probability of not detecting a vessel along route i equals $(1 - c_i)^{\ell_i}$. Hence, the problem for the government is to

$$\min_{\ell_1,\ldots,\ell_I} \max_{p_1,\ldots,p_I} s \sum_{i=1}^{I} p_i (1 - c_i)^{\ell_i},$$

subject to $\sum_i \ell_i \leq \ell$, where ℓ is the overall government budget. The solution to this problem is to allocate each look, incrementally, to the route that yields the largest bang-for-the-buck. However, the solution doesn't yield analytical insights. We can obtain an approximate model that is analytically tractable as follows. We set $c_i \ell_i \approx \gamma_i \lambda_i > 0$ for ℓ_i large, where $\gamma_i > 0$ captures the effectiveness of the government in detecting a vessel, and λ_i measures the time spent looking along route i. Then, $(1 - c_i)^{\ell_i} \approx \exp(-\gamma_i \lambda_i)$ for ℓ_i large, so that the sequential game problem becomes

$$\min_{\lambda_1,\ldots,\lambda_I} \max_{p_1,\ldots,p_I} s \sum_{i=1}^{I} p_i \exp(-\gamma_i \lambda_i),$$

subject to $\sum_i \lambda_i \leq \lambda$, for some $\lambda > 0$ that corresponds to the government budget. The solution to this problem is $\lambda_i^* = \lambda \, \gamma_i^{-1} / \sum_{j=1}^{I} \gamma_j^{-1}$, and $p_1, \ldots, p_I$ can be any probability mass function. In other words, we get the same type of solution as for the problem with one government asset.

4 Conclusions

The main contribution of this work is to estimate the flow of maritime drug shipments out of South America. This should provide insight for how to allocate Blue assets to search, detect, and interdict DTO vessels. This could also be useful to vet informants to check that their information is consistent with the flow estimates. We do stress that our numbers are based on the best available unclassified sources. USSOUTHCOM and JIATF-S should have more detailed classified information. They can plug those numbers into our analysis to generate more accurate estimates of the number of shipments initiated per month and the number of vessels on the water. The final estimates should be compared to the DTO trafficking data in the CCDB. If the flow estimates are much higher than the data in the CCDB, that would suggest there is a significant amount of unknown flow in the AO. We should take efforts to develop more intelligence sources to reduce the unknown flow. If the flow estimates are much lower than the data in the CCDB, that would suggest a non-trivial amount of the entries in the CCDB may be false. That is they represent shipments that never occurred. In this case, we would need to evaluate the intelligence collection and analysis process and examine why we are incorrectly counting so many false shipments.

Our second contribution is the development of a strategic model that considers both the government and DTO as decision makers. This provides insight into how DTOs will react to different search and interdictions efforts by the government, which leads to a corresponding change in the interception rate c_i. We also illustrate the value of information for the government to accurately estimate the true interception rate, so that the government can most effectively plan counter-drug operations.

References

[1] L. Alvarez, *In Puerto Rico, cocaine gains access to U.S.*, New York Times, (2014).

[2] J. P. Caulkins, B. Kilmer, P. H. Reuter, and G. Midgette, *Cocaine's fall and marijuana's rise: questions and insights based on new estimates of consumption and expenditures in us drug markets*, Addiction, 110 (2015), pp. 728–736.

[3] CBS-Miami, *Coast guard intercepts $58 million in cocaine off FL coast*, CBS-Miami, (2011).

[4] ——, *Coast guard captures more than a ton of cocaine*, CBS-Miami, (2012).

[5] B. Fiegel, *The picuda: A wave-breaking go-fast wonder that defies radar detection*, Dialogo, (2014).

[6] W. Gibson, *Shifting drug smuggling routes bring contraband to Florida*, Sun Sentinel, (2014).

[7] M. Hodgson, *Super-speedboats piloting Colombia's cocaine trade*, Christian Science Monitor, (2002).

[8] J. Kandel, *Traffickers using submarines to transport drugs*, NBC Los Angeles, (2012).

[9] B. Kennedy, *More than $110 million worth of cocaine offloaded by coast guard*, Local10 Miami, (2014).

[10] B. Kilmer, S. S. Everingham, J. P. Caulkins, G. Midgette, R. L. Pacula, P. H. Reuter, R. M. Burns, B. Han, and R. Lundberg, *What America's users spend on illegal drugs: 2000-2010*, tech. report, RAND Corporation, February 2014.

[11] C. G. News, *Coast guard cutter midgett returning to Seattle after seizing nearly six tons of cocaine*, Coast Guard News, (2015).

[12] Office Of National Drug Control Policy, *Cocaine smuggling in 2011*, tech. report, ONDCP.

[13] ——, *Cocaine smuggling in 2012*, tech. report, ONDCP.

[14] ——, *Cocaine smuggling in 2009*, tech. report, ONDCP, October 2010.

[15] ——, *Cocaine smuggling in 2010*, tech. report, ONDCP, January 2012.

[16] W. Rhodes, C. Dyous, D. Hunt, J. Luallen, M. Callahan, and R. S. M. A. Cala, *Drug availability estimates in the United States*, tech. report, ONDCP, 2012.

[17] M. Rodriguez, *Coast guard captures more than a ton of cocaine*, CBS-Miami, (2013).

[18] A. Selsky, *Cocaine smugglers using high-tech boats*, Washington Post, (2005).

[19] United Nations Office on Drugs and Crime (UNODC), *World drug report 2011*, tech. report, UNODC, 2011.

[20] ——, *Transnational organized crime in Central America and the Caribbean: A threat assessment*, tech. report, UNODC, September 2012.

[21] United States Coast Guard, *Dangerous self-propelled semi-submersibles (SPSS) proliferating rapidly*, tech. report, DHS, September 2008.

[22] United States Senate Caucus On International Narcotics Control, *Preventing a security crisis in the Caribbean*, tech. report, United States Senate, September 2012.