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Title: Preliminary Exploration of Encounter During Transit Across Southern Africa

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# Preliminary Exploration of Encounter During Transit Across Southern Africa

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# 1 Introduction

## 1.1 Overview

Los Alamos National Laboratory (LANL) is utilizing the *Probability Effectiveness Methodology* (PEM) tools, particularly the *Pathway Analysis, Threat Response and Interdiction Options Tool* (PATRIOT) to support the DNDO Architecture and Planning Directorate's (APD) development of a multi-region terrorist risk assessment tool.

The effort is divided into three stages. The first stage is an exploration of what can be done with PATRIOT essentially as is, to characterize encounter rate during transit across a single selected region. The second stage is to develop, condition, and implement required modifications to the data and conduct analysis to generate a well-founded assessment of the transit reliability across that selected region, and to identify any issues in the process. The final stage is to extend the work to a full multi-region global model.

This document provides the results of the first stage, namely preliminary explorations with PATRIOT to assess the transit reliability across the region of southern Africa.

## 1.2 Study Guidance

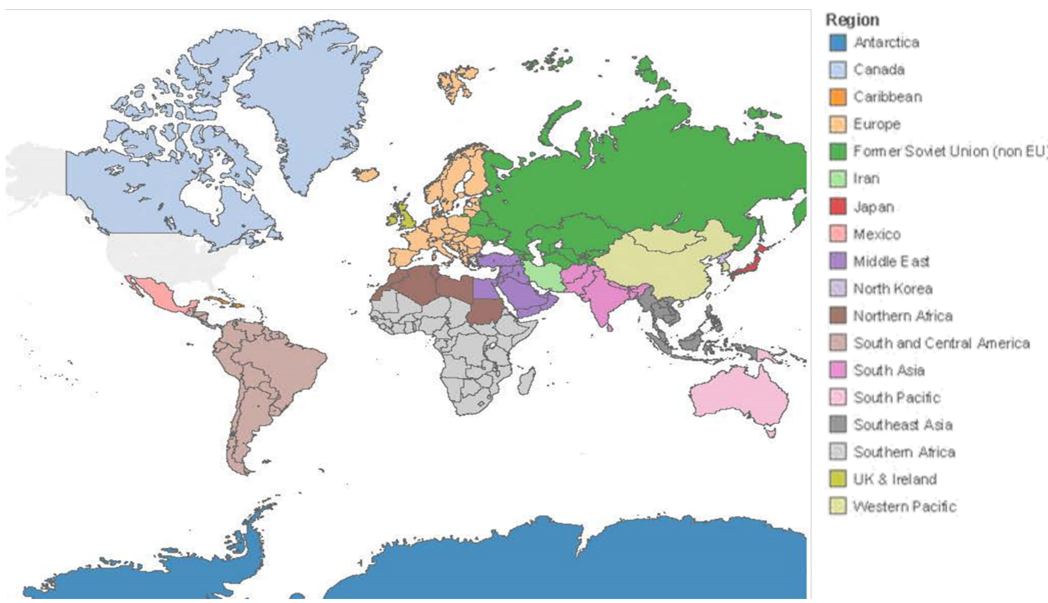
Guidance for a PATRIOT-based regional analysis to support APD was included as an appendix to the "Statement of Work (SOW) for Probabilistic Effectiveness Methodology (PEM) Supplemental II Support" Interagency Agreement. That guidance is summarized here.

***Background:*** *The DNDO Risk Model requires estimates for the probability of interdiction of adversaries moving radiological or nuclear (RN) materials or weapons through international and domestic regions. PEM is a suite of tools uniquely positioned to provide such estimates. This request provides some specifics for what the DNDO Risk Model needs and initial thoughts about how PEM could provide that information.*

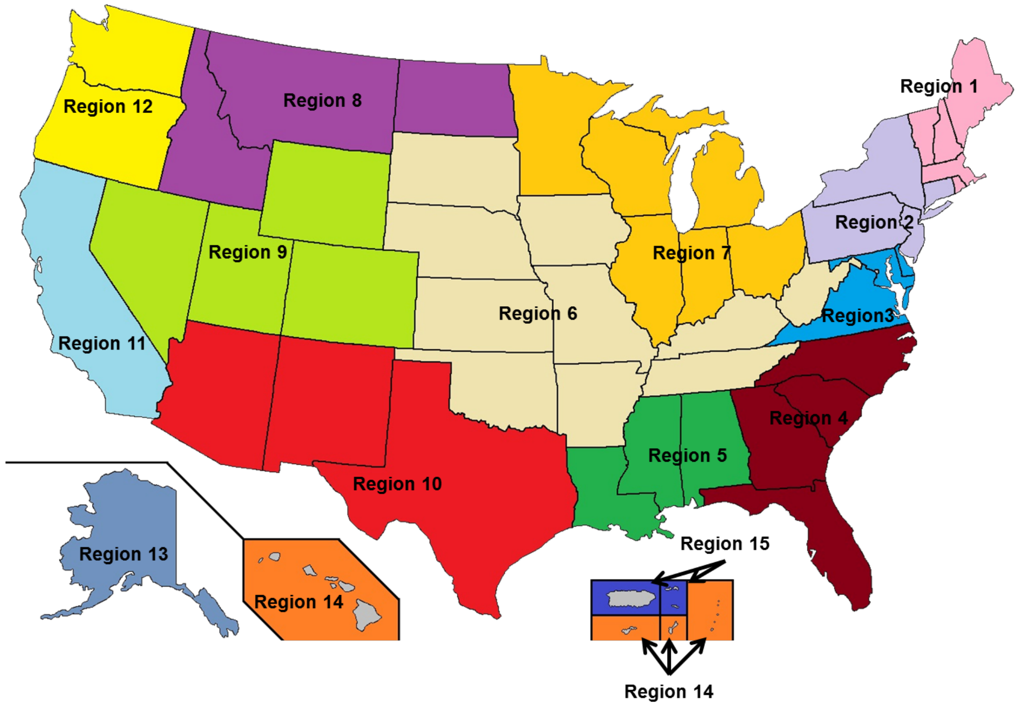
***Basic Premise:*** *Without very specific intelligence, the US Government will not know in advance the exact route an adversary will plan to take when moving RN materials and/or weapons. It is therefore prudent and necessary to deploy detection and interdiction capabilities and assist other nations in* *building up those capabilities to actively deter adversaries from attempting such an attack and to defend against it should the adversary decide to pursue it. The effectiveness of any region's detection and interdiction capabilities can be represented as that region's probability of interdicting an adversary in movement.*

*The DNDO Risk Model considers these layers of defense ("Foreign Transit" and "Regional Transit") as two of several layers of defense an adversary may have to travel through in order to successfully conduct an attack against a target in US. Estimates of the vulnerability of these layers have historically been very broad and not regionally specific. As part of the effort to make the DNDO Risk Model more geographically specific, vulnerability estimates for the Foreign Transit layer in different regions of the world and the Regional Transit layer for different domestic regions are required.*

***Regions of the World:*** *For internal analysis purposes, DNDO APD uses the following list of global regions:*




*And this list of domestic regions:*

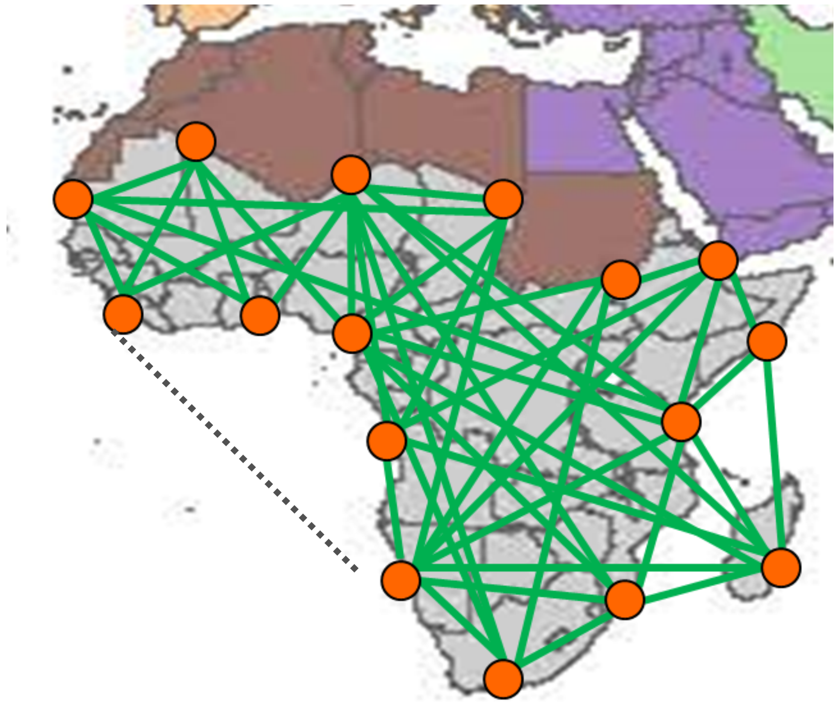



*For each region, the risk model would like PEM to produce an estimate of the transit vulnerability.*

*The risk model takes two inputs related to this concept. The first is the probability of encounter.  This is the probability that an adversary will come into proximity with a law enforcement officer. The second is the probability of interdiction given contact.  This is threat specific and takes into account the effectiveness of any detection assets that may be in use by the law enforcement agencies.  PEM should supply results for the probability of encounter only.  This will limit the number of required runs, as multiple runs will not be required to test different kinds of threats.*

*Ideally, the probability of encounter for each region would be reported back in the form of a beta distribution that reflects the distribution of pathway reliability over all of the segments considered in a region.*

*An example region would look something like this:*



*In this example, the Southern Africa region is shown. 16 sources/sinks are plotted for illustration only. The actual number will depend on the region and should probably be at least 4 but no more than 20. Each pair of nodes will be connected and run through PEM for a probability of encounter. In general, there will be N*(N-1) segments to analyze per region (in this case N=16 so there are 16*15=240 possible segments – not all of these are drawn above). However, human judgment should be applied to consider pruning some of these segments. For example, transiting from a Source Node in Namibia to a Sink Node in Liberia may consist entirely of transiting through the Atlantic Ocean (grey dashed line above). In that case, the transit reliability would be more representative of the Atlantic Ocean than of the Southern Africa region. However, this raises the issue of domains. Before proceeding, DNDO APD would like to ask for the PEM team to consider and recommend options to help scope this idea along the line of the following:*

- *Restrict all travel to land only.*
- *Restrict all travel to land only within the region of interest.*
- *Allow land, air, and sea travel, but exclude segments that result in most reliable paths being mostly outside of the region in question.*
- *For non-contiguous regions (Domestic Region 14) several distinct sets of nodes may be required.*

*DNDO APD also requests that the PEM team suggest a number of source and sink nodes for each international and domestic region such that the total study burden can be estimated. It is likely that DNDO will want to start with a pilot region to ensure the results are coming back in the expected form* *and then expand that to consider all international regions, and then finally to include all domestic regions.*

# 2 Preliminary Network and Data Preparation for Southern Africa

This section describes the network that is used for the preliminary analysis of transit through the southern Africa region. For this preliminary analysis, only the minimal necessary modifications are made to the PATRIOT data.

## 2.1 South Sudan

To properly model the pilot southern Africa region, the PATRIOT database had to be updated to include South Sudan, making sure that the appropriate arcs and nodes were re-assigned to this new country.

## 2.2 Identification of countries

Excluding places that are non-sovereign territories of other countries (such as Mayotte), 48 countries were identified for inclusion in the southern Africa region. These 48 countries are listed in Table 1.

| | | | |
|---|---|---|---|
| Angola | Côte d'Ivoire | Liberia | Senegal |
| Benin | Djibouti | Madagascar | Seychelles |
| Botswana | Equatorial Guinea | Malawi | Sierra Leone |
| Burkina Faso | Eritrea | Mali | Somalia |
| Burundi | Ethiopia | Mauritania | South Africa |
| Cameroon | Gabon | Mauritius | South Sudan |
| Cape Verde | Gambia | Mozambique | Swaziland |
| Central African Republic | Ghana | Namibia | Tanzania |
| Chad | Guinea | Niger | Togo |
| Comoros | Guinea-Bissau | Nigeria | Uganda |
| Congo | Kenya | Rwanda | Zambia |
| Democratic Republic of the Congo | Lesotho | Sao Tome and Principe | Zimbabwe |

**Table 1. The 48 countries assigned to the southern Africa region for the preliminary pilot analysis.**

The pilot region thus contains almost a quarter of all the world's countries.

For the preliminary pilot analysis, we restrict the road and rail network to the 48 countries listed above. Further, we restrict the air and general aviation network to routes that take off and land within the 48-country region. The sea cargo and small maritime vessel networks include arcs that connect to ports or marinas in the 48 selected countries, along with the arcs that connect gather points in the water.

## 2.3 Selection of route endpoint locations

Sixteen locations were selected for route endpoints by identifying significant places near the red circles designated by DNDO on the map of southern Africa above. The 16 selected locations are listed in Table 2.

| Location | Country |
|---|---|
| Nouakchott | Mauritania |
| Freetown | Sierra Leone |
| Lome | Togo |
| Victoria | Cameroon |
| Luanda | Angola |
| Walvis Bay | Namibia |
| Port Elizabeth | South Africa |
| Maputo | Mozambique |
| Mananjary | Madagascar |
| Dar es Salaam | Tanzania |
| Mogadishu | Somalia |
| Djibouti | Djibouti |
| Caraboghe | Ethiopia |
| Fada | Chad |
| Agadez | Niger |
| Mali | Mali |

Table 2. Selected route endpoint locations for preliminary pilot analysis.

## 2.4 Transport network

The road network comes from the VMap0 data set, which contains all major roads worldwide. The road network in the select region is shown in Figure 1.

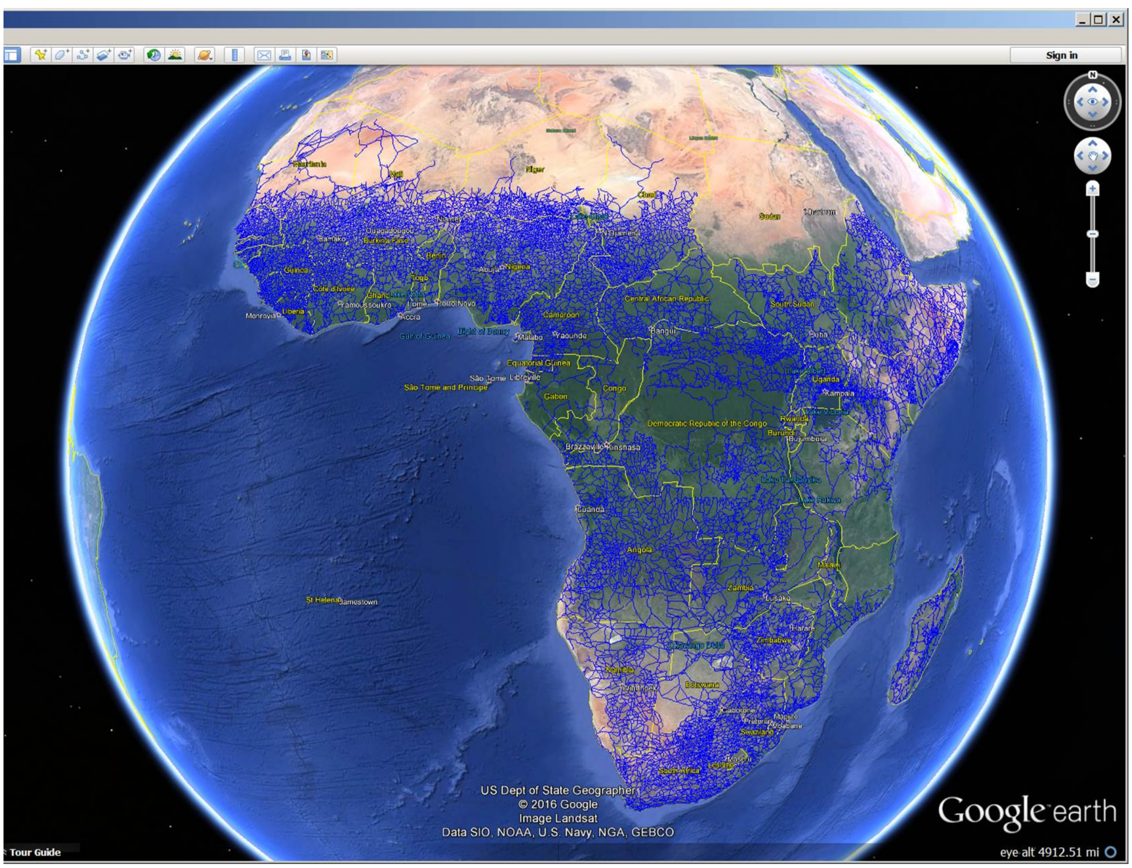



Figure 1. Road network in southern Africa region.

The rail network, also from VMap0, is shown in Figure 2.

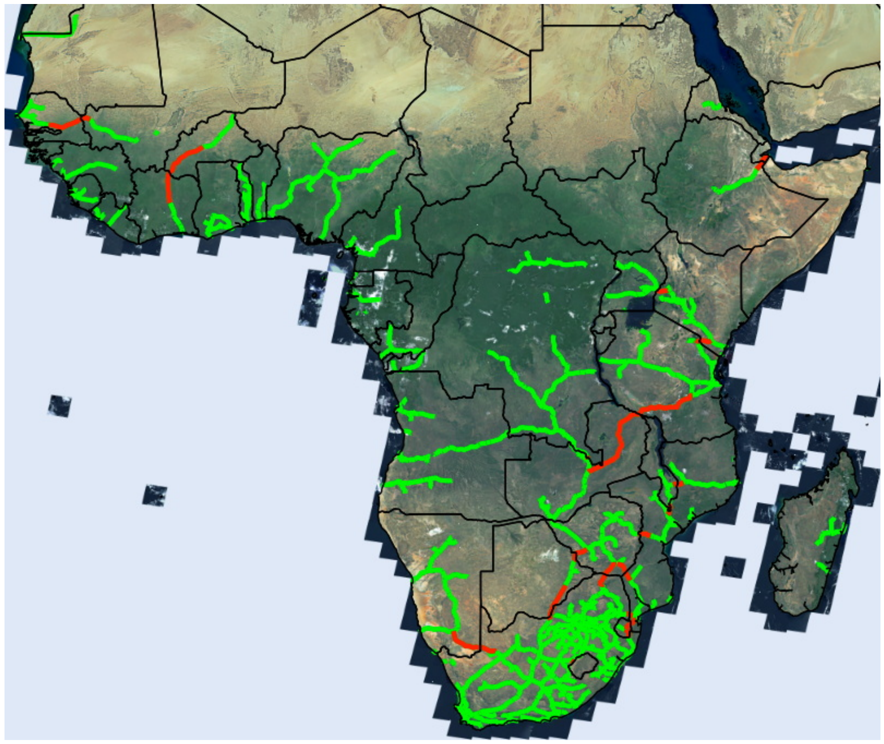


**Figure 2. Rail network in the southern Africa region. Arcs that cross international borders are shown in red.**

The commercial air passenger and air cargo routes are shown in Figure 3. The air network was built from the Online Airline Guide database, and includes all flight segments for which regularly scheduled commercial service is available.

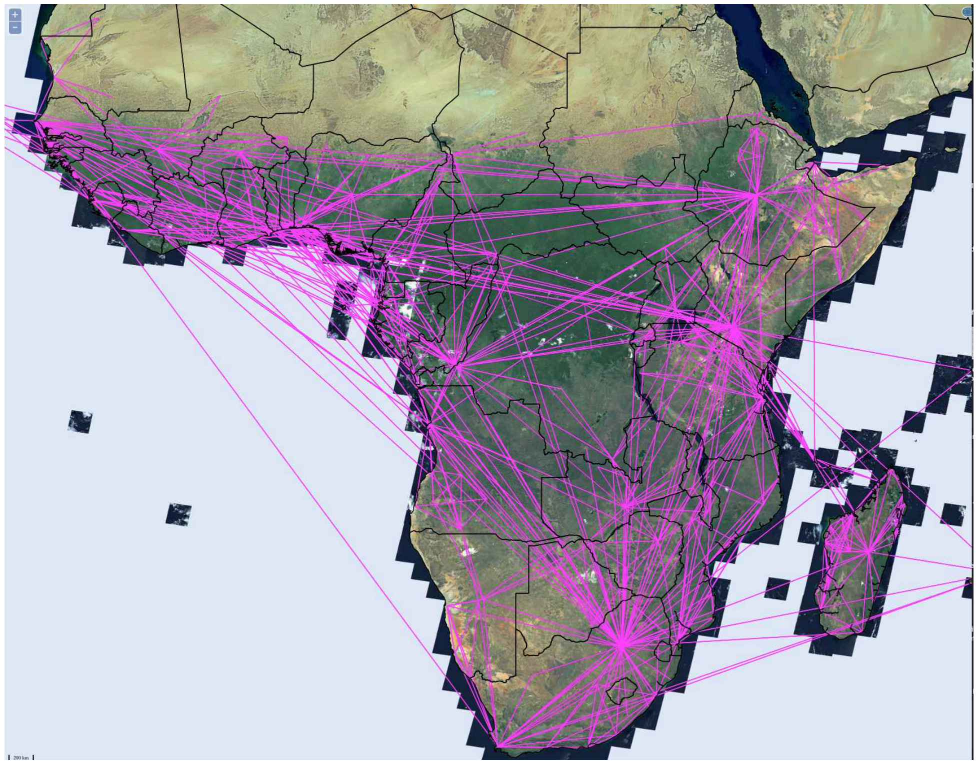


Figure 3. Commercial air network (passenger and air cargo) for southern Africa region.

The general aviation arcs modeled in PATRIOT are shown in Figure 4. The general aviation network includes many smaller airports drawn from the Great Circle Mapper database, in addition to the airports associated with commercial air service.

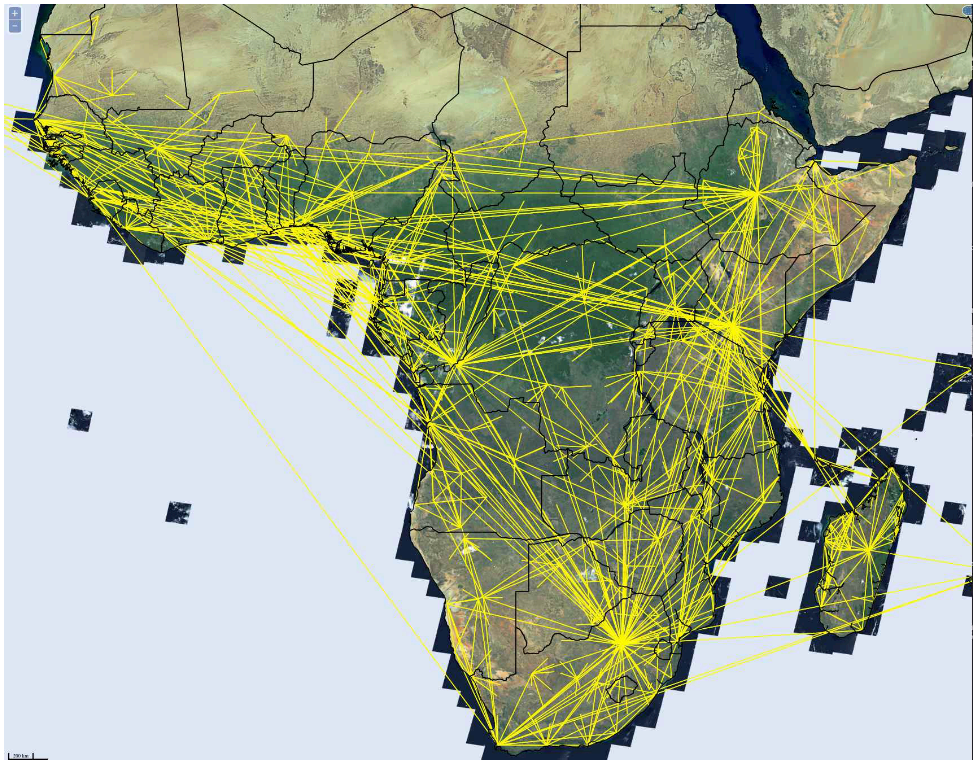


Figure 4. General aviation network for southern Africa region.

The sea cargo and the small maritime vessel networks are shown in Figure 5. The sea cargo transit network was constructed from all containerized cargo movements in the world during 2007, as drawn from the Lloyd's List Intelligence database. The small maritime vessel network was constructed from marina data (marinas.com), with a hierarchical set of gather points placed manually in rivers and oceans. The marina data in the southern Africa region has not been subjected to the level of "scrubbing" that has been done for the North American continent. In particular, we have not ensured that inland waterway marinas and arcs are accurately captured.

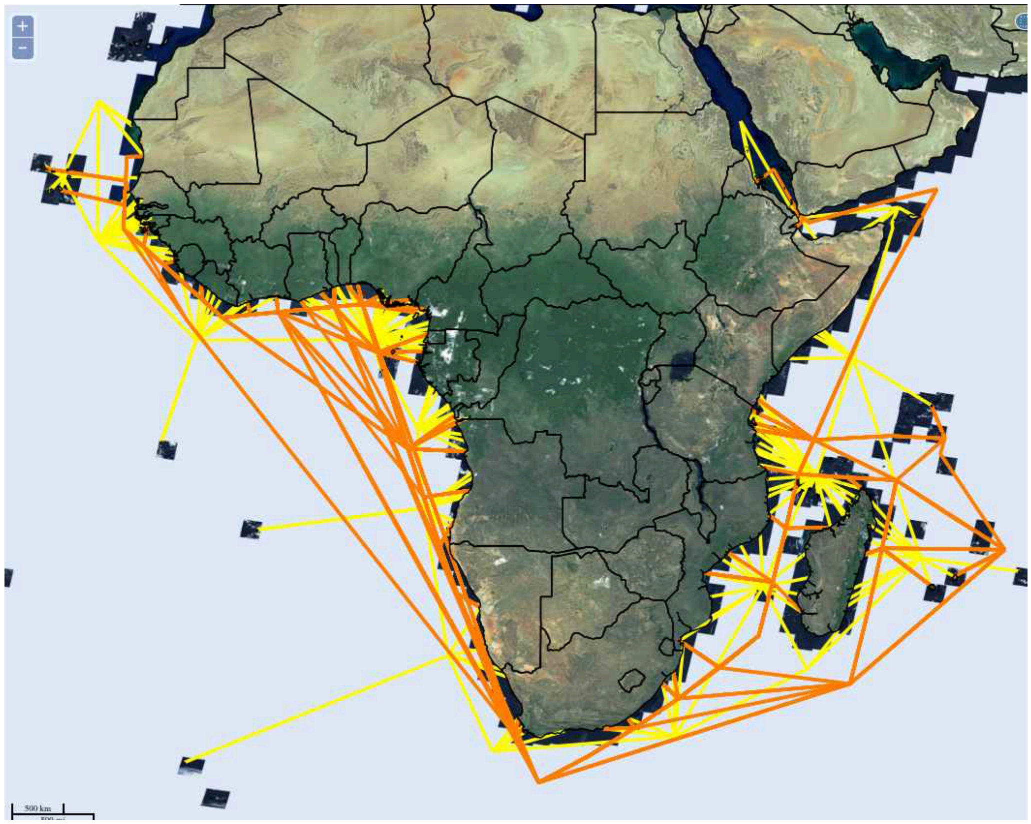


Figure 5. Sea cargo (orange) and small maritime vessel (yellow) networks for southern Africa region.

## 2.5 Encounter parameters

For the preliminary exploration, every road arc in the region is currently assigned a mean distance to encounter of 1E5 miles, which represents random encounters with law/traffic enforcement patrol vehicles. This is implemented in the database by applying base detection BD157 (std_road) to all road arcs. This estimate is based on data from 2008 US traffic enforcement stops with no radiation detection equipment. For a nominal cross-Africa route length of 3000 miles, the encounter probability would be 1-exp(-3000/100,000) ~ 3%. A mean distance to encounter value of 1E6 miles is applied to arcs of all non-road modes of transit.

In addition, each arc has a mean time to encounter of 8760 hours, to represent directed active search. The transit time of an arc is given by the arc length divided by the arc speed. Each arc in the VMap0 dataset has an associated speed, typically 60 mph for a main road and 30 mph for a secondary road. For paths across Africa, we would expect driving times of one or more hundred hours, corresponding to a further one or more percent encounter probability. This encounter rate per unit time is generally insignificant for air transit modes, due to the high travel speed. For sea and small maritime vessel transit, with speeds typically in the 10 to 15 knot range and trips taking multiple days, the mean time to encounter of 8760 hours can produce a significant encounter probability.

**Road vehicles** crossing by road at international borders are subject to a weight-dependent encounter probability. PATRIOT currently models that there is no radiation detection equipment at international land borders in southern Africa. The current encounter probability for very lightweight and lightweight items is 5%; medium weight items have 7.5%, and heavy items have 10% encounter probability. These are applied twice at each border, once leaving one country, and again upon entering the other country. These values are estimates, not based on data.

Very light weight items carried as baggage on **passenger rail** are modeled as having a 1% encounter rate at embarkation, to account for railroad personnel noticing something suspicious. Light, medium and heavy items (representing **rail cargo**) have a 5% encounter rate applied on the terminal-to-depart arc, to capture the likelihood that anomalous shipping manifest entries result in some encounter.

For very light weight items on **commercial passenger flights**, either as passenger carry-on luggage (designated *pax*) or checked baggage, PATRIOT applies a 15% interdiction/encounter probability. Currently, airports in southern Africa are modeled as not having radiation detection equipment, beyond metal detectors and x-ray machines. The modeled 15% encounter probability is an estimate of the likelihood of a random checked bag inspection.

For light, medium, and heavy weight items, travel by commercial air represents **air cargo**, such as carried by Federal Express, UPS and Emirates. PATRIOT currently applies a 5% encounter likelihood for these weight categories, primarily to capture the likelihood that the air cargo item is selected for close inspection based on anomalies in the shipping manifest. This encounter is applied on the terminal-to-depart arc.

For **sea cargo**, a 5% encounter rate is applied between entering the terminal and departing from the terminal, independent of weight. The only Megaport installation modeled in the region is at the Port of Djibouti.

For **small maritime vessel**, a weight-dependent encounter rate is applied at both the embarkation and debarkation marinas, to represent the likelihood that other boaters will notice and report suspicious behavior. The assumed encounter rates are 1% for very light items, 2% for lightweight items, 5% for medium weight items, and 10% for heavy items.

### 2.6 Review of arc weight transformations for Dijkstra algorithm input

PATRIOT generates routes by finding a sequence of arcs that maximizes the adversary's transit reliability. The reliability R of the full route is the product of arc reliabilities, $R=\Pi R_i$. Arc reliability is one minus probability of encounter. Arc weight is $w_i = -\ln(R_i) = \ln(1/(1-P_e))$. For small $P_e$, $w \sim P_e$.

For probabilistic encounter with specified MDE (mean distance to encounter), the arc reliability is $\exp(-L / MDE)$, where L is the arc length and MDE is the mean distance to encounter. Arc weight is $w_i = –\ln(R_i) = L_i / MDE_i$.

For probabilistic encounter with specified speed, the arc reliability is exp( - L / (v MDT)), where L is the arc length in miles, v is the speed in mph, and MDT is the mean time to encounter in hours. Arc weight is $w_i = –\ln(R_i) = L_i / (8760\ v_i)$. Details can be found in the PEM documentation.

# 3 Preliminary Results for Southern Africa Region

## 3.1 All transit modes available

We first consider the case where all modeled transit modes are available, namely road, rail, sea cargo, air cargo, air passenger, general aviation, and small maritime vessel. For each threat weight category, there are 16 X 15 = 240 combinations of route endpoints, of which 120 are the reverse of the other 120. The mean transit reliability and standard deviation over the 120 combinations for each weight category, are shown in Table 3. The corresponding beta distribution parameters are also shown.

| | Mean | St dev | alpha | beta |
|---|---|---|---|---|
| very light | 0.9457 | 0.007207 | 933.27 | 53.53 |
| light | 0.9437 | 0.003633 | 3800.8 | 226.9 |
| medium | 0.9436 | 0.003592 | 3888.8 | 232.3 |
| heavy | 0.9436 | 0.003593 | 3887.5 | 232.2 |

**Table 3. Transit reliability results for case of all modes available.**

The computation result distributions for each of the weight categories are shown in Figure 6.

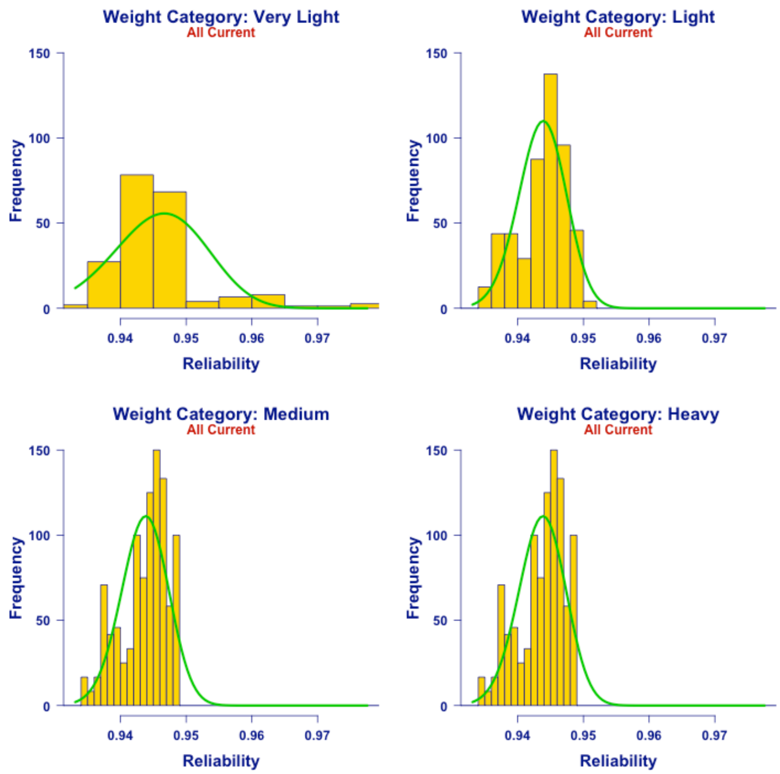



**Figure 6. The frequency distribution of transit reliabilities over the route endpoint combinations, with best fit Beta distributions.**

For very lightweight items, most routes travel by general aviation. A few routes go by small maritime vessel, and two routes use rail passenger baggage. The routes are shown in Figure 7 for the very lightweight category.

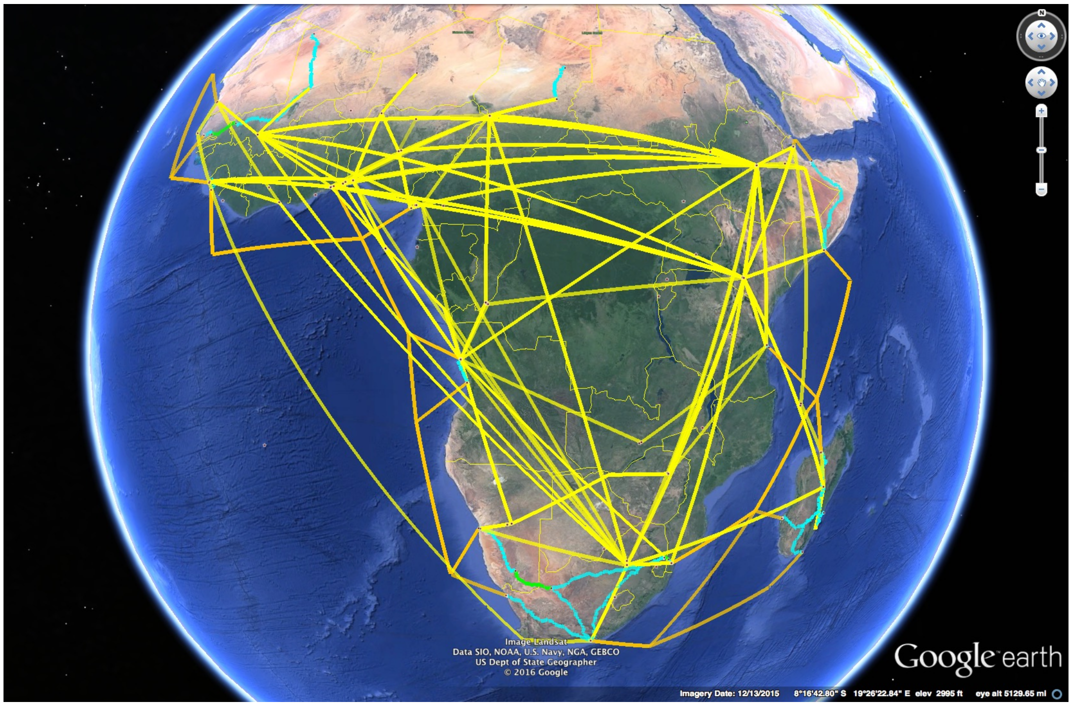



Figure 7. Routes for very light weight items with all transit modes available. Yellow: air pax & bags. Cyan: road. Amber: Small maritime vessel. Green: rail pax & bags.

For light, medium, and heavy items, air cargo routes provide the least encounter probability. Representative routes are shown in Figure 8.

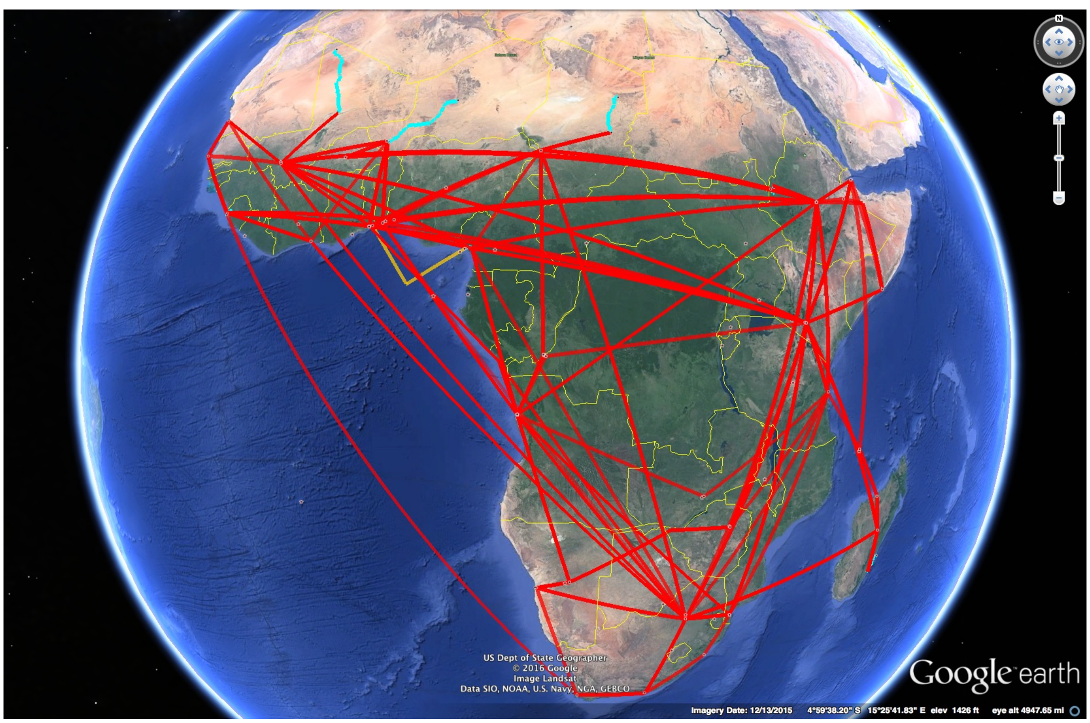



Figure 8. Routes for light, medium, and heavy weight categories with all transit modes available. Red: air cargo.

## 3.2 Results for Road-only Transit

The average transit reliability for 210 origin-destination pairs (excludes Madagascar) is tabulated in Table 4. We verify that for the southern Africa region, PATRIOT obtains the same reliability in one direction as the other. We thus really have only 105 unique scenarios for each weight category.

| | Mean | St dev | alpha | beta |
|---|---|---|---|---|
| very light | 0.5609 | 0.1808 | 3.6632 | 2.8680 |
| light | 0.5609 | 0.1808 | 3.6632 | 2.8680 |
| medium | 0.4416 | 0.2066 | 2.1106 | 2.6692 |
| heavy | 0.3530 | 0.2152 | 1.3884 | 2.5448 |

**Table 4. Road routes generated by PATRIOT, along with the spread and Beta distribution parameters, for the 4 weight categories, for travel between the 16 selected locations, excluding Mananjary, Madagascar.**

The average route length is 3790.8 miles, with a standard deviation over the 105 distinct endpoint pairs of 1854.2 miles. The average route driving time is 125.5 hours, with a standard deviation of 64.4 hours.

The computation result distributions for each of the weight categories are shown in Figure 9.

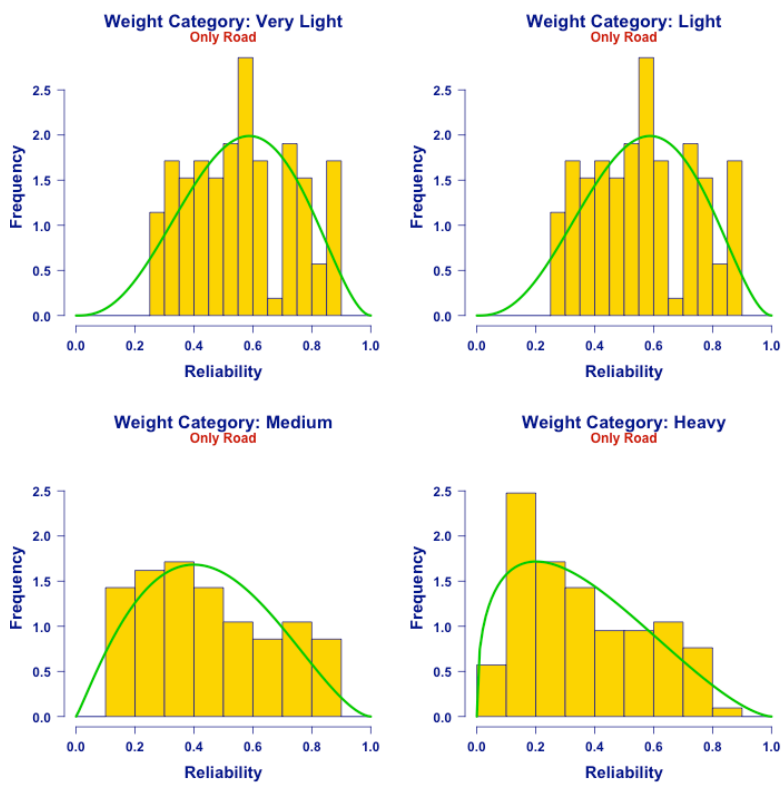



**Figure 9. Frequency distributions of computational transit reliability results, for transit restricted to road (and ferries). Best-fit Beta distributions are also shown for each of the four weight categories.**

Representative road-only routes are shown in Figure 10.

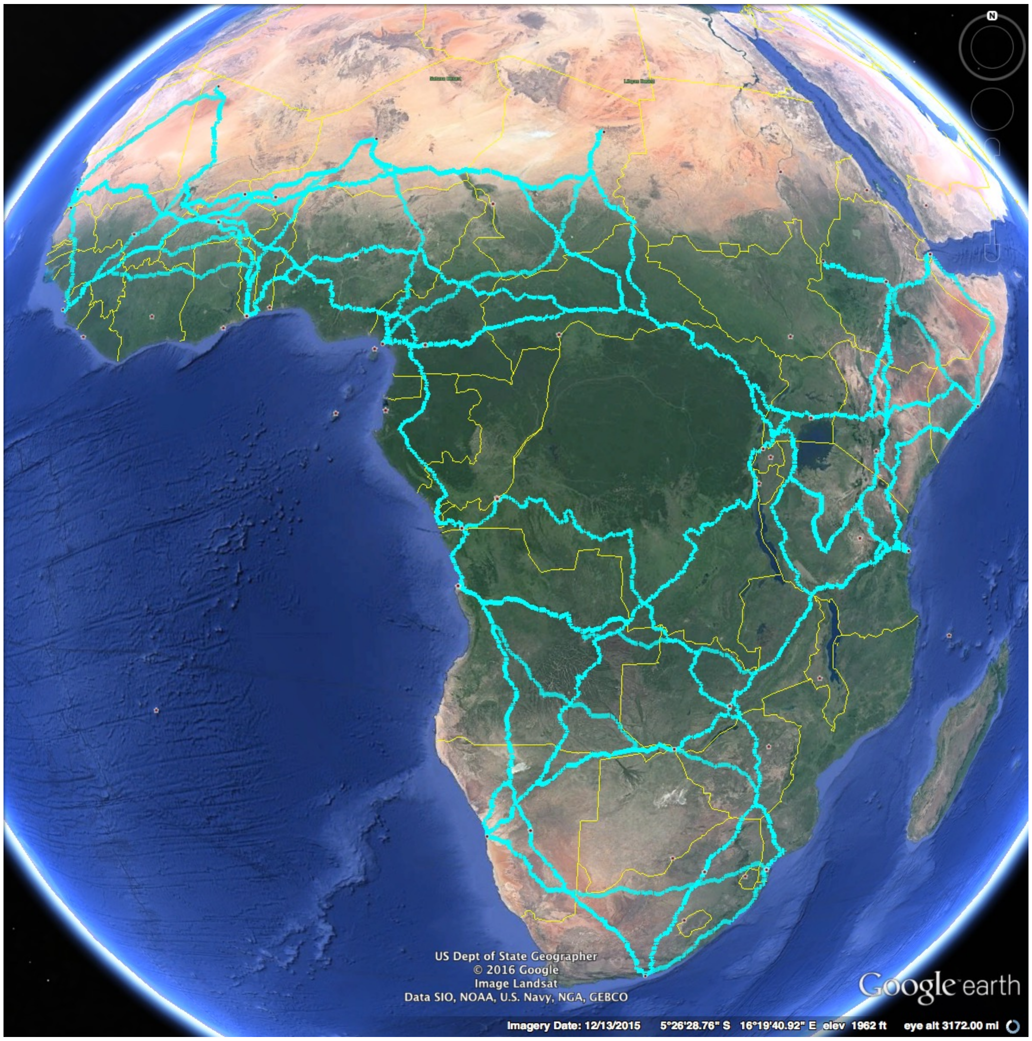



**Figure 10. Routes obtained when transit is restricted to roads and ferries.**

## 3.3 Checks

We attempted to generate a route from Nouakchott, Mauritania to Luanda, Angola using the Open Street Map web site (www.openstreetmap.org). Open Street Map was unable to find a route between these locations.

We attempted to use Google Maps web site (www.google.com/maps) to look for a road route from Nouakchott, Mauritania to Luanda, Angola. An automobile route was generated. The travel time is listed at 103 hours and includes a ferry crossing of the Congo River from Brazzaville, Republic of the Congo to Kinshasa, Democratic Republic of the Congo. The route traverses Mauritania, Mali, Burkina Faso, Benin, Nigeria, Cameroon, Gabon, (two separate short incursions into Equatorial Guinea, then back to Gabon), Republic of the Congo, Democratic Republic of the Congo, and Angola. The route is shown in Figure 11. We note that the route generated by PATRIOT from Nouakchott, Mauritania to Luanda, Angola travels via Rwanda, Uganda, Chad, and Niger. This “long way around” route is slightly more reliable (0.36227 encounter avoidance probability) than going by the Google Maps route via Victoria Cameroon (which PATRIOT evaluates to give a 0.33823 encounter avoidance probability for very light weight items).

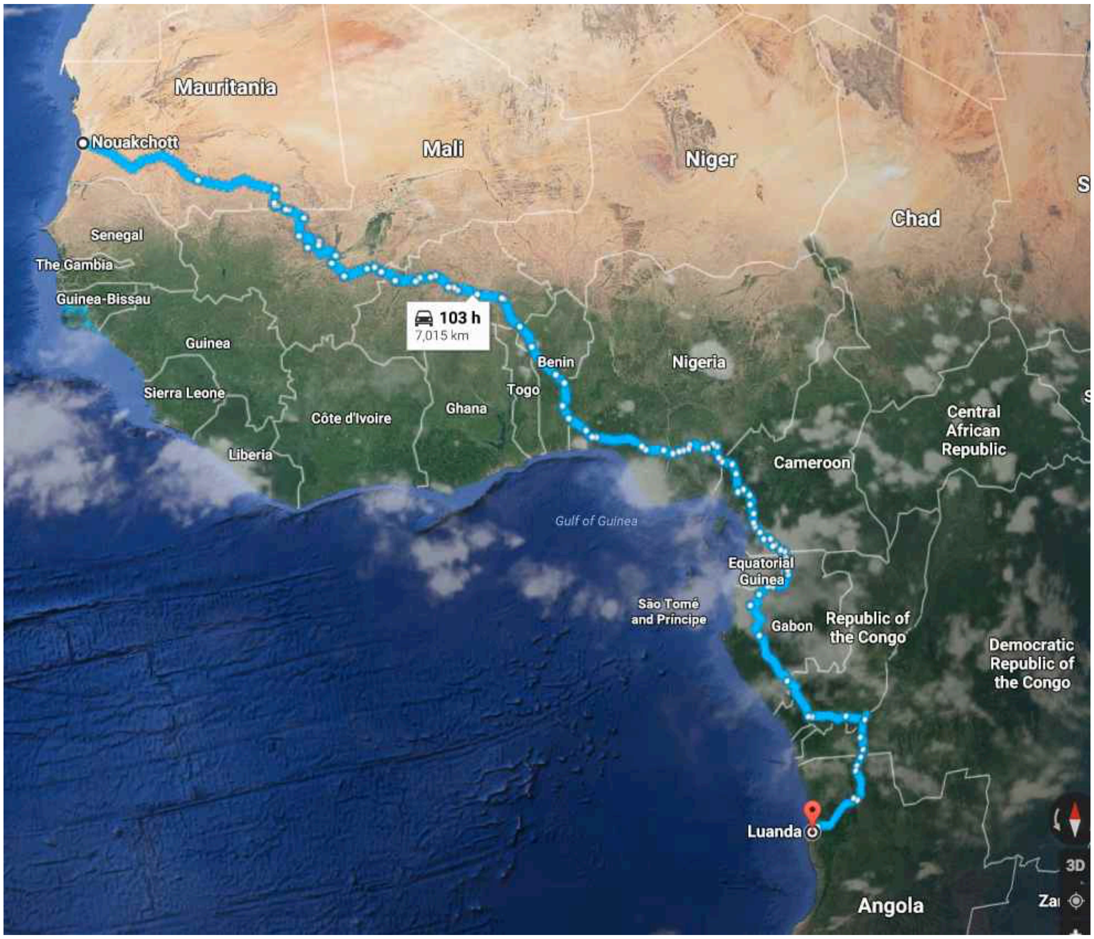



**Figure 11. Automobile route generated by Google maps for Nouakchott, Mauritania to Luanda, Angola.**

Google maps also found a commercial passenger flight with a multi-day layover in Casablanca, Morocco.

# 4 Implementation Plan for Full Pilot Analysis

The preliminary pilot analysis shows what could be done with the PATRIOT database essentially as is. This section describes the modifications for a full pilot region analysis. The planned schedule is to perform and deliver the full pilot region analysis by December 2016.

The full pilot region analysis requires that the mean distance to encounter for road travel be set to an appropriate value *for each country*, based on available data.

## 4.1 MDE by country

For MDEs, we define 48 new base detections in the reference base detection table in the PATRIOT database, BD699-BD746, one for the 48 countries in the southern Africa region. The appropriate MDE value will be put in column L.

The current encounter model while traversing the road network in PATRIOT assumes that there is a random contact process with law enforcement officers. The contacts with law enforcement officers are the result of reported encounters with those officers. We assume then that those encounters are events when the law enforcement officers are not bribed.

This process is modeled as a Poisson process and in our current model, the rate of contacts was estimated as 1 contact for every 100,000 miles driven. This rate was estimated using the yearly number of traffic stops (provided by the Bureau of Justice Statistics) and the total number of miles driven (provided by the Department of Transportation) in the United States. For lack of similar data for other countries, this rate of contacts is currently implemented in the entire worldwide road network in PATRIOT.

### 4.1.1 MDE Model Overview

To obtain a more realistic worldwide representation of Law Enforcement, we develop a parametric model to estimate the contact rate based on the Worldwide Governance Indicators (WGI) [1]. These indicators, developed by the World Bank since 1996, are published annually for over 219 countries and try to capture six key dimensions of governance: Rule of Law, Voice and Accountability, Control of Corruption, Government Effectiveness, Political Stability, and Regulatory Quality. These indicators represent summary measures from various datasets on the views on the quality of governance provided by a large number of enterprise, citizen and expert survey respondents in industrial and developing countries. These data are gathered from a number of survey institutes, think tanks, non-governmental organizations, international organizations, and private sector firms.

We will focus on the first three mentioned indicators to develop a model for the mean distance to contact with a law enforcement officer, and for the operational effectiveness of border patrol officers at border crossings. The definitions of those 3 indicators are:

1. **Rule of Law indicator:** Reflects perceptions of the extent to which agents have confidence in and abide by the rules of society, and in particular the quality of contract enforcement, property rights, the police, and the courts, as well as the likelihood of crime and violence.
2. **Voice and Accountability indicator**: Reflects perceptions of the extent to which a country's citizens are able to participate in selecting their government, as well as freedom of expression, freedom of association, and a free media.
3. **Control of Corruption Indicator**: Reflects perceptions of the extent to

which public power is exercised for private gain, including both petty and grand forms of corruption, as well as "capture" of the state by elites and private interests.

We also looked into the Corruption Perception Index (CPI) [2] developed by Transparency International. This index is reported annually and ranks countries by their levels of corruption as determined by expert assessments and opinion surveys. We found that this index is highly correlated (0.96) with the Corruption Indicators of the WGI, and since it only provides values for 168 countries (as opposed to the 219 countries studied by the WGI), we decided to work with the WGI indicators. Figure 12 shows scatterplots of the 3 WGI indicators defined above and the CPI.

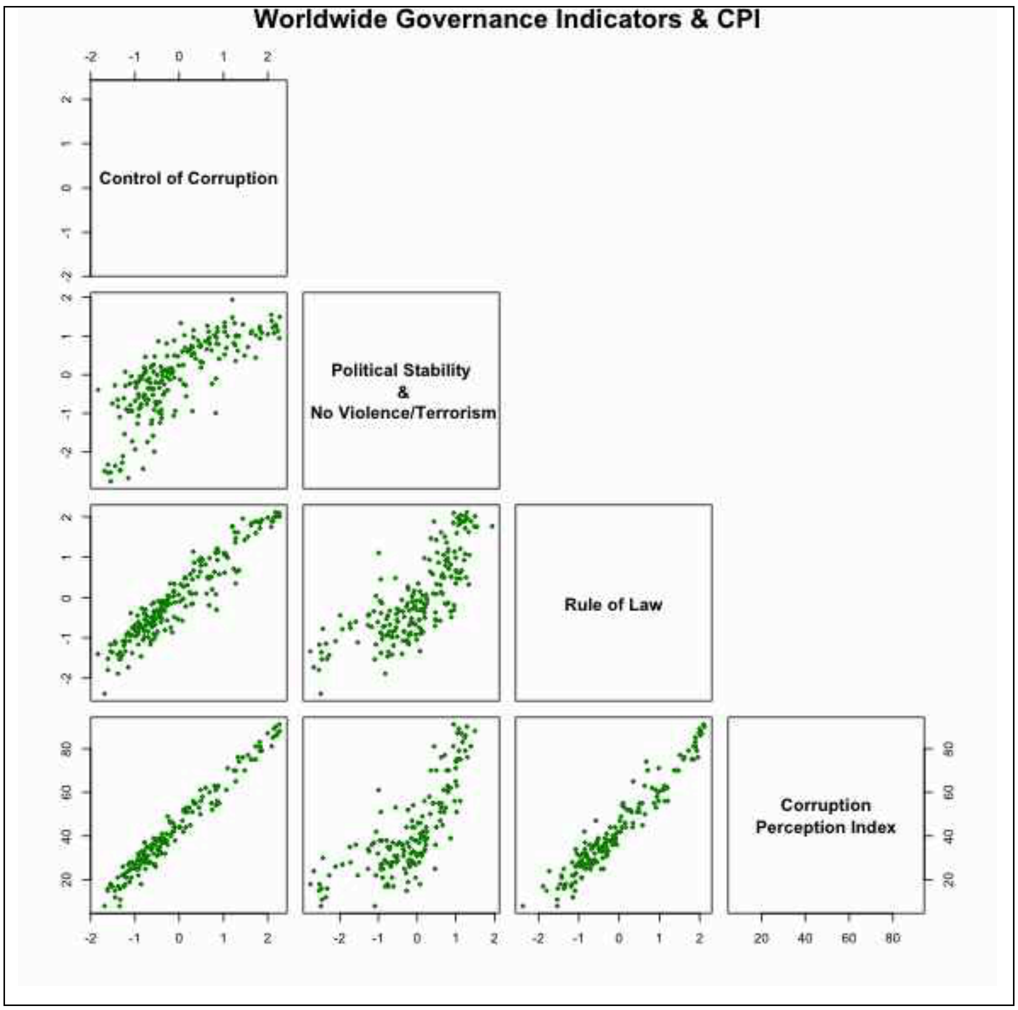



Figure 12 Scatterplots of 3 WGI indexes and the CPI

#### 4.1.2 Mean Contact Distance

As mentioned previously, the contact process is the result of encounters with law enforcement officers that were not bribed. Then the contact rate can be computed as

$$\lambda = \mu (1 - p_B)$$

where $\mu$ is the encounter rate and $p_B$ is the probability of bribing a law enforcement officer.

Next we develop models for the encounter rate and the probability of bribing based on the WGI indicators.

### 4.1.3 Encounter Rate

The encounter rate can be calculated as 1 over the mean distance to encounter. Next, we assume that the mean distance to encounter is inversely proportional to the "Rule of Law" index. This is, the higher the Rule of Law Indicator (a larger value reflects a better Law Enforcement system), the smaller the mean distance to encounter, or equivalently, the more frequently one should encounter law enforcement officers. This behaves mostly as expected, except for countries known as being more totalitarian or where there is no free mobility around the country. In such countries, one would expect to be stopped by law enforcement officers more frequently. To compensate for this effect, we use the Voice and Accountability Indicator that reflects the perceived level of freedom: The lower the value of this indicator (i.e. the less freedom there is in a country), the more often we expect to be stopped. Thus, for each country *k*, we model the mean distance to encounter as

$$MDE_k = \beta \frac{I_{Voice\&Acc}^{(k)} + 3}{I_{Rule\ of\ Law}^{(k)} + 3} \tag{1}$$

The constant 3 is to assure that all indicators values are positive, since typically the indexes take values in the range (-3, 3).

### 4.1.4 Probability of Bribing a Law Enforcement Officer

To model the probability of bribing a law enforcement officer we use the WGI's Control of Corruption Indicator and assume that it follows a logistic model. In other words, we assume that the log odds ratio for the probability of bribing a law enforcement officer is a linear combination of the Corruption Indicator, namely for each country *k*,

$$log\left(\frac{p_B^K}{1 - p_B^K}\right) = a + b\, I_{Corruption}^{(k)}, \tag{2}$$

or equivalently,

$$p_B^K = \frac{e^{a+b\, I_{Corruption}^{(k)}}}{1 + e^{a+b\, I_{Corruption}^{(k)}}}. \qquad (3)$$

For each country the contact rate will then be equal to the encounter rate multiplied by the probability of not bribing the police officer.

### 4.1.5 Model Calibration

To determine the parameter values in these models we use the corresponding values for the United States and benchmark extreme values.

For example, using the contact rate of 1 contact every 100,000 miles driven and a bribing probability of 4 cases every 1 million contacts (derived from information published in [3]) in the United States, and benchmarking Venezuela (which has the highest ratio in equation (1) ) to having an encounter rate of 1 contact about every 130,000 miles, we obtain the distributions for the overall mean distance to encounter, as shown in Figure 13.

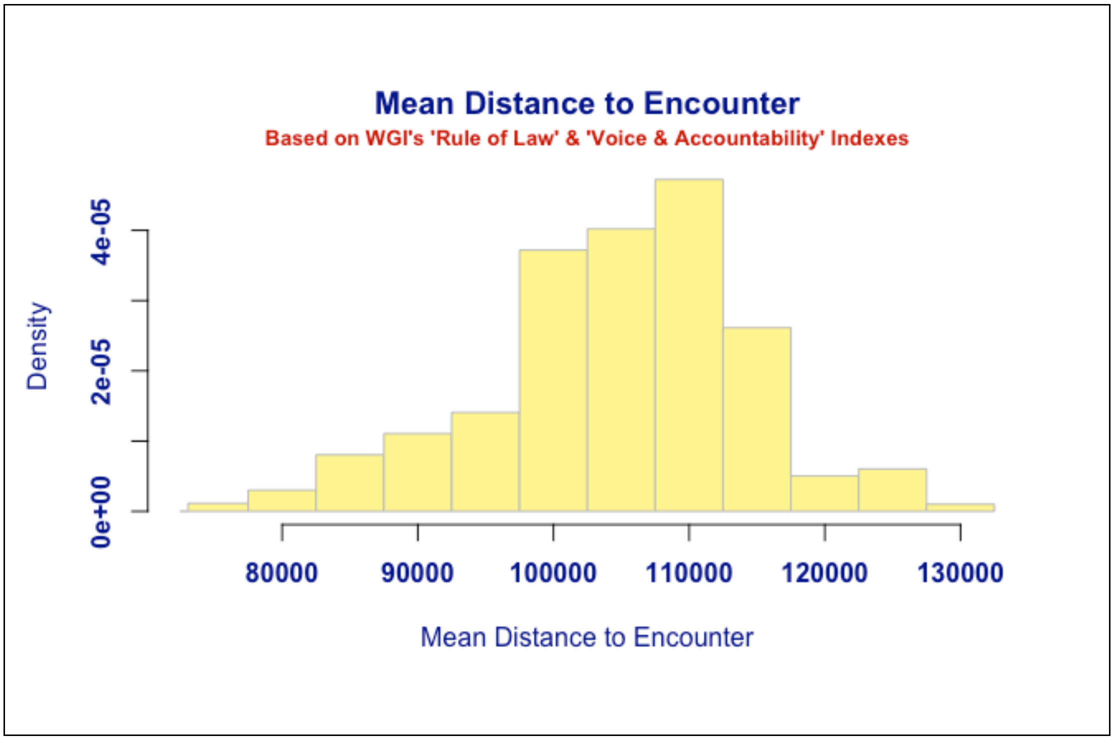



Figure 13 Distribution of the Mean Distance to Encounter

Similarly, using the estimated bribing probability for the United States and setting the probability of bribing a law officer in Equatorial Guinea (that has the worst corruption indicator) to 0.5, we obtain the bribing probabilities for all countries as displayed in Figure 14.

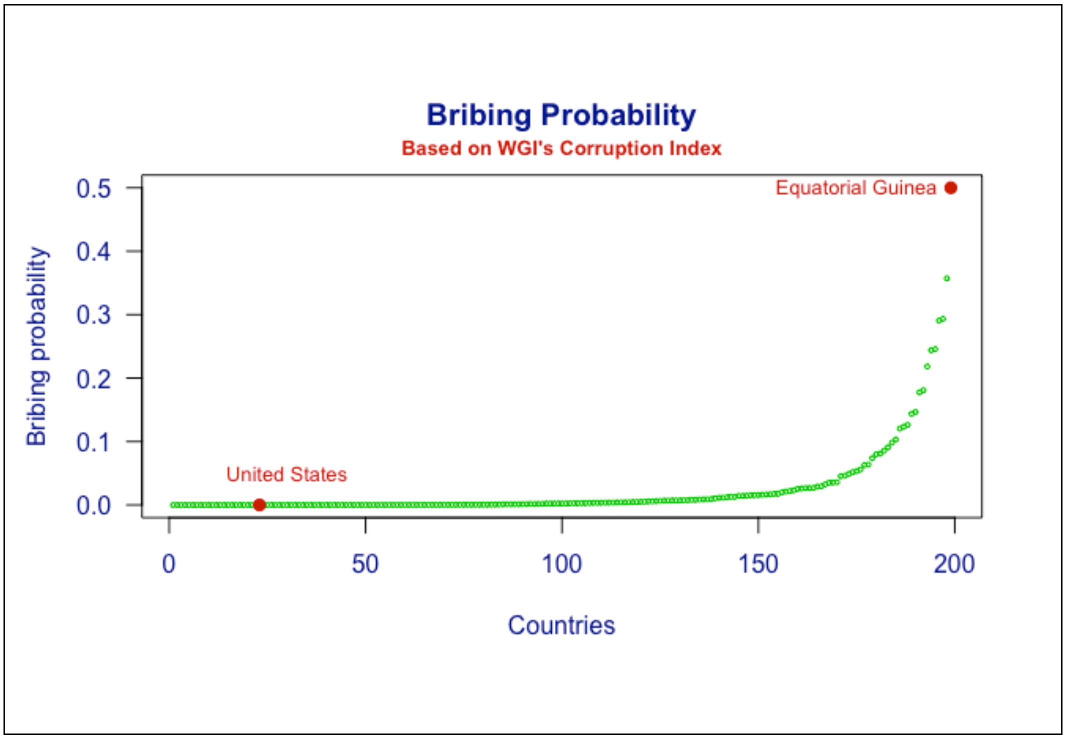



Figure 14 Bribing probabilities

Finally, combining the mean distance to encounter and the bribing probabilities, we obtain the mean contact distances for all countries. The corresponding distribution is displayed in Figure 15.

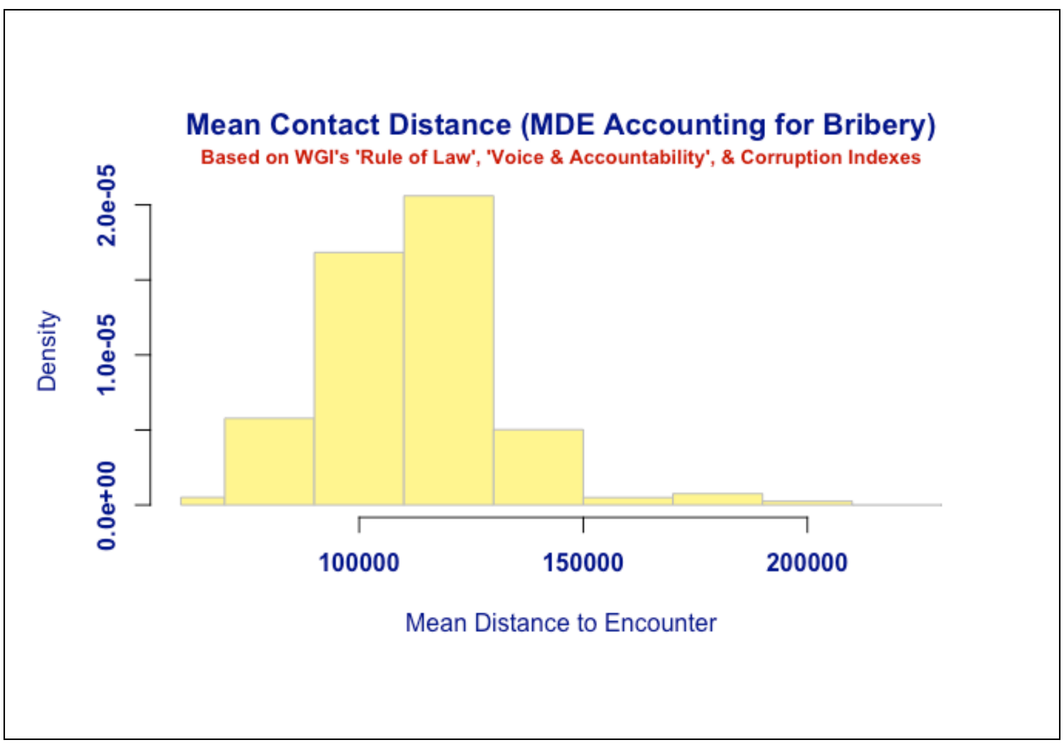



Figure 15 Distribution of the Mean Contact Distance

This process allow us to provide a unique mean distance to encounter for each country that is consistent with their corruption level, the effectiveness of their rule of law system, and their degree of freedom, and allows us to rank-order all countries around the world accordingly.

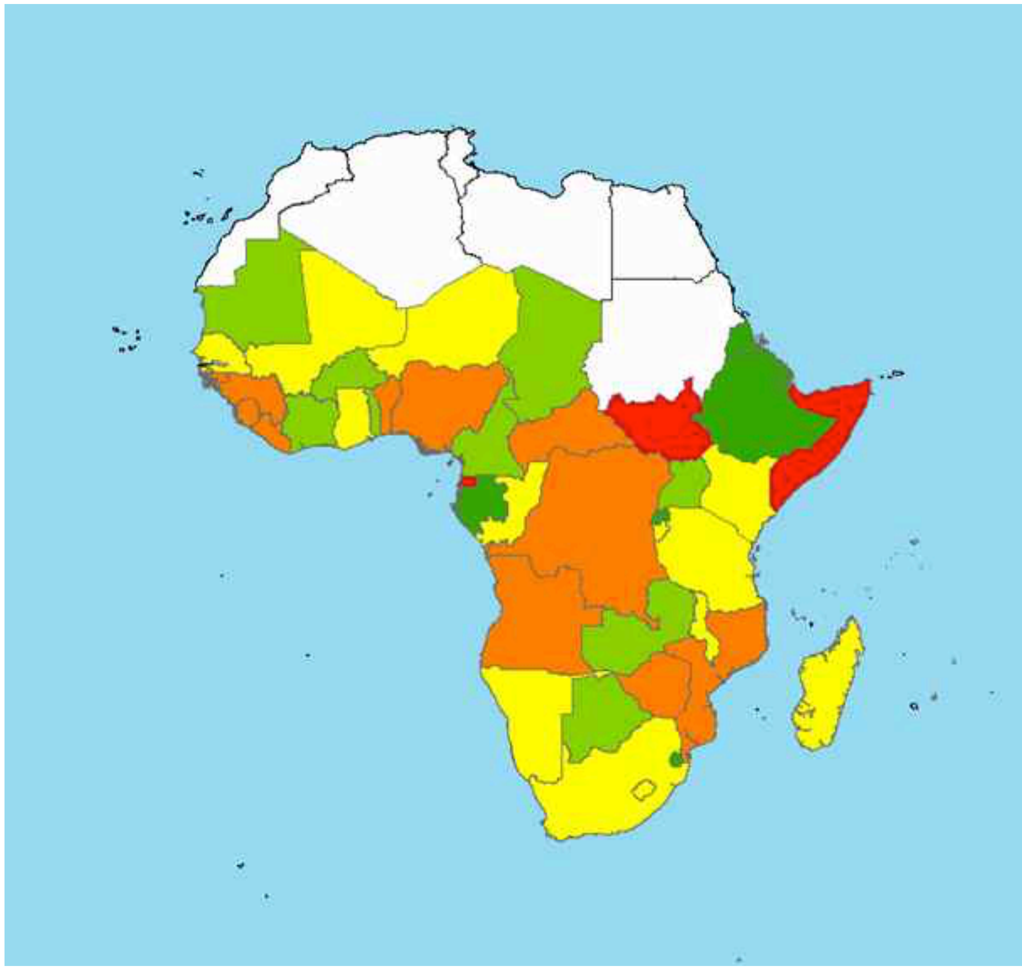


Figure 16 Southern African Countries color-coded according to the derived mean distance

For the Southern Africa countries, the map in **Error! Reference source not found.** is color-coded according to the Mean Contact distance, where yellow countries have lower values for the mean number of miles driven to have a contact with a law enforcement officer, and countries with red values have higher mean contact distances.

Alternatively, we have identified some data sources that characterize the density of road checkpoints. Several countries in the pilot region are characterized as having mean distance between checkpoints of under 20 miles.

## 4.2 Encounter at road international border crossings

### 4.2.1 Closed borders

As of October 3, 2016, data from the site africabordermonitor.com identifies the following country pairs as having closed borders:

- Djibouti-Somalia
- Ethiopia-Somalia
- Ethiopia-Eritrea
- South Sudan-Kenya (There is a corridor/road/rugged track through the wilderness that crosses the South Sudan-Kenya border at Nakodok. There is a project to develop this corridor for trade. We do not know the current status of this crossing.)
- Central African Republic - Chad
- Central African Republic - Cameroon
- Central African Republic - Democratic Republic of Congo
- Liberia - Guinea (closed since March 2016 for Ebola, possibly reopened in September 2016 along with other Liberian borders)
- Sierra Leone-Guinea

As there is some inconsistency in this border status data, we contacted the person that maintains the Africa border monitor website [4], and are in the process of confirming the status of borders in the region. The full pilot study will make sure that borders that are closed in the real world are also closed in the model.

### 4.2.2 Contacts with Law Enforcement on Border Crossings

In PATRIOT, all VMap0 road arcs that intersect an international border generate two terminal nodes, one on each side of the border. These terminal nodes are used to model checkpoints throughout the network allowing to model encounters with law enforcement officers and adding detection capabilities if needed. These terminal nodes are further expanded into three nodes: a terminal, an arrival gate, and a departure gate; and three directed arcs that connect them, called *terminal arcs*.

Currently, there are two default performance values assigned to these road terminal arcs: the first one accounts for the time it takes to traverse the arc, and the second one is a non-radiation-monitor (nrm) detection probability that only depends on the weight of the device and an implicit operational effectiveness of the law enforcement that is assumed to be uniform worldwide.

We propose to use the Rule of Law indicator to model the operational effectiveness at each country border to better reflect the effectiveness of individual countries.

Similarly to the bribing probability model, we assume a logistic model for the operational effectiveness that depends on the Rule of Law Index. Figure 17 displays the resulting operational effectiveness probabilities assuming an operational effectiveness for very light devices of 0.95 in the United States and a 0.75 in Somalia that has the lowest Rule of Law indicator.

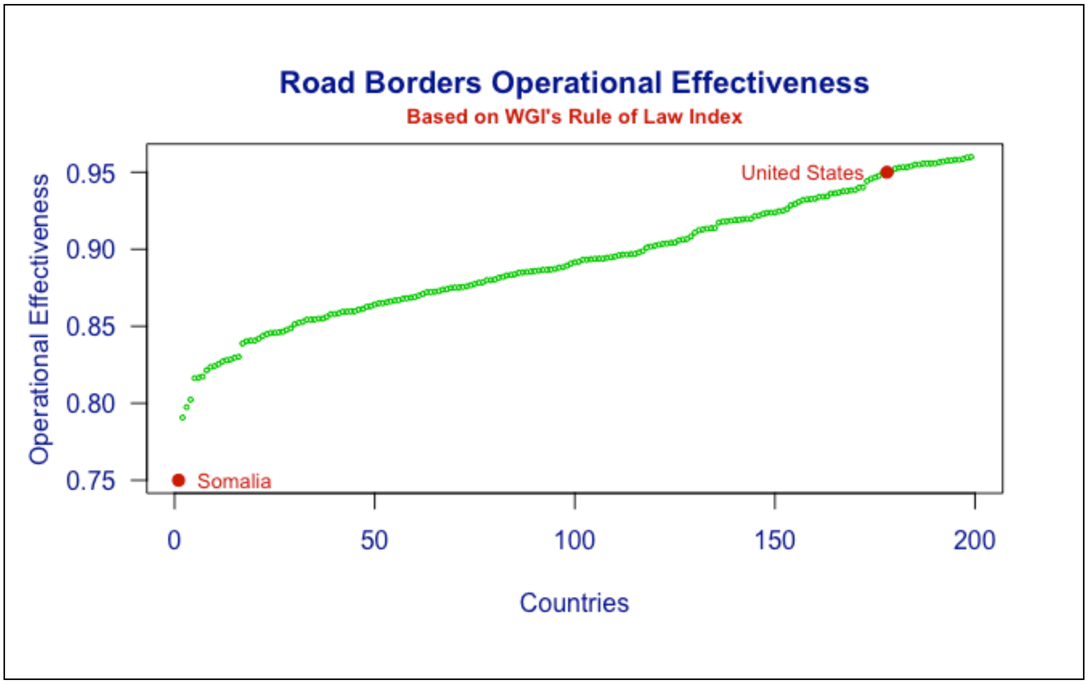



**Figure 17 Operational Effectiveness Probabilities at Road Border Crossings**

For heavier devices we decrease the operational effectiveness accordingly.

# 5 References


1. World Governance Indicators. http://info.worldbank.org/governance/wgi/index.aspx#home
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3. Police Integrity Lost: A Study of Law Enforcement Officers Arrested https://www.ncjrs.gov/pdffiles1/nij/grants/249850.pdf
4. Hadley, Lance. 2015. "Open and Closed Borders in Africa Sept 2013 – Dec 2015." CEO of AfricaBorderMonitor.com site.