 DOI: 10.1111/j.1539-6924.2012.01910.x

Managing Risk at the Tucson Sector of the U.S. Border Patrol

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This article describes a risk analysis used to inform resource allocation at the Tucson Sector of the U.S. Border Patrol, the busiest sector for alien and drug trafficking along the Southwest land border with Mexico. The model and methodology that underlie this analysis are generally applicable to many resource allocation decisions regarding the management of frequently occurring hazards, decisions regularly made by officials at all levels of the homeland security enterprise. The analysis was executed by agents without previous risk expertise working under a short time frame, and the findings from the analysis were used to inform several resource allocation decisions.

KEY WORDS: Frequently occurring hazards; homeland security; resource allocation

1. INTRODUCTION

An essential part of the U.S. Border Patrol's (USBP) strategy is to "detect, apprehend, and deter smugglers of humans, drugs, and other contraband."[(1)] In Fiscal Year 2010 alone (October 2009–September 2010), USBP agents apprehended over 445,000 illegal aliens along the 2,000 mile land border with Mexico, along with approximately 2.4 million pounds of marijuana.[(2)] Drug, cash, and weapons smuggling has fueled a surge of violent activity among cartels.[(3)] Border violence and instability prompted the president to sign appropriation bill H.R. 6080 on August 13, 2010, which allocated $600 million to Southwest border operations, with the U.S. Customs and Border Protection[1] as the primary recipient of the funding.

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[1] USBP is a component of Customs and Border Protection, which in turn is a component of the U.S. Department of Homeland Security.

Pursuant to the Secretary of Homeland Security's policy statement on integrated risk management and in preparation for the incoming funds and resources, the Chief Patrol Agent of the USBP Tucson Sector in Arizona ordered the execution of a risk analysis for his area of responsibility. Working collaboratively with USBP agents, the U.S. Department of Homeland Security's Office of Risk Management and Analysis provided assistance in developing and executing this analysis. We began our involvement in June 2010 and the analysis was completed and presented to the Chief Patrol Agent at the start of October 2010.

Though designed specifically for the USBP, the methodology described in this article can generally be used to inform resource allocation decisions to mitigate the risks from a variety of frequently occurring hazards. In addition to migration and drug trafficking incidents, other examples of frequently occurring hazards in the homeland security domain include burglaries, muggings, and cyber identity theft. Of course, this type of decision is a subset of the decisions homeland security officials must make, meaning this methodology should not be applied to all homeland security decisions.

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This analysis follows in the footsteps of previous data-driven approaches to law enforcement. For example, the concentration of police efforts at "hot spots" has been shown to effectively reduce crime.[4,5] Similarly, the New York City Police Department's CompStat program, institutionalized in the mid-1990s, coupled crime mapping with management accountability to inform resource allocation and performance evaluation.

This article describes the risk analysis executed in Tucson Sector and examples of the resource allocation decisions it informed. The content of the article is organized around the main steps of the DHS risk management process,[6] illustrated in Fig. 1. Section 2 describes the context for the decision and the constraints on the study. In Section 3, we describe the methodology we designed for the risk identification and risk assessment portions of the analysis, as well as the approach used to identify and assess the effectiveness of alternative resource allocation options. Section 4 describes the results of the analysis and the decisions it informed. Section 5 is a discussion of the lessons we learned from this process, many of which we believe are applicable in other contexts.

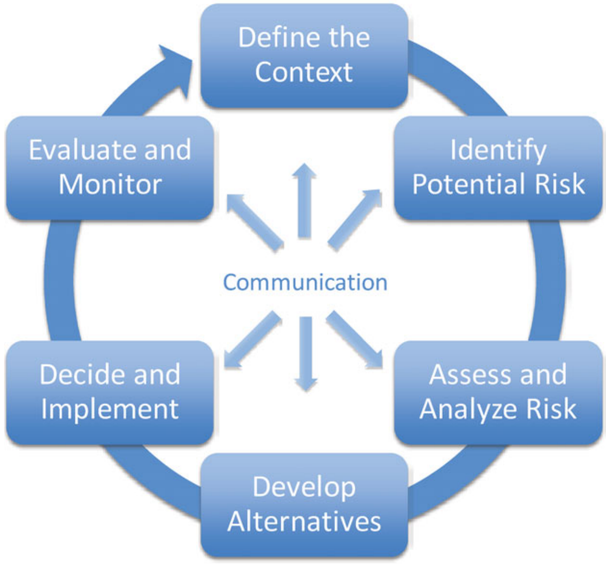

Fig. 1. The DHS risk management process.[6]

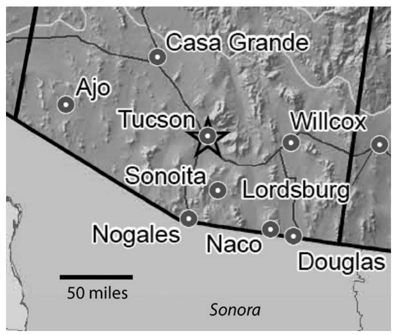

Fig. 2. Map of the southern portion of the Tucson Sector, adapted from Ref. 7. Towns are marked with circles and the sector headquarters with a star. The Mexican side of the border is in lighter gray to the South. Major roads are marked with thin black lines, and the sector border with thick black lines. Rivers appear as light gray lines.

2. DECISION CONTEXT AND STUDY CONSTRAINTS

2.1. Tucson Sector Background Information

The USBP Tucson Sector manages 262 miles of the Southwest border from the Yuma county line to the Arizona/New Mexico state line. The sector stretches north to the northern Arizona border, encompassing 90,500 square miles of terrain (Fig. 2). The western portion of the sector is primarily desert, the central portion contains the town of Nogales (which is bisected by the border), and the eastern portion contains the town of Douglas (separated from the town of Agua Prieta by the border). The Tucson Sector is the busiest of the nine sectors along the Southwest border, with respect to alien and drug trafficking. The sector itself is divided into eight stations, which themselves are subdivided into zones. Some of the zones touch the border with Mexico and the rest are interior zones.

This risk analysis was conducted to inform decisions by the Chief Patrol Agent, who is ultimately responsible for the acquisition and deployment of resources in the Tucson Sector. The Chief Patrol Agent was primarily interested in information regarding which resources to deploy and where in his area of responsibility to deploy them; he allocates resources on a zone-by-zone basis. At the Chief Patrol Agent's request, the risk analysis focused on informing resource allocation decisions in the border zones, rather than the interior zones, and on adjustments to the resource allocation following the supplemental appropriation, rather than a wholesale reallocation of resources. In the context of this assessment, resources include the variety of defensive countermeasures at his disposal: patrol agents, fencing, forward operating bases (FOBs), surveillance technology, and specialized units (horse patrols, all-terrain vehicles, and motorcycles).

Resource allocation at the Southwest border has been the subject of several previous investigations led by both government and academic entities. The Government Accountability Office produced a report on the method and scales used by the USBP to measure the level of operational control of different parts of the border between ports of entry.[2] The report indicated that USBP described varying levels of operational control within Tuscon Sector at the end of Fiscal Year 2010. USBP characterizes sections of the border as "controlled," "managed," "monitored," "low-level monitored," or "remote/low activity," each of which has a qualitative definition.[2] The levels of control can help inform where more resources are needed, but they are not detailed enough to inform which *type* of resource would be most effective at increasing operational control at specific border locations, nor do they provide return-on-investment information. More detailed assessments are required for informing decisions about the most effective types and locations of resource improvements.

Another recent study explored the difficulty of using a single metric for the effectiveness of border security between the ports of entry and as a result offered several metrics to be used in conjunction.[8] The breadth of the mission, including the current focus on drug control, counterterrorism, and illegal migration control, is one of the causes of this difficulty. In addition, the number of people attempting to illegally cross the border depends on a complex interaction of socioeconomic factors beyond USBP control; in other words, USBP does not face the same number and spatial distribution of illegal attempts to cross the border each year. The study recommended measuring the performance of three functions: interdiction, deterrence, and exploiting networked surveillance.

Predd *et al.*[9] also studied security on the border, investigating the use of pattern and trend analysis and systematic randomness to inform decision making. Pattern and trend analysis refers to the study of historical data to identify where and when resources can most effectively be applied to increase interdiction rates; systematic randomness refers to the deliberately unpredictable deployment of resources for the purpose of increasing deterrence and adversary uncertainty. The study suggests that using these two techniques in combination improves interdiction rates compared to using either technique independently or using expanded surveillance.

A different approach to modeling the U.S.-Mexico border was carried out by Wein *et al.*[10] This team built a mathematical optimization model that incorporated several components of the border security apparatus, including border patrol agents, surveillance technology, and detention facilities, and used it to offer recommendations on how to reduce the likelihood of terrorist entry and the frequency of illegal alien entry. The model consists of several constituent pieces, including a discrete choice model for potential illegal aliens, a spatial model for interdiction, a queuing model for removal, and an equilibrium model for wages. This study concluded that detention beds are the current system bottleneck.

2.2. Study Constraints

Given the range of possible resource-allocation decision-support techniques applicable to the Southwest border, before developing a methodology for the Tucson Sector we worked with our USBP partners to identify a number of study constraints. We believe these constraints are not particular to Tucson, but instead generally apply when building decision-informing tools for use by homeland security operational officials. At minimum, the constraints that the analysis must satisfy are: transparency, ability to be executed by nonspecialists, methodological soundness, and ability to be executed with the analytical resources at hand. We will discuss each of these constraints in turn.

The analysis must be transparent because the decisionmakers, who are typically not technical risk analysts, generally do not trust tools that have mysterious inner workings. The connection between the inputs and outputs must be visible and understandable to all parties involved. Ideally, all parties should be able to verify the outputs, given the inputs.

Next, it must be possible for someone with little or no technical expertise to correctly execute the analysis and interpret its outputs. Mathematically straightforward analyses have a strong advantage in this regard. In homeland security, risk and decision analysts are rare, so minimizing the data analytic skills required to populate and interpret the model helps to ensure it will actually be used, and used correctly. It is reasonable to tradeoff decreased precision and increased uncertainty (but not

[2] At the time of this article's writing, USBP is developing a new methodology for measuring operational control of border areas.

decreased accuracy) for improved practicality and usability.

Methodological soundness is necessary because it is imperative to avoid producing incorrect information that then influences a decision. Communicating uncertainty, assumptions, and limitations helps the decisionmaker understand the degree to which he/she should allow the analysis to influence his/her decision making.

Finally, the analysis must be able to be executed with the resources at hand, including staffing, data, and computational hardware and software. Executing a risk analysis often requires staff with specialized skills, such as data gathering, information management, elicitation, and data analysis. It is not helpful to design an analysis that requires the staff to elicit millions of judgments or gather unobtainable data. Most importantly, executing an assessment that cannot be completed before the decision must be made is a waste of resources. Project management techniques are very useful in explaining to the decisionmaker the tradeoffs between the information the analysis provides and the demands on the analysts.

3. METHODOLOGY

Working collaboratively with USBP agents, we applied our knowledge of the decision context and study constraints to develop a methodology to inform the Chief Patrol Agent's resource allocation decisions. The methodology has four steps: risk identification, risk assessment, allocated resource assessment, and risk management. Together these steps constitute the "identify potential risk," "assess and analyze risk," and "develop alternatives" steps of the DHS risk management process (Fig. 1).

3.1. Risk Identification

The first step in the methodology was to identify risks of interest to the USBP by examining the organization's fundamental objectives using value-focused thinking.[11] For homeland security and law enforcement organizations, it can be difficult to determine the appropriate scope of these objectives. For example, though these organizations clearly want to prevent economic damage, models calculating the downstream economic effects of frequently occurring hazards such as drug smuggling or burglaries are far out of scope and will likely fail the transparency and limited expertise constraints described in Section 2.2. Instead of more overarching objectives, it is useful to capture risk through the harmful events and outcomes that the decisionmaker is trying to prevent. In the general law enforcement and homeland security realm, examples of these objectives might include minimizing the number of successful burglaries, minimizing the pounds of drugs crossing a border, and minimizing the number of injuries to the organization's personnel.

For the USBP Tucson Sector, we worked with the agents to identify six fundamental objectives relevant to the resource allocation decision:

(1) Minimize the number of illegal aliens transiting from Mexico to an interior zone through a border zone between ports of entry,
(2) Minimize the likelihood that a terrorist could transit from Mexico to an interior zone through a border zone between ports of entry,
(3) Minimize the quantity of marijuana transiting from Mexico to an interior zone through a border zone between ports of entry,
(4) Minimize the quantity of drugs other than marijuana transiting from Mexico to an interior zone through a border zone between ports of entry,
(5) Minimize violence against civilians, and
(6) Minimize violence against USBP agents.

Some of these objectives could have been broken down more narrowly. For example, the first objective could have been separated into violent and nonviolent offenders, or perhaps aliens traveling alone or in groups. Choosing a set of fundamental objectives is an exercise in satisfying a set of constraints,[11] and given the time allotted for the assessment having a concise set of objectives was paramount.

Once the fundamental objectives had been established, we needed to choose attribute measurements for these fundamental objectives (Fig. 3). One key to this choice was data availability. Many organizations have years of data for the risks they are charged with mitigating, particularly for frequently occurring hazards. If an organization does not have records of the hazards the region has experienced, estimating the risk can also be done using elicitation from subject matter experts.

Three of the USBP objectives had readily available attributes with data. These three fundamental objectives are connected to three hazards: illegal aliens, illegal drugs, and assaults. The USBP keeps records of the number of people crossing into each border zone, constructed from visual sightings and tracking, and it also records the number of

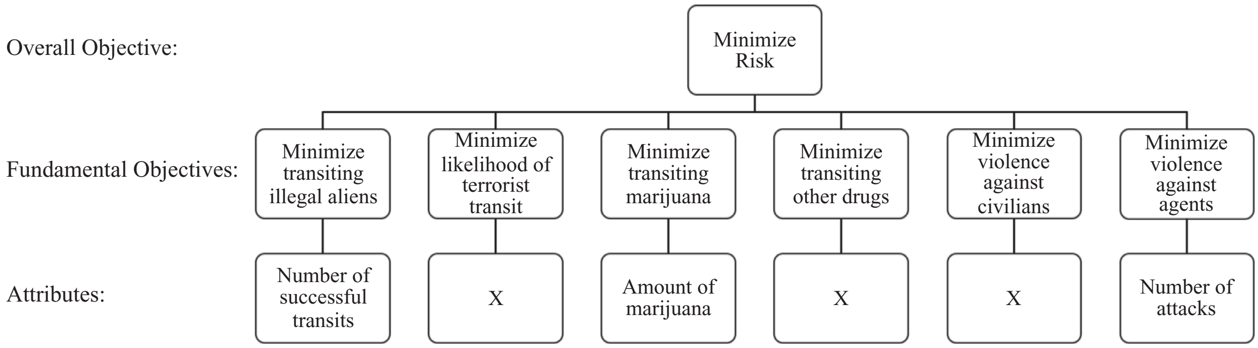

Fig. 3. Fundamental objectives hierarchy and attributes for the USBP Tucson Sector. Xs denote fundamental objectives that did not have identified attributes for this analysis.

people it apprehends or observes being deterred after crossing the border. The difference between these two numbers is an estimate of the number of illegal aliens that successfully transit to an interior zone. Similarly, the USBP records the amount of marijuana seized in each zone; this is related to the quantity that actually successfully transits the zone. The actual amount successfully transiting the zone is not available because the amount of marijuana entering a border zone cannot be estimated accurately from sign tracking or visual inspection. Finally, all attacks on USBP agents are recorded by time and place; this allowed us to count the assaults against agents for each zone.

We did not identify attributes for the other three objectives for a variety of reasons. We assumed that resource allocation alternatives that would reduce the number of illegal aliens entering an interior zone would also be effective at minimizing the likelihood that a terrorist could make a successful illegal crossing. Similarly, we assumed that alternatives effective at reducing marijuana flow would also be effective at reducing the flow of other drugs. Given the limited scope of the alternatives considered in this assessment, we believe both of these assumptions hold within the precision of the rest of the data. We discuss these assumptions further in Section 5. Finally, violence against civilians is generally reported to local law enforcement, rather than to USBP. Therefore, even though minimizing violence against civilians is an important objective to the USBP, we did not include an attribute related to this objective in the assessment because acquiring the relevant data would have required an information exchange and database construction not viable in the time frame allotted to the assessment.

We considered but rejected including an additional fundamental objective: minimize the cost of the resources allocated. Each resource has a different monetary cost, both in one-time upfront costs and in recurring costs over the life cycle of the investment (including salaries and benefits for agents, and operations and maintenance costs for equipment and infrastructure). The resources allocated in pursuit of the USBP fundamental objectives are subject to a complex and fluctuating budgetary constraint. The team was told that no one understands the budgetary constraints better than the Chief Patrol Agent, so the limited time available before the assessment deadline would be better spent gathering other information. In other words, we did not want to spend our time telling the decisionmaker something he already knew.

Note that these objectives alone are not appropriate for use as performance metrics. The number of aliens successfully transiting the border zones into an interior zone is connected to the number of people who attempt an illegal crossing, which in turn is connected to many factors outside of USBP control, such as the economic attractiveness of such a transit. In other words, if the number of people successfully making the crossing increases because more people attempt the crossing, it does not necessarily imply that USBP's performance has declined. To turn these objectives into performance metrics, more information is required.[8]

3.2. Risk Assessment

Once the fundamental objectives and attributes have been chosen, the next step is to estimate the risks associated with each zone. Expected loss is a straightforward measure of risk, and though it is not the only relevant metric, it certainly is an important one. For frequent hazards, the expected loss can be estimated using the data at hand. For example, if a city neighborhood had 10 muggings and 15 burglaries last year, an estimate of the risk associated with that neighborhood is given by those numbers of muggings and burglaries, per year. In other words, a good way to estimate the expected loss because of a hazard this year is to start from the actual loss from last year.

If there are many years of data available, choosing the time period to use for the estimate can be a difficult decision because conditions change over time. For the Tucson Sector, the agents only had data readily available dating back nine months to the start of the Fiscal Year 2010, so this was the time period we used for our assessment. In general, it is best to use the longest time period possible as long as conditions have remained essentially the same. Sensitivity analysis can be used to test the influence of the chosen timescale.

The USBP records the data for the three attributes described in Section 3.1 by zone. For the purposes of the assessment, this was convenient because the Chief Patrol Agent allocates resources either by zone or by station. Because the illegal alien and assaults on agents attributes are direct estimates of the risk, no additional processing steps were required for those data. However, for the drug smuggling attribute, the recorded data pertain to the drugs seized, not the amount that successfully transits the zone. For this reason, the USBP agents carried out a simple expert elicitation of the station chiefs (who report to the Chief Patrol Agent) to estimate the amount of drugs that successfully transited each zone. Details of the elicitation process are provided in Section 3.4.

This process produced an estimate of the three types of risk in each zone and led to a straightforward model for risk. Each occurrence of a hazard, be it a transit or an assault, is associated with a zone. Resources are also associated with a zone through their allocation for the purpose of reducing the risk that occurs in that zone. If new resources are available they can be placed in the zones where they will most effectively reduce risk. Alternatively, resources can be shifted from a zone where they are being used less effectively to one where they would be more effective. We did not use swing weights and utility functions to develop a value model that combined all three types of risk because the decisionmaker preferred to see each risk separately.

In addition, it seemed reasonable to assume a linear value function for each individual type of risk. For illegal aliens and drugs, we considered possible arguments for a concave value function (in which the first few occurrences of each hazard are valued more) or a convex value function (in which there is increasing value placed on each additional hazard that occurs). We could have captured the shapes of these value functions with decisionmaker elicitation. However, we chose not to because in this assessment linear value functions brought several compelling advantages, including simplicity, straightforward risk addition and allocation across zones and time periods, and a reduction in the elicitation workload. Happily, linear value functions also matched with how the agents talked about their own performance in our informal conversations.

Some simple mathematical notation here will become useful later. Let zone i have an associated risk from hazard j given by $R_{i,j}$. Note that the total risk from hazard j in the sector can be found by summing $R_{i,j}$ over i because all of the risks are expected losses.

Capturing uncertainty is an important part of the risk assessment step, particularly when the data available are incomplete, biased, or a change in conditions is anticipated. To meet the criteria described in Section 2.2, we elicited the station chiefs regarding their level of confidence in the gathered data for all three types of risk for each zone, after they had been briefed on the data from the last nine months. The station chiefs provided a best estimate, as well as upper and lower bounds, informed by the data for the amount of each risk that occurred in each zone over the last nine months. In practice, there was very little uncertainty in the data for assaults on USBP agents, but the other two types of risk did have some associated uncertainty.

3.3. Allocated Resource Assessment

The allocated resource assessment is an assessment of the various countermeasures that have already been deployed to manage risk. Along with the assessment of the risk to which the zones are currently exposed, this step completes the picture of the current state of affairs. Each of the countermeasures chosen for adjustment are evaluated in this step, even if some of the resources are not present in some zones.

Some countermeasures are easily measured with ratio scale numbers, such as the number of staff in a zone. Other resources are more appropriately

Table I. Constructed Ordinal Scale for Fencing Resources

Value	Descriptor
1	No Fencing (least preferred)
2	Vehicle Barrier Fencing
3	Landing Mat Fencing
4	Expanded Metal Fencing
5	Bollard Fencing (most preferred)

measured with constructed ordinal scales, such as the varieties of fencing along a border, because they are differentiated by type rather than by number. Both ratio and ordinal scales can be accommodated by this methodology as long as the ordinal levels can be ordered in terms of preference.

Before our analysis began, the Chief Patrol Agent had several types of resources already deployed to manage risk. These resources include patrol agents, fencing (both amount and type), surveillance equipment, FOBs, and specialty units (horse patrols, ATVs, and motorcycles). Of these resources, patrol agents, specialty units, and amount of fencing can reasonably be measured with ratio scales in a given zone. Fencing type, surveillance equipment, and FOBs required ordinal constructed scales like the one shown in Table 1. The Tucson Sector also has other resources it uses to manage risk, but the types listed here were singled out by the Chief Patrol Agent as ready for an adjustment in allocation.

The formalism for this step of the assessment is straightforward. Label the various resources under consideration with the index k. The level of each allocated resource in zone i is given by $A_{i,k}$. Note that in this construction, the dimensionalities of A with different k often do not match. Ratio scale resources are measured with units such as man-hours per day, and constructed ordinal scales are unitless.

Generally, there is comparatively little uncertainty around the resources that have been allocated to any given zone over the period of the assessment. Most organizations keep records of the manpower or equipment they have deployed in a zone, even if just for payroll or budgetary purposes. In the Tucson Sector, these documents were obtained by the risk assessment team and used to assemble the $A_{i,k}$.

On the other hand, the resources allocated to a particular zone can vary over the time period that the risk assessment covers. If this is the case, we recommend using a typical level of allocated resources for ratio scale quantities, and the lengthiest level of resources for ordinal scale quantities. If there are large trends in the allocation of resources to a given zone, it is likely best to remove those zones from this analysis because there is not a steady state to be assessing. Other methodologies may need to be used if those zones are of particular importance to the decisionmaker.

3.4. Risk Management

The final step of the methodology consists of a series of structured questions designed to aid in risk management by directly informing resource allocation. In Tucson, the information for this step of the methodology was gathered through expert elicitation from the commanding officers in the field. These were station chiefs, who report directly to the Chief Patrol Agent.

These questions' purpose is to estimate the change in risk if the region was exposed to the same hazards over the time period of interest, but had different levels of countermeasures in place. The notation we use for an incremented countermeasure in a particular zone is $A^{+}_{i,k}$, whereas a decremented countermeasure is $A^{-}_{i,k}$. The estimated change in risk from hazard j if capability k was incremented in a specific zone i to level $A^{+}_{i,k}$ will be known as $\Delta^{+}_{i,j,k}$, where:

$$\Delta^{+}_{i,j,k} = R_{i,j}|_{A^{+}_{i,k}} - R_{i,j}, \tag{1}$$

and $R_{i,j}|_{A^{+}_{i,k}}$ represents the risk of the expected loss in the zone had the augmented countermeasure been in place (this is the quantity that was elicited from the station chiefs). Similarly, if capability k is decremented in a specific zone i to the level $A^{-}_{i,k}$, call that estimate $\Delta^{-}_{i,j,k}$, where:

$$\Delta^{-}_{i,j,k} = R_{i,j}|_{A^{-}_{i,k}} - R_{i,j}. \tag{2}$$

These terms are structured such that a decrease in risk has $\Delta < 0$ and an increase has $\Delta > 0$.

Most of this formalism was invisible to the USBP agents executing the assessment. We explained how each step in the methodology worked, but kept the notation and calculus to ourselves.

When constructed scales have been used to measure $A_{i,k}$, the incremented countermeasures $A^{+}_{i,k}$ should be found by considering a countermeasure one level better on the scale and the decremented by considering one level lower. Keep in mind that when an ordinal scale is constructed, the differences between the levels are not equal. For example, it may cost a lot more to move $A_{1,1}$ from level 2 to 3 than it costs to move it from 1 to 2.

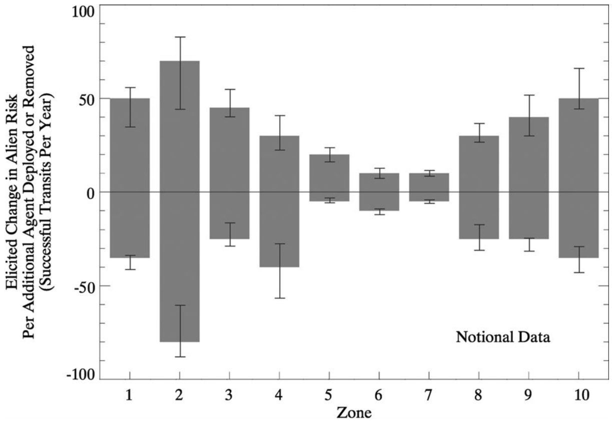

Fig. 4. A notional plot of the elicited change in alien transit risk per additional agent deployed or removed from a zone. The height of each bar above zero represents the increase in alien risk, in successful transits per year, because of removing an agent from the zone. The length of each bar below zero denotes the decrease in alien risk from deploying an additional agent to that zone. Error bars convey the uncertainty in these quantities.

In the case of a ratio scale to measure a resource, more analysis is possible. To start, it is often helpful to estimate $\Delta^{+}_{i,j,k}$ and $\Delta^{-}_{i,j,k}$ based on percentage increments and decrements in $A_{i,k}$. For example, in an assessment where $A_{1,1}$ is the number of man-hours spent patrolling zone 1, how would $R_{1,1}$ have changed if $A_{1,1}$ had increased by 10%? Ratio scales permit the production of very useful information: the risk return on investment for each additional unit of $A_{i,k}$ deployed to each zone (see Fig. 4 for a notional example). Similarly, the increment in risk if a unit of resource $A_{i,k}$ is removed can be estimated. In combination, the decision of moving a unit of resource $A_{i,k}$ and placing it somewhere else can be informed. Using the notional data in Fig. 4, the decisionmaker can see that removing agents from zones 5, 6, or 7 will have the least severe increase in risk, although adding them to zone 2 will have the most risk reduction. These agents would also have effects on the drug risk in each zone, and would be vulnerable to assaults, so plots like Fig. 4 should be made for each type of risk.

We also made plots similar to Fig. 4 for resources that were measured with constructed ordinal scales (as described for fencing in Table I). In these cases, the vertical axis was changed to "Elicited Change in Alien Risk" because there was no equivalent to an additional agent deployed or removed. Also, the tops and bottoms of each bar were labeled with the improvement and decrement that would be required to achieve that change in risk (such as the type of new fence that would need to be installed). Uncertainty was communicated with error bars, as in Fig. 4.

Note that these estimates are perturbative quantities; in other words, they cannot inform the decision of how to place resources in the region starting from a blank slate, only about small changes around the current allocation of resources. Similarly, drastic increases in countermeasures are not well informed by this type of assessment because it does not account for the diminishing returns of placing greater and greater resources in a zone.

In most cases in state and local homeland security risk management, estimating $\Delta^{+}_{i,j,k}$ and $\Delta^{-}_{i,j,k}$ using expert elicitation is a sufficient level of precision to better inform a resource allocation decision. It is also possible to capture the level of certainty these experts have by asking them upper and lower bounds for the two change in risk quantities.

This step in the assessment can require gathering a large amount of data through elicitation. The total number of judgments necessary is equal to the number of zones times the number of countermeasures times two (for a resource increment and decrement) times three (for a best estimate, upper, and lower bound). Of course, the number of judgments can be reduced by making some assumptions, but in Tucson all of the questions were asked.

In summary, quantitative estimates of several parameters used in the risk assessment and management phases of this analysis were obtained through elicitation of expert judgments, including:

- Verification of reported data for number of illegal aliens successfully transiting border zones and number of assaults on agents,
- Estimation of amount of marijuana successfully transiting border zones, and
- Estimation of change in risk attributes given a change in allocated countermeasures.

These judgments were elicited directly from station chiefs, each of whom had expert operational knowledge of the border zones in their area of responsibility and reported directly to the Chief Patrol Agent in Tucson Sector. To obtain elicited judgments of sufficient quality, we worked directly with USBP agents to create a standardized elicitation protocol that would address several well-known heuristics and biases in forming judgments (e.g., Ref. 12) whereas remaining,[12] but remain feasible to execute within time and resource constraints. We trained

USBP agents to serve as elicitors to benefit from the shared lexicon and understanding of the operational domain they shared with the experts. In particular, the elicitations were designed with the following concerns in mind:

(1) Question design—we worked with USBP agents to frame clear, concise, and neutral questions. We also test ran the questions with agents and risk analysts to ensure that the questions were understandable by the operational experts and resulted in analytically useful answers.
(2) Overconfidence—experts were given training questions at the beginning of the elicitation session to provide awareness of overconfidence and a basic understanding of uncertainty. [12] Note that, although training is the best practice to address overconfidence in expert judgment, this bias is difficult to eliminate entirely.
(3) Anchoring—to avoid the potential introduction of anchoring biases because of preselected measurement scales, the experts were free to provide any ratio scale estimate as a judgment, rather than selecting from among a set of quantitative estimates or ranges.
(4) Motivational biases—as station chiefs, the experts had the potential to be directly impacted by any resource allocations informed by this analysis. To address the potential for motivational biases, the final data visualizations allowed the Chief Patrol Agent to easily identify the source of any elicited judgments by geographic station and take this information into account when interpreting the findings.

This methodology does not capture effects that depend on interrelated improvements in countermeasures. For example, an SME might say that "improving countermeasure $C_{1,1}$ (manpower) will not reduce $R_{1,1}$ (muggings) unless countermeasure $C_{1,2}$ (surveillance technology) is also incremented. In fact, improving either $C_{1,1}$ or $C_{1,2}$ without improving the other will not change $R_{1,1}$." These kinds of statements, if they occur, should be captured and passed to the decisionmaker; however, in the assessment they should be represented as $\Delta^{+}_{1,1,1} = \Delta^{-}_{1,1,2} = 0$. The alternative is to capture the mixed partial derivatives with respect to the change in both countermeasures, which requires a number of questions proportional to the square of the number of countermeasures. This amount of information gathering is generally prohibitively lengthy and expensive.

4. RESULTS

Although the specific findings that resulted from this assessment cannot be shared publicly, the findings were presented to the Chief Patrol Agent and informed several resource allocation decisions. In this section, we discuss the general implications of the assessment.

We visualized the results of the assessment with "heat maps" of the risk that were constructed using ArcGIS software to overlay the data from Section 3.2 on top of the geographic zones. We also made plots similar to Fig. 4 for each resource and type of risk, and highlighted for the decisionmaker the zone and resource combinations where the risk return on investment was relatively high or low. We took care to emphasize results that were robust to the elicited uncertainty. Wherever possible, we displayed the elicited data directly for transparency and the Chief Patrol Agent's scrutiny.

4.1. Personnel

With regard to personnel deployments, the analysis identified several border zones where a relatively small increase in manpower would result in a relatively large decrease in risk. If additional personnel were deployed to other zones, it would have minimal impact on the risk. These conclusions were apparent when the results were presented in terms of a per agent risk reduction efficiency, as in Fig. 4.

4.2. FOBs

The analysis also demonstrated that deploying a FOB in a particular zone had a large risk reduction potential. Because FOBs are a limited resource and we had also elicited the impact on risk of removing each of the existing FOBs, we were able to identify which FOBs were good choices for moving to that particular zone, along with the net effect on risk if such a move were to take place.

4.3. Fencing

The analysis identified some segments of fencing that, if improved, would cause a relatively large reduction in the number of assaults on agents. This effect results from the replacement of opaque fencing with fencing that contains gaps large enough to see through; upgrading the fencing in this way would make it much more difficult for anyone to hide on the Mexican side of the fence and throw rocks at agents unseen.

5. DISCUSSION, LESSONS LEARNED, AND CONCLUSIONS

This article has described a straightforward methodology for analyzing risks in domains with frequent hazards, such as law enforcement or other homeland security operations. The study constraints under which this analysis was designed include transparency, the ability to be executed by nonspecialists, methodological soundness, and the ability to be executed with few analytic resources. This analysis provides an alternative to the use of risk matrices, which are often used by homeland security operators when conducting a risk assessment under the above constraints. Risk matrices have many methodological weaknesses and are poor tools for informing risk management and other resource allocation decisions,[13] though there are some exceptions.[14]

The approach presented here is generalizable to other decision contexts beyond border security. As noted above, the methodology is versatile enough to apply to many decisions involving frequent hazards; these hazards are managed by officials at many levels within government. This methodology is useful in many situations when resources must be allocated to portions of a larger whole. For the USBP, border zones are geographic regions of a sector, but in other contexts the zones could represent two-hour blocks of a 24-hour day, with a police chief deciding to which time shift to assign new officers. Alternatively, in a transit system each zone could represent physically separate subway stations where the system manager must choose to deploy a more secure entry system. In addition to informing resource allocation decisions, this analysis has ancillary benefits; for example, if an existing piece of surveillance equipment breaks down, this analysis can tell the responsible official an estimate of the impact on risk. Many other variations are possible.

When compared with data-driven law enforcement techniques, this analysis goes a step beyond the traditional mapping of "hot spots" by providing risk-reduction return on investment information to the decisionmaker. This is a key piece of information because it points out the hot spots that are amenable to mitigation with each resource. Of course, the acquisition of this information requires the additional data gathering step via elicitation, which comes at a cost of additional effort and requisite expertise.

This analysis has become feasible with the widespread availability of data and data storage tools in the law enforcement and homeland security domain. The methodology discussed in this article takes advantage of these data, as well as techniques from multiattribute utility theory. Multiattribute utility theory is particularly appropriate to public sector decision making,[15] especially when the decisions involve value tradeoffs between a variety of objectives, including security, cost, and privacy concerns.[3] Managing risk by including explicit considerations of value tradeoffs between objectives would be a natural extension of this methodology, but care should be taken to do so in a way that does not reduce the transparency of the results for decisionmakers.

Like all risk assessment techniques, this methodology has underlying assumptions and limitations. For example, using a previous time period's data as an estimate of the risk to which the zones will be exposed relies on the assumption that the current time period is adequately represented by past data. Of course, this assumption does not always hold. In fact, a drastic change in conditions can sometimes be the precursor for performing a risk analysis. In this case, it is possible to adapt the framework we have described to account for the changing conditions. First, collect the data from the previous time period, then either elicit from subject matter experts or derive from models how the risk will change if conditions change but capabilities remain in the current configuration. Then, proceed with the risk management step using the adjusted risk.

In Section 3.1, we assumed that resource allocation alternatives that would reduce the number of illegal aliens transiting an interior zone would also be effective at minimizing the likelihood that a terrorist could make a successful illegal transit. If terrorists are likely to attempt transits with a different zonal distribution than other illegal aliens or if allocated resources impact terrorist transit probabilities differently than they do those of illegal aliens, then this assumption will break down. In that case, terrorist transit behavior would best be modeled with a separate attribute, perhaps the multiple of the likelihood of their choosing to cross through each zone times the likelihood of a successful transit in each zone. A similar caveat applies to the assumption

[3] As a prime example of this type of analysis, see Ref. 16.

regarding the flows of marijuana and the flows of other drugs, though other drugs could be more easily included with a single attribute, such as the street value of the other drugs crossing through each zone. In any case, these assumptions, along with the implications of their breaking, were presented to the decisionmaker with the analysis so he was able to weigh them appropriately.

A further limitation of this methodology is that it does not take into account the adversary's response to the change in defensive resources. Such reactions and counterreactions are traditionally the province of game-theoretic methodologies. However, several typical game-theoretic assumptions are violated by this situation. For example, the adversary's knowledge of USBP resource allocation is far from perfect and instantaneous. Of course, the same is true for the defender's knowledge of adversary resources. Furthermore, the utility function for the adversary, which involves the probabilities and tradeoffs of the various repercussions of being detained, is far from simple. In practice, as an alternative to a game-theoretic methodology, periodic updates of the assessment described in this article can be used to inform additional resource-allocation decisions to respond to adversary adjustments.

There are some decisions, though important, to which this methodology should not be applied. For example, decisions pertaining to performance management should not be informed solely by this methodology, for all of the reasons discussed in Willis *et al.*[8] (e.g., the lack of metrics to assess the deterrence provided by USBP or the USBP ability to exploit networked intelligence).

Willis *et al.*[8] argue that the most valid attribute for measuring the objective of stopping a cross-border flow is interdiction rate. We agree that this is an important metric. For this reason, because the interdiction rate is given by the percentage of flow that is intercepted in transit, the estimates elicited in the risk management step of our analysis are mathematically equivalent to the question of how would the interdiction rate have changed if the resources allocated to the zone had been different.

In the course of designing and conducting this analysis, we learned several lessons that we believe are broadly applicable to executing risk assessments in an operational environment. Operational organizations like USBP can execute analyses quickly, but may have a tendency to cut out or tone down analytic details because of their desired speed of execution. When consulting with these types of organizations, we recommend encouraging their focus on analytic protocol. Similarly, operators may tend towards overly complicated methodologies that "sound smart"; these should be discouraged. Emphasizing risk education and thorough understanding of a methodology is rewarding and can result in organizational impacts that have the potential to persist long after the completion of a risk analysis.

ACKNOWLEDGMENTS

This project could not have been completed without the effort and dedication of the USBP team members: Raleigh Leonard, Chris Pietrzak, Wes Northrop, and Lee Goodridge. The authors would also like to thank Steve Bennett, Scott Breor, Tina Gabbrielli, Bob Kolasky, and Matt Stuckey.

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