IDA | RESEARCH NOTES

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This issue of IDA Research notes is dedicated to the winner and finalists of IDA's Larry D. Welch Award for best external publication. Named in honor of IDA former president and U.S. Air Force Chief of Staff, General Larry Welch, the award recognizes individuals who exemplify General Welch's high standards of analytic excellence through their external publication in peer-reviewed journals or other professional publications, including books and monographs. The articles in this edition are executive summaries of the original published pieces. We have identified and credited the original publication for each article and, where possible, we have included a link or QR code to the full piece.

In their article "Mixed Models Analysis of Radar Residuals Data," IDA researchers Carl Gaither, Dawn Loper, Chris Jackson (consultant), and Jasmina Pozderac (Marsh) (former Research Staff Member) investigated the use of random effects modeling as a new approach to system evaluation. Their article was published in *IEEE* Access, May 2013.

The research team of Darrell Morgeson, Yev Kirpichevsky, Tony Fainberg, Jason Dechant, and Vic Utgoff, along with outside co-authors Y. Seda-Sanabria and E.E. Matheu, compared security risks for dams, navigation locks, hydro projects, and similar infrastructure in their article "A Portfolio Approach to Security Risk Assessments," published in *Hydropower & Dams*, Issue Four, 2013.

In her article "Al Qaeda in Mali: The Defection Connections," published in *Orbis*, Volume 57, Issue 3, Summer 2013, IDA's Jessica Huckabey discussed the complex relationships among rebel groups and al Qaeda affiliated groups operating in Mali.

IDA researcher Susan Rose and her former colleagues Laura Williams and Andrew Rehwinkel presented "Competitiveness in the Services Sector: Understanding the Contracting Data," at the Defense Acquisition University Symposium, The Limits of Competition in Defense Acquisition, September 2012.

The research team of Arun Maiya, John Thompson, Francisco Loaiza-Lemos, and Robert Rolfe in their paper "Exploratory Analysis of Highly Heterogeneous Document Collections," published in *Proceedings of the 19th ACM SIGKDD Conference on Knowledge Discovery and Data Mining*, August 2013 illustrated the application of state-of-the-art computational approaches in machine learning and text mining to the discovery of critical information in unstructured collections of text.

IDA's John Biddle and his former colleague Brent Fisher investigated the potential performance of a novel concept for dividing solar radiation into spectral components that separately illuminate photovoltaic cells of different band gaps in their paper "Luminescent Spectral Splitting: Efficient Spatial Division of Solar Spectrum at Low Concentration," published in *Solar Energy Materials and Solar Cells*, Vol. 95, January 2011.

The research team of Alexander Noyes and Janette Yarwood examined the issue of "The AU Continental Early Warning System: From Conceptual to Operational?" in their article published in *International Peacekeeping*, 20:3, November 2013.

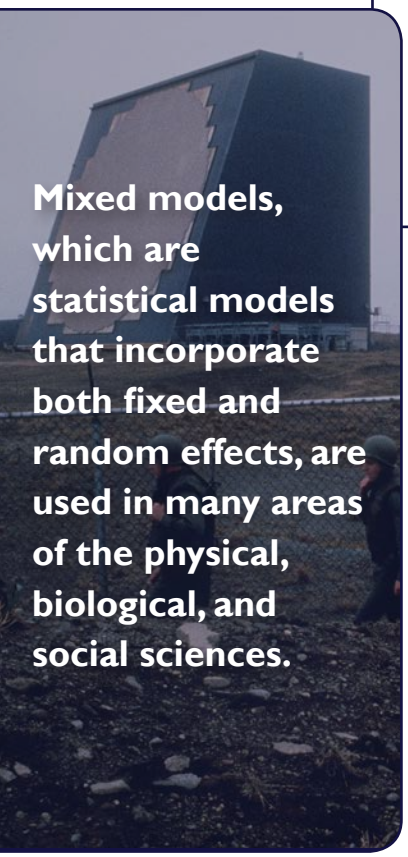
NOVEL APPROACH FOR ANALYZING RADAR TRACKING RESIDUALS

Carl C. Gaither III, Christopher R. Jackson, Dawn C. Foley Loper, and Jasmina Pozderac

Winner

Mixed models provide a novel approach for analyzing radar tracking residuals by accounting for randomness from different sources. By properly accounting for different sources of randomness, the mixed-models approach can provide greater power to determine the statistical significance of various parameters needed for radar calibration.

The authors, in their article, summarize a mixed-models approach applied to the analysis of radar tracking residuals from calibration satellites observed by the Cobra Dane radar. They found that each of the calibration satellites makes its own idiosyncratic contribution to the observed radar tracking residuals. When properly accounted for, these idiosyncrasies increase the statistical power to determine whether systematic effects exist in the data.



Mixed models, which are statistical models that incorporate both fixed and random effects, are used in many areas of the physical, biological, and social sciences.

Biases in radar observations can degrade the correlation and fusion of tracks from multiple sensors. They can also degrade the accuracy of project-ahead trajectories based on limited radar observations from a single radar. One way to minimize these problems is to estimate the bias as part of the state vector using augmented state Kalman filters or Schmidt-Kalman filters (Lin, Bar-Shalom, and Kirubarajan 2005; Novoselov et al. 2005). Such approaches can be computationally intensive, and, although the computational difficulties can be reduced by various methods of decoupling the bias estimation from the state estimation, they are not always able to be implemented in real time (Friedland 1969). For real-time applications, the filter can also be subject to being "ill-conditioned" due to limited or redundant tracking observations (Daum and Fitzgerald 1983). These techniques can also be dependent on the nature of the bias.

Mixed models are an alternative for analyzing radar residuals that do not require physics-based modeling of the radar residuals. Mixed models, which are statistical models that incorporate both fixed and random effects, are used in many areas of the physical, biological, and social sciences (Brown and Prescott 2006; Bolker et al. 2009). They are particularly useful when measurements are made repeatedly on the same objects or in cases where the observations can be grouped into clusters. This is exactly the case when radar observations of

dedicated calibration satellites are made to detect and remove biases in the observations. A drawback to the mixed models approach is that there is no a priori "right" statistical model. Different mixed models can potentially produce nearly equally good results. They do, however, have the advantage of being well suited to the examination of problems where a large amount of data exists and where there are several factors that might contribute to a data trend or variation in which the specific mechanism that produces these trends is unknown.

COBRA DANE RADAR

Cobra Dane is a single-face, L-band phased array radar located on Shemya Island, Alaska. Preliminary studies of Cobra Dane residual data in late 2004 and 2005 indicated a bias in the azimuth residuals whose magnitude and sign were a function of azimuth angle. This azimuth-dependent bias in the radar residuals manifests itself as an apparent slope across the Cobra Dane radar face. If such a slope or bias is not taken into account and compensated for, the accuracy of Cobra Dane's radar tracks and, possibly, any missions that these tracks might support could be degraded. Figure 1 shows the bias across the Cobra Dane radar face. This figure uses Cobra Dane radar calibration data from 2005. The x-axis is the relative azimuth position of the calibration satellite relative to the radar boresight. The azimuth boresight is at a relative azimuth of 0 degrees (which is at 319 degrees from true north). The y-axis is the elevation of the calibration satellite on the radar face.

The radar face is broken up into 5-by-5-degree bins for our analysis. Within each 5-by-5-degree bin in the figure, the average azimuth residual has been computed, and the angle bins have been colored such that black represents either the extreme negative or positive values for the average azimuth residual. The various shades of red represent negative azimuth residuals, and the blues represent positive residuals. This color scheme highlights the transition between negative and positive average azimuth residuals, which is shown by the transition from red to blue. The white angle bins represent locations where no radar calibration satellite was observed. If the radar residual values were random and had zero mean, Figure 1 would have a red/blue speckled appearance. The systematic transition from red to blue (going from left to right) indicates that a slope in the radar residuals exists across the Cobra Dane radar face. The implication is a systematic effect in radar observations across the radar face, which is not sufficient to determine whether this bias is due to the environment or satellite sampling or whether it is inherent to the Cobra Dane radar itself.

RADAR BIAS

Although radar waves propagating through the atmosphere are subject to systematic and random errors in range and elevation angle due to tropospheric turbulence and ionospheric scintillations, it seems unlikely that these effects alone could be the cause of the apparent bias. Such errors are most acute at low elevations (<5 degrees), where

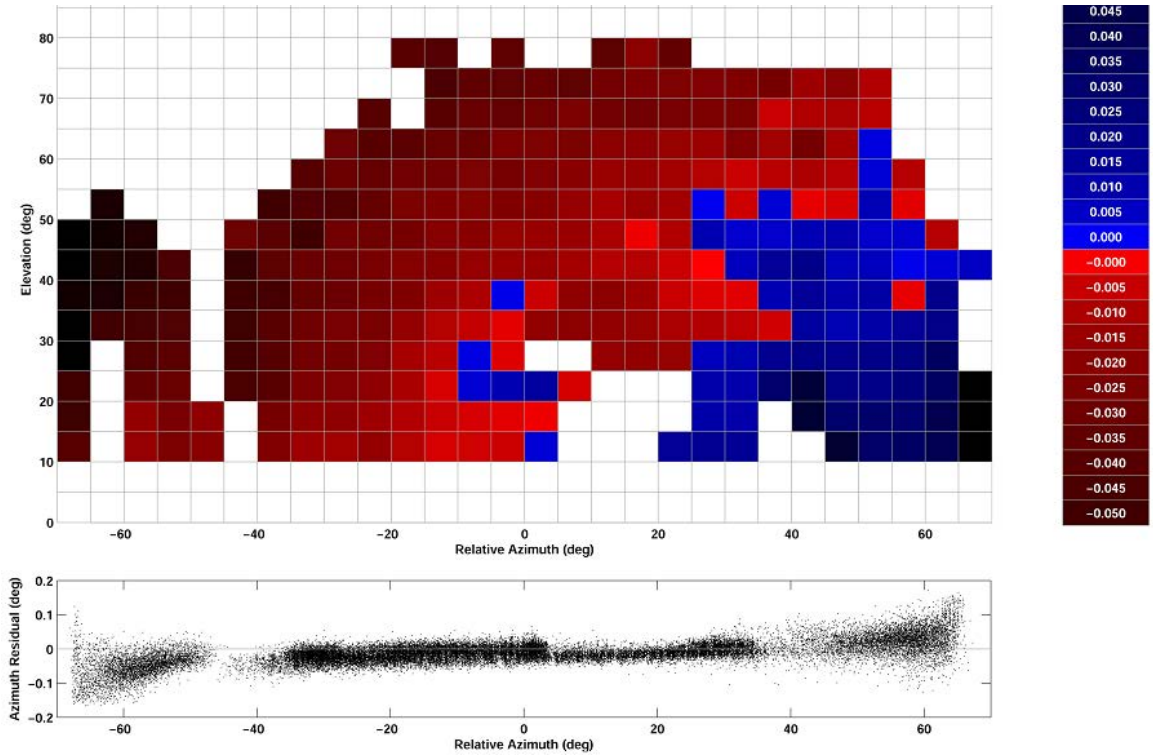


Figure 1. Apparent Bias in Cobra Dane Azimuth Residuals from 2005.

propagation through the lowest layers of the atmosphere is greatest. The apparent azimuthal bias in Figure 1 is, however, observed at elevation angles significantly higher than 5 degrees.

If atmospheric and off-boresight effects are unlikely to result in a systematic bias, perhaps the spatial distribution of the ensemble of calibration satellites could be the cause. Since the calibration satellite sample itself is a convenience sample,[1] the data do not uniformly cover the entire Cobra Dane radar face. Figure 1 shows that the sampling of calibration satellites is clearly not uniform across the radar face.

The calibration satellites that are sampled also change over time, thus making it possible to study the apparent bias under different combinations of calibration satellites. It is also possible that a particular combination of satellites, with their varied presentations to the radar, along with different radar cross-sections (both of which can affect the signal-to-noise ratio) coupled with the non-uniform, clustered satellite sampling, could result in the apparent bias seen in Figure 1.

[1] The ensemble is based on satellites for which independent high-precision ephemeris data are available; it is, therefore, a convenience sample. The ensemble of satellites was not selected based on any other criteria, such as spanning the Cobra Dane radar face or having the same radar cross-section (RCS).

COBRA DANE DATA OVERVIEW

Figure 2 provides a graphical look at the entire data set for the 6-year period plotted against all combinations of azimuth residual, elevation residual, relative azimuth, and elevation and grouped by the calibration satellite ID. Histograms of the azimuth residuals, elevation residuals, relative azimuths, and elevations are plotted along the diagonal.

Consider the plots in panels a) and f) of Figure 2. These panels show histograms of the azimuth and elevation residuals with a normal distribution overlay. These panels indicate that the combined residuals (regardless of satellite and time of the observation) in both azimuth and

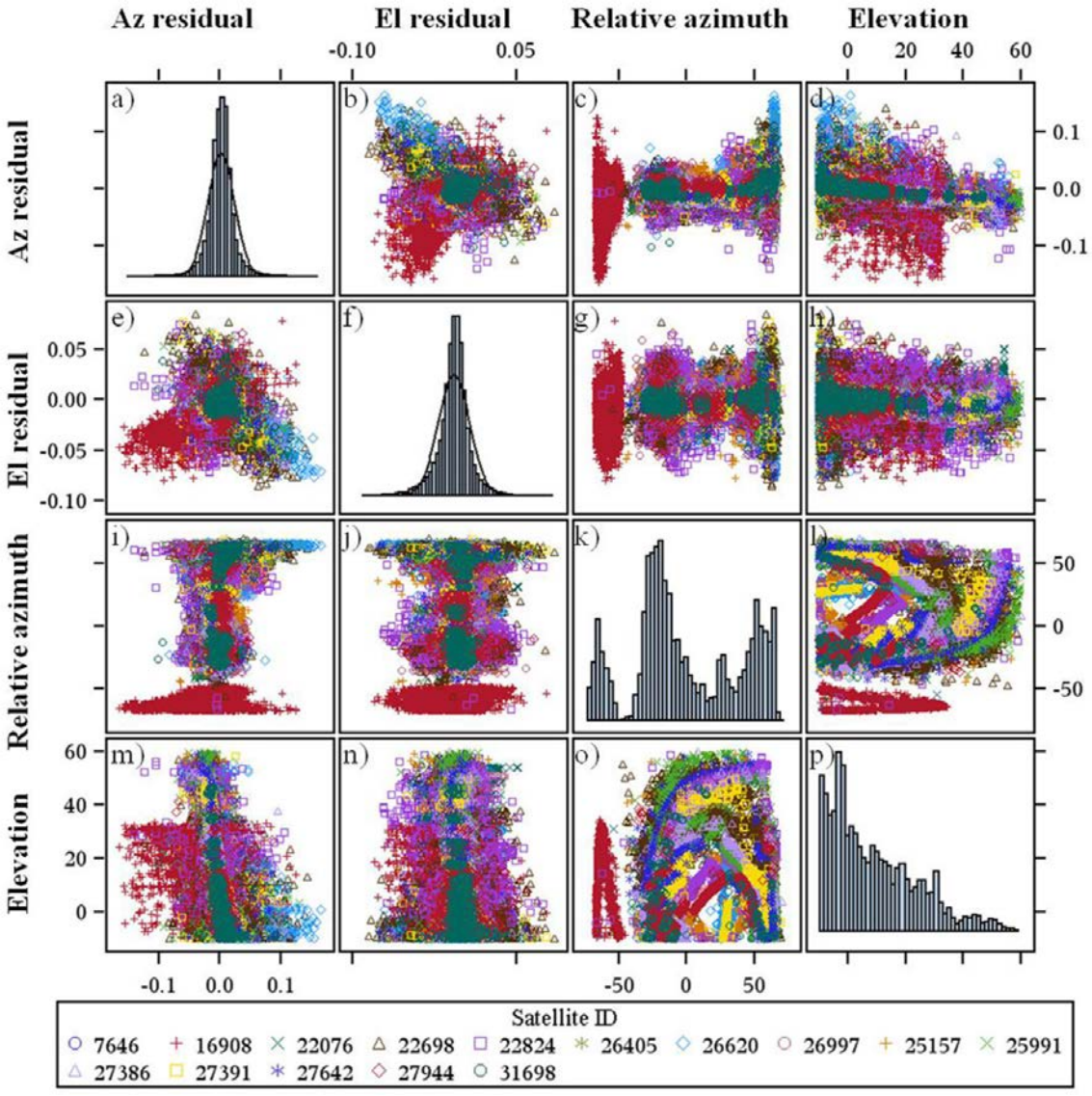


Figure 2. Summary of Cobra Data Calibration Satellite Observations Broken Down by Satellite ID.

elevation appear to be roughly normally distributed, which is beneficial to regression analysis.

Now consider panels k) and p) of Figure 2. These panels show histograms of the relative azimuths and elevations sampled in the dataset. The distributions of calibration satellite observations across the Cobra Dane radar face are clearly not uniform. The azimuth observations are clumped predominantly at the left and right extremes of the field of view (FOV) or are slightly to the left of the azimuth boresight. The elevation observations are mostly at the lower elevations angles and decrease in a nearly linear fashion as elevation angle increases.

Several of the panels (notably panels c), g), i), j), l), and especially o)) also show that the calibration satellite observations are not evenly distributed across the Cobra Dane radar face. Of particular note is satellite 16908 (red plus symbols), which is segregated from the other satellite observations at the extreme left (negative values of relative azimuth) of the azimuth FOV (see panel o)). No other satellites are observed at this extreme azimuth. This satellite also has some of the most negative azimuth residuals observed (see panel c)). Contrast this satellite with satellite 26620 (blue diamonds), which, as panels b), c), d), e), and i) show, has the largest positive values of azimuth residuals observed as well as being observed at the extreme right (positive values of relative azimuth) of the azimuth FOV.

ANALYSIS

Many of the physical parameters of the calibration satellites and the environmental parameters at the time the calibration satellite observations were made, which are needed to develop a physics-based model of the Cobra Dane radar residuals, are not available. For this reason, a statistical model is developed. The model selected to represent these data is a multi-level mixed-effects model, or equivalently a random coefficients model (Schabenberger and Pierce 2002).

The model starts with the following equation

$$azresid_{ij} = b_{0j} + b_{1j} realz_{ij} + b_{2j} el_{ij} + b_{3j} rngrate_{ij} + \epsilon_{ij}, \quad (1)$$

where $azresid_{ij}$ is the i^{th} azimuth residual for observations of the j^{th} satellite. The first two independent variables, $realz_{ij}$ and el_{ij}, are the relative azimuth and elevation positions where the azimuth residuals were observed (see Figure 1 for an illustration of the realz and el coordinates). Also note that $rngrate_{ij}$ is included in the equation. The $rngrate_{ij}$ variable represents the range rate (in kilometers/second) of the satellite relative to Cobra Dane. The inclusion of $rngrate_{ij}$ produces a slightly better model fit than the same model without $rngrate_{ij}$. The coefficients b_{0j}, b_{1j}, and b_{2j} are random variables, and b_{1j} and b_{2j} also depend on the calendar quarter in which the calibration satellite is observed. The b_{0j}, b_{1j}, b_{2j}, and b_{3j} are given by

$$b_{0j} = \beta_{00} + b_{0j}^*,$$

$$b_{1j} = \beta_{10} + \sum_{(n=1)}^{23} \beta_{1n}\ qtr_{nij} + b_{1j}^*,$$

$$b_{2j} = \beta_{20} + \sum_{(n=1)}^{23} \beta_{2n}\ qtr_{nij} + b_{2j}^*, \text{and}$$

$$b_{3j} = \beta_{30}, \quad (2)$$

where β_{00}, β_{10}, β_{20}, β_{30}, β_{1n} and β_{2n} (where n goes from 1 to 23 and represents the quarter in which the observation was made) are estimated fit parameters, and b_{0j}*, b_{1j}*, and b_{2j}* are random variables that take on different values for each satellite. In this manner, the random effects due to each satellite are incorporated into the model.

The b_{0j} term can be interpreted as the random intercept for $azresid_{ij}$. It is random because of the b_{0j}* term in Eq. (2). Thus, each satellite has its own idiosyncratic intercept value. The b_{1j} term is the slope for the relative azimuth term, and it, too, is a random variable because of the b_{1j}* term. In addition, b_{1j} also varies for each quarter because of the $\beta_{1n}\, qtr_{nij}$ term. The way time is modeled here allows each quarter to have its own independent effect on the azimuth residuals. No autocorrelated effects are explicitly accounted for in this model. A similar interpretation applies to b_{2j}. Note that since b_{3j} does not have a random component, it is therefore not a random variable.

The SAS® statistics package was used to compute the parameters in the mixed model.

RESULTS

Solving for the parameters in the mixed model presented in Eqs. (1) and (2) showed that each calibration satellite has its own idiosyncratic slope and intercept, some of which are dramatically different from the others. By properly accounting for these random effects, a larger portion of the variance in the azimuth residual data is explained, thus increasing the statistical power to determine whether a time-varying slope, or bias, exists. After taking into account these random satellite effects, the slope of the azimuth residuals as a function of azimuth position is found to vary depending on time. This time-varying azimuth slope decreases over time. In 2010, the magnitude of the slope was an order of magnitude smaller than it was in 2005. The cause of this decrease has not been determined but could be due to effects either external to the radar (environmental effects) or internal to the radar (such as system upgrades or software updates). If the cause is external to the radar, the model might benefit by including environmental parameters as either fixed or random effects.

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Mixed Models Analysis of Radar Residuals Data

http://www.ieeeexplore.us/xpl/articleDetails.jsp?reload=true&arnumber=6516558

REFERENCES

Bolker, Benjamin M., Mollie E. Brooks, Connie J. Clark, Shane W. Geange, John R. Poulsen, M. Henry H. Stevens, and Jada-Simone S. White. 2009. "Generalized Linear Mixed Models: A Practical Guide for Ecology and Evolution." *Trends in Ecology & Evolution* 24 (3) (March): 127–135.

Brown, Helen, and Robin Prescott. 2006. *Applied Mixed Models in Medicine*. West Sussex, England: John Wiley & Sons.

Daum, Frederick E., and Robert J. Fitzgerald. 1983. "Decoupled Kalman Filters for Phased Array Radar Tracking." *IEEE Transactions on Automatic Control* 28 (3) (March): 269–283.

Friedland, Bernard. 1969. "Treatment of Bias in Recursive Filtering." *IEEE Transactions on Automatic Control* 14 (4) (August): 359–367.

Lin, Xiangdong, Y. Bar-Shalom, and T. Kirubarajan. 2005. "Multisensor-Multitarget Bias Estimation for General Asynchronous Sensors." *IEEE Transactions on Aerospace and Electronic Systems* 41 (3) (July): 899–921.

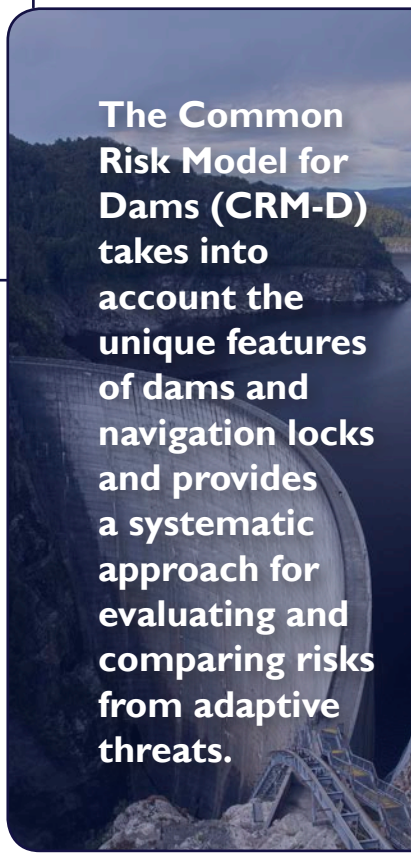
Novoselov, Roman Y., Shawn M. Herman, Sabino M. Gadaleta, and Aubrey B. Poore. 2005. "Mitigating the Effects of Residual Biases with Schmidt-Kalman Filtering." In *Proceedings of the 2005 8th International Conference on Information Fusion, Vol. 1*, 358–365, IEEE.

Schabenberger, Oliver, and Francis J. Pierce. 2002. *Contemporary Statistical Models for the Plant and Soil Sciences*. Boca Raton, FL: CRC Press LLC.

ASSESSING SECURITY RISKS USING THE COMMON RISK MODEL FOR DAMS

Yazmin Seda-Sanabria, Enrique E. Matheu, J. Darrell Morgeson, Yev Kirpichevsky, M. Anthony Fainberg, Jason A. Dechant, and Victor A. Utgoff

The Common Risk Model for Dams (CRM-D), developed as a result of collaboration between the U.S. Army Corps of Engineers (USACE) and the U.S. Department of Homeland Security (DHS), is a consistent, mathematically rigorous, and easy-to-implement method for security risk assessment of dams, navigation locks, hydropower projects, and similar infrastructures. The methodology provides a systematic approach for evaluating and comparing security risks across a large portfolio. Risk is calculated for attack scenarios (specific adversary using a specific attack vector against a specific target) by combining consequence, vulnerability, and threat estimates in a way that properly accounts for the relationships among these variables. The CRM-D can effectively quantify the benefits of implementing a particular risk mitigation strategy and, consequently, enable return-on-investment (ROI) analyses for multiple mitigation alternatives across a large portfolio.



In 2005, IDA initiated the development of the Common Risk Model (CRM) for evaluating and comparing risks associated with the nation's critical infrastructure. The model enables comparisons of calculated risks to assets and systems within and across critical infrastructure sectors.

A modified version of this model has been under development by IDA in collaboration with the U.S. Army Corps of Engineers (USACE) and the U.S. Department of Homeland Security (DHS). The modified model—the Common Risk Model for Dams (CRM-D)—takes into account the unique features of dams and navigation locks and provides a systematic approach for evaluating and comparing risks from adaptive threats across a large portfolio (Seda-Sanabria, Fainberg, and Matheu 2011a).

Risk is estimated for an attack scenario, which is defined as a specific adversary (e.g., a highly capable transnational terrorist group), a specific target (e.g., the main impoundment structure of a specific dam), and a specific attack vector (e.g., a cargo van loaded with explosives). Risk is defined as the expected value of loss and is a function of three variables: threat (T), vulnerability (V), and consequences (C):

$$R = f\,(\mathrm{T}, \mathrm{V}, \mathrm{C}). \qquad (1)$$

Threat is defined as the probability of an attack scenario attempted by the adversary, given the attack on one of the targets

in the portfolio under assessment, or P(A); vulnerability is defined as the probability of defeating the target's defenses, given that the attack is attempted, or P(S|A); and consequences are defined as the expected consequences of the attack, given that the target's defenses are defeated, C. Because of how CRM-D estimates these three variables, it is appropriate to calculate risk as their product:

$$R=P(A)\times P(S|A)\times C.^{1} \qquad (2)$$

CRM-D also defines "conditional risk," or R_C, as risk for the attack scenario, given that this scenario is chosen:[2]

$$Rc=P(S|A)\times C. \qquad (3)$$

The consequence and risk metrics currently considered in the CRM-D are loss of life and total economic impacts. The sum of risks for all the attack scenarios under consideration is termed "portfolio risk." Minimizing portfolio risk subject to available resources is often the focus of risk managers.

METHOD

The CRM-D methodology integrates the outputs of three separate models: consequences (external to CRM-D), vulnerability, and threat. Using modeling is a natural choice for estimating the outcomes of complex physical and economic processes, such as consequences from attack, but is equally important for estimating vulnerability and threat—variables that require more subjective input from subject matter experts (SMEs). Because there are many possible attack scenarios and because the set is continually changing, it is prohibitively costly and time consuming to elicit expert judgments on vulnerability and threat for every scenario and to repeat the elicitation process every time that a new scenario is introduced or old scenarios are modified. As a result, modeling is crucial when developing risk estimates in support of return-on-investment (ROI) analyses because the impacts on risk of potential risk-mitigation improvements need to be assessed quickly.

The vulnerability and threat models are based on data elicited from SMEs in a way that makes it possible to apply elicited SME judgment to any set of attack scenarios. The elicitations were conducted for estimating risk from highly capable, transnational adversary groups. Elicitations in support of estimating risk from other types of adversaries are currently under development. Because the adversaries' capabilities and/or intent are likely to change with time, elicitations should be repeated every few years or as deemed appropriate.

VULNERABILITY

To evaluate the vulnerability of a target to a specific attack by a specific adversary, a model of layered defenses is adopted. The defensive layers protecting a given target could potentially include

[1] The functional relationships among the variables are accounted for by estimating P(A) as a function of the other two variables, but there is no stochastic relationship because P(S|A) and expected consequences are estimated as point values, and not random variables. This justifies the use of the product function (Cox 2008).

[2] Note that the risk metric in Eq. (2) is also conditional—on the attack within a portfolio under assessment. The "conditional risk" metric is further conditioned on the particular attack being chosen.

national defenses (e.g., national counter-terrorism activities), local defenses (e.g., local law enforcement capabilities to detect and respond to potential attacks), and target defenses (e.g., onsite security systems and protective measures). The methodology for producing vulnerability estimates accounting for target defensive layers is described in detail in Seda-Sanabria et al. (2011b). The methodology for producing vulnerability estimates for national and local defensive layers is currently under development.

THREAT

Modeling threats from goal-oriented, adaptive adversaries is fundamentally different from modeling potential hazards associated with forces of nature. Adversaries evaluate potential attacks based on criteria that are important to them and then choose the attack that accords best with their objectives. When the adversary decision criteria change, their choice could change as well. Unlike consequence or vulnerability estimates, a threat estimate for an attack scenario depends not only on the characteristics of that scenario, but also on the characteristics of all attack scenarios from which the adversary is choosing.

To account for these concepts, the CRM-D includes a Probabilistic Adversary Decision Model (PADM), which is composed of two sub-models: the Adversary Value Model (AVM) and the Attack Choice Model (ACM). The decision model is probabilistic because no aspect of the adversary's future decision process can be known with certainty.

CONSEQUENCES

As mentioned, consequence estimates are external inputs into CRM-D. They are typically measured in terms of loss of life and economic impact. To date, they have been generated by the USACE Modeling, Mapping, and Consequences (MMC) Production Center in conjunction with the U.S. Army Engineering Research and Development Center (ERDC).

RESULTS

In 2011, USACE initiated a pilot implementation of the CRM-D at a selected number of dams and navigation locks. Each project in this representative set had unique features, functions, and operational conditions that made it particularly suitable to test the capabilities of the methodology and its applicability to a large portfolio.

Risk was estimated in terms of expected loss of life and total economic damage for 16 attack scenarios associated with 9 dams and 2 attack vectors. Figure 1 shows the product of P(A) and P(S|A) plotted against economic consequences for attack scenarios (the targets are indexed by letters, and the attack vectors are indexed by numbers). Thus, risk in terms of economic consequences could be determined by multiplying the two coordinates together.

Figure 1 shows iso-curves that could represent thresholds of risk as determined by a decision maker (e.g., a portfolio owner). The curves trace those points for which risk is greater than $50 million (above the red line) and greater than $20 million (above the green line). Decision makers could hypothetically use such information to more readily identify those dams on which they choose to focus for developing investment alternatives. The risk values that would define these

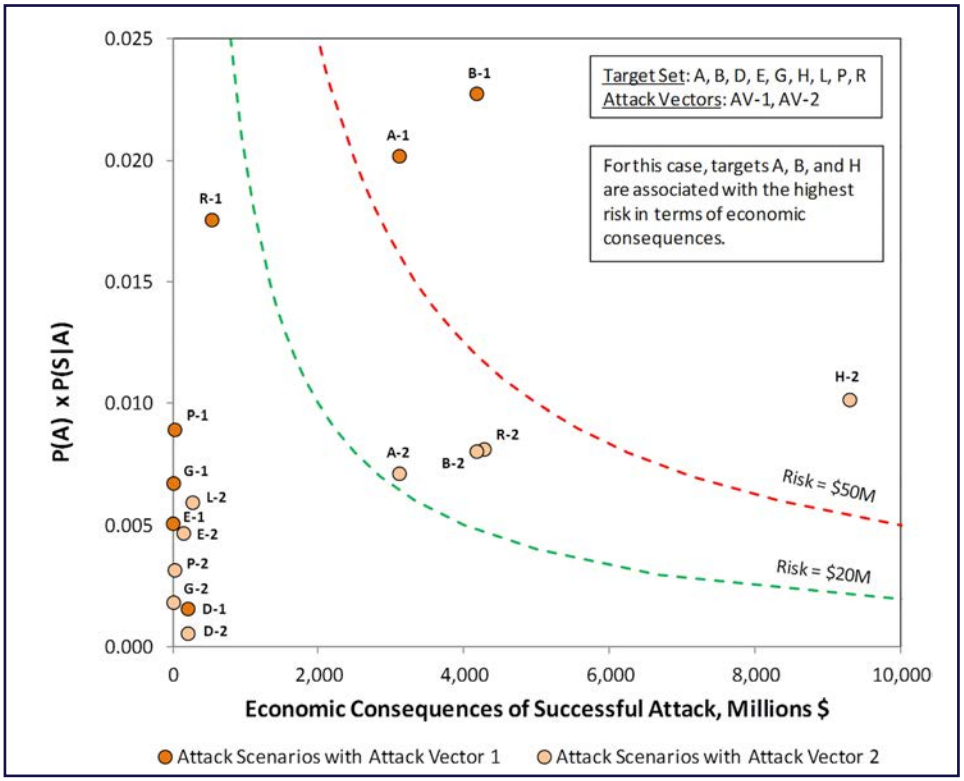


Figure 1. Scenarios by Economic Consequences of Success and Probability of Success.

curves could be chosen in accordance with decision-maker priorities.

A portfolio risk manager might wish to assess the impact of a particular investment on risk. For example, the addition of K12-rated vehicle barriers at seven of the projects where they had not been installed previously at a total cost of under $1 million could reduce portfolio risk given attack by about $66 million in expected economic damage and save an estimated 34 lives in an illustrative attack scenario. To decide whether adding K12-rated vehicle barriers is a worthy investment, a risk manager would have to assume or elicit from SMEs a predicted annual frequency of attacks in the portfolio and then use this information to compare this and other investments with the time-discounted values of the resulting risk reductions.

CONCLUSION

The CRM-D is a consistent, mathematically rigorous, and easy-to-implement method for security risk assessment of dams, navigation locks, hydropower projects, and similar infrastructures.

Risk is calculated for attack scenarios as a function of consequences, vulnerability, and threat. The CRM-D incorporates a probabilistic adversary decision model to estimate the probability of each attack scenario in the set given that one of the scenarios in the set is attempted. The CRM-D can quantify the benefits of implementing a particular risk mitigation strategy and, consequently, enable ROI analyses for multiple risk mitigation alternatives across a large portfolio.

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A Portfolio Approach to Security Risk Assessments

https://idacms.ida.org/upload/idanews/welch14/nsd4943.pdf

REFERENCES

Cox, Louis Anthony (Tony) Jr. 2008. "Some Limitations of 'Risk = Threat × Vulnerability × Consequence' for Risk Analysis of Terrorist Attacks." *Risk Analysis* 28 (6) (December): 1749–1761.

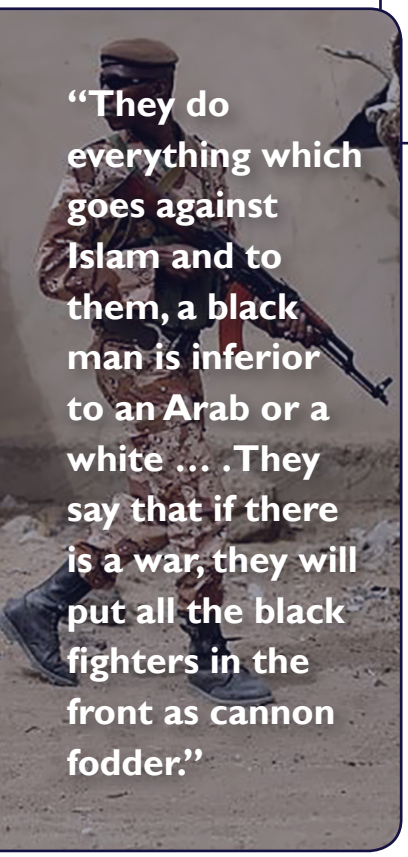
Seda-Sanabria, Yazmin, M. Anthony Fainberg, and Enrique E. Matheu. 2011a. "A Consistent Approach for Vulnerability Assessment of Dams," In *Proceedings of the 31st U.S. Society of Dams Annual Meeting and Conference*, 1117–1128. Denver, CO: U.S. Society on Dams.

Seda-Sanabria, Y., M. A., Fainberg, E. E. Matheu, J. D. Tressler, and M. L Bowen. 2011b. "Implementation of the Common Risk Model for Dams for Security Assessments of USACE Critical Infrastructure." Paper presented at the Dam Safety 2011 Conference, Washington, DC, September 25–29.

CASE STUDY ON RACE-BASED AL QAEDA DEFECTIONS IN MALI

Jessica M. Huckabey

The narrative of one fighter's experience with an al Qaeda (AQ)-associated organization in northern Mali reveals some of the group's intrinsic weaknesses. His brazen defection from the Movement for Unity and Jihad in West Africa (MUJAO), which itself originated as a defection from al Qaeda in the Islamic Maghreb (AQIM), provided the opportunity to analyze an important aspect to the internal dynamics of this emerging AQ-connected threat in Africa. It is directly tied to the case study subject's main complaint: the little-mentioned issue of race within AQ in Africa and beyond.



"They do everything which goes against Islam and to them, a black man is inferior to an Arab or a white … . They say that if there is a war, they will put all the black fighters in the front as cannon fodder."

Al Qaeda (AQ) and its associated movements thrive in ungoverned spaces, which describes much of Mali after a military coup in March 2012. By June, the Salafi-jihadists operating in Mali's chaotic north—al Qaeda in the Islamic Maghreb (AQIM) in the lead, along with the Movement for Unity and Jihad in West Africa (MUJAO) and Ansar Dine (Defenders of the Faith)—had hijacked the Tuareg rebellion and pushed the secular secessionists out of key strongholds to run Mali's vast north according to their radical Islamist rules. Western news stories told of a seemingly race-based, selective application of harsh Islamic law by MUJAO in the city of Gao: "According to Gao residents, the victims of sharia punishments were from Mali's black African ethnic groups, while the jihadis were mostly lighter-skinned Arabs—both Malian and foreign—and Tuaregs" (Hilsum 2013).

An event in November 2012 indicated possible deep racial tensions, discontent, and, above all, fear within MUJAO's own ranks. Hicham Bilal (a *nom de guerre*), the first black African commander of one of MUJAO's katibas (battalions), defected with a few dozen of his fighters and returned home to Niger just across the border. Bilal was so disillusioned with the entire multi-ethnic jihadist enterprise in Mali that he expressed his disgust, in uncompromising language, with the hypocrisy and racism that he witnessed. "These lunatics from MUJAO are not children of God. They are drug traffickers," he told the Agence France-Presse (AFP). According to Bilal, "they do everything which goes against Islam and to them, a black man is inferior to an Arab or a white … . They say that if there is a war, they will put all the black fighters in the front as cannon fodder" (AFP 2012).

THE SUDDEN APPEARANCE OF MUJAO

What sort of AQ franchise did Hicham Bilal join? MUJAO was a new group in Africa's "arc of instability" that did not even exist before the Libyan civil war. In a December 2011 video in the typical "mujahideen-in-the-field" style, MUJAO's members brandished their weapons, exhibited their Western hostages kidnapped for ransom, and made their threats. AFP noted that in this first communiqué from the group, "young black fighters were shown calling for 'pure and tough' Islam" and announcing their intention "to impose sharia across the whole of west Africa" and to export jihad wherever necessary ("Al-Qa'ida Maghreb Splinter Group …" 2012). The movement declared its liberation as defectors from AQIM, the dominant regional AQ affiliate from Algeria.

MUJAO may have promised to bring a unique form of sharia in their video manifesto, but they were far from innovative in their funding. They followed the same illicit path as other AQ-associated groups throughout Africa to become well financed and well armed. As a result, MUJAO was a player and possible competitor in the Sahara-Sahel region's "terrorist economy," which involved smuggling, drug trafficking—taxing the Colombian-originated caravans of cocaine destined for Europe—and kidnapping for ransom (Malagardis 2012; Freeman 2013).

MUJAO, for all its similarities to the standard AQ group formation, distanced itself from AQIM with a new West African identity that merits attention. MUJAO's determination to carve out a separate identity—one that appeared not to be Algerian driven or Arab dominated—that would open up new horizons for jihad in West Africa stands in stark contrast to its subsequent actions in Mali. It was this dichotomy between words and deeds that lay behind the confusion over MUJAO's true purpose and made the group's attitude toward race such a matter of contention. It also made it ripe for defections and potential exploitation of those weaknesses.

MUJAO, during its initial months, drew heavily upon North African leadership and ethnic Arabs for its core membership. As the operational demands in northern Mali increased, MUJAO started to diversify and expand its recruiting base both locally and internationally. MUJAO specifically targeted the Songhai, a West African people of the Gao region, for recruitment and produced a video with symbols that recalled the once mighty Songhai empire of the 15th and 16th centuries and its warrior past. The campaign paid off, at least according to MUJAO's own publicity. By early 2013, the group announced the formation of a new brigade comprising mainly Songhai fighters. One Western news report, however, offered the contradictory view that few black Malians were willing to join MUJAO given its harsh policies and race-based double standards (Hilsum 2013).

As mobilization increased in mid-2012, MUJAO spokesmen began to talk about the "scores" of mainly West African recruits coming to their two camps in Gao for military training and religious instruction. It is possible that MUJAO's decision to make Hicham Bilal a commander of a *katiba* around

this time was an effort to broaden the group's racial appeal. In one of his initial interviews, Bilal predicted that more black Africans would be placed in MUJAO leadership positions: "the world is the same for Muslims [who are] black, white, or other colors" (Daniel 2012b).

THE SUDDEN DISAPPEARANCE OF HICHAM BILAL

On November 7, 2012, following numerous defections from MUJAO's ranks, the group's leader in Gao threatened to kill any fighters who attempted to leave. He warned that win or lose, "we will fight this war together," and then proceeded to enforce cohesion over the next few weeks by fighting the Tuareg rebels. A source inside Gao described the movement in early November as "desperate and on alert, trying by all means to retain recruits" (The Fight 2012).

Hicham Bilal was the leader of the defectors and represented their fears, but, in the end, he was speaking only about his own reasons for his sudden departure. Like many others before him who "joined the caravan" and followed the path to jihad, simply going home again to Niger and returning to a normal life was difficult—if not impossible—given that Nigerien security services would be vigilant and likely aware of his movements. Indeed, he quickly ended up in the hands of the authorities in Niamey. Whether he surrendered through an amnesty deal or, more likely, was captured after a Malian tip-off is unclear. While the details are unknown, it is probable that Bilal provided, either by debriefing or interrogation, valuable insider information on MUJAO's operations—especially its tactics, techniques, and procedures, organizational structure, and plans—that Niger and other partner countries put to good use. Nigerien and Malian security sources confirmed Hicham Bilal's defection story with AFP, saying that he was highly critical of those for whom he had worked (AFP 2012).

What is known for certain is what Bilal thought about MUJAO, as told to the French language press. He spoke with Radio France Internationale (RFI) before and after his defection. He mentioned that he missed his country and his family, and he pointed to the un-Islamic behavior in MUJAO: "They kill, rape, and steal" (Radio France Internationale 2012). He called them madmen who looked at blacks as inferiors and planned to use them as "cannon fodder" in the case of a war with international forces. Hicham Bilal, however, was not always so critical of MUJAO or of fighting for them. He once believed in an Islam without borders. "I am not a Nigerien, I am a Muslim," he told RFI. Moreover, he explained that MUJAO's plans aimed far beyond Mali. Its goal was the unification of all West Africa, like the empires of old ("Bilal Hicham, Rebelle …" 2012).

Bilal was full of tough talk in July 2012 over the possibility of a foreign military intervention and scoffed at the idea of its success, yet he assured the reporter that it was his dream to "die a martyr" ("Bilal Hicham, Rebelle …" 2012). With the

arrival of the sub-Saharan fighters, he expressed surprise at the number of recruits and sensed a renewed unity and purpose among Islamists: "Since all of them want to go to war," Bilal said, "the fighters are no longer divided into separate Islamist movements. We are all mujahedeen," he declared. "Here, there's no more [MUJAO, Ansar Dine, or AQIM]" (Daniel 2012a).

Bilal's belief in MUJAO's unity and purpose did not last. There are at least three possible explanations for Bilal's escape from Gao. First, it could have been a smokescreen for a falling out he had with MUJAO's leadership. They may have accused him of wrongdoing (e.g., taking an unauthorized share of the drug profits), and he may have decided to make a preemptive strike and exact revenge by tarnishing the group's image. AQ does not exactly advertise its role in the drug trade or the fact that some of its members feel they are regarded as lesser Muslims.

Second, it should at least be considered that Bilal's role in MUJAO was not what it seemed because he could have been an infiltrator who was sent by a foreign intelligence service to gather information, provoke the group into self-destructive behavior, and sow dissension within MUJAO's ranks. However, the timing of his departure and his blatant attention-seeking with the media suggest that the defection was more about his wounded pride and personal safety in the face of an impending invasion. By remaining in Gao and further disrupting MUJAO's operations, Bilal could have ensured that they would not fight effectively well into the future, if that were indeed his real intent.

The final, and most likely, explanation is that Bilal was a true believer in MUJAO's mission and AQ-styled rhetoric, at least in the beginning, but was shocked by the ugly reality of an AQ movement from the inside. He was not a professional jihadist, but rather an agronomist by training. Evidently, the Islamic extremism in Mali proved too extreme for him, and so he went home.

Ultimately, what Hicham Bilal and the other fighters most feared led to the rapid collapse of the proto-Islamist state in northern Mali. MUJAO's capture of Konna, where eyewitness accounts reported that a force of mostly black fighters took over the town, triggered the French military intervention in January 2013. After French and Malian forces liberated the former strongholds and after the jihadists, as expected, retreated back to their Saharan hideouts, the ethnic and racial tensions in Gao brought reprisals as its citizens hunted down MUJAO members and suspected collaborators. In one case of vigilante justice, a mob tore "a jihadi fighter limb from limb" (Hilsum 2013). The BBC's reporting summed it all up by noting that "a sinister atmosphere still haunts Gao" (Fessy 2013).

MUJAO'S FAILED RACIAL NARRATIVE

Council on Foreign Relations senior fellow John Campbell notes that "throughout the Mali crisis, the role of racism in shaping the conflict has not received much emphasis, at least in U.S. commentary. Yet, it plays an important role on the ground" (Council of Foreign Relations Africa

in Transition Blog 2012; Council of Foreign Relations Africa in Transition Blog 2013). Hence, there is the need for further research into the role of racial tensions within AQ-linked groups and their impact, if any, on its operations in West Africa and elsewhere. This question—whether racism within AQ associates in general or the impact of Arab racism on AQ operations in Africa—has not been dealt with in great detail in terrorism literature because perhaps they are considered taboo topics to pursue, particularly by non-Muslims (The New Statesman's Blog 2010). Nevertheless, the significance of race's impact upon AQ effectiveness, given what transpired in Mali, is a topic that is too important to ignore. The Salafi-jihadists' experiences in northern Mali fit the paradigm of previous failed jihads but do provide lessons unique to a group like MUJAO and its overt attempts and subsequent failures at ethnic and racial unity.

Is anything to be gained by pursuing the racism narrative through counter-messaging? The U.S. government has, in fact, already gone on record that AQ is racist. In July 2010, President Obama was interviewed by the South African Broadcasting Corporation and used the occasion of the AQ-associated group al Shabaab's suicide bombings in Uganda to broach the subject. Al Shabaab's attack—its first outside Somalia—targeted spectators watching the broadcast of the World Cup final in South Africa and killed 74 people. Obama specifically charged that according to AQ organizations' own statements, "they do not regard African life as valuable in and of itself. They see it as a potential place where you can carry out ideological battles that kill innocents without regard to long-term consequences for their short-term tactical gains" (ABC News Blog 2010).

White House aides wanted to make clear to the media that Obama "was [making] an argument that the terrorist groups are racist." To drive home the messaging, one official elaborated on AQ's racial bias in terms that presaged Hicham Bilal's remarks more than 2 years later: "Al Qaeda recruits have said that al Qaeda is racist against black members from West Africa because they are only used in lower level operations. In short … al Qaeda is a racist organization that treats black Africans like cannon fodder and does not value human life" (ABC News Blog 2010).

While the Obama administration's remarks generated a brief yet intense discussion on AQ racism within the United States, particularly among conservative commentators, Americans were not the intended audience for his remarks. They were meant for AQ's potential recruits throughout sub-Saharan Africa to emphasize that the world's leader in the fight against Islamic extremists also understood what Africans already implicitly understood and have experienced from AQ.

Such a high-level strategic communication effort has not been repeated with Mali. Instead, the United States has used more routine counter-messaging approaches by using the AQ racism narrative to make sure that the Gao defections got wider exposure. U.S. Africa Command's public media website, *Magharebia.com*, is part of

the Pentagon's Trans-Regional Web Initiative that publishes in English, French, and Arabic and is aimed at foreign audiences in Northwest Africa. Not surprisingly, *Magharebia* was at the forefront in online coverage of the story of MUJAO's creation and the defection of Hicham Bilal. Using both wire and commissioned reports from writers in the region, the website ran stories on the "racist practices" and amplified the message of MUJAO's ethnic and racial divisions that resulted in defections: "racism has been a key factor pushing many young Africans of non-Arab descent to defect and return to their normal lives in their countries of origin" (Guèye 2012; Oumar 2012).

The most significant implication of the Mali defection narratives for counter-messaging is not to do too much from too high a platform, but, rather, let AQ-linked groups such as MUJAO continue to harm themselves through their own practices and glaring mistakes on the ground and capitalize upon these errors in the background. The aim is not to build up the threat to be larger than it is by talking too much about the group in any terms, following the "any publicity is good publicity" rule of thumb for terrorist organizations. Moreover, when West Africans face racism from an organization dominated by Arab extremists, the messengers that reinforce AQ's unsuitability should not be outsiders but moderate Muslims within the region who can properly frame the issues and speak firsthand of the injustice of AQ's practices and the insincerity of their words.

As is often the case with AQ-associated groups, real-world events do the best job of advertising AQ's weaknesses and hurting its recruitment efforts. MUJAO's narrative failed of its own accord. The same jihadist forum in which members showed elation at AQ's progress in Mali in 2012 turned to frustration and dejection once the "French crusaders" appeared in early 2013 and once the lack of Muslim outrage and desire to join this failed jihad became apparent. One member expressed frustration that Muslim media continued to show *Star Academy* (an export version of *American Idol*) "while France kills Muslims in Mali" ("Early Perspectives on the Mali Crisis …" 2013).

The "stay on the couch and enjoy Western-style entertainment instead of the horrors of war" message has long been advocated as a standard anti-radicalization approach (Stout, Huckabey, and Schindler 2008[1]). Unfortunately, multitudes of young, grievance-fueled Muslim men of many races and backgrounds still identify with the Salafi-jihadist cause and get off their couches to go fight in distant lands because they still believe in the main AQ narrative of overthrowing apostate governments and establishing a global caliphate. Niger's Hicham Bilal was evidently of that mindset. Once experiences clash with expectations, some of these sudden or accidental jihadists can quickly self-deradicalize when reality sets in. In Bilal's case, he did not have to travel too far in West Africa on the path to jihad or spend too much time in MUJAO before the narrative soured and he returned home to tell a different story of life fighting for AQ in Mali.

[1] See the chapters on strategic communication and recruitment.

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http://www.sciencedirect.com/science/article/pii/S0030438713000318

REFERENCES

ABC News Blog. 2010. "President Obama, White House: Al Qaeda Is Racist." Blog posted by Jake Tapper, July 13. http://abcnews.go.com/blogs/politics/2010/07/president-obama-white-house-al-qaeda-is-racist/.

AFP. 2012. "Head of Mali Extremist Battalion Defects." *AFP World Service*, November 8.

"Al-Qa'ida Maghreb Splinter Group MUJAO Threatening France." 2012. *L'Expression Online*, January 4.

"Bilal Hicham, Rebelle Du Nord Du Mali." 2012. Audio interview translated by Marcus Sivell-Muller. *RFI*, August 4.

Council of Foreign Relations Africa in Transition Blog. 2012. "Racism Obstructs Extremism in Mali." Blog posted by John Campbell, December 20. http://blogs.cfr.org/campbell/2012/12/20/racism-obstructs-extremism-in-mali/.

Council of Foreign Relations Africa in Transition Blog. 2013. "Racism in Mali." Blog posted by John Campbell, February 5. http://blogs.cfr.org/campbell/2013/02/05/racism-in-mali/.

Daniel, Serge. 2012a. "Islamist Fighters Ready for Battle in North Mali." *AFP*, September 26.

Daniel, Serge. 2012b. "Scores of Africans Recruited by Mali Qaeda Offshoot," *AFP*, July 18.

"Early Perspectives on the Mali Crisis from a Jihadist Forum (II)." 2013. *The Moor Next Door*, January 20. http://themoornextdoor.wordpress.com/2013/01/20/early-perspectives-on-the-mali-crisis-from-a-jihadist-forum-ii/.

Fessy, Thomas. 2013. "Mali Prisoner: 'Militants Cut Off My Hand with a Knife.'" *BBC News*, February 15.

Freeman, Colin. 2013. "Revealed: How Saharan Caravans of Cocaine Help to Fund Al-Qaeda in Terrorists' North African Domain." *The Telegraph*, January 26.

Guèye, Bakari. 2012. "Mujao Commander Quits Mali Terror Group." *Magharebia.com*, November 12.

Hilsum, Lindsey. 2013. "Inside Gao Where Arab Jihadis Took Bloody Sharia Retribution on Mali's Black Africans." *The Guardian*, February 2.

Malagardis, Maria. 2012."Terrorism Expert Cites AQIM Links with Colombian Drug Networks." *Liberation*, Jannuary 6.

Oumar, Jemal. 2012. "Racism Spurs Mali Terrorist Defections." *Magharebia.com*, December18.

Radio France Internationale. 2012. "'Ils N'ont Rien De Musulmans': Un Jihadiste Nigérien Quitte Le MUJAO Au Nord Du Mali," *RFI Online*, November 9.

Stout, Mark E., Jessica M. Huckabey, and John R. Schindler. 2008. *The Terrorist Perspectives Project: Strategic and Operational Views of Al Qaida and Associated Movements*. Edited by Jim Lacey. Annapolis, MD: Naval Institute Press.

The Fight. 2012. "MUJAO à Gao: Les Déserteurs Du Mouvement Menacés De Mort." *Maliweb.net*, November 7.

The New Statesman's Blog. 2010. "Is Al-Qaeda Racist? Blog posted by Michael Mumisa, July30. http://www.newstatesman.com/blogs/the-staggers/2010/07/obama-qaeda-black-islamic-book.

COMPETITIVE CONTRACTING IN THE SERVICES SECTOR

Susan L. Rose, Laura M. Williams, and Andrew S. Rehwinkel

The authors investigated whether competed service-sector contracts with a single-offer award or sole-source award indicate a lack of qualified firms or significant barriers to entry. They concluded that the number of service-sector contracts receiving only a single offer is about half as large as the data appear to suggest and that the use of short-term contracts and modifications to fill the gap in services between the end of one contract and the beginning of the next is a significant source of sole-source contracts.

DoD committed approximately $200 billion in contracts for services. More than $28 billion of this total consisted of competed contracts that attracted only a single offer. We were asked to determine whether the prevalence of single-offer and sole-source contracts for DoD services represents an industrial base concern.

The presumption established in the Federal Acquisition Regulation (FAR) is that federal contracts should be awarded on a competitive basis whenever possible and that competed contracts should be available to multiple offerors. This presumption applies to all Department of Defense (DoD) contracts for services.

The data on competition in the services sector raise some questions. In FY 2008, DoD committed approximately $200 billion[1] in contracts for services. More than $28 billion of this total consisted of competed contracts that attracted only a single offer. Moreover, nearly $26 billion in DoD service contracts were awarded sole source. Together, these two categories accounted for $54 billion in FY 2008—or over 25percent of the total volume of DoD spending on service contracts in that year.

In 2009, the DoD Office of Industrial Policy asked IDA to examine DoD contracts for services that (1) are competed but that receive only a single offer and (2) are sole source. We were asked to determine whether the prevalence of single-offer and sole-source contracts for DoD services represents an industrial base concern, such as a lack of qualified firms or significant barriers to entry.

This paper focuses on two findings of the IDA study that highlight the necessity of carefully reviewing top-level statistics before drawing conclusions regarding the level of competition in DoD service contracts. We found that (1) the prevalence

[1] A $13.9 billion data error was discovered after the FY 2008 data set was frozen. Although the error results in an overstatement of service contracts and competed contracts with multiple offers, it does not qualitatively or substantively change our conclusions.

of competed DoD service contracts receiving a single offer is only about half as large as the data cited previously appear to suggest and (2) a significant number of sole-source DoD service contracts are bridge contracts—short-term contracts that fill the gap in services between the end of one competed contract and the beginning of the next.

SINGLE OFFERS—THE PROBLEM IS NOT AS LARGE AS IT SEEMS TO BE

Our baseline plan for this paper was to do a thorough statistical analysis of the available data to test various explanations that have been offered for single offers on competed contracts and the underlying reasons for sole-source contracts. Although we did the analysis, a close examination of that data revealed that the problem—an absence of competition for DoD service contracts—is only about half as large as the data appear to suggest.

This misperception of the size of the problem occurs because of the character of Multiple Award Indefinite Delivery Vehicle (IDV) task orders. An IDV contract does not specify the specific service or actual quantity required. Instead, it provides a quantity range or general description of required services. Actual awards under an IDV occur in two stages. The first stage for a services IDV is a competition to establish a pool of contractors qualified to provide services under the IDV. The data that we examined indicate that there is always competition at this stage and that several firms are usually selected. The second stage is the issuance of a task order by the contracting agency for specific quantities or a particular service. It is typical for many task orders to be issued under a single IDV. All of these task orders are open to competition by the qualified bidders. When only one of the qualified firms bids on the task order, it is recorded in the relevant database as a competed contract that received only one offer. In FY 2008, such task orders accounted for $10.9 billion.

Characterizing the single offers on Multiple Award IDV task orders as having received no competition is inaccurate since the selection of the pool of firms eligible to bid on the task orders was based on an IDV competition with multiple offers. Although it is difficult to quantify the benefit, to the extent that firms believe that other qualified firms will bid on the Multiple Award, the benefits of the competition for the master IDV contract convey to the task orders.

We therefore characterize the single-offer Multiple Award IDV task orders as having received some competition. In short, the fact that a single offer was made does not necessarily mean that the competitive process was ineffective. Firms have limited resources with which to prepare bids and proposals—a time-consuming and costly process. Firms are selective, choosing proposals for which they believe they have a competitive advantage. These subjective expectations are, in part, a result of the firms' beliefs about which other firms will bid the project. For these reasons, the number of offers may not be a sufficient metric

to determine the level or effectiveness of the competition.

Broad Agency Announcements (BAAs) or Small Business Innovation Research solicitations (SBIRs) for Research, Development, Test, and Evaluation (RDT&E) awards present a similar situation. We estimate that $3 billion in apparent RDT&E single-offer contracts are responses to BAAs and SBIRs. Although BAAs and SBIRs are considered competitive solicitation procedures, they are a fundamentally different type of competition and often appear as single-offer contracts in the data, regardless of the number of offers received.

As was noted previously, in FY 2008, about $28 billion of contracts (including task orders) that DoD offered for competition attracted only a single bidder. Of this total, about $14 billion were accounted for by contracting processes that involved some significant competition—$10.9 billion in IDVs and $3 billion in BAAs and SBIRs. Recognizing this adjustment reduces by half—to $14 billion—the value of competed contracts that received only one bid.

SOLE SOURCE—THE CAUSE IS MORE DOD POLICIES AND PRACTICES THAN INDUSTRIAL STRUCTURE

In FY 2008, of the $202 billion in DoD contracts for services, sole-source contracts account for $25.9 billion. In our research, we investigated underlying causes, beyond the stated FAR exceptions, that may be drivers for the number of sole-source contracts.

We found that the use of short-term contracts to fill the gap in services between the end of one contract and the beginning of the next accounts for a significant amount of sole-source contracts. These bridge contracts, as they are called, are due to delays in the acquisition process from various sources:

- The requiring agency—changes to the requirements or not having the requirements documents prepared on schedule;
- The contracting office—the discovery that the planned contract vehicle cannot be used or a problem at any of the several review and approval boards that constitute the process; and
- Other sources—protests of the contract award.

To analyze this issue, we collected Justification and Authorization (J&A) documents from the FedBizOpps website from March through September 2009. Of the non-competed contracts for DoD services posted during this period, nearly one in four was a bridge contract.

The value of these short-term contracts appears to be small, about 10 percent of the total sole-source J&As for those contracts for which we were able to obtain the values. However, the use of bridge contracts represents a potentially large cost to DoD due to process inefficiencies. This cost must include the costs of preparing and administering the bridge contracts at the requiring agency, the contracting office, and

the contractor. In addition, the use of bridge contracts adds to the workload for the limited DoD contracting workforce because these contracts must be put in place and administered along with the eventual competed contracts for the required services.

SUMMARY

In FY 2008, DoD committed approximately $202 billion in contracts for services. Competed contracts that attracted only a single offer accounted for over $28 billion. Nearly $26 billion in DoD service contracts were awarded sole source. Together, these two categories accounted for $54 billion in FY 2008—or over 25 percent of the total volume of DoD spending on service contracts in that year. Does this represent a problem with competition on services contracts?

Single offers on competed contracts probably do not represent a problem. Of the $28 billion in apparent single-offer contracts, we show that half received some competition and we find no clear systemic cause for the remaining $14 billion. The usual suspects of set-asides and contract structure do not explain single offers.

For sole-source contracts, however, the answer is yes. Policies and procedures used by DoD increase the time required to do a competition. This approach can increase the use of bridge contracts, which are costly to DoD.

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Competitiveness in the Services Sector: Understanding the Contracting Data

https://sharepoint.ida.org/sites/IS/TISO/libraryblog/Lists/Test%20Sandbox/Attachments/250/Competitivness%20in%20the%20Services%20Sector%20Understanding%20the%20Contracting%20Data.pdf

REFERENCES

Williams, Laura M., Susan L. Rose, and Andrew S. Rehwinkel. 2012. *Competitiveness in the Services Sector: Understanding the Contracting Data*. IDA Document NS D 4659. Alexandria, VA: Institute for Defense Analyses. https://www.ida.org/~/media/Corporate/Files/Publications/IDA_Documents/CARD/ida-document-ns-d-4659.pdf.

EVALUATING HIGHLY HETEROGENEOUS DOCUMENT COLLECTIONS

Arun S. Maiya, John P. Thompson, Francisco Loaiza-Lemos, and Robert M. Rolfe

This research effort involved the application of state-of-the-art computational approaches in machine learning and text mining to the discovery of critical information in unstructured collections of text. Unlike search (e.g., Google-like keyword searches), discovery finds information for which one may not have even known to look. The authors, in their article, presented an effective multi-faceted system for exploratory analysis of highly heterogeneous document collections. The IDA Text Analytics (ITA) capability, which incorporates these discovery technologies, is currently being used by the Department of Defense (DoD) to facilitate exploration and understanding of document sets across a number of different domains.

Document collections of interest in our work exhibit a high degree of diversity in content and format. The U.S. government, for instance, is often presented with the challenge of what essentially is exploratory analysis of highly heterogeneous document collections.

Given a large and diverse collection of unstructured text documents, how does one characterize the subject areas present and use these discovered subject areas to efficiently navigate the collection to locate critical information? Many previous works have investigated such questions within specific domains such as microblog posts or scientific abstracts, but comparatively less attention has been paid to investigating more general and diverse contexts. Unfortunately, in practice, approaches that may work well for domains consisting exclusively of a single document type (e.g., tweets, emails, or scientific abstracts) do not always translate easily or directly to other more heterogeneous and "messy" document collections.

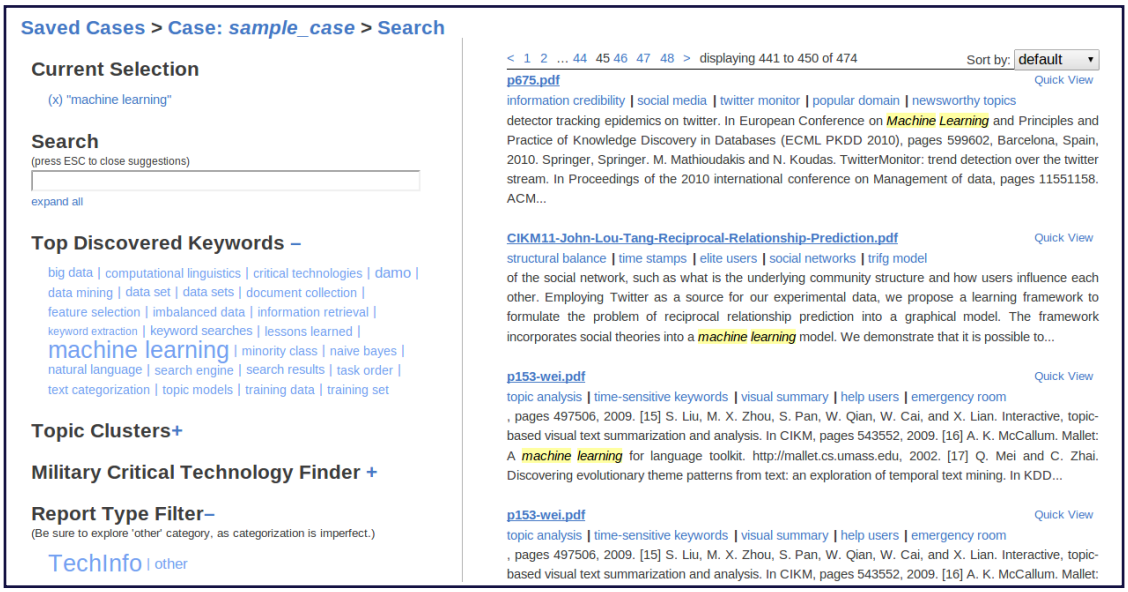
In this work, we present a tag-based system in which tags (i.e., terms or character strings automatically assigned to individual documents) are exploited to efficiently characterize and explore document collections. Document collections of interest in our work exhibit a high degree of diversity in content and format. The U.S. government, for instance, is often presented with the challenge of what essentially is exploratory analysis of highly heterogeneous document collections. Examples include digital investigations, intelligence analysis, and appraisal of electronic records. Our approach to this problem is to mine content from the documents themselves to auto-populate facets: classes of attributes describing objects in an information repository. Such facets can be used to navigate and discover information, as we now describe.

APPLICATION OVERVIEW

IDA Text Analytics (ITA) is a multi-faceted system for exploratory analysis of highly heterogeneous document sets. Although initially intended for facilitating the review of military-related technical reports, the system has been designed in a way that it serves as a general-purpose tool for search and discovery in arbitrary text collections.

Figure 1 shows a screenshot of one of the main interfaces. On the surface, it appears to be a standard search engine interface in which users can type ad hoc search queries and view search results. However, the standard search functionality is enhanced (on the left in Figure 1) with numerous facets. These facets are populated in an automated fashion by intelligently tagging each document in the collection along various dimensions. Most (but not all) of the facets take the form of tag clouds.

Figure 2 shows a sample tag cloud displaying topic-representative keywords discovered using Keyword Extraction for Reports and Articles (KERA), our unsupervised algorithm for key term extraction, which we describe later. This tag cloud facet can be viewed as a "lens" into document collections. The remaining facets can be viewed as controls used to point, zoom, and focus this "lens" to areas of high interest in the corpus. In actuality, each facet can play either the role of a "lens" or a "lens control." For instance, using other facets (not shown in the screenshot but described later), the search results can be filtered by folder location. Subsequently, the tag cloud shown in Figure 2 will dynamically regenerate to display the top discovered keywords



On the left, a rich set of information facets are provided for exploratory analysis. Only a subset (i.e., the Topic Facets) is viewable in this screenshot. The application also provides standard search engine functionality powered by Solr, as shown.

Figure 1. A Screenshot of Our System.

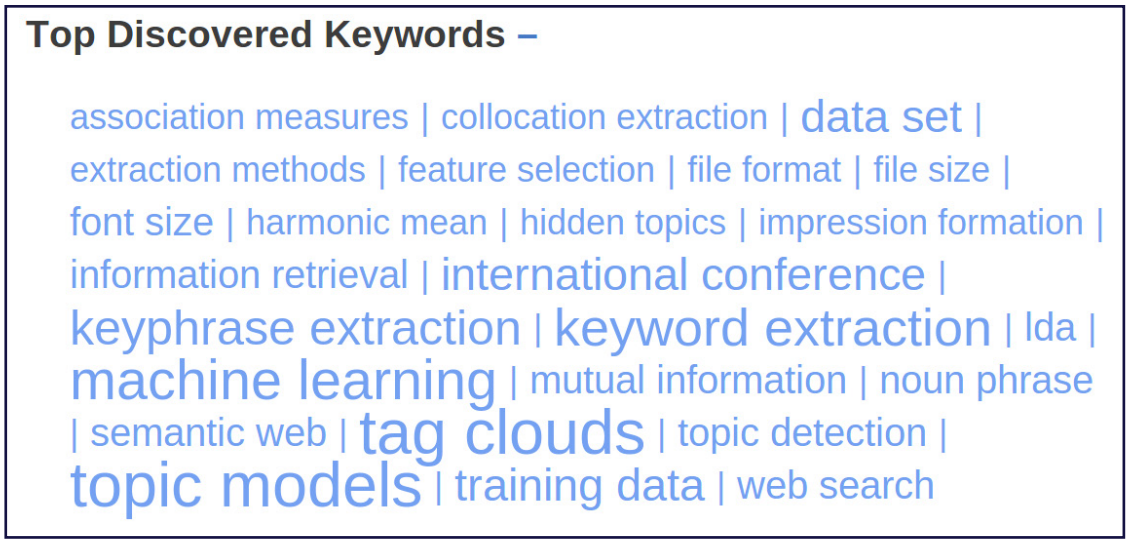


Figure 2. A Tag Cloud generated by the KERA algorithm for 64 documents used as references in this paper.

of only the refined search results (i.e., documents residing in the folder selected). In this way, users can quickly "triage" noisy document collections for information of interest (in some cases, even before opening and reading documents).

In the following sections, we describe the five different categories of facets that we employ: (1) Topic Facets, (2) Mention Facets, (3) Format Facets, (4) Location Facets, (5) Time Facets, and (6) Author Facets.

TOPIC FACETS

Topic Facets are intended to help discover and characterize the subject areas present in a document collection. We employ three different types of *Topic Facets*.

Automated Keyword Extraction

Our first approach to populating a Topic Facet is based on extracting topic-representative terms (i.e., keywords) from documents. (This is shown as *Top Discovered Keywords* in Figures 1 and 2). Here, we present KERA [Keyword Extraction for Reports and Articles], which is an unsupervised algorithm to extract keywords from individual text documents. KERA, at its core, is a descriptive model for keyword assignment based on observations of human-assigned keywords. The KERA algorithm, shown in Figure 3, comprises the following components:

- **Collocation extraction**. We first employ the use of collocation extraction to identify candidate key terms (shown in Line 2 of Figure 3). A collocation is "an expression consisting of two or more words that corresponds to some conventional way of saying things" (Manning and Schütze 1999). Using the log-likelihood ratio test, the collocation score for a bigram (i.e., two-word phrase) of words w^1 and w^2 is

$$2\sum n_{ij} \log \frac{n_{ij}}{m_j}$$

where n_{ij} are the observed

Algorithm 1 KERA algorithm

Require: D, an unstructured text document
Require: K, the number of keywords to extract
1: # generate candidate keywords
2: $terms1 = extractCollocations(D)$
3: $terms2 = extractNounPhrases(D)$
4: $terms3 = extractProperNounUnigrams(D)$
5: $candidates = (terms1 \cap terms2) \cup terms3$
6: # rank candidates
7: **for all** $c \in candidates$ **do**
8: **if** c is unigram **then**
9: α = normalized frequency of term c in D
10: **else**
11: α = normalized collocation score
12: **end if**
13: $\beta = 1 - \frac{\text{index of first occurrence of c in } D}{\text{num. of words in D}}$
14: rank score of term $c = \frac{2 \cdot \alpha \cdot \beta}{\alpha + \beta}$
15: **end for**
16: # optionally prune based on domain-specific criteria
17: # $candidates = prune(candidates)$
18: return top K candidates based on rank score

Figure 3. The KERA Algorithm.

frequencies of the bigram from the contingency table for w^1 and w^2 and m_{ij} are the expected frequencies assuming that the bigram is independent (Dunning 1993; Manning and Schütze 1999).

- **Part-of-speech filtering**. Next, in Line 3 of Figure 3, we filter the set of collocations by removing terms that do not match the pattern (ADJECTIVE)*(NOUN)+, since expressive keywords tend to be noun phrases. Phrases greater than two terms are truncated. To this filtered set, we add extracted unigrams (i.e., one-word phrases) that are proper nouns (in Line 4) since we find such terms can be critical to the topic of documents. The criticality of these terms is especially true of government, scientific, and technical publications since proper nouns often refer to a system, algorithm, program, or initiative being described.

- **Ranking keywords**. Finally, we rank the extracted terms, as shown in Figure 3, and return the top K candidates. Our ranking methodology takes into account the position of terms within a document and the collocation score and term frequency. The final score is taken as the harmonic mean of these metrics. Before returning the final set, one might optionally prune the candidates based on domain-specific criteria. For instance, in our case, the set of proper noun unigrams can be pruned to contain only those unigrams that are upper case since it is those terms that often signify important technical systems and programs.

Topic Modeling and Clustering

A second Topic Facet that we employ is based on the concept of topic clusters. Topic modeling and clustering algorithms segment documents into different groups such that documents in the same group pertain largely to the same topic or theme. Whereas many clustering algorithms produce "hard" clusters or disjoint sets of documents, topic models typically produce "soft" or overlapping clusters. Topic models

[1] Currently, we set K = 5 or K = 10 for KERA.

[2] Other possible variations include discarding candidates when proper noun unigrams also appear as part of extracted bigrams, removing unigrams that do not first appear until later in the document, performing significance testing to filter the set of collocations, and setting α always as normalized frequency.

and clustering strategies may also tag clusters with topic-representative words. Latent Dirichlet Allocation (LDA) is the topic modeling algorithm that we currently employ for topic clustering (Blei, Ng, and Jordan 2003). Documents are assigned to a topic only if the topic proportion assigned by LDA is greater than 0.3, and documents are tagged using the top 10 LDA-derived topic tags. The facet populated by LDA is labeled "Topic Clusters" and appears as a menu showing the list of discovered topics (see Figure 1).

Document Classifier Facets

All of the *Topic Facets* discussed thus far (including topic models) have focused on identifying trends and hotspots within the topic collection. That is, they are not well suited to finding "needles in haystacks." A document pertaining to a lone topic of high interest to a particular user may not be identifiable in the presence of large topic clusters displayed in a tag cloud or other interface. To address this issue, we supplement the facets populated by KERA and LDA with two additional tag cloud facets populated by supervised document classification, which we now describe.

- **Military Critical Technology Finder**. This facet, shown in Figure 1, is populated using a set of binary-supervised machine-learning classifiers. Each binary classifier is trained to identify documents pertaining to a particular critical technology, and each tag in the cloud represents the positive class of a classifier. For any individual document, if no binary classifier categorizes the document as positive, the document is assigned the tag "other," which also appears in the cloud. We use LinearSVM as our main learning algorithm for all classifiers.

- **Report Type Filter**. Using a very similar methodology to the one described previously, we developed an additional classifier to categorize documents based on report type. That is, documents are categorized into one of four categories: Technical Information (e.g., a research paper), Test Information (e.g., a test plan for a system), Programmatic Information (e.g., details of a program for development of a system), and Other (i.e., everything else).

For more technical details on the development of document classifiers in this domain, one can refer to our earlier work in Maiya, Loaiza-Lemos, and Rolfe (2012).

MENTION FACETS

Users sometimes may be interested in locating documents not by topic but by mentions of particular entities, terms, or expressions of interest (e.g., Internet Protocol (IP) addresses, company names). To address this issue, we employ the use of a *Mention Facet*, which allows users to upload a plain text file containing expressions of interest. These expressions can currently take the form of simple lists of terms, gazetteers (i.e., entity dictionaries), or regular expressions for patterns of interest (e.g., a social security number). The results are displayed as either a tag cloud or menu, where the items are either explicit

terms with matches in the document collection or high-level categories described by expressions (e.g., tagging documents containing social security numbers with "PII" [Personally Identifiable Information]). We currently employ such mention facets to navigate and search document sets based on sensitive markings (e.g., "For Official Use Only") and technical entities of particular interest to specific users.

FORMAT, LOCATION, TIME, AND AUTHOR FACETS

Our final set of facets is populated through direct extraction from document metadata. The *Format Facet* (labeled "File Types") is populated by tagging documents based on file type (e.g., .pdf, .doc, .ppt, .txt). The *Location Facet* (labeled "Folders") is populated by tagging each document with the directories in its file path. The *Time Facet* (labeled "Date" in our application) is populated by extracting the *Last-Modified* time from documents. Finally, the *Author Facet* is populated using the *Last-Author* or *Author* name (when available).

The *Location Facet* is displayed as a menu listing the most populous folders, and the Time Facet is displayed as a calendar widget. All other facets are displayed as tag clouds. (Note that none of these facets can be viewed in Figure 1.)

CASE STUDIES

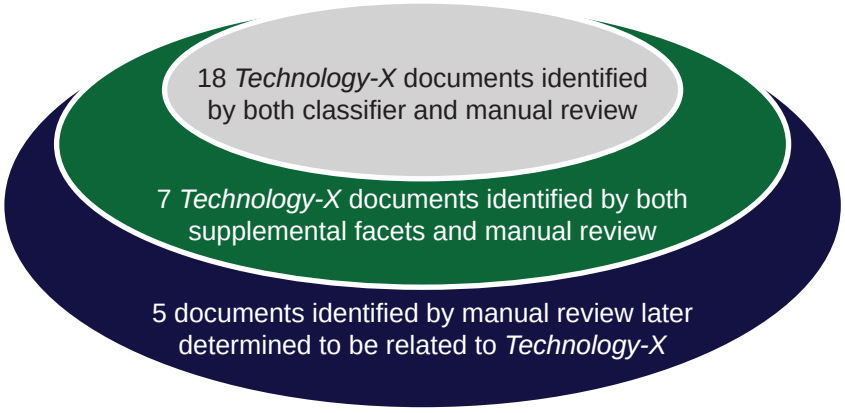
We now briefly describe two case studies that were conducted to more thoroughly evaluate our system. Although our system can be used for many purposes, we focus our evaluation on the current application of interest to our sponsors: locating information pertaining to military critical technologies within heterogeneous document collections. For reasons of sensitivity, we have redacted information, as necessary.

Case Study 1: Search

The search involves the task of finding information pertaining to a particular military critical technology within a document collection. We consider a particular technology of high interest to our sponsors (referred to as *Technology-X*) and assess how well the supervised approaches in our application are able to locate this critical information. A case that contained 30,128 files acquired from workstation hard drives of roughly 11 users was provided to us.

The files spanned numerous file formats including Microsoft Office, HyperText Markup Language (HTML), Portable Document Format (PDF), and plain text. We built machine-learning classifiers and custom-mention searches for *Technology-X*, as described previously. We evaluated these approaches and compared the results to those obtained from a manual review of the case by two analysts using their existing methodology (i.e., ad hoc keyword searches only). Results are shown in Figure 4 as a Venn diagram.

We observed significant time savings in this case study. The two analysts took roughly 7 hours (or 14 person-hours) to locate *Technology-X* documents. By contrast, the classifier identified 18 of the 25 files in mere seconds. The remaining files (i.e., all the seven false negatives) were located in less than 30 minutes using the *Mention Search, Report Type Filter*, and *Top Folders* facets in our application. We attribute most false



The top (innermost) oval shows documents identified by classifier. The middle oval shows documents identified by other facets. The bottom (outermost) oval shows documents identified via a manual review by two analysts.

Figure 4. Venn Diagram of Search Results.

negatives committed by the classifier to the fact that the positive examples available to us at the time were limited. Given this finding and the breadth and depth of military critical technology information, unsupervised topic discovery is of high importance to this domain, which we evaluate next.

Case Study 2: Discovery

Discovery involves browsing document collections and allows users to locate information for which they did not even know to look. A framework to facilitate discovery can also clearly facilitate a search for something specific. Due to logistical and policy-related issues, we were not able to evaluate discovery on the case described in the previous case study, Case Study 1: Search. Instead, we were provided a new case to evaluate, which contained 39,515 files. Unlike the previous case study, we did not have any approximation of ground truth since the case had not been formally reviewed. Here, we assess the knowledge discovered and summarize lessons learned from execution of our application on this case.

Table 1 shows the two topics pertaining to military critical technologies discovered by our application (referred to as *Technology-Y* and *Technology-Z*). During the search,

Table 1. Critical Topics Found and Effective Usage Patterns

Topic	Documents	Facets Employed		
Technology-Y	232	Method A: Topic Clusters (LDA)	→	KERA
		Method B: Report Type Filter	→	KERA
Technology-Z	89	Method A: Topic Clusters (LDA)	→	KERA
		Method B: Report Type Filter	→	KERA
		Method C: Top Folders	→	KERA

89 documents were found that pertained to *Technology-Z* and 232 documents were found that pertained to *Technology-Y* (including duplicate files). Through a subsequent exhaustive manual review of the case, we estimate that no additional information on military critical technologies of interest was present on this case. Using our facet-based system, most documents for these two critical topics were identified in less than an hour (and in many cases only minutes). By contrast, domain experts informed us that cases of this size typically require hours or days of "analyst" analysis to produce similar results, which is consistent with our experience during the manual review. Also shown in Table 1 are facet combinations revealed to be effective on this task. For additional results and technical details for this study, one may refer to the full report of this work (Maiya et al. 2013).

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Exploratory Analysis of Highly Heterogeneous Document Collections

http://dl.acm.org/citation.cfm?id=2487575.2488195

REFERENCES

Blei, David M., Andrew Y. Ng, and Michael I. Jordan. 2003. "Latent Dirichlet Allocation." Journal of Machine Learning Research 3 (4–5) (March): 993–1022.

Dunning, Ted. 1993. "Accurate Methods for the Statistics of Surprise and Coincidence." Computational Linguistics 19 (1) (March): 61–74.

Maiya, Arun S., John P. Thompson, Francisco L. Lemos, and Robert M. Rolfe. 2013. "Exploratory Analysis of Highly Heterogeneous Document Collections." In Proceedings of the 19th ACM SIGKDD International Conference on Knowledge Discovery and Data Mining, KDD '13, 1375–1383. New York, NY: ACM. http://dl.acm.org/citation.cfm?id=2488195.

Maiya, Arun S., Francisco Loaiza-Lemos, and Robert M. Rolfe. 2012. "Supervised Learning in the Wild: Text Classification for Critical Technologies." In Proceedings of the Military Communications Conference, 2012 – MILCOM 2012, 1–6. Curran Associates, October. http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=6415660.

Manning, Christopher D., and Hinrich Schütze. 1999. Foundations of Statistical Natural Language Processing. Cambridge, MA: MIT Press.

LUMINESCENT SPECTRAL SPLITTING: A NEW APPROACH TOWARD CONSTRUCTING HIGH-EFFICIENCY SOLAR CELLS

Brent Fisher and John Biddle

We consider an approach, which we call luminescent spectrum splitting (LSS), for efficiently dividing solar radiation into several spatially divided spectral components. These spectral components separately illuminate photovoltaic cells of different band gaps using a simple optical design that is easy to manufacture and easily extensible to an arbitrarily large number of spectral channels. Because of this extensibility, the number of junctions in the system is limited only by the availability of photovoltaic cells with appropriate band gaps. As a result, significantly high system efficiencies should be accessible. In our analysis of this concept, we find that optical quantum efficiencies as high as 95 percent can be achieved.

We have introduced a spectral-splitting concept that opens up a new design space for constructing high-efficiency PV systems. Although our results show high quantum efficiency at the expense of solar concentration, we have only examined a small portion of the design space in the report. A number of possible extensions are worth further investigation.

For typical solid-state solar cells, a natural tradeoff occurs between current (the number of photons converted to electrical energy) and voltage (the amount of energy converted per photon) that limits the overall solar-to-electric conversion efficiency that can be achieved. This tradeoff, known as the Shockley–Queisser limit, is a consequence of the broadband spectrum of the incident solar power density and the electronic structure of semiconductor p-n junctions. The most common approach to overcoming this limitation is to construct a "multi-junction" photovoltaic (PV) system where each junction is "tuned" to a separate portion of the solar spectrum (Imenes and Mills 2004). A well-known example of such a design is the "tandem" solar cell, where p-n junctions are stacked on top of each other in optical series by epitaxial growth of different layers of material. Very high power efficiencies have been reported with tandem cells; however, the stacked design requires current matching across the p-n junctions.

This current-matching requirement limits the practical efficiency gains when seasonal and diurnal variations in the solar spectrum are considered. A promising alternative to the tandem approach is the use of optical elements to spatially separate portions of the solar spectrum and deliver them to separate, single-junction solar cells. This spatial separation of the solar spectrum avoids the lattice-matching constraints of epitaxial growth and the current-matching requirement that constrains robustness in tandem cells. Some examples of efforts to optically split the solar spectrum include the RAINBOW multi-junction design from the National Aeronautics and Space Administration (NASA) (Lewis et al. 1997; Smith et al. 2000), holographic splitting

(Ludman et al. 1992), and a Defense Advanced Research Projects Agency (DARPA)-funded concentrated PV project (Barnett et al. 2006; Barnett et al. 2009).

A variety of optical designs have been proposed and built to spatially divide the solar spectrum. The design employed by the DARPA-funded PV project, for example, made use of dichroic mirrors (wavelength-dependent reflective surfaces) and tandem solar cells. Dichroic mirrors, however, have proven to be difficult to work with practically in solar cell designs because (1) their reflective properties are sensitive to the angle of the incident light, which is problematic in cases where the light is concentrated; (2) designs based on dichroic mirrors are difficult to extend; and (3) dichroic materials are cost prohibitive.

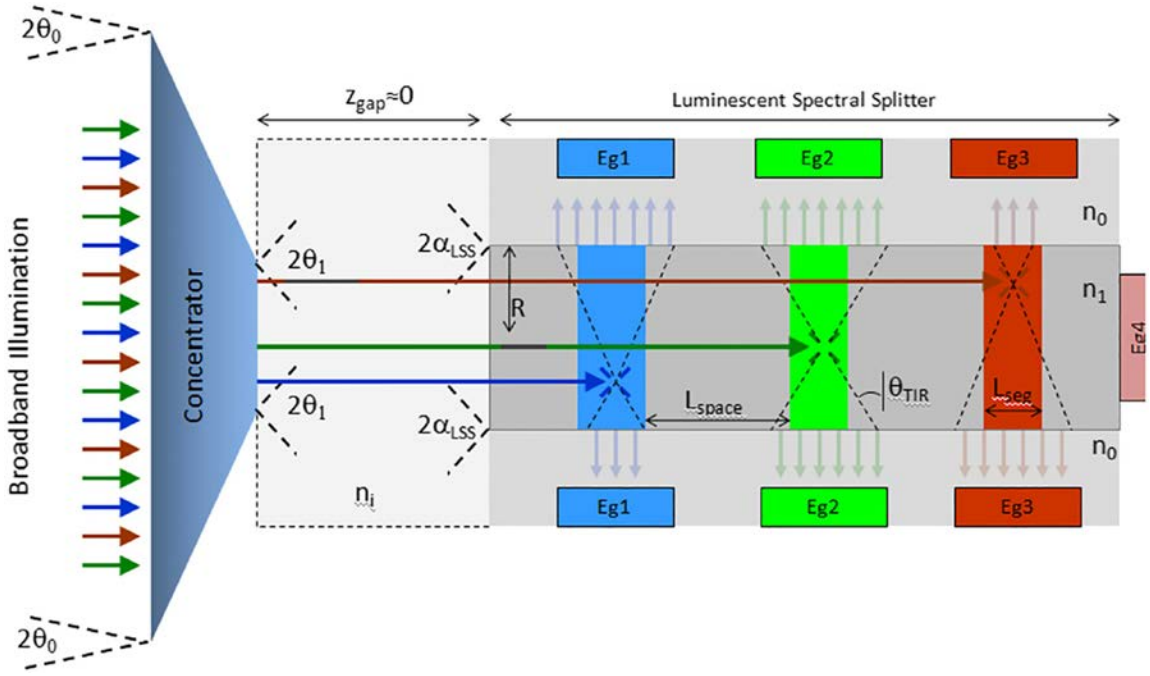
An alternative approach to dichroic mirrors makes uses of stacked arrays of luminescent solar concentrators (LSCs)—waveguides doped with luminescent materials. Stacked LSCs can achieve both spectral division and high concentration of light, which lower the amount of PV material needed. However, the optical efficiencies of LSCs are severely constrained due to reabsorption. In our report, we considered a similar approach, which we call luminescent spectrum splitting (LSS), that aims to split the solar spectrum with maximum optical efficiency by using a simple design that is easy to manufacture and easily extensible to an arbitrary number of subcells.

Although our concept is similar to LSCs, we focus first on high efficiency and good spectral splitting, in contrast to LSCs, where the primary objective is to achieve high light-concentration ratios. This change in focus provides new opportunities in the spectral-splitting design space. In our analysis of this concept, we find that optical quantum efficiencies as high as 95% can be achieved.

THE LSS CONCEPT

The LSS concept is illustrated in Figure 1. Broadband solar illumination is first concentrated by a non-imaging concentrator optic, such as a compound parabolic concentrator. The concentrated solar flux is then fed into an optical waveguide, where light is propagated by total internal reflection (TIR). To achieve spectral splitting, parts of the waveguide are doped with tunable flurophores with very high luminescent quantum yield. This yield can be achieved by embedding semiconductor nanocrystals inside polymer matrices via polymerization or similar methods (Lee et al. 2000; Reisfeld 2001; Lee 2002; Sheng et al. 2006; Olsson et al. 2004; Sundar et al. 2004). With this setup, each ray propagates through the waveguide until it encounters a segment that is doped with nanocrystals whose band gap is lower in energy than the ray's wavelength.

Rays absorbed by the fluorophores are then reemitted isotropically at a lower frequency depending on the nanocrystal's emission profile. Some of the reemitted rays will not meet the TIR condition and will exit the waveguide along the sides, where they can be collected by single-junction PV materials. In the report, we focused on a cylindrical design with rotational symmetry about the z-axis, but rectilinear or other designs are also possible and are worth investigating in future studies.



The gap between primary concentrator and the LSS is inflated so that angle definitions can be illustrated. The diagram is not to scale.

Figure 1. Diagram of LSS Concept.

ANALYSIS

In our analysis of the LSS concept, we identified the following relevant design parameters (some of which are illustrated in Figure 1):

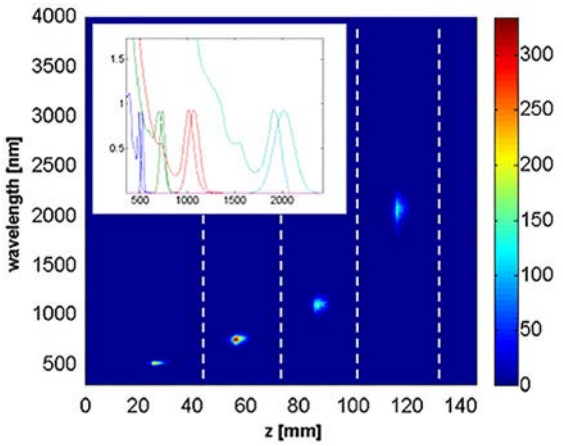
- C_1: Input concentration (not illustrated in figure)
- n_0: Refractive index of cladding on LSS
- n_1: Refractive index of LSS interior
- n_i: Refractive index at input to LSS and exit of primary optic
- L_{seg}/R: Unitless ratio between length of color segment and radius of LSS
- P_{trans}: Probability of a photon to traverse a color segment without absorption when traveling on axis and with wavelength at the color segment's absorption peak(not illustrated in figure)
- L_{space}/R: Unitless ratio of the length of spacing between color segments and the radius of LSS
- θ_0: Acceptance half angle of primary concentrator.

To assess the performance of the LSS concept as a function of these parameters, we constructed a Monte Carlo ray-tracing model to simulate photon propagation through the LSS waveguide. With this simulation, we can examine the optical and power

efficiency of the LSS as a function of the design parameters given previously. For our study, we sought to simulate a system that is realistically feasible using present technology. We selected a refractive index of $n_1 = 1.62$ for the LSS, corresponding to optical glass. The cladding index n_0 was a varied parameter between 1.4 and 1.65. We also varied P_{trans} between 0.0001 and 0.02 and L_{seg}/R between 0.1 and 10 and assumed the ideal case where the quantum yield is 1. For the primary concentrator, we assumed an input concentration $C_1 = 94X$.

With the aforementioned constraints, a number of parameter combinations were identified through the simulation for which the optical quantum efficiency exceeded 90%. Figure 2 shows the output spectrum of one of these combinations ($L_{seg}/R = 5.0$, $n_0 = 1.60$, $P_{trans} = 0.01$). In this figure, we see that the LSS concept accomplishes the main goal of splitting the broadband solar spectrum into four spatially separated narrowband outputs that do not overlap significantly. For this case in particular, we obtained a quantum efficiency (QE) of 94% and a power efficiency (PE) of 75%. (QE = 80% and PE = 70% when only side walls are counted.) The probability of reabsorption inside the same color segment was 0.35 in this run, which is much lower than typical LSC designs.

The caveat to the high QE results is that the color segments deconcentrate the input optical flux. This concern is illustrated in Figure 3. Because of this deconcentration, we need to cover large portions of the waveguide with PV material to fully use the output spectrum, which can be problematic if the costs of the PV materials are high. In Figure 3, net concentration is



Absorption and emission spectra for each color segment are shown in the inset.

Figure 2. Output Spectrum of the LSS Waveguide Monte Carlo Simulation as a Function of Axial Length z and Wavelength for the Case $L_{seg}/R = 5.0$, $n_0 = 1.60$, $P_{trans} = 0.01$, $L_{space}/R = 5.04$, $N = 10^5$.

defined as the ratio of the area of the input primary concentrator to that of the total collection areas covered by the PV materials, or C1 × input area/coverage area. Here, we see that we can obtain reasonable QEs (>90%) for net concentrations less than 10X, which is much lower than the input concentration (94X). Thus, the LSS

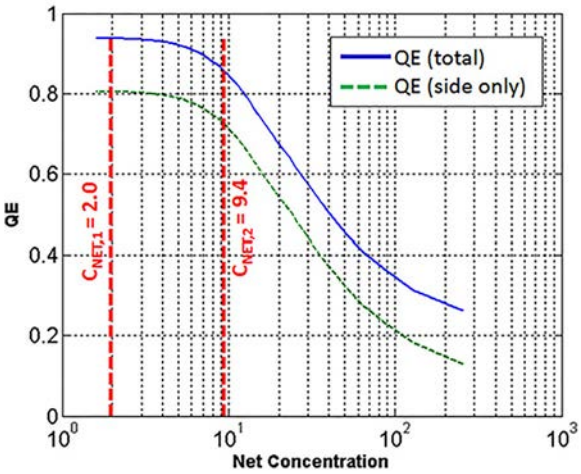


Figure 3. Tradeoff between QE and Net Concentration.

concept can be seen as sacrificing the input concentration to achieve spectral splitting at high QE.

Using these outputs from the Monte-Carlo simulation, we calculated the expected solar-to-electric conversion efficiency if PV cells with band gaps matched to these optical spectra (e.g., aluminum gallium indium phosphide (AlGaInP), indium gallium arsenide (InGaAs), silicon (Si), and germanium (Ge)) were coupled to each of our LSS designs. Based on reported external quantum efficiencies and other relevant PV parameters, we computed the expected current generation in each PV cell and found an overall solar-to-electric conversion efficiency in the neighborhood of 30%. The individual efficiencies of each channel were 58%, 56%, 30%, and 11% (high to low band gap). The lower band gap cells exhibited very high dark currents, which limited their efficiencies.

CONCLUSIONS

We have introduced a spectral-splitting concept that opens up a new design space for constructing high-efficiency PV systems. Although our results show high quantum efficiency at the expense of solar concentration, we have only examined a small portion of the design space in the report. A number of possible extensions are worth further investigation. Non-symmetrical geometries, such as rectangular or hexagonal cross-sections, for example, would permit the tiling of many units into arrays, which could leverage recent developments in the field of solid-state lighting.

The addition of secondary concentrators may also lead to higher net concentration designs. Another possibility is the use of aligned anisotropic luminescence, where flurophores preferentially readmit toward the sides of the waveguide. In addition, future development of inexpensive PV materials may also make the LSS approach more commercially interesting. Regardless of these possibilities, the LSS approach offers a design that is inherently simple, robust, and extensible and that should be relatively inexpensive to manufacture.

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Luminescent Spectral Splitting: Efficient Spatial Division of Solar Spectrum at Low Concentration

http://www.sciencedirect.com/science/article/pii/S0927024811000596

REFERENCES

Barnett Allen, Douglas Kirkpatrick, Christiana Honsberg, Duncan Moore, Mark Wanlass, Kieth Emery, Richard Schwartz, et al. 2009. "Very High Efficiency Solar Cell Modules." *Progress in Photovoltaics: Research and Applications* 17 (1) (January): 75–83.

Barnett, Allen, Christiana Honsberg, Douglas Kirkpatrick, Sarah Kurtz, Duncan Moore, David Salzman, Richard Schwartz, et al. 2006. "50% Efficient Solar Cell Architectures and Designs." *In Proceedings of the Conference Record of the 2006 IEEE 4th World Conference on Photovoltaic Energy Conversion*, 2560–2564. IEEE.

Imenes, A. G., and D. R. Mills. 2004. "Spectral Beam Splitting Technology for Increased Conversion Efficiency in Solar Concentrating Systems: A Review." *Solar Energy Materials and Solar Cells* 84 (1–4) (October): 19–69.

Lee, Jinwook. 2002. "Semiconductor Nanocrystal Composite Materials and Devices." PhD thesis, Massachusetts Institute of Technology. http://hdl.handle.net/1721.1/8039.

Lee, Jinwook, Vikram C. Sundar, Jason R. Heine, Moungi G. Bawendi, and Klavs F. Jensen. 2000. "Full Color Emission from II–VI Semiconductor Quantum Dot–Polymer Composites." *Advanced Materials* 12 (1) (August): 1102–1105.

Lewis, Carol R., Wayne M. Phillips, Virgil B. Shields, Paul M. Stella, and Ivan Bekey. 1997. "Multi-band Gap High Efficiency Converter (RAINBOW)." In *Proceedings of the 32nd Intersociety Energy Conversion Engineering Conference* (IECEC-97, Volume 1, 401–406. IEEE.

Ludman, J. E., J. L. Sampson, R. A. Bradbury, J. G. Martin, J. R. Riccobono, G. Sliker, and E. Rallis. 1992. "Photovoltaic Systems Based on Spectrally Selective Holographic Concentrators." *Proceedings of SPIE*, 1667 (May): 182–189.

Olsson, Ylva K., Gang Chen, Ronen Rapaport, Dan T. Fuchs, Vikram C. Sundar, Jonathan S. Steckel, Moungi G. Bawendi, et al. 2004. "Fabrication and Optical Properties of Polymeric Waveguides Containing Nanocrystalline Quantum Dots." *Applied Physics Letters* 85 (19) (November): 4469–4471.

Reisfeld, R. 2001. "Prospects of Sol–Gel Technology towards Luminescent Materials." *Optical Materials* 16 (1–2) (February–March): 1–7.

Sheng, Wenchao, Sungjee Kim, Jinwook Lee, Sang-Wook Kim, Klavs Jensen, and Moungi G. Bawendi. 2006. "In-situ Encapsulation of Quantum Dots into Polymer Microspheres." *Langmuir* 22 (8): 3782–3790.

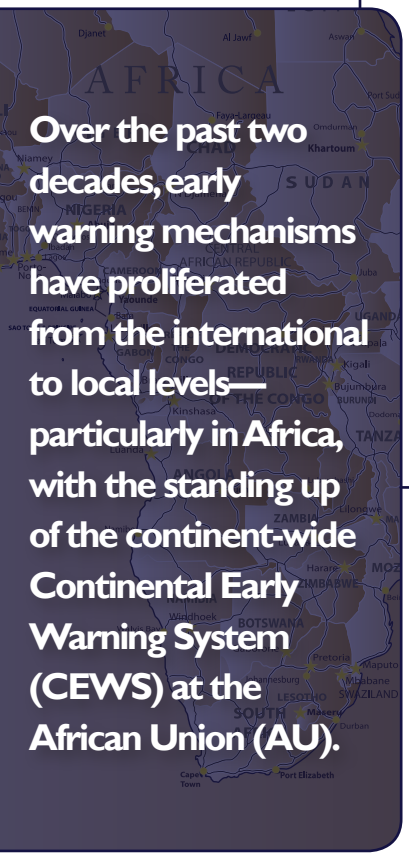
Smith, Mark A., Samar Sinharoy, Victor G. Weizer, Osman Khan, AnnaMarie Pal, Eric B. Clark, David M. Wilt, et al. 2000. "Solar Cells for NASA RAINBOW Concentrator." *Proceedings of the Conference Record of the Twenty-Eighth IEEE Photovoltaic Specialists Conference*, 1139–1141. IEEE.

Sundar, Vikram C., Hans-Jürgen Eisler, Tao Deng, Yinthai Chan, Edwin L. Thomas, and Moungi G. Bawendi. 2004. "Soft Lithographically Embossed Multilayered Distributed Feedback Nanocrystal Lasers." *Advanced Materials* 16 (23–24) (December): 2137–2141.

PROGRESS TOWARD THE AFRICAN UNION CONTINENTAL EARLY WARNING SYSTEM

Alexander Noyes and Janette Yarwood

Despite criticism from scholars, the Continental Early Warning System (CEWS) at the African Union (AU) has recently made significant progress in its capacity to monitor, analyze, and provide warning of impending conflict situations in Africa. CEWS, however, remains constrained by human-resource limitations, developing cooperation and information sharing with the early warning efforts of regional organizations, and unsystematic coordination with the various AU organs focusing on peace and security. In addition, although the early warning-early response gap is narrowing at the AU, early response mechanisms continue to be constrained by limited capacity and issues of political will, as high-level political disagreements and issues of sovereignty militate against effective preventive action. Based on more than two dozen interviews with senior-level CEWS and AU officials, along with other relevant stakeholders, this paper highlights recent operational progress, identifies remaining gaps, and forwards policy options for the AU and international community to build on the gains of CEWS.



Over the past two decades, early warning mechanisms have proliferated from the international to local levels—particularly in Africa, with the standing up of the continent-wide Continental Early Warning System (CEWS) at the African Union (AU).

While early warning frameworks have long been used in military, intelligence, and humanitarian circles, the concept of conflict early warning systems rooted in a human security approach is fairly recent, emerging with United Nations (UN) Secretary-General Boutros Boutros-Ghali's report (Boutros-Ghali 1992). Since then, conflict early warning systems have continually been identified by the UN[1] and international organizations as crucial to effective conflict prevention. Over the past two decades, early warning mechanisms have proliferated from the international to local levels—particularly in Africa, with the standing up of the continent-wide Continental Early Warning System (CEWS) at the African Union (AU); various mechanisms at the regional level, such as the Economic Community of Western African States (ECOWAS) Early Warning and Response Network (ECOWARN),[2] and fledgling national and local systems, as seen in Kenya and Ghana.[3]

[1] For an overview of early warning efforts within the UN system, see Zenko and Friedman (2011).

[2] For an overview of regional early warning mechanisms in Africa, see Cilliers (2005).

[3] For a discussion of national-level early warning systems in Africa, see Affa'a-Mindzie (2012).

In light of the recent expansion of conflict management systems in Africa, a growing academic literature has emerged on the conflict-mitigation capabilities of African institutions, with a developing focus on the role of conflict early warning mechanisms. Some scholars have been highly critical of early warning systems in Africa, highlighting a lack of resources and operational capacity and the political and structural impediments to preventive action that have led to an "early warning-early response" gap.[4] Assessments of the AU's CEWS have been especially critical.[5] Although several studies have explored the implications of African early warning systems, significant gaps remain in the literature—most glaringly, in empirical, field-based research conducted on early warning systems in Africa. In our effort to fill this gap, we interviewed more than two dozen senior-level CEWS officials at the AU in Addis Ababa, Ethiopia, and other local, regional, and international actors involved with the work of CEWS.

The AU's CEWS was established in 2002 under Article 12 of the protocol creating the AU's Peace and Security Council (PSC). CEWS was envisioned to play a major role in the PSC's mission to prevent, manage, and resolve African conflicts by anticipating conflict situations across the continent. Under the protocol, CEWS is tasked with providing the Chairperson of the AU Commission early warning information so that he/she can advise the PSC on "potential conflicts and threats to peace and security in Africa and recommend the best course of action" (African Union 2002). Article 12 calls for the establishment of a monitoring unit at the AU—the Situation Room—as well as monitoring and observation units based at the Regional Economic Communities (RECs) that will feed directly into the Situation Room. The protocol also mandated that the AU Commission liaise with the UN, relevant research centers, and non-governmental organizations (NGOs) to "facilitate the effective functioning" of CEWS (African Union 2002).

As reflected in several scholarly articles and policy reports, CEWS has struggled to become fully operational, with an exceedingly sluggish standing-up process since its inception in 2002 (Wulf and Debiel 2010; Williams 2011; Affa'a-Mindzie 2012). Interviews conducted with CEWS and other AU officials in September 2012, however, revealed a more optimistic and encouraging state of affairs. While coordination and implementation gaps remain, particularly regarding synergy with the RECs, much progress has been made in the past several years in operationalizing the Situation Room and improving the overall capacity of CEWS to monitor and provide early warning on emerging conflicts in Africa. On the other hand, we also found that operational and inherent political challenges at the AU continue to hamper the preventive action side of the early warning/early response equation.[6]

[4] See, for example, Wulf and Debiel (2010).

[5] See, for example, Wulf and Debiel (2010) and Nathan (2007).

[6] Interviews with senior-level CEWS and AU officials, Addis Ababa, Ethiopia, September 13–15, 2012.

CEWS IN ACTION: IMPROVED CAPACITY

The AU's CEWS has roots in the Organization of African Unity (OAU), the predecessor organization of the AU. The first explicit reference to a CEWS at the OAU can be traced back to the 1996 Yaounde Declaration, which hailed the development of an Early Warning System (EWS) located in the Mechanism for Conflict Prevention, Management and Resolution at the OAU (Cilliers 2005, 4). In 1998, a Situation Room was conceptualized and subsequently established with the assistance of donors. The early warning efforts at the OAU, however, remained rudimentary and fundamentally under-resourced, with an internal report asserting in 1999 that the Mechanism "lacks the capacity for in-depth analysis."[7]

At the time of writing, CEWS has a staff of 13, consisting of a director and several levels of analysts organized into regional clusters. According to CEWS officials, five early warning analysts recently joined the program in May 2012.[8] CEWS is housed in the Conflict Management Division (CMD) of the AU, with staff members located inside and surrounding the Situation Room, which operates on a 24-hour-a-day basis to continually monitor conflict indicators and identify potential flashpoints. Based on structural, dynamic, and actor data collection and analysis, CEWS produces multiple regular written products. Interviewees at CEWS emphasized that many of their products provide recommendations and response options to the PSC and other decision makers, including building scenarios and identifying those organs of the AU that could be deployed to help defuse a particular situation.[9]

The members of the CEWS staff use various tools and methods to collect and analyze data from a wide variety of sources. For events (or what CEWS officials term dynamic), data collection, and analysis, CEWS primarily uses three tools: the Africa Media Monitor (AMM), the Africa Reporter, and Live-Mon.[10] The AMM, an in-house tool developed in collaboration with the European Union (EU), captures data from the continent in real time, processing up to 40,000 articles simultaneously in all four AU languages and updating every 10 minutes (Affa'a-Mindzie 2012, 4). The AMM software also has the capability to send news updates via text message. The Africa Reporter gathers primary data from the different field mission and liaison offices of the AU and produces risk scores on conflict situations. The tool is based on predefined templates of incident and situation reporting. Live-Mon is a geo-coded tool that automatically displays news events on a map in the Situation Room as these events develop. CEWS supplements their in-house dynamic data collection capabilities by using

[7] Cited without footnote in Cilliers (2010, 5).

[8] Interview with a senior-level CEWS official, Addis Ababa, September 13, 2012.

[9] Interviews with senior-level CEWS and AU officials, Addis Ababa, Ethiopia, September 14, 2012.

[10] Interviews with senior-level CEWS and AU officials, Addis Ababa, Ethiopia, September 14, 2012.

private analytical sources such as the Economic Intelligence Unit, Oxford Analytica, and BBC Monitoring (Affa'a-Mindzie 2012, 4).

For collecting and analyzing structural information, CEWS uses the Indicators and Profiles Module and Africa Prospects. The Indicators and Profiles Module is a repository of structural data organized into country background briefings and country profiles. Africa Prospects periodically conducts vulnerability assessments of countries based on various economic and demographic indicators. CEWS also collects and monitors actor-based data using the Indicators and Profiles Module (Affa'a-Mindzie 2012). In addition, CEWS has developed the CEWS Portal to facilitate coordination and data sharing with the regional early warning mechanisms. According to CEWS officials, the portal has begun operating, and several RECs have been exchanging data with CEWS. The operationalization of the Situation Room and these various data collection, software, and analysis tools allow CEWS to function at a basic level—monitoring and adequately warning of imminent and escalating conflict situations in Africa.

CEWS IN ACTION: GAPS REMAIN

Despite the significant progress of CEWS, our research revealed four main persisting gaps and challenges:

- Constrained human resources, training, and funding;
- Unsystematic coordination and information-sharing with the RECs early warning mechanisms;
- Insufficient levels of communication and collaboration with other AU peace and security organs relevant to conflict early warning; and
- The perennial problem of translating an early warning into an effective response.

No matter how technically robust the AU's early warning function is, limited capacity and the political nature of the early-response side of the AU's African Peace and Security Architecture (APSA) is likely to continue to constrain the rapid deployment of effective conflict prevention initiatives in the future. What are the causes and consequences of the AU's largely ineffectual preventive response mechanisms?

From its inception, the AU has embraced a fundamental break from the OAU's stance of non-interference in the internal affairs of member states—moving toward a more active position of non-indifference (Williams 2011, 1). Indeed, from 2003 to 2011, the AU staged or participated in nine peace operations—ranging from small-scale election monitoring in the Comoros to approximately 9,000 troops deployed in the AU Mission in Somalia—and imposed sanctions 10 times during the same time period, primarily for unconstitutional changes of government (Williams 2011, 15,

[11] Interview with a senior-level CEWS official, Addis Ababa, Ethiopia, September 14, 2012.

18). Most of these efforts, however, have aimed to lessen or end ongoing conflict or punish recalcitrant behavior after the fact—as opposed to being preventive. Despite a more vigorous conflict management posture, early response mechanisms at the AU remain a work in progress operationally. For example, the African Standby Force (ASF), which has yet to be deployed, has faced a host of difficulties in the standing-up process, while, according to a 2011 study, the Military Staff Committee barely functions in practice (Williams 2011, 10–11, 13). Perhaps more troubling is the revelation from interviews with AU officials that early response organs are often held hostage to political considerations, effectively rendering the early warning reports of CEWS useless. Officials asserted that issues of sovereignty, personal rivalries, high-level political disagreements among member states, and a preference for consensus-based decision-making at the PSC frequently stifle swift and cohesive preventive action, no matter how timely and incisive the early warning of CEWS.[12]

To illustrate the difficulties of translating accurate early warning into an early preventive response, one CEWS analyst cited the recent cases of political instability in Mali and Guinea-Bissau in 2012. He argued that although CEWS provided sufficient early warnings on the potential for conflict in both countries, including the prospective regional fallout from the collapse of the Libyan regime, adequate preventive measures were not taken to forestall violence.[13]

At the same time, the AU has had some success in bridging the early warning-early response divide in other cases of impending conflict. The same analyst noted that CEWS reports prompted a response from the Panel of the Wise, an APSA organ, in the recent cases of escalating tensions in Ghana and Sierra Leone.[14] AU officials also cited election-related conflict situations in Senegal and the Democratic Republic of the Congo in 2012 and Kenya in 2008 as instances where the Panel of the Wise worked with CEWS and other departments to help avoid or mitigate large-scale political violence.[15] Because of the inherent political dimensions, several CEWS and AU officials argued that by the time a particular conflict situation reaches the level of the PSC, it is often too late for any effective early response to be formulated and implemented.

RECOMMENDATIONS FOR CEWS, THE AU, AND THE INTERNATIONAL COMMUNITY

CEWS for Africa has come a long way since its inception. Increased staff and new technology at CEWS

[12] Interviews with senior-level CEWS and AU officials, Addis Ababa, Ethiopia, September 13-15, 2012.

[13] Interview with a senior-level CEWS analyst, Addis Ababa, Ethiopia, September 14, 2012.

[14] Interview with a senior-level CEWS analyst, Addis Ababa, Ethiopia, September 14, 2012.

[15] Interview with a senior-level member of The Panel of the Wise Secretariat, Addis Ababa, Ethiopia, September 14, 2012.

greatly aid data collection and analysis on conflict indicators and potential flashpoints although substantial gaps remain. In the words of one senior CEWS analyst, the system's "capacity is quite good, but not sufficient."[16]

To consolidate the gains of CEWS and bridge existing gaps, our article offered the following six main recommendations:

- Further improve relations and data-sharing with the RECs by instituting a staff rotation policy and redoubling support for the development of regional early warning systems.
- Formally institutionalize relationships with other AU organs working on issues of peace and security, particularly within the CMD.
- Increase, regularize, and sustain the budget, with a particular emphasis on pooled and longer term funding from donors.
- Expand human resource capacity by hiring five more analysts who have specialized expertise and by implementing more extensive and focused training.
- Improve the comprehensiveness and quality of data by expanding partnerships with international actors and civil-society organizations.
- Increase the capacity of AU response mechanisms and encourage regional and international actors to apply private and public pressure on the PSC to respond adequately to crisis situations as they develop.

CONCLUSION

During the past several years, the AU's continent-wide conflict early warning system has made considerable progress in its capacity to monitor, collect, and analyze information from a variety of sources and to provide warning of imminent and escalating conflict situations in Africa. Despite this progress, however, CEWS continues to suffer from human resource and funding constraints, inchoate cooperation and information-sharing with the conflict early warning efforts at the RECs, and unsystematic coordination with other AU organs focusing on peace and security. In addition, early response mechanisms continue to be constrained by low capacity and a debilitating lack of political will.

Despite the political impediments and capacity constraints at the AU that militate against converting early warning into a muscular early response, the fact remains that successful preventive measures are possible only with timely and forceful early warning. As Africa continues to experience bouts of political instability and armed conflict and as African institutions continue to shoulder more of the continent's

[16] Interview with a senior-level CEWS analyst, Addis Ababa, Ethiopia, September 14, 2012.

conflict management responsibilities, accurate early warning at the AU is vital. Although CEWS has made progress, substantial operational and political challenges persist.

Taking steps to help solve these remaining pieces of the early warning puzzle would improve the overall effectiveness of the AU's conflict early warning and response systems.

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The AU Continental Early Warning System: From Conceptual to Operational?

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REFERENCES

Affa'a-Mindzie, Mireille. 2012. "Preventing Conflicts in Africa: Early Warning and Response." Meeting Note. New York, NY: International Peace Institute, August.

African Union. 2002. "Protocol Relating to the Establishment of the Peace and Security Council of the African Union." Last accessed December 6, 2012. http://www.au.int/en/sites/default/files/Protocol_peace_and_security.pdf.

Boutros-Ghali, Boutros. 1992. An Agenda for Peace: Preventive Diplomacy, Peacemaking and Peacekeeping. Report of the Secretary-General Pursuant to the Statement Adopted by the Summit Meeting of the Security Council on 31 January 1992. New York, NY: United Nations.

Cilliers, Jakkie. 2005. "Towards a Continental Early Warning System for Africa." ISS Papers, ISS Paper 102 (April).

Nathan, Laurie. 2007. "Africa's Early Warning System: An Emperor with No Clothes?" South African Journal of International Affairs 14 (1): (Summer/Autumn): 49–60.

Williams, Paul D. 2011. "The African Union's Conflict Management Capabilities." International Institutions and Global Governance (IIGG) Program Working Paper." New York, NY: Council on Foreign Relations, October. Last accessed December 6, 2012. http://www.cfr.org/african-union/african-unions-conflict-management-capabilities/p26044.

Wulf, Herbert, and Tobias Debiel. 2010. "Systemic Disconnects: Why Regional Organizations Fail to Use Early Warning and Response Mechanisms." Global Governance: A Review of Multilateralism and International Organizations 16 (4) (October–December): 525–547.

Zenko, Micah, and Rebecca R. Friedman. 2011. "UN Early Warning for Preventing Conflict." International Peacekeeping 18 (1): 21–37.

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