2016-12

Using crowdsourced geospatial data to aid in nuclear proliferation monitoring

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http://hdl.handle.net/10945/51570

NAVAL POSTGRADUATE SCHOOL

MONTEREY, CALIFORNIA

THESIS

USING CROWDSOURCED GEOSPATIAL DATA TO AID IN NUCLEAR PROLIFERATION MONITORING

by

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December 2016

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REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE December 2016	3. REPORT TYPE AND DATES COVERED Master's thesis

4. TITLE AND SUBTITLE USING CROWDSOURCED GEOSPATIAL DATA TO AID IN NUCLEAR PROLIFERATION MONITORING	5. FUNDING NUMBERS
6. AUTHOR(S) Kenyon M. Leno and Steven J. Miller	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) Naval Postgraduate School Monterey, CA 93943-5000	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING /MONITORING AGENCY NAME(S) AND ADDRESS(ES) N/A	10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government. IRB number ____N/A____.

12a. DISTRIBUTION / AVAILABILITY STATEMENT Approved for public release. Distribution is unlimited.	12b. DISTRIBUTION CODE

13. ABSTRACT

In 2014, a Defense Science Board Task Force was convened in order to assess and explore new technologies that would aid in nuclear proliferation monitoring. One of their recommendations was for the director of National Intelligence to explore ways that crowdsourced geospatial imagery technologies could aid existing governmental efforts. Our research builds directly on this recommendation and provides feedback on some of the most successful examples of crowdsourced geospatial data (CGD).

As of 2016, Special Operations Command (SOCOM) has assumed the new role of becoming the primary U.S. agency responsible for counter-proliferation. Historically, this institution has always been reliant upon other organizations for the execution of its myriad of mission sets. SOCOM's unique ability to build relationships makes it particularly suited to the task of harnessing CGD technologies and employing them in the capacity that our research recommends. Furthermore, CGD is a low cost, high impact tool that is already being employed by commercial companies and non-profit groups around the world. By employing CGD, a wider whole-of-government effort can be created that provides a long term, cohesive engagement plan for facilitating a multi-faceted nuclear proliferation monitoring process.

14. SUBJECT TERMS counter-proliferation, crowdsourcing, CGD, social networks, recursive incentive structure, query incentive structure	15. NUMBER OF PAGES 109
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UU

NSN 7540-01-280-5500 Standard Form 298 (Rev. 2-89) Prescribed by ANSI Std. 239-18

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USING CROWDSOURCED GEOSPATIAL DATA TO AID IN NUCLEAR PROLIFERATION MONITORING

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MASTER OF SCIENCE IN DEFENSE ANALYSIS

from the

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ABSTRACT

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LIST OF ACRONYMS AND ABBREVIATIONS

CGD	Crowd-Sourced Geospatial Data
CIA	Central Intelligence Agency
CNS	Center for Nonproliferation Studies
CP	Counterproliferation
CT	Counterterrorism
CTBT	Comprehensive Test Ban Treaty
CWMD	Combating Weapons of Mass Destruction
DARPA	Defense Advanced Research Projects
DOD	Department of Defense
DPRK	Democratic Republic of Korea
DSBTF	Defense Science Board Task Force
EMT	Emergency Medical Technician
GPS	Global Positioning System
HEU	Highly Enriched Uranium
IA	Interagency
IAEA	International Atomic Energy Agency
ICBM	Intercontinental Ballistic Missiles
IP	Internet Protocol
MIT	Massachusetts Institute of Technology
NPT	Non-Proliferation Treaty
TEL	Transporter-Erector-Launch
TIGER	Topological Integrated Encoding and Referencing
TTP	Tactics Techniques and Procedures
UCP	Unified Command Plan
USG	United States Government
USSOCOM	United States Special Operations Command
VGI	Volunteered Geographic Information
WMD	Weapons of Mass Destruction

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ACKNOWLEDGMENTS

We would like to first thank our families for their unwavering support in the long hours that we spent researching and writing this document. While we volunteered for our given professions, it is they who ultimately pay the costs of our global mission sets. Without their support, we would not have been able to accomplish any of the achievements that we have made.

We would also like to thank our thesis advisors, Dr. Leo Blanken and Dr. Zachary Davis. They perceived through countless hours of debating a way forward for our research and provided desperately needed feedback. Without their guidance, we would not have been able to put together this document. Dr. Davis, especially, deserves particular credit for enduring hours of frantic telephone conversations and wasted dry-erase markers as we struggled to find a way for crowdsourcing to be integrated into current nuclear proliferation monitoring.

Finally, we would also like to thank Rob Schroeder in the Core Lab for giving us some of his valuable time and feedback. We immersed ourselves into a world that was practically foreign to us. He provided the light for us and showed us where to look for answers. His input was priceless.

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I. INTRODUCTION

"Determining where we are, necessarily requires familiarity, first with where we have been."

— Henry D. Sokolski,
Underestimated: Our Not So Peaceful Nuclear Future

A. THE PROBLEM

The frequency of cyber-attacks over the last decade should indicate to U.S. policymakers and military planners that the cyber domain poses a credible risk to the U.S. Homeland and its citizens. The overall security posture of the United States in the future will depend heavily on its ability to effectively merge new realities with innovative policies that are aligned against current, and near future threat(s). The cyber domain can be manipulated in numerous ways, but perhaps the most alarming aspect of the associated risks are the opportunities this domain presents to facilitating the proliferation of weapons of mass destruction (WMD). Barriers to entry for rogue and non-state actors into the realm of strategic weaponry are falling rapidly; as disruptive technology offers nefarious actors new opportunities for undermining the security of the U.S. Homeland with the ultimate possibility of a nuclear 9/11.

Five of the nine states that are in possession of nuclear weapons attained them prior to the Non-Proliferation Treaty (NPT) of 1968. The fact that nuclear technology has spread since the inception of NPT speaks to the persistent nature of nuclear black markets.[1] As a result of the nuclear proliferation network that Abdul Qadeer Khan created, state and non-state actors' acquisition of nuclear weapons are limited only by

[1] "Treaty on the Non-Proliferation of Nuclear Weapons," taken from the International Atomic Energy Agency IAEA. Accessed May 24, 2016. https://www.iaea.org/sites/default/files/publications/documents/infcircs/1970/infcirc140.pdf.

financial resources, technical skills and desire.[2] Despite A.Q. Khan's eventual apprehension, he left behind easily accessible, comprehensive nuclear knowledge that presents a persistent and challenging threat U.S. National Security.[3] The post-Khan era has ushered in numerous factors that have led to a renewed level of scrutiny within the counter-proliferation arena. These factors are:

- Higher yields, smaller warheads, and the increased precision of modern weaponry.
- Pervasive access to nuclear knowledge; including numerous open source materials, on-line resources; social media platforms; and imagery mediums that provide an unprecedented level of accuracy in nuclear technology.[4]
- Increased cooperation amongst proliferation networks and nations.[5]
- Actual and threatened acquisition of nuclear weapons by malignant state and non-state actors that show little regard for treaties and international agreements.[6]

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[2] David Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies* (NewYork: Free Press, 2010); Joe Vaccarello, "U.N. Report Alleges North Korea Exported NuclearTechnology," CNN News, accessed November 12, 2010, http://edition.cnn.com/2010/WORLD/asiapcf/11/11/un.north.korea/index.html?eref=mrss_igoogle_cnn.

Before his capture, A.Q. Khan served as the pioneer for economizing proliferation, establishing a one stop shop and central hub for nuclear parts, knowledge and components. He made nuclear technology (that was exclusive to five countries that maintained the knowledge) more available to any entity that possessed the means to pay for the materials.

[3] Gordon Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A. Q. Khan Network* (New York, NY: Oxford Univ. Press, 2009): 242–243.

[4] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," Office of the Under Secretary of Defense for Acquisition, Technology, and Logistics. Washington, D.C., January 2014, 1; Bruno Gruselle, "Proliferation Networks and Financing" (Technical Report, Fondation pour la Recherche Stratégique, Paris, March 3, 2007, 22; David Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies* (New York Free Press, 2010), 244–246.

[5] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," 1; David Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies* (New York Free Press, 2010), 245.

[6] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," 2.

– Innovations that magnify future risk of continued proliferation.[7]

These dangers speak to the increased importance of an effective counter-proliferation (CP) strategy and policy that is commensurate with the changing environment. Monitoring in support of existing treaties and agreements has been a cornerstone of thwarting illegal nuclear transactions since the Baruch Plan of 1946.[8] However, as highlighted by a 2014 Defense Science Board Task Force (DSBTF),

> The technical approach for monitoring cannot continue to derive only from treaty and agreement dictates for "point" compliance to the numbers and types formally agreed upon and geographically bounded. Proliferation in this future context is a continuous process for which persistent surveillance, tailored to the environment of concern, is needed. This leads to the need for a paradigm shift in which the boundaries are blurred between monitoring for compliance and monitoring for proliferation, between cooperative and unilateral measures. Monitoring will need to be continuous, adaptive, and continuously tested for its effectiveness against an array of differing, creative and adaptive proliferators.[9]

The DSBTF also concluded that a portion of the long-term, cohesive engagement plan for facilitating a multi-faced monitoring process included a necessity for exploring crowdsourced applications that can aid on-going CP efforts.[10] To this end, we have tailored our research to explore low-cost, high impact crowdsourcing tools to augment traditional CP lines of efforts that are focused on covert sensors, classified imagery analysis, and human intelligence.

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[7] David Albright, Andrea Stricker, and Houston Wood, "Future World of Illicit Nuclear Trade: Mitigating the Threat," *Institute for Science and International Security*, July 29, 2013.

[8] Henry D. Sokolski, *Best of Intentions: America's Campaign Against Strategic Weapons Proliferation* (Santa Barbara, California: Praeger Publishers, 2001), 14–24. The Baruch Plan was the first plan to try and control nuclear activities and materials between the United States and Russia and was an attempt for international "monitoring" of nuclear stock piles.

[9] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," 2.

[10] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," 9.

B. RESEARCH STATEMENT AND QUESTION

The Department of Defense (DOD) plays an integral role, but is only one of various government institutions that fulfill a responsibility towards CP.[11] The DOD possesses unique capabilities, and authorities which are nested within its plan for Combating Weapons of Mass Destruction (CWMD).[12] In accordance with the Unified Command Plan (UCP) Change, signed by the president on August 4, 2016, U.S. Special Operations Command (USSOCOM) has officially assumed responsibility of the DOD portion of this national mission.[13] As such, USSOCOM assumes the primary role of coordinating the Department of Defense's CP plans with the rest of the U.S. Government.

History has clearly demonstrated that USSOCOM excels at a variety of crisis operations, but now faces the challenge of integrating a broad array of CP activities with a wide variety of agencies and ongoing programs associated with CP. Additionally, USSOCOM will assume its new mission *in addition to* numerous other tasks within its purview – most notably Counterterrorism (CT). As with any entity, USSOCOM will be faced with prioritizing and appropriating resources to adequately address the full range of its responsibilities. This thesis looks to highlight innovative, low cost, high impact tools to gain a more thorough understanding of proliferation network operations in the steady state.

As part of the effort to integrate USSOCOM within existing CP efforts, we argue that there is additional human capital that has untapped potential for contribution to the CP mission. There are multiple pilot programs, including the "Force of the Future Initiative" and "Hack the Pentagon," that seek the assistance of the technologically adept,

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[11] Derek W. Lothringer, Matthew S. McGraw, Matthew D. Rautio, and Leif Thaxton, "Counterproliferation, Disruptive Innovation, and the Need to Improve Collaboration." Master's Thesis, Naval Postgraduate School, December 2015, 14.

[12] Department of Defense, "Joint Publication 3-40 – Countering Weapons of Mass Destruction," http://www.dtic.mil/doctrine/new_pubs/jp3_40.pdf. Accessed August 19, 2016.

[13] Department of Defense, "Unified Command Plans – USSOCOM." http://www.defense.gov/Military-Services/Unified-Combatant-Commands. Accessed August 19, 2016.

commercial sector.[14] In light of the UCP modification, new opportunities exist to advance USSOCOM, the Department of Defense, and National CP policies. While the task of monitoring contemporary nuclear black markets has become an increasingly more difficult task, we believe that technology may be exploited to play a more pivotal role in undermining proliferation rings, rather than an obstacle.

In the same 2014 DSBTF report, a recommendation was put forward to the Director of National Intelligence to "expand the use of open source and commercial information to focus search areas and reduce demand on the national collection assets so that the collection system can keep up better with the expansion of targeted areas of interest."[15] The underlining emphasis on this recommendation was that, crowdsourcing applications provide an opportunity to alleviate resources and manpower from open-source commercial satellite imagery analysis. This is an acknowledgement of the growing acceptance of crowdsourcing applications as a whole.

Missing from this recommendation, however, is a detailed analysis of the types of crowdsourcing platforms that present credible opportunities for CP policies and operations. So far, little research has been conducted into successful crowdsourcing applications to ascertain relevant methodologies that may be useful to CP. With USSOCOM's new role in CP, exploring these new techniques is imperative. Our research question is as follows:

Are there successful crowd-sourcing techniques and can they be used to augment existing efforts for monitoring nuclear proliferation networks?

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[14] Ash Carter, "Force of the Future, Initiative by Defense Secretary Ash Carter," *Defense.Gov*, accessed June 29, 2016. http://www.defense.gov/News/Special-Reports/0315_Force-of-the-Future.

Additionally, the Defense Innovation Unit Experimental (DIUX) is an Ash Carter initiative that attempts to link technology to the military as an established mechanism for the private sector and Armed Forces interface. https://www.diux.mil/#intro-2.

[15] Department of Defense Defense Science Board, "Task Force Report: Assessment of Nuclear Monitoring and Verification Technologies," 3.

C. SCOPE OF RESEARCH

Our research suggests that crowdsourcing solutions can aid on-going, open-source intelligence gathering methods that are already being conducted by DOD and the interagency to further illuminate portions of a nuclear proliferation network. There is room for leveraging the capacity of concerned citizens who share the same ideals on ensuring that non-state actors and rogue states do not acquire nuclear components, materials, or weapons. Furthermore, our research suggests that USSOCOM may have an unconventional tool for in-extremis search operations.

While our research highlights the benefits of crowd-sourcing and the use of incentive structures for galvanizing everyday citizens to participate in CP, it also addresses skepticism about this new tool. Our recommendations on utilizing everyday citizens as a means for geo-locating nuclear material takes into account claims about the inaccuracy of information that is obtained in this manner. There is potential for crowdsourcing materials to be maliciously infused with misleading information and errant conclusions. We also recognize that the recruitment of these individuals towards CP presents significant policy considerations and most likely, revisions in authorities for it certain applications of this technology to fully harnessed. However, previous research has already concluded current CP policy is muddled with over-lapping roles and authorities that cause confusion and a systemic lack of coordination.[16]

Our literature review will introduce the reader to the role of social networks in society and the foundation behind incentive based rewards structures. The networks and societal structures discussed are viewed through a contemporary, technologically dominated lens that sheds light on the ease and manner in which ideas diffuse between individuals. Additionally, this chapter will explore current research into the field of crowdsourcing so that the reader understands the history behind these concepts and its burgeoning role in the United States Government (USG). Furthermore, it will introduce

[16] Lothringer et al., "Counterproliferation, Disruptive Innovation, and the Need to Improve Collaboration," 53–58.

to the reader the concept of crowdsourced geospatial data and the potential role that this specific area of crowdsourcing has future CP operations

Chapter III will then provide the reader with a baseline knowledge of the evolution of proliferation. We will chronicle proliferation by providing a line of departure so that the reader can understand the organizational characteristics of a proliferation network. The final portion of this chapter will apply a modern business practice model to proliferation networks and critically examine motivations to determine the inherent strengths and vulnerabilities of these networks. The chapter will conclude after having provided the reader with an understanding of how proliferation networks can be targeted by crowdsourcing applications.

Chapter IV will discuss time critical social mobilization, specifically focusing on crowdsourcing and its potential towards real-time reporting, geo-locational searches, and information validation. Multiple case studies will be reviewed in order to demonstrate to the reader the pervasiveness of these applications in modern society, as well as, provide insights into how future crowd-sourcing programs can be applied to CP.

Chapter V will address the skeptical views of crowdsourcing tools and provides feedback on how crowdsourcing is a self-regulating process. This chapter presents arguments and counterarguments that look at how crowdsourcing can spread misinformation, is limited when applied in denied environments, and is susceptible to false identity attacks. However, by the end of this chapter, the reader is able to realize that many of the perceptions, about the limits of crowdsourcing, are largely misattributed and that the open-source nature of crowdsourcing means that the drawbacks of this methodology are consistently being remedied.

Our final chapter will provide the reader with specific methodologies that have proven successful in crowdsourcing exercises and applications. We will show this low-cost, high impact tool may provide USSOCOM with timely and accurate analysis that can complement existing CP lines of effort. The incorporation of these new tools for enhancing monitoring efforts against proliferation networks is imperative as nefarious organizations leverage new technologies for themselves. It is our desire to ensure that

USSOCOM remains ahead of these technological curves and is positioned to thwart the ambitions of those who seek to use nuclear weapons before the consequences become catastrophic.

II. SOCIAL NETWORK INCENTIVES AND CROWDSOURCING

One of the more alarming aspects of the nuclear proliferation market today is the existence of files that detail the entire nuclear acquisition and production process.[17] Given this, the exponential growth of the internet over the last two decades seems to indicate that the task of CP is becoming an increasingly more difficult mission to accomplish. However, the ascendency of the internet as the world's primary medium for communication presents unique opportunities for monitoring proliferation networks. Our review of the relevant literature seeks to explore two veins of research: the role of social networks and the development of incentive mechanisms for rallying large numbers of people.

The first approach explores the *small world phenomenon* and examines how information gathering tasks are facilitated between nodes in a network. The second approach examines contemporary theories that explore methods for incentivizing nodal feedback when information requests are distributed across these networks. We end this portion by exploring how these two areas of research have become the cornerstones for foundational research and application into the world of crowdsourcing. The combination of these theoretical approaches provides a more illuminated picture for understanding how the ascendance of the internet presents an opportunity for better understanding the networks of nuclear ambitious rogue state and actors, instead of a veil for their operations.

A. THE ROLE OF SOCIAL NETWORKS

A social network can best be described as a collection of individuals with corresponding ties to other individuals in subnetworks, where links between every individual in a network ties all together.[18] A closer examination of social networks can,

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[17] Corera, *Shopping for Bombs: Nuclear Proliferation, Global Insecurity, and the Rise and Fall of the A. Q. Khan Network*, 242–243.

[18] Duncan J. Watts, Peter S. DODds, and M.E. J. Newman, "Identity and Search in Social Networks," Science 296 (2002): 1302.

in many instances, highlight the emergence of what is known as the small world phenomenon, where seemingly unknown individuals share one or more ties to one another through a series of intermediaries. Jon Kleinberg best described this occurrence as "two individuals in the network [who] are likely to be connected through a short sequence of intermediate acquaintances."[19] In other words, the number of individuals that separate two individuals who are unknown to one another is relatively small. While researchers have often used this phenomenon to describe occurrences in a variety of fields, it is seen as one of the fundamental building blocks of the internet in describing its ability to serve as a medium for the rapid dissemination of ideas and information.[20]

Prior to the emergence of the Internet, a well-known sociologist named Stanley Milgram began, in 1967, one of the first empirical studies to demonstrate that individuals across the world are in varying degrees all connected to one another.[21] His seminal work into the small world phenomenon continued to be researched and explored by many others over the next forty years. Their findings revealed that social networks are indeed highly effective at identifying individuals through the shortest possible pathways.[22] Furthermore, these small networks are often irregularly, highly concentric and almost never random.[23] Indeed, in 2002 over 60,000 individuals took part in an email experiment that demonstrated that social networks could be bridged across continents to one of 18 target persons with an average of only 4.1 degrees of separation.[24] While it could be theorized that social media innovations, such as Facebook and Pinterest, have exacerbated the interconnectedness of the global community, foundational research

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[19] Jon M. Kleinberg, "The Small-World Phenomenon: An Algorithmic Perspective," *Cornell Computer Science Technical Report* 99–1776 (1999), 1.

[20] Reka Albert, Hawoong Jeong, and Albert-Laszlo Barabasi, "The Diameter of the World Wide Web," *Nature* 401 (1999) accessed September 2, 2016, https://arxiv.org/pdf/cond-mat/9907038v2.pdf.

[21] Stanley Milgram, "The Small World Problems," *Psychology Today* 2 (1967): 60–67.

[22] Jon M. Kleinberg, "Navigation in a Small World," *Nature* 406 (2000): 845; Lada Adamic and Eytan Adar, "How to Search a Social Network," *Social* Networks 27 (2005): 187–203.

[23] Duncan J. Watts and Steven H. Strogatz, "Collective Dynamics of 'Small-World' Networks," *Nature* 393 (1998): 440–442.

[24] Peter S. DODds, Roby Muhamad, and Duncan J. Watts, "An Experimental Study of Search in Global Social Networks," *Science* 301 (2003): 827–829.

seems to conclude that even before their arrival the world was much smaller than it is sometimes believed.

In pursuit of a better understanding of the small world phenomenon, it is important to conceptually understand what exactly the small world phenomenon is. To this end we revisit Milgram's experiment to better grasp the relevance of social networks in establishing links to rogue proliferation networks. His experiments typically began with a random individual living in a remote location, such as Kansas or Nebraska, who was then given instructions to send a package to individual unknown to them in Massachusetts. The person chosen to send the package was then given the target person's name, address, and occupation, as well as, instructions to only mail the package to individuals that they intimately knew. The idea was for individuals in the experiment to only use their personal contacts towards finding a "friend of a friend of a friend," so that eventually the package would reach the specified individual in Massachusetts. This experiment was successfully replicated over the course of several more trials and became the cornerstone of the pop-culture phrase "six degrees of separation."[25]

While the study of small world phenomenon has mostly been focused on friendship[26] or religious[27] networks, there is growing literature into the implications of the phenomenon on acquaintance networks. In these types of networks, the link between individuals can almost be described as economic in nature as the tie between each is for mutual benefit.[28] The utility of these studies is that they serve as useful tools in illuminating collaboration patterns between individuals and expose patterns that can aid in understanding how ideas and innovation are disseminated. Unsurprisingly, the

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[25] John Guare, *Six Degrees of Separation: A Play* (Vintage Books: New York, 1990), 5.

[26] T.J. Fararo and Morris J. Sunshine, *A Study of a Biased Friendship Network* (Syracuse, NY: Syracuse University Press, 1967), accessed August 28, 2016, https://www.researchgate.net/publication/248715600_A_Study_of_a_Biased_Friendship_Net; James Moody and Douglas R. White, "Structural Cohesion and Embeddedness: A Hierarchical Concept of Social Groups," *American Sociological Review* 68(1) (2003): 1120–1134.

[27] Rodney Stark and William Sims Bainbridge, "Networks of Faith: Interpersonal Bonds and Recruitment to Cults and Sects," *American Journal of Sociology* 85(6) (1980): 1376–1395.

[28] L. A. N. Amaral, A. Scala, M. Barthelemy, and H. E. Stanley, "Classes of Small-World Networks," *Proceedings from the National Academy of Science* 97 (2000): 11149-11152 accessed September 2, 2016 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC17168/#B2

scientific and academic world has produced substantial literature over the years with regards to the phenomenon's impact on their networks.[29] One of the most revealing of these studies was one conducted by M. E. J. Newman. In this study he systematically analyzed millions of papers and authors who were published in varying scientific fields over the course of five years. While his results generally supported the small world phenomenon across all the fields, there were notable differences between each scientific community. A significant aspect of his results was the staggeringly high levels of collaboration amongst scientists involved in the arena of experimental high-energy physics.[30] However, the truly unique feature in each of these networks, a trait that remains consistent amongst even internet social media sites, is that collaboration amongst these networks of scientists and researchers is being organized by themselves. From this beginning we sought to determine if there were ways that incentives could be used to create demands for information within these pre-existing networks that are not rooted in merely the altruistic nature of individuals.

B. THE ROLE OF INCENTIVES

Over the last decade-and-a-half, significant research has been dedicated to better understanding the nature of querying across networks of peers and determining how ideas

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[29] Leo Egghe and Ronald Rousseau. *Introduction to Informetrics* (Amsterdam: Elsevier Science Publishers, 1990).; Paul Hoffman, *The Man Who Only Loved Numbers* (New York: Hyperion, 1998); Diana Crane, "Social Structure in a Group of Scientists: A Test of the 'Invisible College' Hypothesis," *American Sociological Review* 34–3 (1969): 335–352; G. Melin and O. Persson, "Studying Research Collaboration Using Co-Authorships," *Scientometrics* 36 (1996): 363–377; G. Melin, "The Networking University," *Scientometrics* 35 (1996): 15–31; Ying Ding, Schubert Foo, and Gobinda Chowdhury, "A Bibliometric Analysis of Collaboration in the Field of Information Retrieval," *The International Information & Library Review* 30 (1999): 367–376.

[30] M. E. J. Newman, "The Structure of Scientific Collaboration Networks," *Proceedings from the National Academy of Science* 98 (2001): 408–409, accessed September 21, 2016 https://www.ncbi.nlm.nih.gov/pmc/articles/PMC14598/pdf/pq000404.pdf.

are distributed in a non-hierarchical fashion.[31] The genesis of this research has obviously been the arrival of internet social networking websites that have successfully served as platforms for individuals to not only connect to one another as friends, but also in the assistance of finding homes, jobs, or even raising money for charitable causes. These social networking websites successfully allow individuals to pose queries and receive answers across networks of indirect individual through an informal method of vetting and merely replicate in the online world our natural inclinations of information gathering.[32] It is for this very reason that several research systems were developed to create artificial reference systems to duplicate humanity's innate method of referrals.[33]

Unfortunately, unlike computer-based referral systems, not all social networks are successful at providing answers to queries that are promulgated. In our own daily lives it is not uncommon to find an email or text has gone unanswered for days even though it was sent to the right person. Previous studies into human network querying noted this frequent occurrence and sought ways to end the premature termination of query chains.[34] Simply put, altruism and the pursuit of information is sometimes not enough to always get answers when they are posed. Additional incentive mechanisms, whether positive or negative, were therefore seen as necessary in eliciting timely responses. Researchers first

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[31] Eng Keong Lua, Jon Crowcroft, Marcelo Pias, Ravi Sharma, and Steven Lim, "A Survey and Comparison of Peer-toPeer Overlay Network Schemes," *IEEE Communications Survey and Tutorial* (March 2004): Eric Hand, "Citizen Science: People Power," *Nature* 466 (2010): 685–687; Jan Lorenz, Heiko Rauhut, Frank Schweitzer, and Dirk Helbing, "How Social Influence Can Undermine the Wisdom of Crowd Effect," *Proceedings of the National Academy of Sciences* 108 (2011) accessed September 29, 2016, doi: 10.1073/pnas.1008636108; James Surowiecki, *The Wisdom of Crowds: Why the Many are Smarter Than the Few and How Collective Wisdom Shapes Business, Economics, Societies, and Nations* (New York: Double Day Books, 2004).

[32] Bonnie A. Nardi, Steve Whittaker, and Heinrich Schwarz, "It's Not What You Know, It's Who You Know: Work in the Information Age," *First Monday* 5 (2000) accessed September 27, 2016 http://firstmonday.org/article/view/741/650.

[33] Henry Kautz, Bart Selman, and Mehul Shah, "Referral Web: Combining Social Networks and Collaborative Filtering," *Communications of the ACM*, 30, 3 (March 1997); Bin Yu and Munindar P. Singh, "Searching Social Networks," *In Proceedings of the Second International Joint Conference on Autonomous Agents and Multiagent Systems, ACM* (2003): 65–72; Michael N. Huhns, Uttam Mukhopadhyay, Larry M. Stephens, and Ronald D. Bonnell, "DAI for Document Retrieval: The MINDS Project," in *Distributed Artificial Intelligence*, ed. Michael N. Huhns (London: Pitman/Morgan Kaufmann, 1987), 249–283.

[34] Winter Mason and Duncan J. Watts, "Financial Incentives and the 'Performance of Crowds,'" *SIGKDD Explorations* 11 (2009): 100–108.

began their efforts into the creation of incentive mechanisms by transplanting economic theory into the world of peer-to-peer networks.[35] In lieu of information, individuals were incentivized to respond to network queries via the reception of tangible goods, services, or money.

The development of financial incentives to orchestrate successful feedback in large-scale querying networks is therefore seen as a necessary task in ensuring that individuals answer questions that are posed to them. A second necessary task though, is financially incentivizing individuals to play a role in the recruitment of others when they themselves are unable to provide the right answers.[36] To solve this dilemma, Kleinberg and Raghavan created the *Query Incentive Model*.[37] Their model was built upon prior models that sought to mathematically recreate the same principles that marketing companies use to elicit similar results in the rapid diffusion of ideas, services, and goods.[38] The process is a variant of the sub-contracting process and requires the use of *fixed payments* to gain user feedback. Figure 1 shows a branching tree model of this idea. Fixed rewards are established along a tree of individuals where rewards are provided to each of the nodes along the process to encourage participation. These rewards are established prior to the commencement of querying and terminate when the chain reaches a pre-established threshold for participation, or an answer is provided. It is from this

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[35] Alberto Blanc, Yi-Kai Liu, and Amin Vahdat, "Designing Incentives for Peer-to-Peer Routing," *In Proceedings IEEE 24th Annual Joint Conference of the IEEE Computer and Communications Societies* 1 (2005): 374–385; Sepandar, Kamvar, Beverly Yang, and Hector Garcia-Molina, "Addressing the Non-Cooperation Problem in Competitive P2P Systems," *In Workshop on Peer-to-Peer and Economics (*2003); Barath Raghavan and Alex C. Snoeren, "Priority Forwarding in Ad Hoc Networks with Self-Interested Parties," *In Workshop on Peer-to-Peer and Economics* (2003); Bin Yu and Munindar P. Singh, "Incentive Mechanisms for Peer-to-Peer Systems," *In Proceedings of the Second International Workshop on Agents and Peer-to-Peer Computing, ACM* (2003).

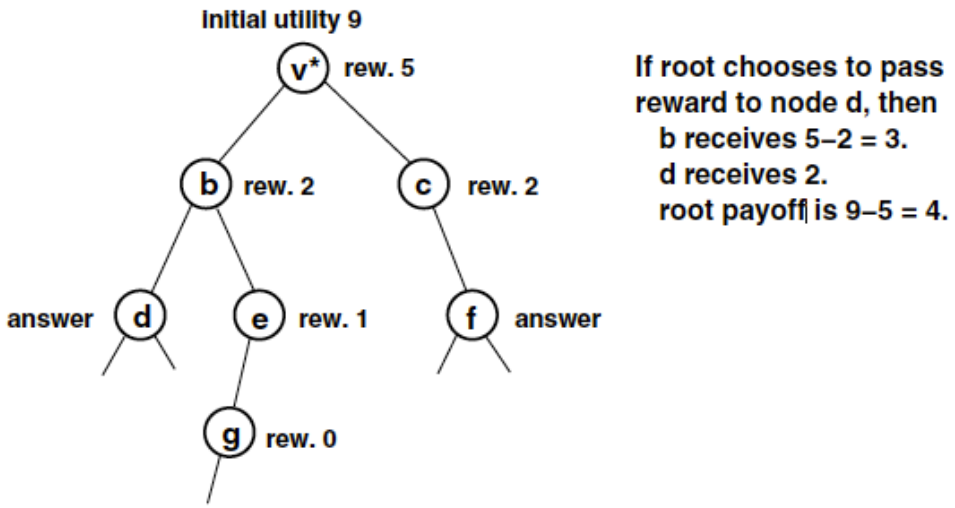
[36] Duncan J. Watts and Jonah Peretti, "Virtual Marketing for the Real World," *Harvard Business Review* (May 2007) accessed September 28, 2016 https://hbr.org/2007/05/viral-marketing-for-the-real-world.

[37] Jon Kleinberg and Prabhakar Raghavan, "Query Incentive Networks," in *Proceedings of the 2005 46th Annual IEEE Symposium on Foundations of Computer Science* (2005).

[38] Cuihong Li, Bin Yu, and Katia Sycara, "An Incentive Mechanism for Message Relaying in Peer-to-Peer Discovery," *2nd Workshop on Economics of Peer-to-Peer Systems* (2009) accessed September 15, 2016 https://www.cs.cmu.edu/~softagents/papers/p2p_econ.pdf; Eyal Biyalogorsky, Eitan Gerstner , and Barak Libai, "Customer Referral Management: Optimal Reward Programs," *Marketing Science* 20 (1) (2001): 82–95.

model that many of the case studies that we will analyze in Chapter IV extrapolate their methodology for incentivizing individuals to participate in their exercises.

Figure 1. Kleinberg and Raghavan's Propagation of a Query with Rewards.



Source: Jon Kleinberg and Prabhakar Raghavan, "Query Incentive Networks," in *Proceedings of the 2005 46th Annual IEEE Symposium on Foundations of Computer Science* (IEEE Computer Society, Washington, D.C., 2005), 2.

So far our literature review has comprehensively explored how social networks provide simple and short paths between individuals across continents that would seemingly have no connection to one another. We have also explored the importance of developing incentive mechanisms that encourage individuals to not only play a role in answering questions posed to them, but also encouraging others to do so. It is at this point that we began to explore how technology has married itself to the previously mentioned literature and provided a new tool for exploring ways in which USSOCOM can continue to analyze proliferation networks in a more innovative way.

C. CROWDSOURCING 101

In the modern world, elements of online social communities pervade nearly every element of life and have exposed radical new ideas on collaboration. Message boards and instant messaging have given way to behemoth social collaboration tools such as

Facebook, Twitter, and Instagram. These new tools have, on several occasions, demonstrated their unique ability to organize large networks of people to perform collective operations towards the same purpose through the internet; a technique known as *crowdsourcing*. Crowdsourcing was originally conceived as a way for software and digital video firms to outsource their developing projects for cheap labor around the world.[39] Since its inception, however, the rise of social media tools have shown that crowdsourcing can be an excellent way for leveraging communications and information technologies in search operations.

Defining exactly what constitutes crowdsourcing can be a bit tricky since there's no academic consensus on its exact definition. The term was first coined by Jeff Howe in the June 2006 issue of *Wired* magazine and was later given a more definitive definition by its author in one of his later blogposts.[40]

> Simply defined, crowdsourcing represents the act of a company or institution taking a function once performed by employees and outsourcing it to an undefined (a generally large) network of people in the form of an open call. This can take the form of peer-production (when the job is performed collaboratively), but is also often undertaken by sole individuals. The crucial prerequisite is the use of the open call format and the large network of potential laborers.[41]

However, this initial attempt at defining what crowdsourcing is can be a bit restrictive as it only enlists people for *explicit* collaboration. A variety of platforms now exist that *implicitly* enlist individuals for crowdsourcing purposes, such as the labeling of images within the contexts of a game.[42] Furthermore, there are other examples, such as Amazon's Mechanical Turk-based systems, that were used to aid in the geo-location services of a person lost out at sea but were supported by no known community of

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[39] Jeff Howe, "The Rise of Crowdsourcing," Wired Magazine 14.06 (2006), accessed May 16, 2016, http://sistemas-humano-computacionais.wdfiles.com/local--files/capitulo%3Aredes-sociais/Howe_The_Rise_of_Crowdsourcing.pdf.

[40] Jeff Howe, "The Rise of Crowdsourcing," 1.

[41] Jeff Howe, "Crowdsourcing: A Definition," *Crowdsourcing: Tracking the Rise of the Amateur*, June 2, 2006 http://crowdsourcing.typepad.com/cs/2006/06/crowdsourcing_a.html.

[42] Luis von Ahn and Laura Dabbish, "Labeling Images with a Computer Game," *In Proceedings of CHI* (2004) accessed October 3, 2016 http://ael.gatech.edu/cs6452f13/files/2013/08/labeling-images.pdf.

individuals (merely unidentifiable Internet users who were altruistically motivated to help find him).[43] This system though was nonetheless performing a crowdsourcing type function even though it did not quite fit into Howe's first definition.

A much simpler and clearer way of defining crowdsourcing would be that *it is any system that harnesses the collective capabilities of humans to solve a clearly defined problem set.* By defining crowdsourcing in this fashion we can remove any restrictions that could be imposed by the types of collaboration that are being conducted or the types of problems we are trying to solve. Doan et al. came to the same conclusion that our literature review found and expounded on this more open definition of crowdsourcing by developing four questions that would help them characterize some of the challenges and solutions to crowdsourcing programs.[44] We used their questions as a basis for the formation of our own, to organize and characterize the crowdsourcing case studies discussed in this research: *How does this platform recruit and retain individuals?, What contributions can these individuals make to the platform?, How does this platform use crowdsourcing to solve the target problem? How does this platform evaluate user contributions and address false-identity attacks?* These questions provide our research with a method for analyzing the different types of crowdsourcing platforms that the government could use and distinguishes each from one another.

D. WHERE IS CROWDSOURCING?

One of the most well-known crowdsourcing platforms in existence is Wikipedia,[45] a commercial company whose entire business platform is centered on the idea that the knowledge base of the many is equal to that of an expert few. As a participant in the world of short factual information displays, Wikipedia's biggest competitor is the Encyclopedia Britannica, the standard-bearer for expert facts and

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[43] Michael Olson, "The Amateur Search," *SIGMOD Record* 37, 2 (2008) accessed October 8, 2016 http://sigmod.org/publications/sigmodRecord/0806/p21.olson.pdf.

[44] Anhai Doan, Raghu Ramakrishnan, and Alon Y. Halevy, "Crowdsourcing Systems on the World-Wide Web," *Communications of the ACM* 54(4) (2011) accessed October 1, 2016 doi:10.1145/ 1924421.1924442.

[45] "Wikipedia – The Free Encyclopedia," n.d., http://www.wikipedia.org.

opinions. However, since 2012, Encyclopedia Britannica has gone completely online and debate has loomed over the reliability of crowdsourced facts and ideas versus the generated input of experts in a variety of fields.[46] Recent studies though have shown that the reliability of Wikipedia versus the Encyclopedia Britannica indicate only slight differences in factual accuracy and editorial bias between the two.[47] In many ways this has validated the concept that there is room in commercial and intellectual enterprises for harnessing the power of the many to create viable solutions and answers.

The rise of these crowdsourcing platforms has paralleled the radical expansion of social media enterprises over the last ten years. During the time, corporations have increasingly sought ways of harnessing the collective wisdom of crowds and have turned towards social media platforms to generate user-input that will strengthen what they are producing or developing.[48] With nearly 80 percent of the world population, including those living in remote locations in Africa, Latin America, and Asia, now having some medium for accessing social media sites, the growing emphasis on looking to crowds for answers seems to be a growing trend.[49] The ability of social media sites to galvanizes individuals towards a cause has fundamentally altered the way that many of these citizens

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[46] Joab Jackson, "Encyclopedia Britannica Goes Online-Only," *Computer World*, March 26, 2012, accessed October 4, 2016, "http://www.computerworld.com/article/2503203/internet/encyclopaedia-britannica-goes-online-only.html.

[47] Michael Blanding, "Wikipedia Or Encyclopedia Britannica: Which Has More Bias?," *Forbes*, January 20, 2015, accessed October 16, 2017, http://www.forbes.com/sites/hbsworkingknowledge/2015/01/20/wikipedia-or-encyclopaedia-britannica-which-has-more-bias/#759a8d931ccf; Shane Greenstein and Feng Zhu, "Do Experts or Collective Intelligence Write with More Bias? Evidence from Encyclopedia Britannica and Wikipedia," (working paper, Harvard Business School, Harvard University, 2016); Daniel Terdiman, "Study: Wikipedia as Accurate as Britannica," *CNET*, December 16, 2005, accessed October 15, 2016, https://www.cnet.com/news/study-wikipedia-as-accurate-as-britannica/.

[48] Paul Massey, "The Rise of Crowdsourcing in Corporate Social Responsibility," *HuffingtonPost*, May 25, 2011, accessed October 3, 2016, http://www.huffingtonpost.com/paul-massey/the-rise-of-crowdsourcing_b_821357.html.

[49] William D. Eggers and Paul Macmillan, *The Solution Revolution* (Boston: Harvard Business Review Press, 2013), 63.

interact with their governments and in places such the US, India, and Iraq, have been a cornerstone for citizen-driven policy changes.[50]

In recognition of the significance that social media and crowdsourcing is having, many agencies within the U.S. Government have begun to explore the potential of these platforms to complement their current capabilities. For instance, the CIA's Open Source Center analyzes and aggregates massive amounts of Facebook messages, Twitter feeds, and online blogs to gauge social media attitudes abroad on a daily basis.[51] This information is then cross-referenced with newspapers and reports to assess local sentiment in foreign countries. Even the Defense Advanced Research Projects Agency (DARPA), the tech incubator of the Department of Defense (DOD), has invested in this technology, known as *meme-tracking*, to "track the formation, development and spread of ideas and concepts, use linguistic clues to ferret out purposeful or deceptive misinformation, and use sentiment analysis and opinion mining … [to] identify credible threats reverberating across cyberspace."[52] On November 1, 2016, the U.S. Navy began testing a crowdsourced mobile application that would provide its sailors with a way to report safety concerns and violations, as well as, propose new ideas for risk management called LiveSafe.[53] All this points to the fact that these tools are not simply meant for business or educational enterprises, but are also being increasingly used to complement existing U.S. Government programs.

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[50] Jenna Wortham, "Public Outcry over Antipiracy Bills Began as Grass-Roots Grumbling," *New York Times*, January 19, 2012, accessed October 3, 2016, http://www.nytimes.com/2012/01/20/technology/public-outcry-over-antipiracy-bills-began-as-grass-roots-grumbling.html?pagewanted=all; "Cleaning Out Corruption in India," *Avaaz*, accessed October 3, 2016, www.avaz.org/en/highlights--corruption.php; "Profit with Purpose," *Economist*, January 26, 2013, accessed October 3, 2016, www.economist.com/news/business/21570763-how-profit-firm-fosters-protest-profit-purpose?fsrc=scn/tw_ec/profit_with_purpose.

[51] Jared Keller, "How the CIA Uses Social Media to Track How People Feel," *The Atlantic*, November 4, 2011, accessed October 4, 2016, http://www.theatlantic.com/technology/archive/2011/11/how-the-cia-uses-social-media-to-track-how-people-feel/247923/.

[52] Jared Keller, "The Pentagon Enters the Social Web with a Call for Memetrackers," *The Atlantic*, August 2, 2011, accessed October 4, 2016, http://www.theatlantic.com/technology/archive/2011/08/the-pentagon-enters-the-social-web-with-a-call-for-memetrackers/242942/.

[53] Mark D. Faram, "Navy to test crowd-sourcing safety app in Hampton Roads, Spain," *NavyTimes*, November 1, 2016, accessed November 2, 2016, https://www.navytimes.com/articles/navy-to-test-crowdsourcsing-app-in-hampton-roads.

E. CROWDSOURCED GEOSPATIAL DATA (CGD)

Unfortunately, the relatively new application of crowdsourcing and the closely related field of studying social media has created confusion in terms of names. Many books have labeled crowdsourcing as other names, such as *Wikinomics* or the *Wisdom Crowds*.[54] The Center for Non-Proliferation Studies (CNS) at the Middlebury Institute of International Studies even has an all-encompassing term for the amalgamation of these two ideas, plus other related fields, known simply as *new media*.[55] Our research is focused specifically on the application of crowdsourcing technologies that allow users to participate in geospatial analysis. By this we are referring to the employment of a large body of users who actively collaborate to create, contribute, edit, and display geospatial data to help solve problems outside of the normal governmental channels.

Over the last decade, advancements in geo-technology and the internet have increased interests in geospatial science.[56] Two terms have been used to describe the crowdsourcing of geospatial data. The first to describe this specific field of crowdsourcing was Michael F. Goodchild. He labeled the participation of users towards the aggregation of geospatial data as *volunteered geographic information* (VGI).[57] In a follow-up study in 2013 by the Army Corps of Engineers, the application of VGI for governmental purposes was referred to as *crowdsourced geospatial data* (CGD).[58] In this study, CGD was defined as a non-authoritative approach to geospatial data

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[54] James Surowiecki, *The Wisdom of Crowds* (New York: Doubleday, 2004); Don Tapscott and Anthony D. Williams, *Wikinomics: How Mass Collaboration Changes Everything* (New York: Portfolio, 2006).

[55] Bryan S. Lee, Jeffrey Lewis, and Melissa Hanham, "Assessing the Potential of Societal Verification by Means of New Media" (CCC PASCC Report, James Martin Center for Nonproliferation Studies, January 2014).

[56] Sanjay Rana and Thierry Joliveau, "Neogeography Phenomena-Some Thoughts on It's Beginning, Future and Related Issues" (2007), accessed November 8, 2016, https://www.researchgate.net/publication/237585578

[57] Michael F. Goodchild, "Citizens as Sensors: The World of Volunteered Geography," *GeoJournal* 69, 4 (2007): 211–221.

[58] Matthew T. Rice, Fabiana I. Paez, Aaron P. Mulhollen, Brandon M. Shore, and Douglas R. Caldwell, "Crowdsourced Geospatial Data – A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data" (Annual Report, U.S. Army Topographic Engineering Center, November 2012).

production and distribution.[59] The specification of CGD as a non-authoritative approach is meant to clearly delineate the separation of geospatial data production on the internet from the more traditional production of this type of information by government agencies or publishing firms such as Rand McNally or the National Geographic Society.

Amateur production of geospatial data has traditionally been impeded by the immense technical and financial resources required to undertake these types of operations. This has led many in the government and the afore-mentioned agencies to view with skepticism the benefits of CGD. However, the emerging benefits of CGD are now being realized and new ways of incorporating CGD into parallel authoritative processes is now being investigated.[60] Studies into these benefits have focused specifically on the benefits of local expertise that CGD provides to the more traditional, authoritative production of geospatial data. As Goodchild suggests, "hybrid solutions to the production of geographic data may very well represent the best of both worlds."[61]

This study expands on the definition of CGD as merely a platform for reviewing, vetting, and editing commercial imagery. We add to the growing literature on crowdsourcing for geospatial purposes by including within CGD any application that seeks to answer the question of *where a person, place, or thing is*. A broader definition of this term allows our recommendations to build upon existing terminology and explore crowdsourced applications that have specific utility in unraveling where proliferation networks are operating. While social media analysis is a similar to CGD in many ways, it is distinct from CGD in the sense that users in social media analysis are only studied, not queried for answers or solutions. CGD requires user participation and is a distinct methodology designed to harness collective information, thoughts, and opinions towards a specific cause or solution.

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[59] Rice et al., "Crowdsourced Geospatial Data – A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data," 7–8.

[60] Peter A. Johnson and Renee E. Sieber, "Situating the Adoption of VGI by Government," in *Crowdsourcing Geographic Knowledge*, ed. Daniel Sui, Sarah Elwood, and Michael Goodchild (Dordrecht: Springer Netherlands, 2013), 65–81.

[61] Michael F. Goodchild, "Assertion and Authority: The Science of User-Generated Geographic Content," *In Proceedings of the Colloquium for Andrew U. Frank's Birthday*, 3:82-96, Department of Geographic Information and Cartography, Vienna University of Technology, 2008, 16.

F. CONCLUSION

The purpose of this study is to utilize the insights of this body of knowledge to examine methods to incentivize social networks towards realizing the recommendations of the 2014 Defense Science Board's *Assessment of Nuclear Monitoring and Verification Technologies* about harnessing crowdsourcing technologies. Our research looks at the commercial and academic application of CGD techniques to determine if there is a way to complement existing CP efforts. Our intention is to review case studies of crowdsourcing programs and then extrapolate from these programs methods that could then be used as the cornerstones for a USSOCOM sponsored program where CGD it is used as part of a multilateral approach to analyzing commercial imagery and time-critical search operations. Furthermore, it is our intention to demonstrate that outreach into the online world can provide an innovative, low-cost, high impact medium for unraveling ways in which specific social networks could be harnessed to expose potentially new ways that proliferation networks are evolving themselves with new technologies. In the following chapter we scope our research so that the reader will begin to understand how nuclear proliferation networks operate and where CGD can best be applied to.

III. NUCLEAR PROLIFERATION NETWORKS

This chapter aims to characterize proliferation networks in a manner that lends to a more thorough interpretation of contemporary and future network structure that is applicable to counter-proliferation efforts. The chapter will do this by beginning with a concise historical overview. The following section will define a nuclear proliferation network and discuss the general structure of nuclear proliferation networks to ascertain points of vulnerability. Next, it will explore common business practices that apply to typical proliferation network functions and reveal the supply and demand side to proliferation. Supply and demand will then segue into a description of first and second tier proliferation in relation to historic, contemporary, and future networks. Finally, characteristics of a proliferation network are highlighted with an overall aim to discern shortcomings and weak-points in network structure and/or characteristics that can aid in analyzing illicit nuclear trade.

A. PROLIFERATION FROM INCEPTION

An introduction to nuclear proliferation history creates a helpful framework for understanding current and future proliferation trends. Proliferation, for the purposes of this research, carries with it a nuclear connotation and is defined as, "the spread of nuclear weapons, fissionable material, and weapons-applicable nuclear technology and information."[62] This definition is used on an international level and recognized by all nation states party to the NPT.

With its roots in the Manhattan Project, The United States (with assistance from scientists from many other countries) was the pioneer of nuclear weapons, fostering

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[62] "Treaty on the non-proliferation of nuclear weapons" Taken from website of the International Atomic Energy Agency IAEA. Accessed May 24, 2016. https://www.iaea.org/sites/default/files/publications/documents/infcircs/1970/infcirc140.pdf.

The Treaty officially recognized Great Britain, China, France, the Soviet Union, and the United States as the Five Nuclear Nation States. Stipulations within the treaty require the nations to agree not to spread nuclear bomb-making technology; the only two that did not sign the treaty (until 1992) were China and France.

nuclear technology from concept to employment.[63] In 1949, Russia was able to reach nuclear parity following a clandestine penetration of the Manhattan Project. Subsequently, Great Britain, with assistance from the US, was the next nation to acquire nuclear capability, closely followed by France, and then China in 1964. Though not acknowledged officially, reports suggest that Israel was successful in its quest to become a nuclear state in 1967.[64]

Until the 1960s, many believed that only advanced nation-states possessed the intellectual capital and technical infrastructure necessary to construct a nuclear weapon. However, the rapid evolution of technology diffusion caused proliferation concerns to take center stage. President John F. Kennedy feared that "by the early 1970s, more than 20 nation states may possess the [nuclear] weapons."[65] The ensuing nuclear phobia resulted in the Nuclear Non-Proliferation Treaty (NPT)[66] of 1970, which was drafted as a preventative approach – non-proliferation approach – to controlling nuclear proliferation, and contained three main premises: Civilian Nuclear Sharing, Non-Proliferation, and Strategic Arms Reductions.[67] The treaty required that special attention be paid to the five states in possession of nuclear weapons - as officially recognized by the NPT. Additionally, the NPT stipulated that nations wishing to pursue nuclear exploits for civilian purposes, such as for alternative energy production, could do so with the understanding they would be subject to random inspection by the International Atomic Energy Agency (IAEA). As another means to curb appetites for nuclear weaponry, the NPT outlined that the five states possessing nuclear weapons would pursue disarmament,

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[63] Leslie R. Groves, *Now It Can Be Told: The Story of the Manhattan Project* (New York: Harper, 1962). xiii.

[64] Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 101; Avner Cohen, *The World's Worst Kept Secret: Israel's Bargain with the Bomb* (New York: Columbia University Press, 2010).

Israel, although they developed nuclear capability, did not publicly admit it for fear of reprisal by allied and enemy nations.

[65] Albright. *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 6.

[66] "Treaty on the non-proliferation of nuclear weapons" Taken from website of the International Atomic Energy Agency IAEA, accessed May 24, 2016, https://www.iaea.org/sites/default/files/publications/documents/infcircs/1970/infcirc140.pdf.

[67] Sokolski, *Underestimated*, 17.

as stipulated by Article V. Though the aim of the Nuclear Nonproliferation Treaty was to prevent additional nations from acquiring nuclear weapons, it contained shortcomings. The main loophole within the agreement "legitimized the sale of civil nuclear facilities (some of which could make nuclear explosive materials) if the recipient state or private company agreed to place these facilities under IAEA inspections and not to misuse them to make nuclear weapons."[68]

India, a nation that was not a signatory of the NPT, purchased a reactor from Canada for "civil nuclear energy development" and subsequently conducted an underground nuclear detonation in 1974. This "peaceful nuclear explosion" – as India would claim – motivated the U.S. and other countries to establish a system of controls on the sale of nuclear facilities capable of manufacturing weapons grade nuclear materials, no matter the intent.[69] As nuclear supplier nations implemented new restrictions, proliferators such as South Africa and Pakistan discovered that nuclear facilities could be assembled by ordering pieces separately to avoid the international scrutiny of the IAEA. The two countries were then able to exploit the ambiguous nature of dual-use commodities exchanged in order to obscure standing import/export control measures. As safeguards and controls expanded to address the evolving threat, so too did the proliferation networks continue to adapt.

B. KHAN'S PROLIFERATION ACADEMY

Abdul Qadeer Khan constructed the most well-known, comprehensive international nuclear smuggling network by taking advantage of policy short-comings within the international controls system, and using his position within a Dutch nuclear engineering corporation. His exploits were made possible by capitalizing on the interdependence of global trade, but more specifically, the varying degrees and effectiveness of import/export control measures across the world. Additionally, his network enabled Pakistan to build an infrastructure for its bomb program and produce its

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[68] Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 8.

[69] Henry D. Sokolski, *Best of Intentions: America's Campaign Against Strategic Weapons Proliferation* (West Port, Connecticut: Praeger Publisher, 2001), 49.

first weapon by the mid 1980s. Abdul Qadeer Khan's black market activities directly resulted in Pakistan becoming a nuclear armed state. Furthermore, his network played a direct role in facilitating the nuclear weapons programs of the Democratic People's Republic of Korea (DPRK), Iran, and Libya.[70]

The interdiction of the *BBC China* in 2003, a ship carrying nuclear components to support Libya's now defunct nuclear weapons program, as well as the emergence of state actors who acquired nuclear weapons in direct violation of the NPT, demonstrated to the non-proliferation community that it had failed at its mission of halting the spread of nuclear weapons knowledge.[71] Khan successfully established a network that reduced the barriers to entry for nuclear ambitious states. Over the course of two decades, he established a robust nuclear proliferation network capable of supplying "customers" with the plans, components, and technical expertise to produce a nuclear bomb. India's "peaceful nuclear explosion" invigorated Pakistan to leverage Khan's access to nuclear weapons knowledge and materials to achieve nuclear parity in the region.[72] In addition to being directly responsible for Pakistan's subsequent assent to the status of a nuclear armed state, Khan was ushered onto the international stage as the most well-known proliferator of nuclear secrets in history.

When A.Q. Khan was eventually forced to take asylum in Pakistan in 2003, his efforts had already left reverberating effects for non-proliferation and counter-proliferation policy. Increased emphasis on CP operation was appropriate in light of non-proliferation failures in Libya, North Korea and Iran. In addition to having profound policy implications, the nuclear networks themselves now have the blueprints to proliferate the most lethal weapons on the face of the earth.[73] Pakistan's assent to

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[70] Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 20–34; Alexander H. Montgomery, "Ringing In Proliferation" International Security, Vol. 30, No. 2 (Fall 2005), 153–187.

[71] Bruno Gruselle, "Proliferation Networks and Financing," 22.; "A Tale of Nuclear Proliferation: How the Pakistani Built His Network," *The New York Times* http://www.nytimes.com/2004/02/12/world/a-tale-of-nuclear-proliferation-how-pakistani-built-his-network.html?_r=0.

[72] Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies* (New York Free Press, 2010), 8.

[73] Corera, *Shopping for Bombs: Nuclear Proliferation*, 242–243.

nuclear power paved the way for the emergence of second tier proliferation and heightened CP efforts.

Proliferation networks are the intermediaries which procure, market and traffic illegal nuclear materials and sub-components to the querying party. Albright expands on the definition of illicit nuclear trade stating that:

> Trafficking in nuclear commodities is trade that is not authorized by: 1) the state in which it originates; 2) under international law; 3) the states through which it transits; or 4) the state to which it is imported.[74]

Research indicates that proliferation networks are, in fact, business oriented and naturally shrink from violence.[75] Albright's definition of illicit nuclear trade personifies the nuclear proliferation realm as an ambiguous market-place that manipulates common business practices to subvert import/export control measures designed to regulate dual-use technologies. The Khan network incorporated various dummy corporations, intermediaries, trans-shipment locations, off-shore manufacturing in Malaysia and falsified documents and end-user certificates to navigate the murkiness of international regulations.[76] Current proliferation networks will likely adapt themselves to satisfy the demands of malignant actors seeking nuclear weaponry, similar to the manner that Khan adapted his legitimate business practices to accommodate illegitimate endeavors.

C. CHARACTERIZING PROLIFERATION NETWORKS

USSOCOM is unparalleled in its ability to track and disrupt terrorist networks, but understanding the differences between counterterrorism and counter-proliferation will be critical to applying the appropriate force toward the vulnerabilities of a nuclear proliferation network. Nuclear proliferation networks cannot be likened to a door-to-door salesman that blindly pedals his/her merchandise to anyone willing to purchase it. Rather, as explained by Gruselle, a proliferation network is comprised of two distinct networks

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[74] Albright et al., "Future World of Illicit Nuclear Trade: Mitigating the Threat," 32.

[75] Zachary S. Davis, "DA 4500 – Proliferation Class Notes," while in attendance at the Naval Postgraduate School, Monterey, CA. June 2016.

[76] Zachary S. Davis, "Bombs Away" *The American Interest.* Vol. 4, Number 3, January 1, 2009

working in concert with one another.[77] Supplier networks and acquisition networks work conjointly to transform a demand signal into a deliverable product.

For the purposes of this research, proliferation organizations are typically classified as rings, stars, or cliques based on their structure and the potential cut-points or cut-sets within their structure (see Figure 2).[78] Cut points are the locations within the networks that if severed would result in the network separating into one or more pieces, while cut-sets are the removal of multiple pieces, that would yield the same shattering results.[79] A ring is characterized by having each node within the group connected with two other nodes.[80] A cut-point within the ring would not have adverse effects on the organization, albeit, the removal of two non-adjacent nodes or a cut-set may well yield the organization ineffective.[81] The "star" model is highly vulnerable to an attack on the central person/organization, as it is the lifeline to the remaining members since every node runs through a central hub.[82] Conversely, if a peripheral node of a star-shaped organization is targeted, there will be little consequence to the remaining members.

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[77] Gruselle, "Proliferation Networks and Financing," 13.

[78] Montgomery, "Ringing In Proliferation," 153–187.

Although characterized as stars, cliques and rings, Montgomery also acknowledges that there are variations of the three, but the three that are mentioned are the models that can be applied to the structures for a baseline understanding.

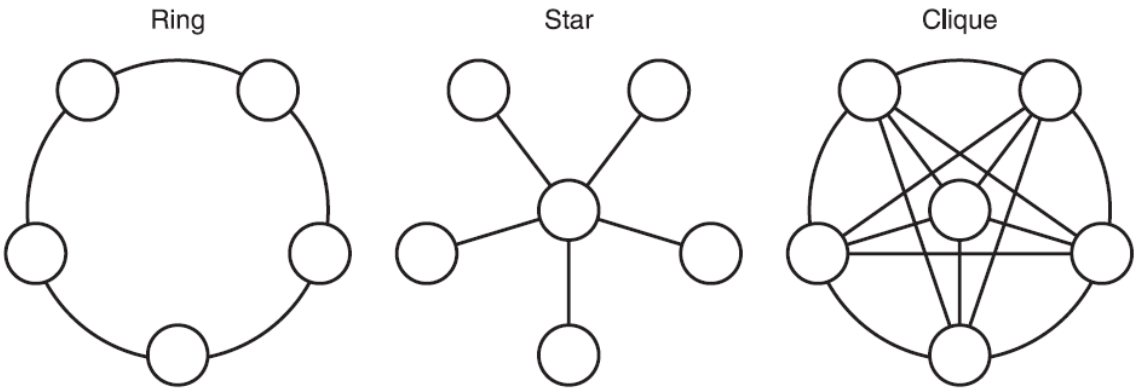
[79] Montgomery, "Ringing In Proliferation," 153–156.

[80] Montgomery, "Ringing In Proliferation," 160–166.

[81] Alexander H. Montgomery, "Proliferation Networks in Theory and Practice" *Strategic Insights*, Vol V, Issue 6, July, 2006.

[82] Montgomery, "Ringing In Proliferation," 170–174.

Figure 2. Simple Network Structures



Source: Alexander Montgomery, "Ringing In Proliferation" International Security, vol. 30, no. 2 (Fall 2005): 153.

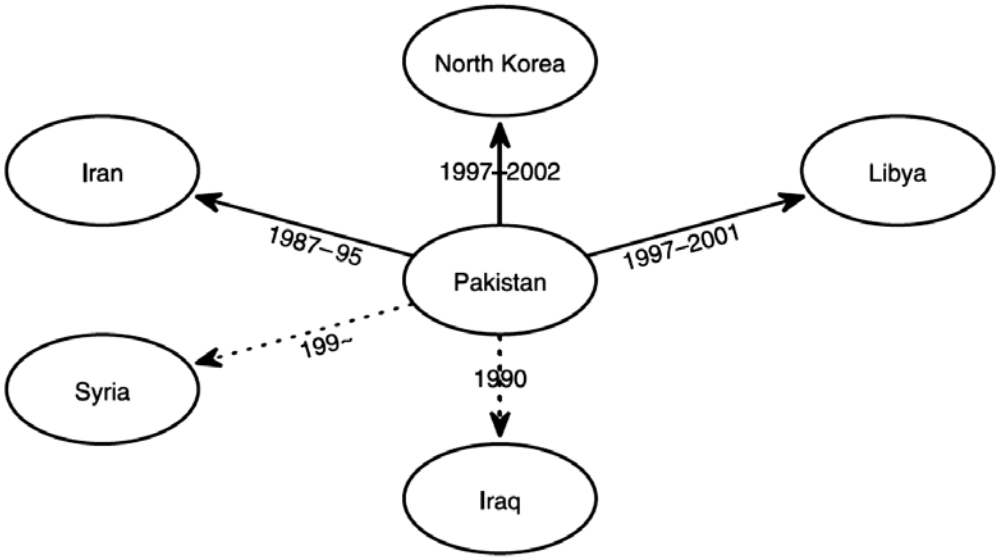
A clique network is one in which every node is connected to the other nodes through n-number of ties.[83] An attack on a singular node in the network is ineffective within a clique, but actions against a set of nodes can serve to isolate an organization within the node.[84] State actors seeking to facilitate nuclear proliferation often use this form networking.[85] As a result of the highly decentralized, robust nature of a clique organization, they are only vulnerable when an international coordinated attack against all of the nodes is undertaken. Pakistan was the central hub for Iran, Libya, Iraq, Syria, and North Korea when these countries sought to acquire illicit nuclear weapons capabilities (see Figure 3 for a representation of the "star" nature of the Pakistani second tier proliferation network). With an understanding of the general structure of the different types of proliferation networks and their respective vulnerabilities, we now focus our attention towards how proliferation businesses prosecute their endeavors. This is to ascertain whether or not there are opportunities for using crowd-sourcing techniques to better understand the fundamental structure of these businesses and how they operate.

[83] Alexander H. Montgomery, "Ringing In Proliferation," 171.

[84] Alexander H. Montgomery, "Ringing In Proliferation," 180–181.

[85] Alexander H. Montgomery, "Ringing In Proliferation," 186.

Figure 3. Pakistani Second Tier Proliferation Network



Source: Gaurav Kampani, "Proliferation Unbound: Nuclear Tales from Pakistan" (Monterey, California: Center for Nonproliferation Studies, Monterey Institute for International Studies, February 23, 2004), http://cns.miis.edu/pubs/week/040223.htm.

D. RISKY BUSINESS

When discussing proliferation networks, it is important to note that they operate very similar to any modern, legitimate business. Since the aim of any actor seeking a nuclear yield can only be achieved using plutonium or highly enriched uranium (HEU), we already know exactly what product they are looking for. Plutonium production and Uranium enrichment are processes that require a high degree of technical acuity and precise machining capabilities.[86] In the same way that a legitimate business enterprise operates, parts and equipment must be aggregated to construct a production/maintenance facility that weaponizes nuclear material. Many of the parts for nuclear production are what are known as *dual-use items*, meaning that they have commercial and military application.[87] These items are what can be considered a "shopping list." Most are in fact

[86] Albright et al., "Future World of Illicit Nuclear Trade: Mitigating the Threat," 23.

[87] Gruselle, "Proliferation Networks and Financing," 16.

already found on U.S. control lists.[88] However, the up-side for proliferators, with regards to these lists, are that they are now becoming so extensive that international inspectors face a herculean task when reviewing the export of controlled dual-use items. Additionally, not all states are party to international effort to counter proliferation, such as the Nuclear Suppliers Group,[89] The Zangger Committee,[90] or the Wassenaar Arrangement.[91] As technology advances, the efficacy of these lists in thwarting nuclear proliferation will become increasingly more difficult to achieve.[92]

Throughout this process, proliferation networks must maintain the ability to contact foreign companies for the purchase of dual-use commodities while simultaneously preventing the proper authorities from being alerted. To this end, intermediaries are often contracted and strategically chosen because of their ground-level, operational knowledge on export controls systems and what "normal" looks like in terms of shipments. A proliferation network will utilize front companies or dummy corporations to make purchases from the intermediaries and ensure the materials are transferred to their actual destination, using multiple cut-outs, or ways to disassociate themselves from an illicit purchase, whenever possible. After acquiring the necessary materials and component, the next step for proliferators is hiring consultants, such as nuclear scientists, specialists in metallurgical processes, and experts in circumnavigating

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[88] Department of State "Overview of the U.S. Export Controls System" http://www.state.gov/strategictrade/overview/. Accessed on 1 Nov. 2016.

[89] The Nuclear Suppliers Group (NSG) - With 39 member states, the NSG is a widely accepted, mature, and effective export-control arrangement which contributes to the nonproliferation of nuclear weapons through implementation of guidelines for control of nuclear and nuclear-related exports.

[90] Zangger Committee - The purpose of the 35-nation Nuclear Non-proliferation Treaty (NPT) Exporters (Zangger) Committee is to harmonize implementation of the NPT requirements to apply International Atomic Energy Agency (IAEA) safeguards to nuclear exports. The Committee maintains and updates a list of equipment and materials that may only be exported if safeguards are applied to the recipient facility (called the "Trigger List" because such exports trigger the requirement for safeguards).

[91] Wassenaar Arrangement (WA) - The regime with the most extensive set of control lists; it seeks to prevent destabilizing accumulations of arms and dual-use equipment and technologies that may contribute to the development or enhancement of military capabilities that would undermine regional security and stability, and to develop mechanisms for information sharing among the 34 partners as a way to harmonize export control practices and policies.

[92] Jennifer Snow, "Entering the Matrix: The Challenge of Regulating Radical Leveling Technologies" (Master's Thesis, Naval Postgraduate School, 2015).

import/export controls.[93] Countries with stringent export controls will force these contractors and sub-contractors to engage in a plethora of illegal activities, such as falsifying end-use documents, in order to attract as little attention from the authorities as possible.

Finally, like every business, the illicit nuclear market has financial transactions that will take place at numerous points while products are being purchased, shipped, and delivered to their final destinations. Though this portion can vary, proliferation networks can potentially conduct transactions valued at hundreds of millions of dollars.[94] Since proliferation networks operate with such large amounts of illicit funds, they must diversify these funds in order to prevent market flooding, which would raise flags if noticed. Local front companies and intermediaries are paid in cash when possible; however, proliferation often spans trans-national borders, and results in finances inevitably deposited into banks and financial institutions globally.[95] Proliferation networks employ economically-based tools of internationalization to circumvent prohibition systems in order to supply their customer. (See Figure 4 for an illustration of their business model.).

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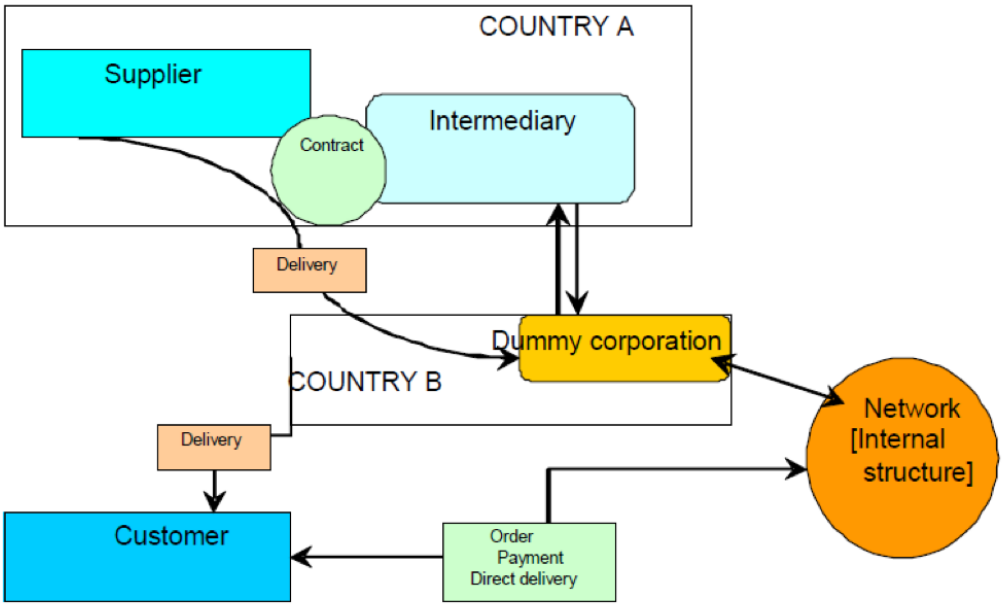
[93] Gruselle, "Proliferation Networks and Financing," 13.

[94] Gruselle, "Proliferation Networks and Financing," 14; David Albright, Andrea Stricker, and Houston Wood, "Future World of Illicit Nuclear Trade: Mitigating the Threat" *Institute for Science and International Security*, July 29, 2013, 15; Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 10.

[95] Gruselle, "Proliferation Networks and Financing," 15.

Figure 4. Diagram of Proliferation Network Operations



Source: Bruno Gruselle, "Proliferation Networks and Financing," *Fondation pour la Recherche Stratégique*, 2007, 28.

Insights from the case of the A.Q. Khan network illustrate that not only did Khan utilize legitimate business practices and state sponsorship to circumvent international controls, but legitimate, unwitting businesses were also used to transit materials and equipment.[96] The network he erected is beneficial as a case of reference for two reasons: 1) It serves as a historic example of a mature and successful nuclear proliferation model that can be applied in the context of our present circumstances. 2) Khan's activities had more effect on nuclear proliferation than any individual or country in the last 30 years.[97] In addition to the A.Q. Khan exploits, a look at the contemporary and near future of second tier nuclear proliferation efforts of states like China, North Korea and Pakistan

[96] Albright. *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 52–69.

[97] Corera, *Shopping for Bombs: Nuclear Proliferation*, 5; Rebekah K. Dietz, "Illicit Networks: Targeting the Nexus between Terrorists, Proliferators and Narcotraffickers." Naval Postgraduate School, Master's Thesis, Monterey CA, December, 2010, 35.

demonstrate that many of the characteristics between proliferators (no matter the network structure) remain the same.

Additional literature on illicit nuclear trade networks presented by Braun and Chyba expand on the effects of the supply and demand portion of proliferation in terms of first and second tier proliferation.[98] First-tier proliferation technology are material sold/stolen from private companies or when state nuclear programs assist non-nuclear weapons states in developing illegal nuclear weapons programs and delivery systems.[99] Second-tier nuclear proliferation is when states with developing nuclear capabilities trade technical capabilities among themselves to bolster one another's nuclear and strategic weapons efforts.[100]

The early days of the A.Q. Khan network serves as an illustrative example of first-tier proliferation. Khan used his employment in the Dutch engineering company URENCO to gain unauthorized access to nuclear blueprints. In turn, Khan used his acquired knowledge to serve as the launch-pad for Pakistan's nuclear program, and later his own nuclear proliferation organization. In an egregious example of post NPT, second-tier proliferation, China jump-started the Pakistani nuclear program, supplying essential nuclear components and materials that included:

> [A] complete design of one of its early uranium nuclear war-heads, sufficient quantities of HEU for two weapons, short-range ballistic missiles and construction blueprints, assistance in developing a medium-range missile, support in developing second generation uranium

[98] Chaim Braun and Christopher F. Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime" International Security, Vol 29, No. 2, 10, 5.

[99] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," 5.

[100] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," 5–6.

> centrifuges, including the provision of 5,000 ring magnets, and a 40 MW(th) heavy-water plutonium and tritium production reactor located at Khusab.[101]

Second-tier proliferation is projected to grow more popular amongst developing countries because they are able to leverage their relaxed import/export control laws and manufacturing and machining capabilities, to exchange with one another for nuclear materials or components that they are unable to produce.[102] Additionally, second tier proliferation is attributed to the inability of non-proliferation efforts to control the diffusion of nuclear information. Although second-tier proliferation is not a new concept, the extensive diffusion of the technological know-how, largely as a result of the Khan Organization, and the rapid growth in international trade, have made second tier proliferation increasingly more likely to persist.[103] Developing countries with uncontrolled markets are ripe for continued and future illicit proliferation endeavors. However, it is imperative to understand that first and second tier proliferators will continuously adapt their network structures to realize their goals.

Proliferation networks are shaped by their function and are highly responsive to outside influencers (i.e., import/export control measures, law enforcement, diplomatic demarches, international control lists, sanctions, and intelligence collection efforts)[104] If the current trend of inter-state procurement of nuclear materials/expertise persists, it can be inferred that opportunity exists to further characterize maligned nuclear procurement organizations based on their dependency on outside resources.[105] Although A.Q. Khan,

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[101] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," 21.

China's supply of HEU to Pakistan has been called unconfirmed by one unnamed U.S. official. See Albright and Hibbs, "Pakistan's Bomb."

[102] Albright et al., "Future World of Illicit Nuclear Trade: Mitigating the Threat," 7.

[103] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," 21.

[104] Zachary S. Davis, "DA 4500 – Proliferation Class notes," while in attendance at the Naval Postgraduate School, Monterey, CA. June 2016.

[105] Albright et al., "Future World of Illicit Nuclear Trade: Mitigating the Threat," 34; Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 244–255.

contributed widely to the availability of nuclear knowledge, the only states that appear to be self-sufficient, and do not have the necessity to augment their nuclear ability abroad are the United States, the United Kingdom, France and Russia.[106]

E. ORGANIZATIONAL CHARACTERISTICS OF PROLIFERATORS

In the same way that legitimate enterprises strive for maximum optimization of resources, proliferation networks seem to maximize profits, minimize risk, and provide a product that meets the consumer's expectation to drive future business. In that light, this portion of the research will examine six characteristics of an illicit nuclear procurement organization in order to codify their inherent strengths and weaknesses. The characteristics to be examined are: Leadership, Motivations, Nature of Operations, Associates, Specialization, and Financing (see Table 1). The end state is to shed additional light on the nature of the nuclear procurement world.

Table 1. Comparative Table of the Characteristics for Terrorist and Proliferation Networks

Organizational Characteristics		
	Terrorist	**Proliferation**
Leadership	Decentralized/Centralized	Decentralized/Centralized
Motivations	Ideological/Narrative Based/ Financing only a means to an end	Monetary
Nature of Ops	Violent	Non-Violent (Adamantly opposed)
Associates	Kinship/Close Ties	Witting/Unwitting Participants
Specialization	Innovative/Latency	Business Oriented/Technical abilities/ Dual-Use Technologies
Financing	Hybrid – Hawalas/Front Companies/Illicit Activities	Front Companies/Legitimate Businesses/Middlemen/Financial Institutions

The literature cites Pakistan's smuggling operations to improve their nuclear arsenal, India and its exploits to obtain key elements for its unsafeguarded nuclear facilities, as well as Chinese endeavors seeking outside materials to improve their nuclear capabilities.

[106] Albright et al., "Future World of Illicit Nuclear Trade: Mitigating the Threat," 33–41.

1. Leadership

In terms of leadership, nuclear procurement networks can be centralized and decentralized.[107] The A.Q. Khan network serves as an illustrative example of a centralized leadership structure, however, when we examine leadership from the lens of second tier-proliferators, the leadership structure has the potential to be more decentralized and uncertain. Solely targeting the chief individual, or central node are not always effective at dismantling hub and spoke proliferation networks.[108] As Gruselle notes, successful proliferation organizations maintain informal relations along the formal channels to provide redundancy, resulting in a more resilient organization that is not largely affected by the removal of an individual.[109] Fully understanding the complete mechanics and personalities of this type of organization is imperative if this type of network is going to be targeted.

When considering second tier proliferation, the structure can be star-like or ring-like, as the participants trade nuclear weapons components and missile technology with other state actors to augment their shortcomings. It is possible there is not an identifiable leader because they are dealing more on a *quid-pro-quo* basis in which each party has something to gain. An example is the situation in which the DPRK turned to Pakistan for nuclear technology. This request coincided with the successful DPRK test of the Ghuari 1 missile, and resulted in an agreement to exchange missiles for enrichment capabilities between the two states.[110] When dealing with second tier proliferators, they are likely to be state actors and will not have a participant that is "in charge."

2. Motivations

Motivations of an organization are helpful tools that aid in further characterizing the nature of an organization and predicting future behavior. Generally, identifying a

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[107] Montgomery, "Ringing In Proliferation," 4–5; Gruselle, "Proliferation Networks and Financing," 13.

[108] Montgomery, "Ringing in Proliferation," 5.

[109] Gruselle, "Proliferation Networks and Financing," 13.

[110] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Non-Proliferation Regime," 5–49.

motivation of an individual/group of people is difficult unless it is explicitly stated; however, as a matter of observation, proliferation networks primarily operate like any other business enterprise with revenue as a staple of its existence. Although A.Q. Khan's motivation to proliferate may have begun for the development of his home country, it also appears as though he was an opportunist.[111] He found a niche market in which he led Pakistan to their acquisition of the bomb, but saw a very lucrative opportunity for himself and some of the colleagues he acquired over the years. The high involvement of legitimate businesses among illegal transactions necessitate that the network remains a lucrative venture. It can be inferred that intermediaries, front companies and financial institutions will not take on risk that is not commensurate with satisfactory compensation.

Second-tier proliferation, in terms of financial gain, appears to be slightly more dependent on the situation, as was the case with the trade deal between DPRK and Pakistan. Pakistan did not have the currency to acquire the missile technology it was seeking, but it did have the nuclear technology to barter with. Perhaps potential for further insight within second-tier proliferators could involve determining those countries seeking a nuclear solution who do not have the capital to do so.

3. Nature of Operations

Nuclear proliferation networks do not typically use high levels of violence as a means of operation. Khan's network was international and operated within the confines of import/export controls and common business practices. A non-violent approach is paramount for proliferation networks to remain inconspicuous as the illegal freight transits multiple ports and authorities. Violence would do nothing more than draw additional scrutiny onto a web interwoven with forged paperwork, bribed businessmen, intermediaries, corroborating banks, and false companies. Proliferators tend to be loosely associated businessmen who shrink from violence and do not adhere to religious or criminal codes of conduct.

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[111] Albright, *Peddling Peril: How the Secret Nuclear Trade Arms America's Enemies*, 19–41.

When considering second-tier proliferation, violence against co-conspirators could be disastrous, specifically if a particular country owns a niche market. The likelihood of violence against a conspiring state could result in the loss of secrecy and credit among malevolent actors. This characteristic differs drastically from conventional terrorist networks who rely on terror as a means to induce cooperation.

4. Associates

Proliferation networks are comprised of both witting and unwitting participants. A.Q. Khan employed colleagues that he developed business ties with throughout his career at URENCO as witting participants in his operations. Likely there were additional unwitting parts companies, shipment companies, and others that were used throughout the operation as well. This can be deduced through the extensive efforts to falsify end-user certificates and other shipping information.

Second-tier proliferators associate with one-another, but may pose an unforeseen risk as they are less hindered by red-tape because the exchanges are state to state. They likely have unwitting participants within the networks, to maintain secrecy and it can be assumed there are far fewer witting participants.

5. Specialization

Proliferation networks are distinct in that their financial status and legitimate business connections allow them to operate with the very latest in technology as well as exploit the seams that dual use commodities (or commodities that have civilian and military application) provide. Libya's attempt at a nuclear arsenal was a hundred-million-dollar venture alone,[112] and as such, the technology applied to false documents, certificates, trans-shipment sites, tracking mechanisms and shipping containers and vessels are in place to ensure the product meets the end-user. Proliferation networks' familiarity with import/export regulations allows them "to navigate through the

[112] Braun and Chyba, "Proliferation Rings: New Challenges to the Nuclear Nonproliferation Regime," 40.

international *gray* market that exists between licit and illicit enterprise, and often blurs the lines between."[113]

Among the emergence of second-tier proliferation, technology will continue to play a pivotal role in proliferation activities to minimize unwanted international knowledge of illicit nuclear activities that could result in sanctions or worse.

6. Financing

A.Q. Khan's organization was financed by operating within legitimate businesses, front companies, and financial institutions. The potentially high volume of cash flow and money transfers produced by a proliferation network are substantial and require diversifying funds into multiple banks and financial institutions. The A.Q. Khan network, from what has been released appears to have conducted transfers between suppliers and front companies and contracts executed through letters of credit[114] or bills of exchange.[115] Other methods indicate bulk cash over several payments that ostensibly, were then deposited into off-shore accounts.[116]

Second-tier proliferators, could engage in much of the same financial hop-scotch to mask origins, but are also unique in that, transactions do not have to be of the financial nature. In an instance there is no "money trail" it may not be inconceivable another commodity is being bartered. In a proliferation network, the bottom line, is that no one does "something for nothing!"

F. CONCLUSION

Over the course of this chapter, we reviewed the fundamental nature of proliferation networks and their characteristics. Quite often the characteristics of

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[113] Dietz, "Illicit Networks: Targeting the Nexus between Terrorists, Proliferators and Narcotraffickers," 44.

[114] Letter of credit: commitment by the issuing bank to make a payment to a supplier at the request of an order given, on presentation of documents certifying that the goods have been shipped or a contract has been executed.

[115] Bill of exchange: document that the beneficiary submits to the creditor, and by accepting it the creditor orders.

[116] Gruselle, "Proliferation Networks and Financing," 22.

proliferation networks include illicit transactions under the guise of legitimate business and involve the following things:

- Measures to circumvent export controls
- Generally low levels of violence
- Utilizing front companies
- Maintaining quasi-governmental affiliation
- Utilizing mainly licit, but also illicit means of smuggling materials
- Arrangements for the sole purpose of profit[117]

Proliferators, like most criminal networks, exhibit the "…capacity …to conceal their activities within a variety of licit transactions, to act rapidly in order to exploit new opportunities, and to reconfigure and reconstitute organizational structures in response to law enforcement successes."[118] Proliferation networks are businesses that adapt their practices to remain successful.

The chapter has also illustrated that preventing the spread of nuclear weapons and materials routinely occurs in a non-kinetic environment, and as such, military authorities such as Title 10 under the U.S. Code of Federal Regulations are rarely central to CP operations.[119] CP requires the application of multiple assets and agencies to gather intelligence, discern suspicious dual-use technologies, understand international export control measures, conduct diplomacy, engage law enforcement, direct financial intervention, and ultimately disrupt illicit activity that is strikingly similar to legitimate business operations. Our research has shown that nuclear proliferation networks will likely continue to evolve and persist as technology and the global business landscape creates new opportunities. The North Korea-Pakistan example serves as an indicator that second-tier proliferation is a trend likely to persist.

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[117] Dietz, "Illicit Networks: Targeting the Nexus between Terrorists, Proliferators and Narcotraffickers," 33.

[118] Phil Williams and Roy Godson, "Anticipating Organized and Transnational Crime," *Crime, Law & Social Change* (2002), 327.

[119] Lothringer et al., "Counterproliferation, Disruptive Innovation, and the Need to Improve Collaboration," 66.

However, while advances in technology may seem to favor proliferation networks, they are in fact opportunities for CP lines of efforts. The fact that proliferation networks operate by using legitimate business practices means that there is room for harnessing crowdsourcing technologies to target them. While terrorist organizations prefer to operate more covertly, proliferation networks, especially second tier proliferators, must operate in commercial areas that are exposed to open-source intelligence. From creation to distribution, nuclear proliferation is visible to commercial imagery and dedicated online searches of unclassified, import/export requests.

The key take-away from this chapter is that throughout the execution of their illicit business, proliferation networks will expose themselves at multiple times to open-source techniques that can monitor and assess their actions. Furthermore, their attempts at acquiring dual-use technologies that aid their efforts to circumvent trade controls presents opportunities for incorporating the collective wisdom of many. Indeed, considering the number of devices that are remotely-connected exceeding the global population and the increasing usage of smartphone technology, there are incredibly new ways for harnessing instantaneous, real-time information from concerned citizens around the world.[120]

[120] Cisco, "Cisco Visual Networking Index: Global Mobile Data Traffic Forecast Update, 2015–2020-Cisco," accessed September 19, 2016, http://www.cisco.com/c/en/us/solutions/collateral/service-provider/visual-networking-index-vni/complete-white-paper-c11-481360.pdf.

IV. CASE STUDIES IN CROWDSOURCED GEOSPATIAL DATA

A changing set of counter-nuclear proliferation problems requires a paradigm shift in monitoring that should include big data analytics and crowdsourcing

—Defense Science Board[121]

Our research will now shift toward case studies of different types of CGD applications. Some of the ones that are discussed are applications that are in common use to this day and others are examples of exercises that demonstrate the capacity of time-critical social mobilization to find answers to geo-locational problems. The flow of this chapter will begin with an application that has found ways to harness government geospatial data and local reporting to produce aggregated results that influence our lives. After this we will review crowd-sourcing applications that explore reporting in denied environments and another where simple CGD technology was used by concerned individuals to produce the location of a likely North Korean missile-launch site. These case studies should provide an idea of how the collective analysis of commercial imagery and use social networks for geo-locational problems can be harnessed towards aiding USSOCOM's efforts at unraveling where proliferation networks are currently operating.

A. CGD FOR REPORTING

The rapid growth of the internet and the widespread distribution of smartphones across the globe has made reporting one of the most viable options for CGD applications. Smartphones, specifically, provide individuals with a readily accessible tool for identifying and documenting real-time events as they are unfolding. Whether it's through pictures, videos, or audio, transmissions through these devices provide CGD applications easy collaboration tools for reporting information. Just prior to the debut of smartphones as the ascendant version of cellphones, Goodchild published a paper called "Citizens as Sensors: The World of Volunteered Geography," where he laid out his vision for average

[121] Stefaan Verhulst, "Use Big Data and Crowdsourcing to Detect Nuclear Proliferation, says DSB," *GovLab*, January 23, 2014, accessed October 31, 2016, http://thegovlab.org/use-big-data-and-crowdsourcing-to-detect-nuclear-proliferation-says-dsb/.

individuals to become sensors of the world.[122] The development and mass dissemination of the smartphone in today's era made Goodchild's prediction a reality.

Currently, many of the most common uses of CGD applications for reporting are in regards to events in the daily lives of individuals, such as vehicular traffic, government elections, or local weather feedback. However, these applications have also crossed over into areas that do not necessarily impact the lives of immediate users, but nonetheless build significant followings, such as natural disasters or human rights abuses in war-torn countries. Examples of these types of crowdsourced reporting applications include the dissemination of traffic information that can then be manipulated through algorithms to provide better routes for users in Waze,[123] or the real-time reporting of human-rights abuses from the current Syrian Civil War in Syria Tracker.[124]

There are key attributes to not from each of these CGD tools that should be taken into context while reviewing each one. First, Waze exemplifies a hybrid model where government map data is amplified with local user information. In this model the users play an equal role in the creation of information as the developer of the application does. The combination of the two sources makes it an arguably powerful competitor in the world of navigation aids. The second example, Syria Tracker, is a prime example of a CGD application that uses an open-source software and is actively built around user contributions that can then aid government and non-government agencies in their analysis of the Syrian Civil War. In this application information is completely built and distributed by the users and it is the developer that benefits from their input. These distinctions are important for understanding the two methods by which CGD reporting is processed.

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[122] Goodchild, "Citizens as Sensors: The World of Volunteered Geography," 212.

[123] "Waze – Social Traffic & Navigation App," n.d., http://www.waze.com/.

[124] "Syria Tracker," n.d., http://www.humanitariantracker.org/syria-tracker/.

1. Waze

With over 50 million users, Waze is one of the largest community-based traffic reporting and navigation tools.[125] The ability of the program to rapidly synthesize active and passive real-time inputs from drivers with algorithms that are then interfaced with map data from the U.S. Census Bureau's TIGER[126] database has made it a highly successful crowdsourced application.[127] Since its debut in 2008, the program has been fully developed in 12 other countries and was even used by Rio de Janeiro's city planners prior to the beginning of the 2016 Summer Olympics to manage traffic congestion.[128] The cost of the application is completely free to the user, but it does require that a smartphone have its GPS technology turned on in order to be used. While the user does not need to actively report any real-time traffic or road conditions, information such as travel speeds and location are passively collected from their phone by the program (see Figure 5).

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[125] Tom Vanderbilt, "Waze: The App That Changed Driving," *Men's Journal*, February 8, 2016, http://www.mensjournal.com/gear/cars/waze-the-app-that-changed-driving-20160208.

[126] "US Census Bureau Geography Division – TIGER Products," n.d., "http://www.census.gov/geo/maps-data/data/tiger.html/.

[127] "Map Editing," last modified April 18, 2016, https://wiki.waze.com/wiki/Map_Editing_(obsolete).

[128] "Waze, Outsmarting Traffic Together," n.d., http://www.gonomad.com/5549-waze-outsmarting-traffic-together; Vanderbilt, "Waze: The App That Changed Driving."

Figure 5. User Interface for Waze Application

Source: "Waze Navigation App Now Reads Destination from iOS and Android Calendars," last modified February 20, 2014, https://www.engadget.com/2014/02/20/waze-update-calendar-integration/.

How does this platform recruit and retain individuals? The appeal to users is that the program has no cost associated to it other than the requirement that a smartphones GPS technology be turned on for the program to work. Users are incentivized to participate through two methods. The first, is that users who participate and then recruit others to participate are immediately rewarded with increasingly higher levels of aggregated traffic information that benefits from maximum user participation. In addition to having the best routes provided, users are also made aware of potholes, traffic jams, and even the presence of police speed traps. The second incentive is a points system that is supplied based on the amount of active participation a user provides and then used to regionally build hierarchical points based lists so that other Waze users know who has the most.

What contributions can these individuals make to the platform? In addition to the passive and active contributions that users can make directly on the mobile application platform of Waze, users can also go to the Waze website and directly edit and update the map databases. According to Waze there are approximately 100,000 users that perform

this function with some reportedly spending hours each day constantly making adjustments to the maps.[129]

How does this platform use crowdsourcing to solve the target problem? According to Waze, around 20 to 100 accurately reported trips are enough to trigger automatic updates to the program.[130] A significant aspect of the program though is the passive collection of the millions of users who travel along the same routes daily. This builds into a predictive model for the program which it then aggregates with the active input of drivers to account for real-time events that cannot be predicted for, such as slow moving commercial trucks or accidents.

How does this platform evaluate user contributions and address false-identity attacks? In the same way that Waze uses the active input of Waze users to develop trafficking solutions, it also uses Waze users to evaluate and verify the information that is provided to the program. While this arguably leaves the program susceptible to false inputs, the ease with which other users can quickly update and validate information means that this information can be quickly deleted. More importantly though, since the heart of the program is the predictive modeling that is based on the passive collection of repetitive traffic routes, any attempt to redirect traffic for malicious purposes would require the participation of a significant number of the Waze users.

2. Syria Tracker

When the Syrian Civil War first began in early 2011 there was relatively minor reporting on events as they were unfolding. Once the Syrian government barred the entry of international journalists, reporting on incidents in the country became increasingly more difficult.[131] In an effort to track the development of the escalating humanitarian crisis that was unfolding, Taha Kass-Hout, a social data scientist and Hend Alhinnawi, an

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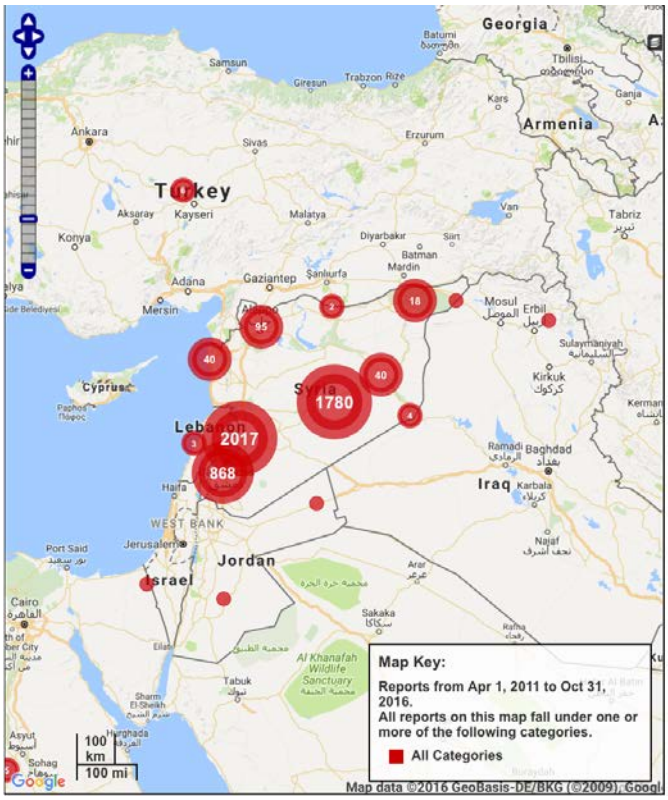
[129] Vanderbilt, "Waze: The App That Changed Driving," *Men's Journal.*

[130] "Timeline of Updating Process," last modified February 2, 2016, https://wiki.waze.com/wiki/Timeline_of_updating_process.

[131] Souraya Tafrah, "Syria Tracker, A Project of Humanitarian Tracker," *News Challenge,* September 30, 2015, https://www.newschallenge.org/challenge/data/entries/syria-tracker.

international development professional, launched Syria Tracker.[132] Built on the Ushahidi platform,[133] Syria Tracker was envisioned as a way for these two men to use crowdsourcing to provide a visual overlay of real-time events (see Figure 6). According to Will Haydon's news report on the program in March of 2015, "Syria Tracker synthesizes two pre-existing data-sourcing platforms: Harvard University's Healthmap, which mines online sources to monitor disease outbreaks; and the crowdsourcing tool Ushahidi, originally built in 2007 to monitor post-election violence in Kenya."[134]

Figure 6. Syria Tracker Map Overlay of Reports



Source: "Map Printing," *Syria Tracker*, n.d., https://syriatracker.crowdmap.com/printmap.

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[132] Mariane Pearl, "Syria Tracker: Women Dying in Numbers," *Huffington Post*, December 5, 2015, http://www.huffingtonpost.com/mariane-pearl/syria-tracker-women-dying_b_8710524.html.

[133] "Ushahidi," *Ushahidi*, n.d., http://ushahidi.com/.

[134] Will Haydon, "#IndexAwards2015: Digital activism nominee Syria Tracker," *Xindex*, March 11, 2015, https://www.indexoncensorship.org/2015/03/indexawards2015-digital-activism-nominee-syria-tracker/.

How does this platform recruit and retain individuals? Once Syria Tracker was conceived, its designers recognized that receiving credible and reliable reporting from individuals in the war-torn country would be difficult. The process of reaching out to victims began via word of mouth references and recommendations from trusted organizations and individuals in the country. While this method was slow at first, the site has now logged "over 100,000 eyewitness reports, mined over 300,000 news articles and over 200 million tweets."[135] Much of their success lay in Syria Tracker's ability to combine the wide-spread attention that Twitter feeds produce with the legitimacy of a conventional website that brings further trust and veracity to an organization, thus strengthening an altruism based community response to a problem.

What contributions can these individuals make to the platform? Victims are asked to submit their reports, videos or photos to Syria Tracker's Twitter site or to email Syria Tracker directly. The analytical aspects of the contributions are conducted by Humanitarian Tracker, the sponsoring program manager of Syria Tracker.

How does this platform use crowdsourcing to solve the target problem? The overwhelming support and responses provided to Syria Tracker over the last five years has largely been motivated by victims within the country who are seeking ways to bring greater international attention and scrutiny to the current civil war. While it would be extremely presumptuous to argue that Syria Tracker has played a significant role in heightening international attention of the war, it can be argued that Syria Tracker is producing the formative stages for an area of crowdsourcing that may become the future of reporting in denied areas. In a 2011 study from Internews Center for Innovation & Learning, it was determined that fewer than one third of contributors to a crowdsourcing project such as Syria Tracker produced results that would be delivered to policy-makers.[136] However, this study also concluded that crowdsourcing for reporting is

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[135] Pearl, "Syria Tracker: Women Dying in Numbers."

[136] Catie Bailard, Rob Baker, Matt Hindman, Steven Livingston, and Patrick Meier, "Mapping the Maps," *Crowdglobe*, July 12, 2012, 16.

continuing to gain traction in the online world and may yet become a powerful tool for the political and policy process.[137]

How does this platform evaluate user contributions and address false-identity attacks?? One of the more difficult, as well as critical, aspects of crowd-sourced reporting in a denied area is assessing the veracity and legitimacy of the information that is being reported. When interviewed about this Kass-Hout stated, "out of the 600-plus reporters [who have posted] over the past few years, we consider about a dozen of those to be credible." He further stated that only 5,000 of the more than 80,000 reports were ever published as a part of their findings.[138] This seems to indicate that while crowdsourcing can produce considerable results, some level of moderating still has to exist to bring legitimacy to the program.

B. CGD FOR SEARCHING

Coordinating the efforts of multiple individuals across a distributed geographical area is a challenging and perplexing dilemma.[139] However, research has shown that there is potential for social media to be leveraged towards galvanizing individuals to participate and contribute in a concerted effort towards search operations using CGD maps.[140] In an article written about the power of using open-source communities for search operations, Dorothy Denning stated that these systems offered, "the opportunity to magnify the mobilization of persons and resources, data collection and dissemination, and verification of acquired data."[141] The advantages of these tools are that they provide almost

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[137] Bailard et al., "Mapping the Maps," 5.

[138] Joanna Plucinska, "Crowdsourcing During a Crisis Has Its Drawbacks," *Poynter*, September 12, 2014, http://www.poynter.org/2014/crowdsourcing-during-a-crisis-has-its-drawbacks/268581/.

[139] Abdellah Bedrouni, Ranjeev Mittu, Abdeslem Boukhtouta, and Jean Berger, *Distributed Intelligent Systems: A Coordination Perspective* (New York: Springer Science & Business Media, 2009), v.

[140] Rebecca Goolsby, "Social Media as Crisis Platform: The Future of Community Maps/Crisis Maps." *ACM Transactions on Intelligent Systems and Technology*, vol. 1, no. 1 (2010), 7–9; Jame Morgan, "Twitter and Facebook Users Respond to Haiti Crisis," *BBC News*, January 15, 2010, http://news.bbc.co.uk/2/hi/americas/8460791.stm; Huiji Gao, Huan Liu, and Xufei Wang, "Promoting Coordination for Disaster Relief – From Crowdsourcing to Coordination," *DBLP Conference Paper* (March 2011): 1–9, accessed September 28, 2016, doi:10.1007/978-3-642-19656-0_29.

[141] Dorothy E. Denning, "Tags, Tweets, and Tethers," *CTX* Vol. 4, No. 1, February (2014): 27–36.

instantaneous feedback (including user requests and reports), provide unparalleled opportunities for aggregating data from a wide variety of communication mediums (emails, tweets, etc.), and they allow geo-locational data to be received from user submissions.[142] These capabilities make CGD searching operations a potentially powerful tool of analysis.

Shortly after the January 27, 2007 disappearance of a computer scientist named Jim Gray, who was sailing alone along the Northern California coast, close associates and long-time friends of his in the scientific and computer-software industries began developing one of the first crowd-sourced search projects. Despite the considerable time and resources that were dedicated to the project by the volunteers, Jim Gray and his vessel were never found. However, their volunteer search operation was not done in vain as it explored a path for crowdsourcing that has since grown into a viable method for augmenting traditional search operation methods that rely heavily on the physical presence of individuals to locate a particular individual or object of interest.[143]

When Gray's close associates became involved in efforts to locate him out at sea they brought with themselves a multitude of experience in drift-modeling, computer software development, and access to commercial satellite imagery courtesy of DigitalGlobe.[144] Their use of crowdsourcing to aid in Gray's recovery efforts laid the framework for the use of CGD during disaster relief operations. Follow-up deployments of CGD tools during disasters in Kenya, Mexico, Afghanistan, and Haiti, highlighted the benefits of using the Ushahidi program for open source crisis map platforms.[145] The relatively well-known functions of the Ushahidi platform make it an excellent mechanism for social activism and collective contributions of information. This enabled governments

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[142] Huiji Gao, Geoffrey Barbier, and Rebecca Goolsby, "Harnessing the Crowdsourcing Power of Social Media for Disaster Relief," *IEEE Intelligence Systems*, 26, 3 (2011), 10–14.

[143] Joseph M. Hellerstein and David L. Tennenhouse, "Searching for Jim Gray: A Technical Overview," (Technical Report, University of California at Berkley, 2010).

[144] Hellerstein and Tennenhouse, "Searching for Jim Gray: A Technical Overview."

[145] Gao et al., "Harnessing the Crowdsourcing Power of Social Media for Disaster Relief," 11.

and non-government agencies to more effectively operate alongside one another through a visualization tool that mapped incidents and responses.

The driving incentive behind getting users to participate in CGD crisis mapping during disasters is altruism. However, there are times when altruistic incentives cannot be used by a CGD application for search operations. In the following case studies, we branch away from the use of CGD for crisis map platforms and review how DARPA setup an exercise to explore how the online community could be used to find ten red balloons across the continental United States. We then look at how the Department of State (DoS) expanded on this case study by asking the online community to find the location of five individuals across two continents. In both exercises we seek to extrapolate how internet users were incentivized to participate in a CGD search operation where the tangible benefits were not rooted strictly in altruism.

1. Red Balloon Challenge

On December 5, 2009, DARPA issued a social networking mobilization challenge that has come to be known as, the Red Balloon Challenge. Teams were asked to "identify distributed mobilization strategies and demonstrate how quickly a challenging geolocation problem could be solved by crowdsourcing."[146] Ten red balloons were floated across the United States and each team was asked to identify and report the location of each for a grand prize of $40,000 (see Figure 7). Remarkably, a team from Massachusetts Institute of Technology's (MIT) Media Lab reported the correct locations of all the balloons in less than nine hours.[147] By the end of the exercise DARPA reported that over 4,000 teams across 39 countries participated in their exercise. Based on follow-up interviews and their estimates of network size, DARPA believes that more than 350,000 people participated in their exercise.[148]

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[146] DARPA, "DARPA Network Challenge, Project Report," Arlington, VA., 16 February 2010, accessed May 24, 2016. http://www.eecs.harvard.edu/cs286r/courses/fall10/papers/ProjectReport.pdf.

[147] DARPA, "DARPA Network Challenge, Project Report," 9.

[148] DARPA, "DARPA Network Challenge, Project Report," 4.

While most of the teams used some method of social media outreach, it was arguably the extrinsic financial incentives that Media Lab created that made their team ultimately successful.[149] However, their success was not simply marked by an unprecedented recruitment scheme, but also by a clearly laid plan that combined common-sense geo-locational information with direct verification to ensure that the information that their team received was legitimate.[150] In the following analysis we explore the winning formula that Media Lab employed in order to extract pertinent information for using crowd-sourcing tools for time-constrained social mobilization.

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[149] Galen Pickard, Wei Pan, Iyad Rahwan, Manuel Cebrian, Riley Crane, Anmol Madan, and Alex Pentland, "Time-Critical Social Mobilization," *Science*, 334 (2011): 509–512; John C. Tang, Manuel Cebrian, Nicklaus A. Giacobe, Hyun-Woo Kim, Taemie Kim, and Douglas Wickert, "Reflecting on the DARPA Red Balloon Challenge," *Communications of the ACM*, 54, 4 (2011): 78–89; Manuel Cebrian, Lorenzo Coviello, Andrea Vattani, and Panagiotis Voulgaris, "Finding Red Balloons with Split Contracts: Robustness to Individuals' Selfishness," *Proceedings of the 44th Annual ACM Symposium on Theory of Computing* (2012): 775–788.

[150] Victor Naroditskiy, Iyad Rahwan, Manuel Cebrian, and Nicholas R. Jennings, "Verification in Referral-Based Crowdsourcing," *PLOS One*, 7, 10 (2012): 1.

Figure 7. Red Balloon Locations during DARPA Challenge

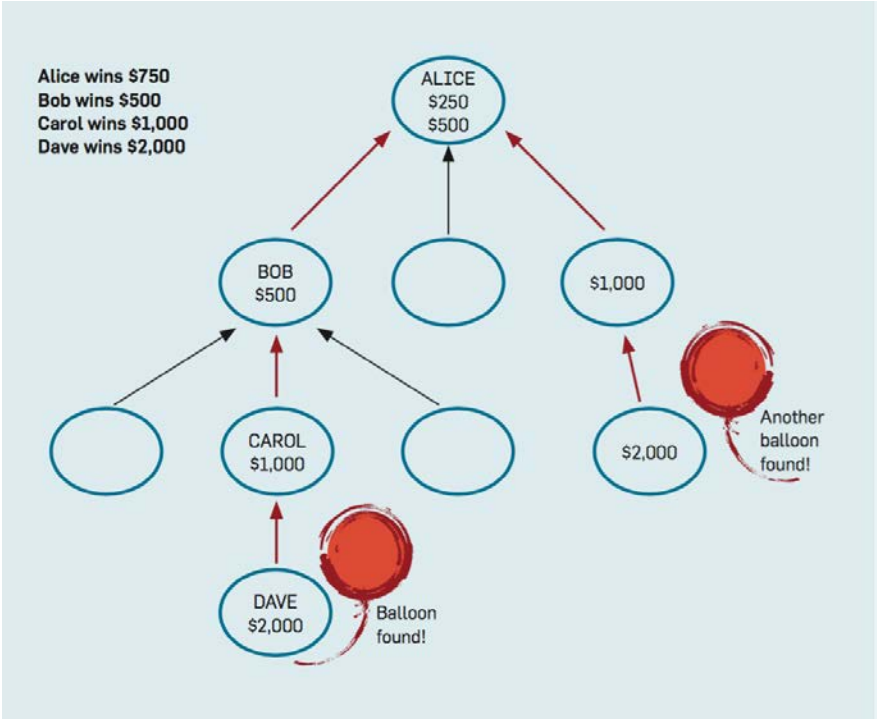
Source: *Map*. PNG Image, 819 x 480 pixels, n.d., http://archive.darpa.mil/networkchallenge/BalloonMap.html.

How does this platform recruit and retain individuals? Clearly distinct recruitment strategies were employed by each of the top-ranked teams in the challenge and reflected the varying strengths of each team's initial capabilities and the value of their later approaches at recruitment. Media Lab, the winning team, employed a variation of Kleinberg and Raghavan's Query Incentive Network strategy for the recruitment and retention of participants for their team that they referred to as the *recursive incentive-structure*.[151] However, instead of using a *fixed payment system* for monetary rewards, they issued a *split contract payment*. This meant that the Media Lab's reward system would scale with the size of the recruitment tree and not be fixed towards benefitting only those that are immediately connected to the individuals that helped find the red balloons.

[151] Pickard et al., "Time-Critical Social Mobilization," 510; Jon Kleinberg and Prabhakar Raghavan, "Query Incentive Networks," *In Proceedings of the 2005 46th Annual IEEE Symposium on Foundations of Computer Science* (2005).

For their model this meant that the individual who reported the correct location of the balloon received $2,000, that the person that had recruited that person received $1,000, the recruiter of this person then received a reward of $500, and so on (see Figure 8).[152] This system was based on dividing the $40,000 prize into ten pots for each of the red balloons so that $4,000 was available for the tree of each successfully reported balloon. By dividing this pot in half, Media Lab created a nearly limitless pool of financial incentives. However, since we can hypothesize from Milgram's Small World Phenomenon that nearly everyone in the world is only separated by no more than six degrees, the smallest amount paid out would most likely never be lower than $125.

Figure 8. Recursive Incentive Structure for Red Balloon Challenge



Source: Tang et al., "Reflecting on the DARPA Red Balloon Challenge," 81.

[152] Tang et al., "Reflecting on the DARPA Red Balloon Challenge," 80.

The performance of the *recursive incentive-structure* in this exercise reflected three important properties that should be considered for future crowdsourcing applications. First, the scalable incentive model ensures that rewards can be provided without exceeding the budget of the program. Once an individual is recruited to participate in locating a balloon, they have no financial incentive to create their own network of individuals and are instead incentivized to continue helping the tree of nodes that they are already operating within. Second, this model provides incentives for individuals to not only participate in the crowdsourcing application, but also recruit other individuals towards their cause.

Finally, in a time-critical situation, this model for financial incentives maintains the attention and participation of its users for a longer period of time than other strategies. For example, the model employed by George Hotz, a well-known hacker with a huge Twitter following, was heavily dependent on his access to tens of thousands of users via his Twitter page during the competition. While this gave him a huge advantage during the opening hours of the competition (four balloons were found by his followers), the number of tweets that he received rapidly declined once Media Lab's financial incentives were more widely distributed across the web.[153] This reinforces the notion that some form of financial incentive must be provided to maintain interest in the competition if there is no personally vested reason for person to participate in the program. An altruism-based strategy for crowdsourced applications may be feasible for programs like Syria Tracker, but they're not sustainable for something that does not arouse emotions, like finding red balloons or scouring the internet for traces of an unidentifiable nuclear proliferation ring.

What contributions can these individuals make to the platform? During this competition, users were asked to either play a role in recruiting individuals who would be able to help find the red balloon, or to report the location of the red-balloon. In order to successfully report the location of a balloon, individuals were asked to submit a picture of

[153] Pickard et al., "Time-Critical Social Mobilization," 511–512.

the red balloon and to report the exact location of the balloons using street addresses, crossroads, or landmarks.[154]

How does this platform use crowdsourcing to solve the target problem? For this crowdsourced problem set, Media Lab did not employ any remarkable method for compiling the information that they received other than by asking that users go through their website for the recruitment of individuals and balloon reporting. During this exercise, Media Lab created a website on the MIT server and then had each of the teams that were helping theirs distribute links to this site via email, direct messaging, etc.[155] For example, if Jon wanted to recruit his friend Ed to help he would send him a link to http://balloon.mit.edu/jon. This provided Media Lab with an easy way of managing user submissions and analyzing the flow of information distribution.

How does this platform evaluate user contributions and address false-identity attacks? In order to ensure that the information that Media Lab received was authentic, they developed a strategy for filtering false information that relied on two critical ideas.[156] First, balloon sightings that were only reported by one person were ignored. During this exercise, Media Lab frequently received balloon sighting reports for the same red balloon. The submission of multiple reports on the same balloon in the same location meant that there was consistency that could be relied upon and that the balloon's reported location was accurate. Second, user submissions were compared to the reports generated internet protocol (IP) address. For example, if a balloon was reported in Florida but the IP address stemmed from California then the geo-locational information was deemed false. By using this process of elimination the team was able to protect themselves from malicious subversion.

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[154] Tang et al., "Reflecting on the DARPA Red Balloon Challenge," 81.

[155] Tang et al., "Reflecting on the DARPA Red Balloon Challenge," 80.

[156] Tang et al., "Reflecting on the DARPA Red Balloon Challenge," 81.

2. Tag Challenge

The DOS raised the bar on using crowdsourced applications for geo-locational purposes when they developed the "Tag Challenge."[157] On March 31, 2012, they issued the following statement:

> The 2012 Tag Challenge calls on technology enthusiasts from several nations to set their sleuthing skills loose on a mock gang of jewel thieves in an international search contest to take place Saturday, March 31.
>
> The social gaming contest will have participants use technological and social resources to locate and photograph five "suspects" in five different cities—Washington, D.C., New York City, London, Stockholm, and Bratislava—based only on a picture and a short description of each one.
>
> The first person to upload pictures of all five suspects to the Tag Challenge website will earn international bragging rights—and a cash prize of $5,000.[158]

Participants in this challenge were given mugshots of the individuals and a quick back story on them that gave clues to their location. For example, one of the thieves, Teresa Bay, was described as being responsible for counterfeiting Starbucks gift cards. She was later identified while sitting at a Starbucks café.[159] However, the problem of identifying lone individuals in cities with millions of residents persisted and the difficulty of this challenge increased significantly from the Red Balloon Challenge because of the ability of the thieves to "hide in plain sight."[160] For the purposes of this case study our research once again focuses on the winning team, Team CrowdScanner, and the strategy that they employed to locate, identify, and report the location of three of the five individuals.[161]

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[157] "Challenge website – Tag Challenge," n.d., http://www.tag-challenge.com/.

[158] "Challenge website – Tag Challenge," n.d., http://www.tag-challenge.com/.

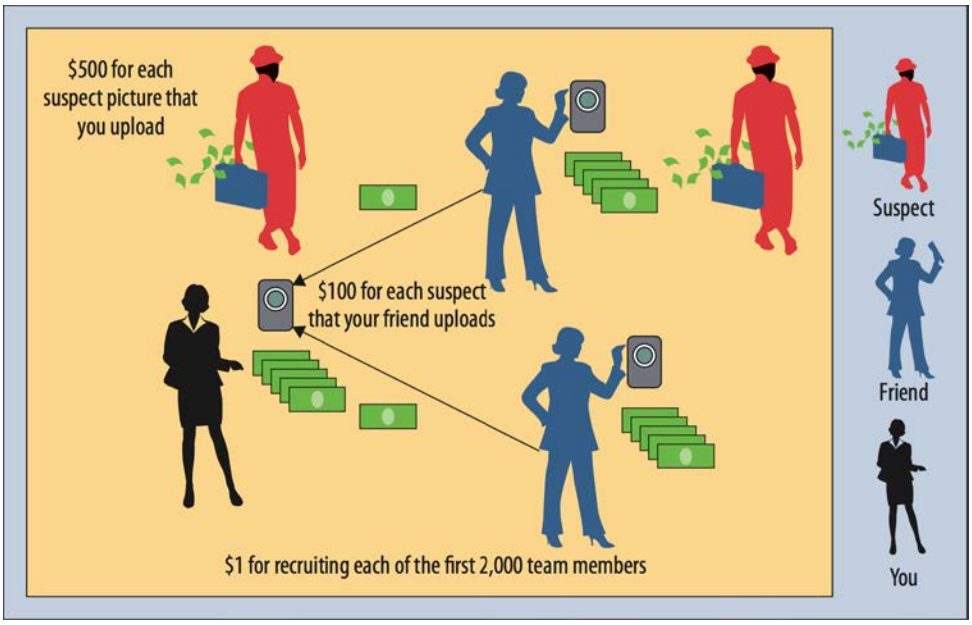
[159] Rebecca Boyle, "POPSCI Q&A: How to Track Down International Jewel Theives via Facebook," April 3, 2012, http://www.popsci.com/technology/article/2012-04/popsci-qampa-how-social-networks-can-succeed-and-fail-solving-international-manhunt.

[160] Alex Rutherford, Manuel Cebrian, Sohan Dsouza, Esteban Moro, Alex Pentland, and Iyad Rahwan, "The Limits of Social Mobilization," *Proceedings of the National Academy of Sciences of the United States of America*, 110, 16 (2013): 6281–6286.

[161] Iyad Rahwan, Sohan Dsouza, Alex Rutherford, Victor Naroditskiy, James McInerney, Matteo Venanzi, Nicholas R. Jennings, and Manuel Cebrian, "Global Manhunt Pushes the Limits of Social Mobilization," *IEEE Computer Society*, 46, 4 (April 2013): 68–75.

How does this platform recruit and retain individuals? Team CrowdScanner was composed of many of the former members of MIT's Media Lab team and as a result used many of the same approaches that they had used in 2009 for the recruitment and retention of users. The *recursive incentive-structure* was once again employed in order to financially incentivize individuals to not only help find the thieves, but also recruit their friends to help them. For this exercise, however, a slight modification to the payouts was made as a result of the reduced prize money.[162] A prize of $500 was awarded by the team to anyone who could upload a picture of one of the thieves, an additional $100 was given to the person that referred them to that person, and $1 was provided to recruiters for each person that they got to sign up and participate (see Figure 9).

Figure 9. Recursive Incentive Structure for Tag Challenge



Source: Rahwan et al., "Global Manhunt Pushes the Limits of Social Mobilization," 71.

What contributions can these individuals make to the platform? As with the Red Balloon Challenge, individuals were asked to not only help in finding the location of the thieves, but also play a direct role in recruiting others. A successful identification of a

[162] Rahwan et al., "Global Manhunt Pushes the Limits of Social Mobilization," 70.

thief during this competition included their location at time of siting, as well as, a picture of their shirt, which the Department of State labeled with key images in order to root out any attempt at false identification.[163]

How does this platform use crowdsourcing to solve the target problem? Team CrowdScanner once again developed a website for the management of user contributions and referrals, but also added a mobile application for this competition.[164] Surprisingly, many of the participants elected not to use the website or mobile apps during this competition when reporting the location of a thief, but instead chose to directly email Team CrowdScanner, indicating the value of direction communication when information is deemed important enough.[165]

How does this platform evaluate user contributions and address false-identity attacks? During this exercise, Team CrowdScanner experienced no issues with the aggregation and verification of the data that it received. Much of this had to do with the coded images that were labeled on the shirts of the thieves, thus making manual verification relatively simple. Additionally, the fact that the team only received one image from each of the three cities that thieves were successfully found in made aggregation of information a non-requirement. However, this is not say that participation in the exercise was minimal as Figure 10 shows the global participation that Team CrowdScanner reached.

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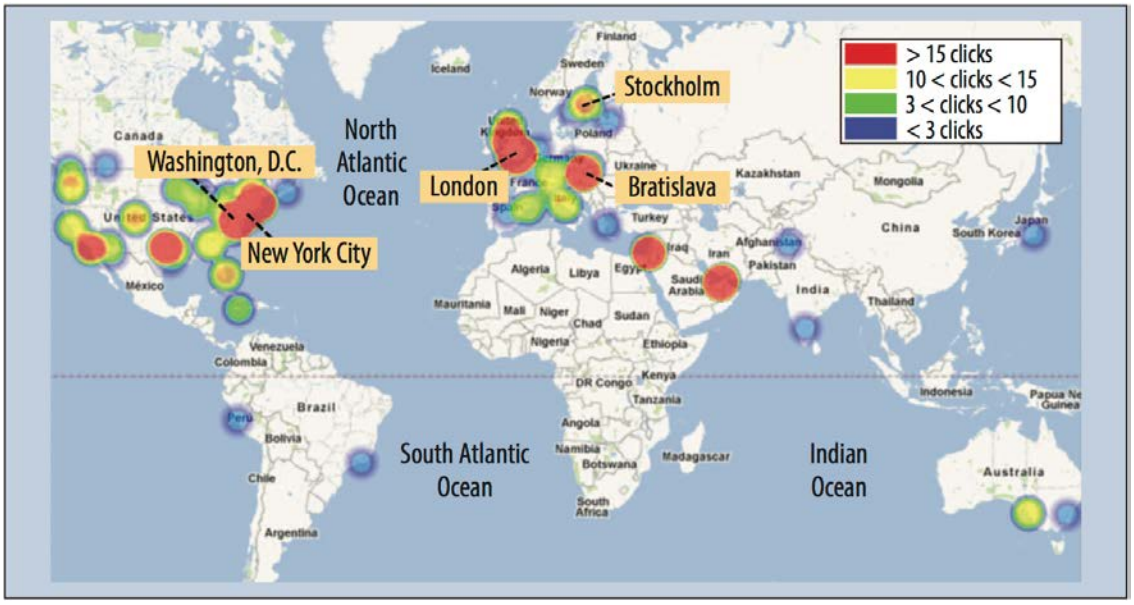
[163] Kim Stephens, "The Social Media Tag Challenge: CrowdScanner Describes How They Won," *idisaster 2.0*, April 16, 2012, accessed October 15, 2016, https://idisaster.wordpress.com/2012/04/16/the-social-media-tag-challenge-crowdscanner-describes-how-they-won/.

[164] Rahwan et al., "Global Manhunt Pushes the Limits of Social Mobilization," 71.

[165] Rahwan et al., "Global Manhunt Pushes the Limits of Social Mobilization," 71.

Figure 10. Heat Map Showing the Distribution of Visitors to Team CrowdScanner's Website.



Source: Rahwan et al., "Global Manhunt Pushes the Limits of Social Mobilization," 71.

C. CGD FOR NUCLEAR PROLIFERATION VALIDATION

Regardless of the source, once information is collected and aggregated it has to be validated somehow in order to ensure authenticity. Within the U.S. Intelligence Community this usually takes the form of multiple, reliable human reports and corroboration with other forms of collection tools, such as satellite imagery, geographic sensors, or signal reports. However, CGD applications are particularly adept at the validation of information where multiple views of data can help identify flaws in analysis or even help report anomalies.[166] Eric Raymond, the author of "The Cathedral and the Bazaar," referred to this as Linus's Law when he stated that, "given enough eyeballs, all bugs are shallow."[167] Towards this end we explore a case study where faculty from CNS used crowdsourcing tools to validate the People's Republic of China's assertions that

[166] Rice et al., "Crowdsourced Geospatial Data – A Report on the Emerging Phenomena of Crowdsourced and User-Generated Geospatial Data (2012)."

[167] Eric S. Raymond, "The Cathedral and the Bazaar," *First Monday* (1998): 3, 3–2 accessed October 19, 2016, doi:10.5210/fm.v3i2.578.

they had not provided North Korea with transporter-erector-launcher (TEL) vehicles that could then be used as mobile intercontinental ballistic missile (ICBM) platforms.[168]

In the last few years, North Korea has increasingly used its nuclear arsenal to threaten retaliation and respond to what it has deemed as existential threats to its regime's existence.[169] The international community's growing concern over the willingness of North Korea to use these weapons has provided significant incentives to finding alternative methods for monitoring and verifying international adherence to the various nuclear non-proliferation treaties (e.g., NPT, CTBT, and the proposed Fissile Material Cut-Off Treaty).[170] Over the last few years, the Institute of Nuclear Materials Management has explored an area of crowdsourcing that they referred to as *outsider reporting*, an innovative approach that looks to foreigners to use emerging technology, such as DigitalGlobe's free satellite imagery, to help report treaty violators.[171] As Ronald Mitchell stated,

> Outsiders have stronger incentives to monitor and provide information, although they have more limited capacities, since the risk from the suspect government is far less. Indeed, most governments would consider any effort to retaliate against their citizens for helping to reveal clandestine nuclear activity as warranting severe sanctions. Thus, these actors face far

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[168] This case study is drawn from Lee, Lewis, and Hanham, "Assessing the Potential of Societal Verification by Means of New Media"; Bryan L. Lee, "Societal Verification 2.0: Online Technologies and Inspection by the People," *CNS, INMM Annual Meeting Proceedings 2014, Institute of Nuclear Materials Management* (2014), accessed October 16, 2016 http://www.inmm.org/source/proceedings/files/2014/a667_1.pdf.

[169] Ryan Browne and Barbara Starr, "North Korea Threatens Nuclear Strike Amid US-South Korea Drill," *CNN*, August 22, 2016, accessed October 31, 2016, http://www.cnn.com/2016/08/22/politics/north-korea-south-korea-us-military-exercise/; Greg Price, "North Korea Threatens U.S. Base With Nukes: Kim Jong Un Regime Warns Of 'Uncontrollable' Nuclear War," *International Business Times*, September 23, 2016, accessed October 31, 2016, http://www.ibtimes.com/north-korea-threatens-us-base-nukes-kim-jong-un-regime-warns-uncontrollable-nuclear-2420951.

[170] Frank V. Pabian, "The New Geospatial Tools: Global Transparency Enhancing IAEA Safeguards," (paper presented at the 54th Annual Meeting for the Institute for Nuclear Material Management, Palm Desert, California, July 17–22, 2011).

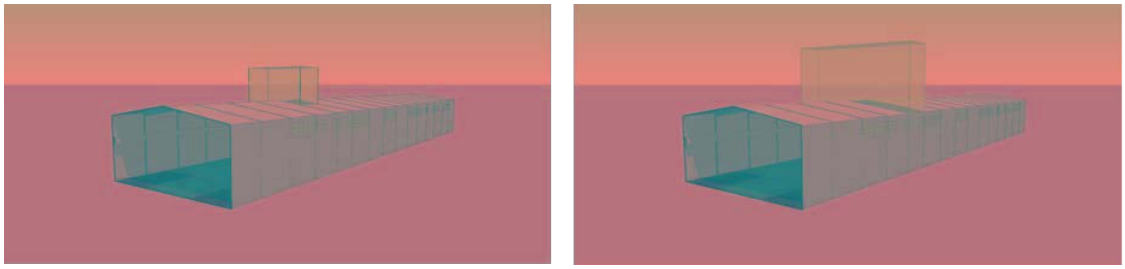
[171] Jessica Bufford, "Societal Verification: Past and Present," *Workshop Proceedings on Information Analysis Technologies, Techniques and Methods for Safeguards, Nonproliferation and Arms Control Verification* (July 2014), 27–37.

> less risk of retaliation, assuming they are outside the suspect country at the time the information becomes public.[172]

As Mitchell points out, this method for crowdsource reporting has significant limitations, but a successful application of this idea was in fact realized.

In April of 2012, Chinese officials reported the sale of highly specialized vehicle chassis to North Korea the previous year.[173] While these vehicles were sold to North Korea with the understanding that they would be used for commercial purposes, they were instead repurposed into TEL vehicles. The team from CNS then used free, three-dimensional computer modeling software from a company called SketchUp[174] to construct a drawing of the housing structure for this vehicle based on imagery from the commercial Chinese company's website and a YouTube posted North Korean propaganda video (see Figure 11).[175]

Figure 11. SketchUp Drawing Developed by CNS.



Source: Lee, Lewis, and Hanham, "Assessing the Potential of Societal Verification by Means of New Media," 17.

Once the team had an idea of what the building might look like they began data mining South Korean social media sites for North Korean defector information about the

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[172] Ronald P. Mitchell, "Identifying Undeclared Nuclear Sites: Contributions from Nontraditional Sources," *Proceedings from the Second Workshop on Science and Modern Technology for Safeguards* (September 2014), 66.

[173] United Nations, S/2013/337, http://www.un.org/ga/search/view_doc.asp?symbol=S/2013/337

[174] "SketchUp – 3D Modeling for Everyone," n.d., http://www.sketchup.com/.

[175] "Kim Jong Il's Efforts to Defend the Country," YouTube video, 46:47, posted by Korean Friendship Association (USA), August 28, 2013, https://www.youtube.com/watch?v=4L99vxPy3N8.

possible location of missile launch sites and discovered that Changang Province was a highly likely location.[176] At this point they then used Wikimapia, as well as, a North Korea Uncovered KMZ file, courtesy of the blog North Korean Economy Watch, to ascertain the most likely location of the buildings by searching in the vicinity of North Korea's surface to air missile launch sites.[177] In this way they took two different CGD tools to create an analysis of an area that in essence created a new CGD map. With this information they were able to identify a structure using GoogleMaps[178] that was an almost identical match to the structure that they created using the SketchUp software (see Figure 12). The ability of the team from CNS to use social media analysis and CGD map analysis to extrapolate the location of the North Korean TEL is remarkable. It underscores how these tools can be successfully leveraged towards real-world threats in a denied environment.

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[176] Lee, Lewis, and Hanham, "Assessing the Potential of Societal Verification by Means of New Media," 18.

[177] Lee, Lewis, and Hanham, "Assessing the Potential of Societal Verification by Means of New Media," 19; SAMs are frequently identified on www.wikimapia.org, http://geimint.blogspot.com, and www.nkeconwatch.com/north-korea-uncovered-google-earth, because their distinctive shapes are easily recognizable.

[178] "GoogleMaps," n.d., http://www.googlemaps.com/.

Figure 12. GoogleMaps Imagery of Suspected TEL Housing Structure.

Source: Lee, Lewis, and Hanham, "Assessing the Potential of Societal Verification by Means of New Media," 21.

D. CONCLUSION

In this chapter we explored a variety of examples of how CGD has been used to solve a problem or create better solutions. CGD applications can vary in terms of how user input is synthesized with government data. In the Waze example, the two played equal roles in providing a traffic and navigational solution. In the Syria Tracker, it was the users that provided all the information with the responsibility of aggregation being the purview of the sponsoring non-governmental agency. The Red-Balloon and Tag Challenges showcased an example of CGD where commercial imagery analysis played an almost insignificant role in location, but user input in the form of social networking geo-locational, was critical for the success of this type of CGD. A critical note from these two examples was the use of recursive incentive structure to leverage the support of users to participate in solving the problem, but also in the recruitment of others to aid in this

effort. In the final case study, we reviewed an example of how multiple CGD maps and applications were used to ascertain the possible location of a North Korean missile site.

The scale and breadth by which crowdsourcing can impact the diverse spectrum of nuclear proliferation threats constitutes a serious consideration of how they can be developed for use by the CP community. CGD tools are pervasive and have already become integral parts of our daily lives. While the application of these tools by the U.S. Government has been minimal, there are exponential opportunities for how they can be used towards real-time reporting, geo-locational searches, and information validation. The application of these tools can provide USSOCOM with innovative methods at better answering the question of where proliferation networks are operating and may help expose how they are operating. We now turn our thesis towards the challenges that CGD applications face and make specific recommendations for how USSOCOM can apply these techniques.

V. ADDRESSING THE SKEPTICS

On the afternoon of April 15, 2013, two bombs went off near the finish line of the Boston Marathon. In the immediate aftermath of the attack, the Federal Bureau of Investigation issued an unprecedented call for any and all images that could possibly aid in efforts to identify possible suspects.[179] By this time, photos and videos of the attack were already saturating social media sites, such as Twitter, Facebook, and YouTube. On one site, Reddit.com,[180] users were already coming together to make their own conjectures about who the possible suspects were. In an effort to unravel the case on their own, they used crowdsourced images and information to create their own individual investigations.

Well before the authorities released any leads, some of these users began offering to the public their own conclusions on who the possible suspects were. What ensued was an online witch-hunt that devastated the lives of several individuals and their families. Two men, labeled as the "backpack brothers," were barraged on Facebook and had their pictures featured on the front page of the *New York Post*.[181] Another man, Sunil Tripathi, was erroneously identified as a suspect despite having been missing for almost eight weeks.[182] His family's Facebook page, "Help Us Find Sunil Tripathi," was saturated with

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[179] Spencer Ackerman, "Data for the Boston Marathon Investigation will be Crowdsourced," Wired Magazine 13.04 (2013), accessed November 1, 2016, https://www.wired.com/2013/04/boston-crowdsourced/.

[180] "Reddit," n.d., https://www.reddit.com/.

This is a website where news and information are crowdsourced. Users provide all the content and decide through voting, what should be read or not read.

[181] David A. Fahrenthold and Caitlin Dewey, "Backpage Brothers an Example of the Drawbacks to Internet Sleuthing," *WashingtonPost*, April 18, 2013, accessed November 1, 2016, https://www.washingtonpost.com/local/dc-politics/backpack-brothers-an-example-of-the-drawbacks-to-internet-sleuthing/2013/04/18/8c0ea9fa-a852-11e2-b8ad-87b8baf4531b_story.html.

[182] Alyson Shontell, "What it's Like When Reddit Wrongly Accuses Your Loved One of Murder," *Business Insider*, July 26, 2013, accessed November 1, 2013, http://www.businessinsider.com/reddit-falsely-accuses-sunil-tripathi-of-boston-bombing-2013-7.

hate messages and condemnations. He was later found dead.[183] While Reddit users were inspired to aid in locating the Boston Marathon Bombing suspects, in the end, their spread of misinformation only led to wrongful accusations.

A. CROWDSOURCED MISINFORMATION

In the end, it came down to more traditional police work that led authorities to the Boston marathon Bombing suspects.[184] While the authorities' lead came from a video obtained from the vicinity of the attack, it was not one of the ones that had been uploaded to the internet or submitted to authorities by eyewitnesses. This case calls into questions the utility of crowdsourcing in time-critical events. Crowdsourced reporting is particularly vulnerable to the spread of these types of misinformation, especially in denied or war-torn areas. On November 9, 2015, a video link was released on Twitter purporting to be documentation of 200 children being executed by Islamic State militants.[185] The video in question turned out to be approximately one-year-old and had in fact been a video depicting Islamic State militants murdering 200 Syrian Assad regime soldiers after their base was overrun.[186] While no one can effectively argue that the Islamic State does not use deplorable tactics, crowdsourcing on the internet led to misattribution and the spread of false information.

To say though, that crowdsourcing information is fundamentally flawed because of a lack of expert opinion and that trusted authorities and news media outlets do not themselves get things wrong, is false. Government agencies routinely misattribute and

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[183] Pamela Engel, "Brown Student Falsely Linked to Boston Bombing Found Dead," *Business Insider*, April 25, 2013, accessed November 1, 2016, http://www.businessinsider.com/brown-student-falsely-accused-of-bombing-dead-2013-4.

[184] Julianne Pepitone, "Boston's Legacy: Can Crowdsourcing Really Fight Crime," *NBCNews*, April 12, 2014, accessed November 1, 2016, http://www.nbcnews.com/tech/internet/bostons-legacy-can-crowdsourcing-really-fight-crime-n74831.

[185] Daily Star, Twitter post, November 9, 2016, 9:16 a.m., https://twitter.com/Daily_Star/status/663767023256637440

[186] Corey Charlton, "Anti-Isis Activists Use Horrific Jihadi Propaganda Film to Claim Brutal Militants Executed Hundreds of Children," *DailyMail*, November 9, 2015, accessed November 1, 2016, http://www.dailymail.co.uk/news/article-3310486/Shocking-footage-shows-ISIS-militants-massacring-200-captive-Syrian-children-bloodthirsty-jihadis-latest-mass-execution.html.

make wrongful accusations all the time. On July 27, 1996, Richard Jewell was working as a temporary security guard when he noticed an oddly placed green backpack outside of where the Atlanta Summer Olympics were being held.[187] After he notified authorities and assisted in getting pedestrians away from the backpack, a bomb went off, killing one and wounding hundreds of bystanders. In the aftermath of the explosion, Jewell went from being called a hero by news outlets, to being labeled as the number one suspect by authorities and vilified by the media, and then back again as a recognized hero. The trusted and vetted authority of national news media and law enforcements agencies were soon called into question as Jewell had his life turned upside down and then back again.

The inherent strengths of crowdsourcing rests in the fact that these applications serve as living platforms that are consistently being enhanced by more and more feedback. The often criticized reliability of Wikipedia is particularly vulnerable to these types of condemnations. However, a cursory glance at the edit pages for the articles on Wikipedia reveals a detailed list of amendments, the responsible editors, and when these edits were made. It is true that an individual can go on this site and change the date of the Pearl Harbor Attack from December 7, 1941 to December 8, 1941. However, these changes have to be accepted by other users before they are accepted and are subject to quick amendments by concerned historians who do not wish to have these facts falsely distributed. Another website, Bellingcat,[188] is an example of crowdsourced information self-correcting. This site is comprised of individual experts from around the world who routinely fact-check and verify the authenticity of images, videos, and reports that surface on social media sites. The ability of crowdsourced information to auto-correct itself gives itself enough credibility to stand as a complementary tool to traditional forms of information gathering and analysis.

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[187] Kevin Sack, "Richard Jewell, 44, Hero of Atlanta Attack, Dies," *NewYorkTimes,* August 30, 2007, accessed November 1, 2016, http://www.nytimes.com/2007/08/30/us/30jewell.html.

[188] "Bellingcat – by and for citizen investigative journalists," n.d., https://www.bellingcat.com/.

B. THE LIMITS OF CGD IN DENIED ENVIRONMENTS

Two of the case studies reviewed dealt with reporting in denied environments. While each of them show-cased successful CGD applications in their respective situations, fundamental weaknesses in the data obtained must be addressed. The most critical factor in recognizing the limits of CGD in denied environments is the incredible risks that the use of these applications pose to the citizens that employ them. As Kass-Hout, one of the founders of Syria Tracker, states, "along the way, we have lost reporters. We get reports from them for months and months and then we stop getting reports from them."[189] Asking citizens in these denied environments to participate in CGD tools that support CP policies in effect makes them vulnerable to accusations that they are spies for America.

The second factor that must be considered is the age of the information that is being collected. A significant aspect of the CNS study on finding the potential location of the North Korean TEL was the social media blogs that were posted by North Korean defectors who were commenting on the location of North Korean air defense sites. The use of CGD tools in this case study was predicated on the assumptions gleaned from these blog sites. However, since these were North Korean defectors, it calls into question how recent the information that they were sharing was. While it seems to have worked out for CNS in this case study, the same may assumptions not always hold true. Is information truly considered reliable if it is derived from individuals who came from a denied environment possibly two years earlier?

These factors speak to an aspect of CGD employment that USSOCOM must consider, that deploying these tools in denied environments should only be regarded as part of in-extremis operation. Furthermore, using CGD tools for an emergency search operation should be regarded as a final measure when all other methods for proliferation monitoring have failed and determining the location of a nuclear device is considered a national priority. While it is possible to protect the identities of users in a denied

[189] Plucinska, "Crowdsourcing During a Crisis Has Its Drawbacks."

environment by having them use Tor software,[190] this program is becoming increasingly less adept at protecting user anonymity.[191] There are many benefits to using CGD, namely being its low-cost and high-impact medium for analyzing geospatial data, but using it as a CP tool that harnesses individuals in a hostile, denied environment is only recommended in emergency circumstances.

C. SYBIL ATTACKS ON THE RECURSIVE INCENTIVE STRUCTURE

One of the benefits of the recursive incentive structure is its efficacy at producing recruiters that provide a clear path towards individuals who can produce answers to queries. In the Red Balloon and Tag Challenge case studies, the monetary rewards were highly effective at incentivizing individuals to participate in the recruitment and querying process. However, one of the challenges that were encountered by the Media Lab team was the submission of false information from false identities, otherwise known as sybils. The Media Lab team was able to effectively navigate around these sybil-attacks by closely scrutinizing IP addresses and conducting a comparative analysis of sybil submissions with other user-generated submissions. This methodology quickly isolated the sybil-attacks and protected the validity of the balloon location submissions.

However, if USSOCOM proceeds with the development of CGD application that leverages the support of internet users in monitoring open-source satellite imagery, the scale by which the CGD application will need to protect itself from sybil-attacks will be significantly larger. To this end, research is being conducted into the creation of algorithms that are variations of the recursive incentive structure and provide arguably sybil-proof solutions.[192] Many of these algorithms focus on the production of split-

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[190] Tor is an open-source software that directs internet traffic through a worldwide network of thousands of relays to conceal a user's location and usage from anyone conducting network surveillance or traffic analysis.

[191] Xinwen Fu and Zhen Ling, "One Cell is Enough to Break Tor's Anonymity," *White Paper for Black Hat DC 2009*, accessed November 1, 2015, http://www.blackhat.com/ presentations/bh-dc-09/Fu/ BlackHat-DC-09-Fu-Break-Tors-Anonymity.pdf.

[192] Wei Chan, Yajun Wang, Dongxiao Yu, and Li Zhang, "Sybil-Proof Mechanism in Query Incentive Networks," *In Proceedings of the Fourteenth ACM Conference on Electronic Commerce*, 197–214, accessed November 1, 2016, https://arxiv.org/abs/1304.7432.

contract payments that vary themselves depending on the quality of the user submissions, as well as, the responsible recruiters. Its argued that this methodology reduces the desire of sybil-attacks by de-incentivizing individuals from spending the time to create false identities if the payout structure is not large enough to warrant the effort. Even a dedicated sybil-attack that relies upon multiple bots to create sybils can be quickly isolated and denied access to the CGD application once it is found.

D. CONCLUSION

Inevitably there will always be impediments and drawbacks to the deployment of CGD applications for CP operations. Whether it is information that is wrongly misattributed or a malicious sybil-attacks, some effort will have to be dedicated to protecting the integrity of CGD applications at providing reliable feedback that complements existing nuclear proliferation monitoring efforts. The unique nature of crowdsourcing means that along the process of CGD deployment, this requirement will not be the sole responsibility of USSOCOM. Users that are incentivized to participate in a CGD application that aids nuclear proliferation monitoring can be just as quickly incentivized to find solutions that might threaten these systems. The Ushahidi platform is now on its third edition and code lines are constantly being added by users to streamline its performance.[193] This is indicative of crowdsourced, open software systems and speaks to their ability to leverage concerned users towards maintaining their efficacy. While there are those who will be skeptical of the performance of CGD tools to complement existing nuclear proliferation monitoring efforts, there will also be users ready to address their concerns.

[193] "Add Code to Ushahidi," n.d., https://www.ushahidi.com/support/add-code-to-ushahidi.

VI. CONCLUSION

Crowd-sourced Geospatial Data is an instrument that has practical application toward monitoring efforts in support of counter proliferation operations and policies. Although we recognize that CGD is not a "silver-bullet" to address a problem that has metastasized over time, we assert that it should be seen as a viable and inexpensive (in terms of financial and personnel resources) tool available to those who can creatively implement it. We recommend that USSOCOM, and any other governmental agency that employs these tools, use the following recommendations from this study. First, deploy a CGD application through the Ushahidi application. As one of the first open-source software programs capable of aggregating and displaying large amounts of data on to geo-spatial imagery, it stands as the most widely recognized and usable application for concerned citizens around the world. Second, incentivize individuals to participate in CGD by using the recursive incentive structure. In multiple exercises and studies, this methodology has repeatedly shown itself to be far superior to other methods in galvanizing support for geo-locational purposes. Finally, build the CGD application in with other commercial, off the shelf nuclear detection sensors around the world. The results of these sensors could be displayed using the Ushahidi platform with users being given the ability to comment on results and make recommendations.

A. USE THE USHAHIDI PLATFORM

Since its inception in 2008, the Ushahidi platform has been deployed by organizations around the world, including the United Nations, British Broadcasting Channel, the World Bank, and the Red Cross. The strength of the program lies in its ability to quickly receive data through multiple mediums, such as twitter feeds, emails, instant messages, etc., while simultaneously allowing the creator of the map to manage and triage reports. This provides an unparalleled capability for filtering data and building multiple map layers and configurable charts that provide easy to read display results. These features are significantly more developed then similar CGD programs, such as

LiveUAMap.[194] By deploying a tool through Ushahidi, USSOCOM would be working off a capability that has been thoroughly vetted and trusted by agencies and individuals from around the world. Furthermore, the continuous updates to the Ushahidi program has made the software much more durable against crashes and the crowdsourced nature of its current version makes fixes less of a concern for USSOCOM.

B. USE THE RECURSIVE INCENTIVE STRUCTURE

In the Red Balloon and Tag Challenge case studies the recursive incentive structure was found to be far superior at galvanizing individuals than any other incentive structure. While other teams in these competitions attempted to rely upon heavily built social media followings or altruism based incentive structures, the winning team from these two competitions showed the power that small amounts of well-placed money have in getting internet users involved in simulated geo-locational exercises. For this incentive structure to be fully realized, USSOCOM would need to build a website that allows it to manage user submissions and user references. It would then need to tie this website in with its Ushahidi software so that users can see the fruits of their labor. By deploying these two together, USSOCOM can potentially get individuals from the world involved in the tedious task of nuclear proliferation monitoring.

C. BUILD CGD INTO OTHER SENSORS

A DARPA initiative utilizing a crowd-sourced radiation sensor showed considerable promise for further applications of CGD to augment CP monitoring efforts. At a demonstration of the devices in September of 2015, the sensor transmitted a signal through a paired cell phone that was sending the data to a server that was recording the readings from the sensor and all the other sensors in use at the conference.[195] The data that was received was aggregated in a government cloud bank for analysis. This information was then used to produce a heat map of the radiation levels at the event. The

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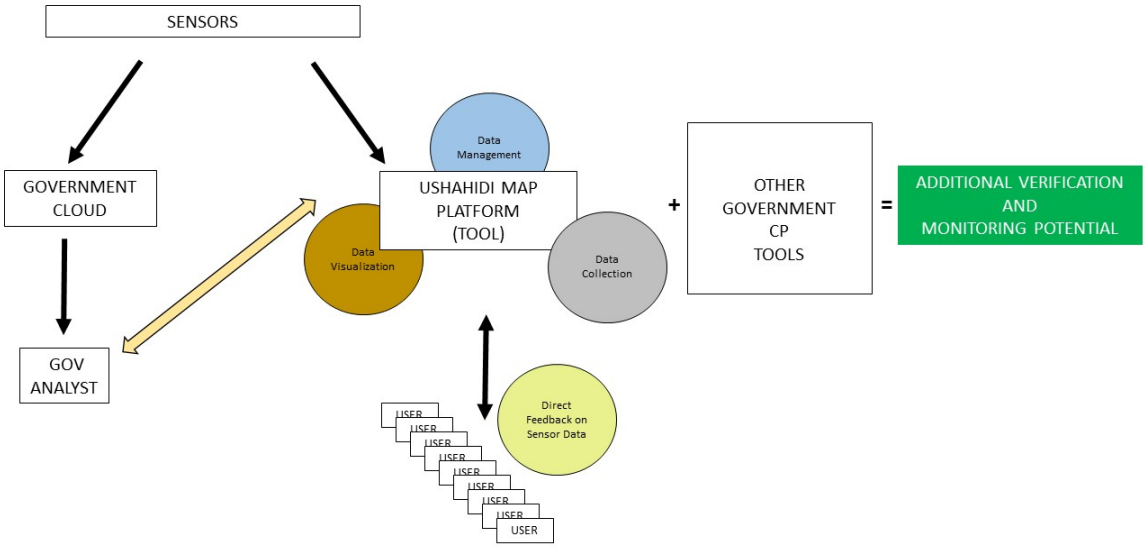
[194] "LiveUAMap," n.d., http://liveuamap.com.com/.

[195] Martyn Williams, "DARPA shows off a crowd-sourcing radiation detector," CIO from IDG. September 9, 2015, http://www.cio.com/article/2983232/darpa-shows-off-a-crowd-sourcing-radiation-detector.html. Accessed November 9, 2016.

demonstration of the relatively cheap DARPA device, working in concert with mobile-connected devices, show potential for strategic placement of sensors around the globe to corroborate nuclear inclinations. However, since these sensors are being created using commercial, off the shelf technology and being first deployed around the U.S. to first responders (i.e., police officers, EMT personnel), there is a huge potential for synching this technology with a CGD application.

Our recommendation to USSOCOM would be to tie CGD tools into sensor programs similar to the one now being deployed by DARPA. Rather than sending the information collected by the sensors to a government cloud for analysis, we recommend that the sensors report to the government cloud, as well as, a server that can then feed the information into a Ushahidi crisis map. This would be a hybrid solution similar to the one created in the Waze case study, where public and private interests converge to form a better product. By relaying the data this way it allows for outside analysis to aid in focused monitoring efforts. Furthermore, by employing the recursive incentive structure alongside the CGD tool and nuclear detection sensors, USSOCOM can encourage a wider array of participation (see Figure 13).

Figure 13. Overlay of Proposed Sensor Network with the Ushahidi Platform.



Another possible contemporary application of CGD, with a recursive incentive structure, lies in targeting the emerging second-tier proliferation networks efforts to acquire nuclear components and materials abroad. The need for outsourcing materials provides an opportunity to partner with logistics companies and offer monetary incentives for reporting "irregular" shipments. This method of monitoring has the potential to limit the needle in a haystack approach to import/export control lists that consume multiple hours of customs agents time. Additionally, it plays to the weakness of a proliferation network that is primarily motivated by money. Moreover, an incentive based approach which rewards the location of illicit shipments as well as recruiting additional businesses to contribute to the efforts, can cause considerable logistics concerns to proliferators. Overlaying the Ushahidi based CGD would also allow an on-line open source profile of these questionable shipments that can be monitored and edited as the chameleon-like nuclear smuggling networks adapt.

Of particular interest to USSOCOM are the potential avenues available through our partnerships with foreign militaries and police units. The dispersal of similar devices can aid on-going proliferation partnerships, training and future operations. Due to the classified nature of military CP Tactics, Techniques and Procedures (TTP), much of the knowledge concerning proliferation is not something that is shared liberally with foreign partners. As such, the DARPA sensor model is a tool for CP that can be considered for implementation within foreign units responsible for WMD response, but lack the technical monitor/search capability. The sensors mentioned are not classified (an assumption made from the publication in a journal) and the information would be routed through Ushahidi, allowing the partner nation to have uninhibited access and editorial rights to the data collected. This type of real-time incident population to Ushahidi could lead to more timely notification for US/allied forces awareness as well as a shorter response time to a crisis.

CGD tools are pervasive and have already become integral parts of our daily lives. There are on-going crowd-sourcing initiatives of commercial map imagery as a monitoring option, but this type of CGD is more applicable to monitoring for treaty and agreement infringements. The scale and breadth by which crowdsourcing can impact the

diverse spectrum of nuclear proliferation threats constitutes a serious consideration of how they can be developed for use by the CP community. The herculean task the IA and DOD shoulder in support of CP and security is noteworthy. By using CGD, USSOCOM is investing in a low-cost, high-impact tool that may potentially have huge benefits in amplifying existing efforts aimed at preventing the illegal acquisition of nuclear material, components, or weapons.

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