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QUANTITATIVE GEOSPATIAL ANALYSIS OF OPEN-SOURCE DATA TO PROVIDE MEASURES OF EFFECTIVENESS OF OPERATIONS IN THE INFORMATION ENVIRONMENT

by

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Evaluating the effectiveness of U.S. military information operations (IO) remains a complex task for IO professionals. Nevertheless, assessment is an indispensable component of any military operation. This thesis, therefore, seeks to examine the feasibility and practicality of employing data-driven geospatial analysis to assess operations in the information environment (OIE). To achieve this objective, the study utilized open-source data, including social media messages, violent death records, and news articles, to evaluate the impact of U.S. military and coalition forces' leaflet drop operations against the Islamic State of Iraq and Syria (ISIS). The findings of this research indicate that the leaflet drop operations were associated with an uptick in social media communications, a decline in positive sentiment expressions on social media, and a reduction in violent deaths. Based on the preliminary evidence presented here, it seems that these operations had a mixed overall effect as they stimulated social media discussions and reduced violent deaths but led to a decrease in positive sentiment expressions on social media. However, the overarching message of this study extends beyond the mere utility of social media or the specific outcomes of the operations. Instead, it highlights how a data-driven geospatial approach to operational assessment can yield more rigorous judgments by modeling the behavioral effects of operations.

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QUANTITATIVE GEOSPATIAL ANALYSIS OF OPEN-SOURCE DATA TO PROVIDE MEASURES OF EFFECTIVENESS OF OPERATIONS IN THE INFORMATION ENVIRONMENT

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ABSTRACT

Evaluating the effectiveness of U.S. military information operations (IO) remains a complex task for IO professionals. Nevertheless, assessment is an indispensable component of any military operation. This thesis, therefore, seeks to examine the feasibility and practicality of employing data-driven geospatial analysis to assess operations in the information environment (OIE). To achieve this objective, the study utilized open-source data, including social media messages, violent death records, and news articles, to evaluate the impact of U.S. military and coalition forces' leaflet drop operations against the Islamic State of Iraq and Syria (ISIS). The findings of this research indicate that the leaflet drop operations were associated with an uptick in social media communications, a decline in positive sentiment expressions on social media, and a reduction in violent deaths. Based on the preliminary evidence presented here, it seems that these operations had a mixed overall effect as they stimulated social media discussions and reduced violent deaths but led to a decrease in positive sentiment expressions on social media. However, the overarching message of this study extends beyond the mere utility of social media or the specific outcomes of the operations. Instead, it highlights how a data-driven geospatial approach to operational assessment can yield more rigorous judgments by modeling the behavioral effects of operations.

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LIST OF ACRONYMS AND ABBREVIATIONS

AQI	al Qaeda in Iraq
DOD	Department of Defense
EPW	enemy prisoners of war
GDP	gross domestic product
GED	Georeferenced Event Dataset
GPW	Gridded Population of the World
GRIP	Global Roads Inventory Project
IE	information environment
IO	information operations
ISIS	Islamic State of Iraq and Syria
JP	Joint Publication
MISO	military information support operations
MOE	measure of effectiveness
NPS	Naval Postgraduate School
OE	operating environment
OIE	operations in the information environment
OIR	Operation Inherent Resolve
PAI	publicly available information
PSYOP	psychological operations
SOCOM	Special Operation Command
UCDP	Upsala Conflict Data Program

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EXECUTIVE SUMMARY

This thesis addresses the challenge of assessing operations in the information environment (OIE), which often aim to change non-physical aspects such as human behavior, perceptions, and attitudes. The assessment is further complicated by the concurrent occurrence of multiple events, making it difficult to attribute observed changes specifically to one operation. Therefore, this study examined the potential of using open-source data to assess the impact of OIE, emphasizing the potential of data-driven methods like social media and geospatial analyses for evaluating OIE effectiveness.

This thesis employs a spatiotemporal methodology, analyzing social media and open-source data to evaluate the effectiveness of U.S. coalition forces' leaflet drop operations in Raqqa and Mosul from 2014 to 2016 against the Islamic State of Iraq and Syria (ISIS) during Operation Inherent Resolve (OIR). OIR serves as a unique case study due to its involvement with ISIS, one of the first terrorist organizations to effectively utilize social media and other online platforms for spreading its message and recruiting new members.

The spatiotemporal methodology employed in this study utilized a 5-kilometer grid cell unit of analysis and 2-week to 4-week time periods to assess the impacts of operations on social media communications and the rate of violence. Additionally, Poisson regression was used to examine the relationship between the interaction of two independent variables: Time (pre- and post-leaflet drop) and treatment distance (Raqqa Binary and Mosul Binary, defined based on a radius of 65 kilometers from the city center) and three dependent variables: Total Message Count, Positive Message Count, and Death Count for each leaflet drop operation.

The study yielded three key findings: 1. Leaflet drop operations were associated with an increase in social media communications. 2. These operations also corresponded with a decline in expressions of positive sentiment. 3. A decrease in violent deaths was observed following leaflet drop operations. Based on the preliminary evidence presented here, it seems that these operations had a mixed overall effect as they stimulated social

media discussions and reduced violent deaths but led to a decrease in positive sentiment expressions on social media. We also observed important differences between operations, for instance, in the operation on March 10, 2016, in Mosul, Iraq, we observed an increase in violence following the leaflet drop, rather than a decrease. These partially divergent outcomes seen in these cases point strongly towards the need for additional research to unpack the conditions under which operational approaches lead to different outcomes in different operations.

While these findings provide a valuable tool for assessing OIE, the study's overarching message is not merely about the utility of social media or specific operational outcomes. Instead, it highlights the power of a data-driven, geospatial approach to operational assessment in producing more rigorous evaluations by modeling the behavioral effects of operations. Therefore, this study demonstrates the feasibility of using data-driven methods to evaluate the impact of OIE efforts on both online and offline behaviors, including communication patterns and violent activities, and by integrating data from various sources such as publicly available information (PAI), social media, news outlets, and other open-source data, it provides a holistic understanding of OIE's impact on behaviors.

Based on these findings, our core recommendation is that the joint force should adopt these data-driven geospatial approaches to the assessment of OIE. This would provide transformative capability leveraging ongoing open-source streams to dynamically assess operations and effects at scales that were previously impossible. In contrast to the current assessment approaches which tend to be ad-hoc and subjective, this new approach leverages cutting-edge statistical techniques to provide quantifiable metrics of actual behavioral impacts.

In addition, this research points to two secondary recommendations. The first recommendation emphasizes the importance of real-time data collection and analysis in an operational setting. While this study utilized historical archive data, the dynamic nature of information operations (IO) hinges on real-time data collection and analysis. However, the collection and analysis of real-time data requires substantial investments in data infrastructure and personnel capable of continuously monitoring social media, news, and

other sources of data. The second recommendation suggests early integration of assessment planning into the overall operation, which would facilitate establishing behavioral baselines before an operation begins by collecting data on key indicators like public sentiment or communication patterns. These baselines provide a clear comparison point, enabling a more precise assessment of OIE.

The data-driven geospatial approach to operational assessment presented in this study offers a promising framework for evaluating OIE effectiveness across a wider range of activities, including traditional media campaigns, public opinion analysis, targeted messaging, and online counter-disinformation efforts. This approach can also aid in producing data-driven visualizations, which clearly represent the impact and reach of OIE activities. Such maps can provide a dynamic and concise representation of the data, making it easier to understand and interpret the effectiveness of OIE activities, enhancing our understanding of OIE, and providing a practical tool for strategizing and optimizing future OIE activities.

Finally, this study paves the way for future research by demonstrating the potential of data-driven, geospatial approaches to assessing OIE effectiveness. Future research should continue to explore the potential of open-source data by expanding the scope of data collection to encompass a wider range of sources to evaluate the impact of OIE. Additionally, future research should focus on extending the application of this data-driven geospatial approach to a broader range of military operations assessment processes. The implications of this study should encourage further exploration and application of these methodologies, contributing to the advancement of our understanding of military operations.

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I. INTRODUCTION

The U.S. military's OIE involve using information forces such as psychological operations (PSYOP), civil affairs, public affairs, cyberspace, and space operations forces combined with information and communication technologies to influence foreign relevant actors to gain an advantage in the information environment (IE).[1] The U.S. military aims to achieve an 'information advantage' by influencing, disrupting, or degrading adversaries' decision-making processes. According to Joint Publication (JP) 3–04, *Information in Joint Operations*, "Information advantage is the operational advantage gained through the joint force's use of information for decision making and its ability to leverage information to create effects on the IE."[2] OIE plays a critical role in U.S. military operations by providing forces and effects to gain an advantage over adversaries. OIE can support U.S. military operations in various ways, including the impact on the adversary's decision-making process, the reduction of the adversary's ability to communicate, and the disruption of the adversary's information flow.[3]

As a part of OIE, social media played an important role in OIR, a U.S.-led military campaign against ISIS, also known as Da'esh. The operation officially began in October 2014, after ISIS captured the Iraqi cities of Mosul and Tikrit and threatened to expand its control over the entire country and its neighboring country, Syria.[4] The U.S. and its coalition partners conducted airstrikes against ISIS targets in Iraq and Syria, as well as provided training and support to Iraqi security forces.[5] In addition to these kinetic operations, the U.S. military and its coalition partners also conducted PSYOP against Da'esh. These operations included influence operations using different means such as

[1] Joint Chiefs of Staff, "JP3-04 Information in Joint Operations" (Joint Chiefs of Staff, September 14, 2022), VII–1.

[2] Joint Chiefs of Staff, II–2.

[3] Joint Chiefs of Staff, VI–1.

[4] Christopher Eng, "History of Combined Joint Task Force – Operation Inherent Resolve," Department of Defense, Operation Inherent Resolve, 20200903, https://www.inherentresolve.mil/WHO-WE-ARE/History/.

[5] Eng.

social media, leaflets, and broadcasting speakers that targeted both ISIS fighters and the civilian population in ISIS-controlled territories.[6] While some have argued that the success of these influence operations was crucial in achieving the overall success of OIR, assessing their effectiveness remains one of the greatest challenges to the U.S. military.

Influence operations are difficult to assess because they often aim to change human behavior, perceptions, and attitudes, which are non-physical. As Grohoski et al. explain, capturing and measuring non-physical effects is especially challenging because it produces intangible results and requires deep analysis of data.[7] Additionally, the authors note that assessing the effects of influence operations is further complicated by the fact that they are rarely the only events happening at a given time, and it can be difficult to attribute observed changes to the influence operation specifically.[8] For example, if friendly forces are conducting an air bombing campaign at the same time as an influence operation, and the number of enemy soldiers surrendering increases, it is difficult to say whether the increase is due to the air bombing campaign, the influence operation, or both. Similarly, if friendly forces are conducting multiple influence operations simultaneously, it can be difficult to isolate each operation and determine which operation is causing which effect.[9]

This thesis aims to develop new and innovative ways to use geospatial and social media analysis to measure the effectiveness of OIE. It uses available social media and open-source data to assess the effectiveness of U.S. coalition forces' influence operations during OIR. OIR provides a unique and insightful case study because it involved ISIS, which was one of the first terrorist organizations to effectively use social media and other online platforms to spread its message and recruit new members. At its peak, social media enabled ISIS to recruit over 40,000 foreign fighters from 110 countries, many of whom

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[6] Jared Tracy, "MISTF-C In Operation INHERENT RESOLVE," Org, ARSOF History, 2017, https://arsof-history.org/articles/v13n1_mistf_c_page_1.html.

[7] David Grohoski, Steven Seybert, and Marc Romanych, "Measures of Effectiveness in the Information Environment," *Military Intelligence Professional Bulletin 29* No. 3 (2003): 1, https://jfsc.ndu.edu/Portals/72/Documents/JC2IOS/Additional_Reading/3F_Measures_of_Effectivenes_In_the_Information_Environment.pdf.

[8] Grohoski, Seybert, and Romanych, 3.

[9] Grohoski, Seybert, and Romanych, 3.

were young.[10] While ISIS provides a useful set of cases for measurement, the broader objective is to demonstrate improved ways of assessing OIE.

This study explores the potential of utilizing open-source data from the respective timeframes of the U.S. military influence operations against ISIS to assess the effectiveness of operations through geospatial statistical analysis. Thus, this thesis aims to answer the following research question: *how can quantitative geospatial analysis of open-source data provide measures of effectiveness (MOE) for OIE?* To answer this question, this study focuses on quantifying the impact of the U.S. military and its coalition partners' influence operations by analyzing social media metadata and historical violent event datasets. Specifically, the study compares the changes in social media message traffic, sentiment in social media messages, and the number of violent events in the region before and after each operation. This comparison allows for the examination of the relationship between these operations and the observed changes.

This research has yielded three key findings that provide insights into the effectiveness of U.S. military's information operations (IO). First, the leaflet drop operations were associated with an increase in social media communications. Second, these operations also corresponded with a decline in positive sentiment expressions on social media. Third, a decrease in violent deaths was observed in conjunction with the leaflet drop operations. These findings underscore the potential of using open-source data to assess the impact of OIE in both online and offline behaviors, thereby emphasizing the strength of data-driven methodologies in evaluating OIE effectiveness. Ultimately, this research could offer a novel method for assessing influence operations for IO professionals, potentially paving the way for more effective assessment methods for the U.S. military.

[10] BBC News, "IS Foreign Fighters: 5,600 Have Returned Home – Report," *BBC News*, October 24, 2017, sec. Middle East, https://www.bbc.com/news/world-middle-east-41734069.

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II. LITERATURE REVIEW

Since the early 2000s, the rapid advancement of technology has revolutionized how people communicate and share information. Information can now travel globally in seconds with the advent of the internet and social media. Additionally, the proliferation of digital devices has led to a massive surge in internet users worldwide, with 5.16 billion as of January 2023.[11] The prevalence of smartphone usage also led to staggering amounts of content being shared among different social media platforms. For example, Facebook has 1.91 billion users spending an average of 2 hours and 24 minutes on the platform daily, Twitter (now called X) users post 456,000 tweets every minute, YouTube users watch 1 billion hours of videos daily, and Instagram has 500 million daily users.[12]

Zeng et al. explained that social media's ability to reach a wide range of audiences, including users, consumers, voters, businesses, governments, and nonprofit organizations, has dramatically intensified interest in social media from various fields, including application and research perspectives.[13] Particularly, social media has emerged as a highly sought-after information resource for quantitative researchers, providing access to a vast amount of data to examine social behavior to gain a better understanding of individuals, groups, and societal dynamics.[14] Therefore, Marcellino et al. from the RAND Corporation stated that social media has become a very important part of the IE, and the U.S. military needs to be able to understand and analyze social media data in order to conduct successful IO.[15] These authors further explained that social media has become a valuable tool for

[11] Ani Petrosyan, "Internet and Social Media Users in the World 2023," Statista, February 14, 2023, https://www.statista.com/statistics/617136/digital-population-worldwide/.

[12] Jason Wise, "How Much Data Is Generated Every Day in 2023? (NEW Stats)," Earthweb, February 21, 2023, https://earthweb.com/how-much-data-is-created-every-day/.

[13] Daniel Zeng et al., "Social Media Analytics and Intelligence," *IEEE Intelligent Systems* 25, no. 6 (November 2010): 14, https://doi.org/10.1109/MIS.2010.151.

[14] Subhayan Mukerjee and Sandra González-Bailón, "Social Media Data: Quantitative Analysis," in *SAGE Research Methods Foundations* (1 Oliver's Yard, 55 City Road, London EC1Y 1SP United Kingdom: SAGE Publications Ltd, 2020), https://doi.org/10.4135/9781526421036873634.

[15] William Marcellino et al., "Monitoring Social Media: Lessons for Future Department of Defense Social Media Analysis in Support of Information Operations" (RAND Corporation, June 14, 2017), ix, https://www.rand.org/pubs/research_reports/RR1742.html.

understanding what people are thinking and feeling, and how they are being influenced by information.[16] They also argued that the information from social media is essential for the U.S. military to conduct IO, which are designed to shape the perceptions, attitudes, and behaviors of people in order to achieve U.S. strategic objectives.[17]

While social media has become a valuable tool for the U.S. military, the Committee on Armed Services reported that the Department of Defense (DOD) is not doing enough to monitor and use social media data to understand and support awareness of the operating environment (OE).[18] The committee also argued that the DOD has been limited in using social media data to conduct assessments of IO because the DOD lacks clear policies and procedures for using social media data.[19] Recognizing the importance of social media analytics, the committee directed the Secretary of Defense to assess and improve the department's capabilities in this area.[20] Similarly, Marcellino et al. attributed the DOD's lack of social media analytics problem to a lack of analytical tools and expertise, complex legal and ethical considerations, and the military's slow adaptation to the changing social media landscape.[21] However, they also argued that this limitation could be addressed by the U.S. military investing in social media analytical tools and training.[22]

Social media analysis is the process of collecting and analyzing data from social media platforms, such as Facebook, Twitter, Instagram, and LinkedIn, to extract insights and trends that can inform decision-making for the military, businesses, organizations, and individuals.[23] Social media analysis has seen a sharp increase in popularity with the

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[16] Marcellino et al., x.

[17] Marcellino et al., x.

[18] U.S. House of Representatives, Committee on Armed Service, "Committee on Armed Services, Report on H.R. 4909, National Defense Authorization Act for Fiscal Year 2017" (Washington, D.C., May 4, 2016), 246, https://www.congress.gov/114/crpt/hrpt537/CRPT-114hrpt537.pdf.

[19] U.S. House of Representatives, Committee on Armed Service, 246.

[20] U.S. House of Representatives, Committee on Armed Service, 246.

[21] Marcellino et al., "Monitoring Social Media," ix.

[22] Marcellino et al., x.

[23] Katie Terrell and Ed Burns, "What Is Social Media Analytics?," Business Analytics, July 2021, https://www.techtarget.com/searchbusinessanalytics/definition/social-media-analytics.

unprecedented growth of the user base of social media platforms since the mid-2000s, and as a result, scientists and industry professionals have found innovative ways to collect and analyze data through automation.[24] The growth in the user base also led to social media analysis gaining popularity in a wide range of fields, including retail, finance, bioscience, social science, political science, and military operations including OIE.[25]

The development of social media analytics has also been associated with improvements in related techniques such as sentiment analysis, geospatial analysis, and spatiotemporal analysis. Sentiment analysis is one of the fastest-growing and widely used research areas in social media analytics because it provides a simple yet effective way of gauging opinions and attitudes from social media content.[26] Sentiment analysis is a technique that uses machine learning and automation to identify the sentiment of text, determining whether it is positive, negative, or neutral.[27] Artificial intelligence and machine learning have enabled the automation of sentiment analysis of social media data through different applications, such as natural language processing and deep learning, which can be combined with other quantitative techniques, such as computational linguistics to analyze a large amount of data more quickly.[28] Due to its benefits and advancement, the U.S. Special Operations Command (SOCOM) is exploring the use of sentiment analysis to gain deeper understanding into the effectiveness of its IO.[29] James Smith, the head of acquisition for SOCOM, argued that sentiment analysis is a tool that

[24] Bogdan Batrinca and Philip C. Treleaven, "Social Media Analytics: A Survey of Techniques, Tools and Platforms," *AI & SOCIETY* 30, no. 1 (February 1, 2015): 90, https://doi.org/10.1007/s00146-014-0549-4.

[25] Batrinca and Treleaven, 90–91.

[26] Mika V. Mäntylä, Daniel Graziotin, and Miikka Kuutila, "The Evolution of Sentiment Analysis—A Review of Research Topics, Venues, and Top Cited Papers," *Computer Science Review* 27 (2018): 1, https://doi.org/10.1016/j.cosrev.2017.10.002.

[27] Andrew Eversden, "Watching Ukraine, U.S. Special Ops Realizes It's behind on Information War Capabilities," *Breaking Defense* (blog), May 20, 2022, https://breakingdefense.sites.breakingmedia.com/2022/05/watching-ukraine-us-special-ops-realizes-its-behind-on-information-war-capabilities/.

[28] Batrinca and Treleaven, "Social Media Analytics," 90.

[29] Eversden, "Watching Ukraine, U.S. Special Ops Realizes It's behind on Information War Capabilities."

could give its forces the ability to "message and counter-message in that environment at a speed and a scale that matches the pace of adversaries."[30]

As sentiment analysis is used to identify the sentiment of text, geospatial analysis can create visualizations that show the spatial distribution of sentiment. Geospatial analysis is the analysis of data that has a geographic component, such as coordinates, latitude, longitude, and altitude.[31] It can visualize complex datasets by identifying patterns and trends in data that would not be visible if only the location of the data points were displayed in rows and columns.[32] Geospatial analysis can also create visualizations such as a heatmap by providing "a visual representation of data that looks at identifying spatially related patterns between events and/or individuals and their locations.[33] For instance, a previous thesis at the Naval Postgraduate School (NPS), used geospatial analysis to generate heatmaps of Iraq and Syria to visually represent the rate of references to the Islamic State during the study period.[34] These maps allowed the researcher to track the group's rise and fall in popularity over time and to identify areas where it was most active.[35] Additionally, the U.S. government has been using geospatial intelligence to visualize and understand battlegrounds by exploiting and analyzing imagery, imagery intelligence, and geospatial information."[36] For example, the U.S. intelligence community was able to detect the

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[30] Patrick Tucker, "Special Operators Want AI to Help Discern Public Opinion," Defense One, May 20, 2022, https://www.defenseone.com/technology/2022/05/special-operators-want-ai-help-discern-public-opinion/367105/.

[31] Casey D. Cobb, "Geospatial Analysis: A New Window Into Educational Equity, Access, and Opportunity," *Review of Research in Education* 44, no. 1 (March 2020): 98, https://doi.org/10.3102/0091732X20907362.

[32] John Tysseling, "How Geospatial Data Analytics Provide Strategic Insight for Organizations," MossAdams, November 9, 2021, https://www.mossadams.com/articles/2021/11/benefits-of-geospatial-data-analytics.

[33] Andrew K. Bourret, Joshua D. Wines, and Jason M. Mendes, "Assessing Sentiment in Conflict Zones through Social Media" (master's thesis, Naval Postgraduate School, December 2016), 10, https://calhoun.nps.edu/handle/10945/51650.

[34] Murad Z. Altarawneh, "Terrorist Group Brands: Understanding Terrorist Group Strategies Through Measuring Brand Awareness on Social Media" (master's thesis, Naval Postgraduate School, December 2022), 25, https://calhoun.nps.edu/handle/10945/71425.

[35] Altarawneh, 25.

[36] Office of Geospatial-Intelligence Management, "National System for Geospatial Intelligence: Geospatial Intelligence (GEOINT) Basic Doctrine" (National Geospatial-Intelligence Agency, 092006), https://irp.fas.org/agency/nga/doctrine.pdf.

Russian troops massing in Belarus prior to its invasion of Ukraine in 2022 by analyzing the geospatial imagery.[37]

Dong and Guo explained that spatiotemporal analysis is the analysis of data that has both a geographic and temporal component, meaning that it is collected across both space and time.[38] These authors also stated that spatiotemporal analysis is used in a variety of fields such as "society, economy, population health, military, environment, ecology, geology, and geography."[39] This type of analysis can help identify patterns and trends in data that would not be visible if only one dimension, either space or time, were considered. In his study, Altarawneh used a spatiotemporal approach to measure changes in armed groups' brand awareness over time and space by analyzing social media messages in Syria and Iraq for a year.[40] As this study showed, by analyzing geocoded social media messages over time, a spatiotemporal analysis can show the change in the population's attitude or behavior towards certain events or organizations.[41]

The concept of cognitive warfare, deeply rooted in cognitive psychology, has been a strategic tool in military operations since the dawn of warfare. Cognitive psychology is the study of how people think, including how emotions, creativity, and problem-solving skills affect our thoughts and behaviors.[42] It is an important field of psychology because it is critical to understand how thinking affects behavior, and it teaches us about what works and does not work in messaging and influence.[43] According to Dr. Western, people are more likely to be persuaded by messages that are emotionally resonant because our

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[37] Kimberly Underwood, "U.S. GEOINT Is Clear Driver in Ukrainian Defense," AFCEA International, September 15, 2022, https://www.afcea.org/signal-media/intelligence/us-geoint-clear-driver-ukrainian-defense.

[38] Zhenmin Dong and Chunfang Guo, "A Literature Review of Spatio-Temporal Data Analysis," *Journal of Physics: Conference Series* 1792, no. 1 (February 1, 2021): 1, https://doi.org/10.1088/1742-6596/1792/1/012056.

[39] Dong and Guo, 1.

[40] Altarawneh, "Terrorist Group Brands," 24.

[41] Altarawneh, 24.

[42] Candina Jordan, "What Is Cognitive Psychology?," WebMD, 20220531, https://www.webmd.com/mental-health/what-is-cognitive-psychology.

[43] Jordan.

emotions are what motivate us to act, and our reason helps us figure out how to achieve our goals.[44] The author also suggested that people are more likely to be persuaded by messages that are framed in a positive way because "positive emotions draw us toward things, people, and ideas we believe are good for ourselves and the people we care about; negative emotions lead us to avoid or fight them."[45] He also stated that people are more likely to be persuaded by messages that are relevant to their interests and needs because people are more motivated to pay attention to and process information that is relevant to them.[46] Finally, in their study, Hovland et al. explained that based on source credibility theory, people are more likely to be persuaded by messages "when the source presents itself as credible."[47]

The U.S. military uses military information support operations (MISO), formerly known as PSYOP, to influence enemy behavior and achieve military objectives. MISO have been used by armies since the dawn of warfare to influence enemy behavior and achieve military objectives.[48] According to JP 3-13.2, MISO are " planned operations to convey selected information and indicators to foreign audiences to influence their emotions, motives, objective reasoning, and ultimately the behavior of foreign governments, organizations, groups, and individuals in a manner favorable to the originator's objectives."[49] The publication also stated that the purpose of MISO is to "degrade the enemy's relative combat power, reduce civilian interference, minimize collateral damage, and maximize the local populace's support for operations."[50]

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[44] Drew Western, "How to Win an Election," Psychology Today, 04292020, https://www.psychologytoday.com/us/articles/202004/how-win-election.

[45] Western.

[46] Western.

[47] C.I. Hovland, I.L. Janis, and H.H. Kelley, "Source Credibility- Persuasion Context," Education, University of Kentucky, 1953, https://www.uky.edu/~drlane/capstone/persuasion/sourcecred.htm.

[48] Frank L Goldstein, Benjamin F Findley, and Daniel Jacobowitz, "Psychological Operations: Principles and Case Studies," *Air University Press*, 091996, 11.

[49] Joint Chiefs of Staff, "JP 3-13.2, Military Information Support Operations" (Joint Chiefs of Staff, December 20, 2011), vii, https://jfsc.ndu.edu/Portals/72/Documents/JC2IOS/Additional_Reading/1C1_JP_3-13-2.pdf.

[50] Joint Chiefs of Staff, viii.

Additionally, the publication explained that the following factors must be present for MISO to be effective: early planning and sustained employment, integration into the overall communication strategies, leverage of indigenous assets, command emphasis, sufficient funding, a responsive approval process, and quantifiable and timely assessment criteria.[51]

The Gulf War is a significant example of how the U.S. military effectively used MISO. During the war, the U.S. military dropped 29 million leaflets, broadcast radio messages for 17 hours a day, and broadcast aerial loudspeaker messages for 19.5 hours a day.[52] To make the leaflet drops more effective, the U.S. military dropped leaflets immediately after a powerful bomb, warning Iraqi soldiers that they would be the next target.[53] Goldstein and Jacobowitz argued that the effectiveness of MISO depends on whether the target audience believes that the actor sending the message has the ability to carry it out.[54] In the case of the Gulf War, Iraqi soldiers witnessing the U.S. military bombing knew that the leaflets were credible and this made the operations incredibly effective. These carefully planned MISO reached 73,000 Iraqis, and 70 percent of enemy prisoners of war (EPWs) said that the messages influenced their decision to surrender.[55] The effectiveness of MISO was also proven when an Iraqi division commander confessed that "the impact of the psychological war on Iraqi morale was second only to the bombing by the Allied forces."[56]

As the example from the Gulf War displays, leaflet drop operations are a crucial means in the U.S. military's MISO. According to Gabrys, the use of leaflets in war dates back to World War I, when the Germans first used them to spread propaganda and demoralize enemy troops.[57] The author also described leaflet drop operations as "bombing

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[51] Joint Chiefs of Staff, viii.

[52] Goldstein, Findley, and Jacobowitz, "Psychological Operations: Principles and Case Studies," 349.

[53] Liang Qiao, Al Santoli, and Xiangsui Wang, *Unrestricted Warfare: China's Master Plan to Destroy America* (Panama City, Panama: Pan American Publishing, 2002), 62.

[54] Goldstein, Findley, and Jacobowitz, "Psychological Operations: Principles and Case Studies," 7.

[55] Goldstein, Findley, and Jacobowitz, 349.

[56] Qiao, Santoli, and Wang, *Unrestricted Warfare*, 62.

[57] Jennifer Gabrys, "Leaflet Drop: The Paper Landscapes of War," *InVisible Culture*, no. 7 (March 1, 2004): 11, https://doi.org/10.47761/494a02f6.caa06098.

the enemy with ideas" because leaflets are carefully orchestrated to contain text that has the power to both inform and mislead in the context of war and can be used to imagine new possibilities, both good and bad.[58] The leaflets are also often accompanied by photographs or other graphic images as proof of destruction done by the originator that is designed to shock and appall the enemy. Additionally, she explained that MISO print products such as leaflets are easy and inexpensive to produce, lightweight, and readily reproducible.[59]

Goldstein and Jacobowitz highlighted the effectiveness of leaflets and print MISO products during the Gulf War, noting that 29 million leaflets were dropped and 98% of the 300,000 targeted Iraqi troops were aware of the leaflets.[60] They also reported that 88% of Iraqi troops were influenced by the leaflets, and 77% were persuaded to surrender because of the leaflet drop operations and other Allied forces' actions.[61] The authors stated that many captured Iraqi troops were found with leaflets in their possession when they surrendered.[62] These authors attributed the success of leaflet drops to the simplicity and straightforwardness of the language used, the heavy use of visuals, the sheer volume of leaflets dropped, low leaflet loss due to good weather, the effectiveness of the overall message, the exploitable vulnerabilities of the target audience, and Allied military actions.[63] They also suggested that "The leaflets enabled many Iraqi soldiers, who were not highly motivated to support Saddam's war of conquest, to avoid sacrificing their lives in a doomed cause."[64]

During OIR, the U.S.-led coalition forces' leaflet drop operations illustrated the potential impact of informational influence on the adversary, highlighting the need to further assess the impact of these operations more carefully. As reported by Reuters, on July 19, 2015, the U.S. military dropped leaflets in Raqqa, Syria, with the message

[58] Gabrys, 2.

[59] Gabrys, 3.

[60] Goldstein, Findley, and Jacobowitz, "Psychological Operations: Principles and Case Studies," 353.

[61] Goldstein, Findley, and Jacobowitz, 353.

[62] Goldstein, Findley, and Jacobowitz, 353.

[63] Goldstein, Findley, and Jacobowitz, 353.

[64] Goldstein, Findley, and Jacobowitz, 354.

"Freedom will come" written in Arabic.[65] The article also stated that these leaflets, combined with the intensified aerial bombing in the area, prompted ISIS to implement stringent measures to control information flow by banning wireless networks in private homes and raiding internet cafes to prevent news of their activities from leaking to the U.S. coalition forces.[66] ISIS also shut down its own internal networks to prevent potential information leaks to intelligence agencies.[67] It is unclear if these leaflets achieved the desired effect of assuring the civilian population in Raqqa, but it appears that they did force ISIS to take measures that may have been unfavorable to them, such as taking away access to the internet in certain areas.

Like the assessment of other MISO, the effectiveness of leaflet drop operations is difficult to measure, but their effectiveness is crucial to the success of military campaigns as shown in the previous wars. According to JP 3-04, assessment of operations and activities in joint operations is important because it helps the commander to understand how well the joint force is using its information capabilities to achieve its mission, and then this information improves the joint force's use of information in future operations.[68] In other words, correct assessment of MISO can enhance the military's overall campaign. By understanding how influence operations affect the enemy, the military can better tailor its messaging and strategies to support its objectives.

While previous studies have used social media to assess the impact of military operations, there has not been a study that directly assesses the impacts of specific leaflet drop operations on a geospatial basis. This is a significant gap in the literature, as leaflet drops are a common MISO tactic used by the U.S. military, and social media and open-source data provide a unique opportunity to assess the impacts of leaflet drop operations. This research addresses this gap by using social media and open-source data to assess the

65 Reuters, "Islamic State Cracks down on Internet Use in Syrian Stronghold – Monitor," *Reuters*, July 20, 2015, sec. World News, https://www.reuters.com/article/uk-mideast-crisis-syria-internet-idUKKCN0PU1MB20150720.

66 Reuters.

67 Reuters.

68 Joint Chiefs of Staff, "JP3-04 Information in Joint Operations," VI–1.

impacts of specific leaflet drop operations on a geospatial basis. This approach will provide a more comprehensive and nuanced understanding of the impact of leaflet drop operations. This information can then be used to develop more effective leaflet drop operations and to better integrate leaflet drop operations into other military operations.

III. THEORY AND HYPOTHESES

A. LEAFLET DROP OPERATIONS

This research aims to provide MOE for OIE by analyzing six different leaflet drop operations that the U.S. military and its coalition forces conducted against ISIS during OIR from 2014 to 2016 in Raqqa, Syria, and Mosul, Iraq. These leaflets informed civilians not to cooperate with ISIS and promised that they would be freed from the terrorists. They also targeted ISIS fighters with messages to degrade their will to fight.

The first leaflet drop examined here (Figure 1) occurred on August 20, 2014, when U.S. jets dropped leaflets on Mosul, Iraq urging residents to support security forces against Da'esh. The leaflets also said it was "time that we all stand together on the land of our sacred city."[69] Based on the messages, these anti-ISIS propaganda leaflets were likely trying to rally support for Iraqi security forces, demoralize ISIS fighters, and sow discord between ISIS and the local population.

Figure 1. Image of Leaflet Dropped over Mosul, Iraq on August 20, 2014[70]

69 Alexander Smith and Mohammed Muslemany, "U.S. Drops Leaflets on Iraq's Mosul Urging Fight Against ISIS," NBC News, August 21, 2014, https://www.nbcnews.com/storyline/iraq-turmoil/u-s-drops-leaflets-iraqs-mosul-urging-fight-against-isis-n185691.

70 Source: The Iraqi National Army, "Iraqi aviation drops leaflets on Mosul," Tweet, *Twitter*, August 20, 2014, https://twitter.com/ArmY_Iq/status/502230720803536896.

The second case focuses on the U.S. military leaflet drop operation on March 16, 2015, over Raqqa, Syria, the self-proclaimed capital of the ISIS. These leaflets (Figure 2) depicting ISIS as a meat grinder, warned potential Da'esh recruits that joining the group would lead to death and destruction.[71] The leaflet's message was "If you allow yourself to be recruited by Da'esh, you will find yourself in a meat grinder."[72] The U.S. military dropped about 60,000 of these anti-ISIS recruitment propaganda leaflets in the city.

Figure 2. Image of Leaflet Dropped over Raqqa, Syria on March 16, 2015[73]

The third leaflet drop operation was conducted over Raqqa on May 17, 2015. The leaflets (Figure 3) contained a message to ISIS fighters that they would be defeated and lose the war.[74] The leaflets warned ISIS fighters about the constant threat of death, citing the death of their leader, Abu Sayyaf, and it also highlighted the diminishing territory under

[71] Luis Martinez, "US Drops Anti-ISIS Leaflets Over Syria," ABC News, March 26, 2015, https://abcnews.go.com/Politics/us-drops-anti-isis-leaflets-syria/story?id=29930980.

[72] Martinez.

[73] Source: Martinez.

[74] Tom Vanden Brook, "Pentagon Fires Second Propaganda Salvo in Syria," USA TODAY, 20150604, https://www.usatoday.com/story/news/world/2015/06/04/pentagon-propaganda-syria-isil/28470813/.

their control and their inability to stop the ongoing attacks.[75] The leaflet was a warning to Da'esh fighters that they were destined to lose.

Figure 3. Image of Leaflet Dropped over Raqqa, Syria on May 17, 2015[76]

The fourth and fifth leaflet drop operations were conducted over Raqqa, Syria on July 19, 2015, and February 08, 2016, respectively. The fourth leaflet showed a cartoon depicting dead ISIS fighters and a group of armed fighters advancing along a road with the words "Freedom will come" in Arabic.[77] The next set of leaflets (Figure 4) dropped on February 08, 2016, showed ISIS fighters fleeting in terror, dropping their weapons and flags, as troops drove them from the streets and civilians around were smiling and cheering in the background.[78] The leaflets also said, "The democratic forces of Syria are advancing to liberate the city of Raqqa from ISIS."[79] The intended message of the leaflets to the civilians in the Raqqa region seemed to be that ISIS would be defeated and the city would be liberated.

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[75] Brook.

[76] Source: Brook.

[77] Agencies, "US-Led Coalition Warplanes Drop New Leaflets over Isis Stronghold in Syria," *The Guardian*, July 19, 2015, sec. World news, https://www.theguardian.com/world/2015/jul/19/islamic-state-leaflets-syria-air-strikes.

[78] Leda Reynolds, "Leaflets Dropped from Coalition Warplanes Promise ISIS Will Be Defeated SOON," Express.co.uk, February 8, 2016, https://www.express.co.uk/news/world/641462/Leaflets-dropped-from-coalition-war-planes-promise-ISIS-will-be-defeated-SOON.

[79] Reynolds.

Figure 4. Image of Leaflet Dropped over Raqqa, Syria on February 08, 2016[80]

The sixth and last leaflet drop operation covered in this research occurred on March 10, 2016, when the U.S.-led coalition and the Iraqi army dropped leaflets over Mosul, Iraq.[81] The leaflet was intended to let the residents know that they had not been forgotten and that Iraqi security forces were coming to liberate them. The potential goal of the leaflets was to undermine the terrorist group's control over the city and to boost the morale of the Mosul residents. Some reports indicated that the leaflet drop may have struck a nerve with ISIS, as they locked down the population in the neighborhood where the leaflets fell and collected some of them.[82]

B. BACKGROUND – RAQQA AND MOSUL

ISIS took control of Raqqa and Mosul in 2014, causing widespread death and destruction.[83] In these cities, ISIS imposed a harsh version of Islamic law, turning everyday

[80] Source: Reynolds.

[81] Steve Warren, "Transcript – Department of Defense Press Briefing by Colonel Warren via Teleconference from Baghdad, Iraq," U.S. Department of Defense, 20160311, https://www.defense.gov/News/Transcripts/Transcript/Article/691794/department-of-defense-press-briefing-by-colonel-warren-via-teleconference-from/https%3A%2F%2Fwww.defense.gov%2FNews%2FTranscripts%2FTranscript%2FArticle%2F691794%2Fdepartment-of-defense-press-briefing-by-colonel-warren-via-teleconference-from%2F.

[82] Warren.

[83] Sarhang Hamasaeed and Garett Nada, "Iraq Timeline: Since the 2003 War," United States Institute of Peace, May 29, 2020, https://www.usip.org/iraq-timeline-2003-war.

activities into punishable offenses.[84] The terrorists created an atmosphere of fear among the residents with public executions and other forms of violence. Women's rights were violated in both cities, with ISIS not allowing women to walk alone, forcing them to cover up their bodies, and removing them from getting an education.[85] ISIS also blocked the cities from allowing people to leave freely.[86] The economy was devastated due to the war and ISIS rule, leaving many residents struggling to afford basic necessities.[87] The intense bombing campaign by the U.S.-led coalition was necessary to defeat ISIS, but it also caused significant damage to the cities' buildings and infrastructure.

C. HYPOTHESES

Building on prior research, this study seeks to narrow the gap in the difficulties of measuring the effectiveness of leaflet drop operations by addressing the question: *How can quantitative geospatial analysis of open-source data provide MOE for leaflet drop operations?* Based on the research questions and given these specific dynamics in the two cities, three core hypotheses underpin this research. (1) First, *I hypothesize that leaflet drop operations are likely to result in an increased volume of social media messages in the operation's vicinity.* Leaflets often contain messages designed to evoke strong emotions among the target audience or to provide information that recipients may want to seek more clarity or additional information about. Both factors can prompt individuals to express their feelings and thoughts on social media platforms like Twitter, leading to an increase in message volume. (2) Second, *I hypothesize that leaflet drop operations are likely to lead to a decrease in the number of positive sentiments in social media messages.* Leaflets that provide hope and support to those living under ISIS control could foster resentment

[84] Alexander Smith and Ghazi Balkiz, "What Life Is Like Inside ISIS' Capital City of Raqqa, Syria," NBC News, September 25, 2014, https://www.nbcnews.com/storyline/isis-uncovered/what-life-inside-isis-capital-city-raqqa-syria-n211206.

[85] Lydia Green, "Inside Mosul: What's Life like under Islamic State?," *BBC News*, June 8, 2015, sec. Middle East, https://www.bbc.com/news/world-middle-east-32831854.

[86] Laila Ahmed, "Since Islamic State Swept into Mosul, We Live Encircled by Its Dark Fear," *The Guardian*, August 29, 2014, sec. Opinion, https://www.theguardian.com/commentisfree/2014/aug/29/islamic-state-isis-mosul-encircled-fear-trapped-in-dark-ages.

[87] Smith and Balkiz, "What Life Is Like Inside ISIS' Capital City of Raqqa, Syria."

towards ISIS for causing their current predicament. This resentment could lead to people posting fewer positive sentiment messages on social media. (3) *The third hypothesis is that leaflet drop operations are likely to lead to an increase in the number of violent events in the surrounding area.* The leaflets often carry messages intended to provoke strong emotional responses among Da'esh fighters, such as threats, warnings, or insults, potentially leading to violent reactions or retaliatory actions. Additionally, some leaflets serve as propaganda tools designed to incite distrust within the group, which could escalate tensions among ISIS fighters and result in increased violence.

IV. METHODOLOGY

The research used a spatiotemporal methodology, which considers both space and time, to thoroughly assess the impact of operations. In terms of spatial analysis, a grid cell unit of analysis was created, with each square grid cell measuring approximately 5-kilometers by 5-kilometers across Iraq and Syria. This approach facilitated the overlaying of a consistent unit of analysis across all variables—dependent, independent, and control variables—onto the grid. This not only enabled data aggregation but also allowed for direct comparison between different variables.[88] In terms of the temporal dimension of the methodology, the research utilized a period of 14 calendar days, divided into two segments: 7 days before and after each leaflet drop operation for the first two dependent variables: the total number of Twitter messages and the count of positive sentiment Twitter messages. However, the third variable, the total number of violent deaths, used a 28 calendar-day period, divided into 14 days before and after each operation. These timeframes were chosen as they provided a sufficient number of observations for each leaflet drop operation and ensured that the data sizes were manageable for data analysis.

A. DEPENDENT VARIABLES

Three dependent variables were used to test the hypotheses in this research. The first dependent variable, *Total Message Count*, was derived from a historical archive of Twitter messages, licensed for research by the NPS. For each operation, a dataset was constructed to align with the spatiotemporal methodology used in this research. Each dataset consisted of all messages sent from within a 100-kilometer radius of the city centers in a 14-calendar day timeframe (7 days before and after each operation). These messages were geocoded using publicly available metadata from Twitter user profiles and assigned approximate latitude and longitude coordinates based on the users' self-reported

[88] Harold G. Frost, Anthony W. Evans, and Jr. Hodges Robert H., "Understanding Violence through Social Media" (Monterey, California: Naval Postgraduate School, December 2017), 20, https://hdl.handle.net/10945/56920.

hometown. This first dependent variable is equal to the total count of messages seen in a given grid cell over these temporal windows, before and after each operation.

The second dependent variable, *Positive Message Count*, was calculated based on the sentiment analysis of Twitter messages observed for each leaflet drop operation timeframe. This research utilized the positive and negative word lists from the NRC Word-Emotion Association Lexicon, also called EmoLex, to create a custom sentiment dictionary for the languages that are most common in this sample of Twitter messages (Turkish, Arabic, and English). EmoLex is "a list of English words and their associations with eight basic emotions (anger, fear, anticipation, trust, surprise, sadness, joy, and disgust) and two sentiments (negative and positive)," and it has been translated to over 100 languages including Turkish and Arabic.[89] The custom sentiment dictionary, produced by combining these translated word lists, was used with the sentimentr package in R to perform sentiment analysis on the messages, generating a continuous valence score for each message in which scores greater than '0' indicate more positive emotions. This approach is not perfect because it may not be able to capture all of the nuances of sentiment in each language. However, it is a good way to get a general sense of the sentiment of the messages, especially when the majority of messages are not in English. This second dependent variable is equal to the count of positively valanced messages seen in a given grid cell, in the 7 days before and after each operation.

The third dependent variable, *Death Count*, was obtained from the Upsala Conflict Data Program (UCDP) Georeferenced Event Dataset (GED) Global version 23.1. This dataset provided detailed information on individual instances of organized violence, with precise geographical locations and daily temporal resolution, at the village level.[90] It was used to represent the total number of deaths from violent events over the same timeframe

[89] Saif Mohammad and Peter Turney, "Explore the NRC Word-Emotion Association Lexicon," Tableau Software, July 10, 2011, https://public.tableau.com/views/NRC-Emotion-Lexicon-viz1/NRCEmotionLexicon-viz1?:embed=y&:showVizHome=no&:host_url=https%3A%2F%2Fpublic.tableau.com%2F&:tabs=no&:toolbar=yes&:animate_transition=yes&:display_static_image=no&:display_spinner=no&:display_overlay=yes&:display_count=yes&:showVizHome=no&:showTabs=y&:loadOrderID=0.

[90] Ralph Sundberg and Erik Melander, "UCDP Georeferenced Event Dataset (GED) Global Version 23.1," 2013, https://ucdp.uu.se/downloads/index.html#ged_global.

in each grid cell. Figure 5 depicts the aggregate level of violent deaths in Iraq and Syria during the study period, spanning from August 20, 2014, to March 10, 2016. The figure employs a color scale ranging from dark to light, with yellow representing the highest number of deaths and black indicating no deaths.

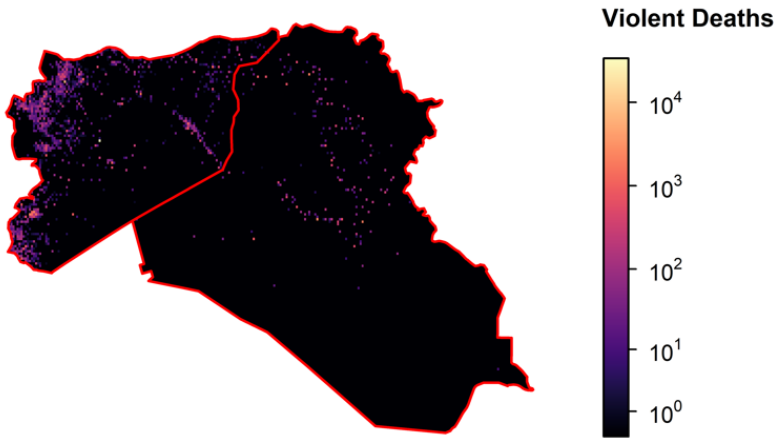

Figure 5. Violent Deaths in Iraq and Syria, August 01, 2014 – March 31, 2016

B. INDEPENDENT VARIABLE

The key independent variable used in this study was the *Distance* in kilometers from the city center of each leaflet drop location. The second independent variable, *Time*, utilized a window of 7 days before and after each operation when assessing the first two dependent variables based on social media measurements, and a window of 14 days when assessing the third dependent variable based on violent deaths. This variable was coded dichotomously to equal '0' for the pre period and '1' for the post period. By also including an interaction term between *Distance* and *Time*, the model aims to capture the effects of being near the operation in both space and time, by comparing the effect of *Distance* in the "pre" period to the effect of *Distance* in the "post" period. To simplify the assessment of these effects, a binary spatial "treatment" indicator was created, by coding as '1' for all cells within 65-kilometers of the city center, and '0' for all other cells. This binary measure was interacted with *Time* to assess the significance of differences between "pre" and "post"

periods. In statistics, this is sometimes referred to as a "difference-in-differences" model. The advantage of this approach is that even if overall trends in time are leading to rising or falling levels of the dependent variable, as long as those trends would have been "parallel" between treated and untreated units, then a statistically significant result for the interaction term indicates evidence for an operational effect (an outcome that is significantly different than what would have been expected in the absence of the operation).

C. CONTROL VARIABLES

Control variables play a crucial role in data analysis by helping account for alternative factors that may influence the measured outcomes.[91] They are particularly important in observational studies, where the researcher cannot randomly assign participants to different treatment groups.[92] By controlling for potential confounders, researchers can increase the confidence that their results are due to the independent variable and not other factors. This study used five control variables to enhance internal validity by adjusting for potentially confounding factors: Population Density, Gross Domestic Product (GDP) per capita, Road Density, as well as the effects of prior rates of violence and communication. These variables were selected based on theoretical knowledge and prior research.

1. Population Density

The population density data was obtained from the Gridded Population of the World (GPW) v4 dataset developed by Columbia University's Center of International Earth Science Information Network.[93] This dataset provides population density information with a resolution of approximately 1-kilometer at the equator.[94] Figure 6

[91] Pritha Bhandari, "Control Variables | What Are They & Why Do They Matter?," Scribbr, March 1, 2021, https://www.scribbr.com/methodology/control-variable/.

[92] Mukerjee and González-Bailón, "Social Media Data."

[93] Center For International Earth Science Information Network-CIESIN-Columbia University, "Gridded Population of the World, Version 4 (GPWv4): Population Density, Revision 11" (Palisades, NY: Socioeconomic Data and Applications Center (SEDAC), 2017), https://doi.org/10.7927/H49C6VHW.

[94] Center For International Earth Science Information Network-CIESIN-Columbia University.

displays the population density in Iraq and Syria using a red-to-blue color scale. Blue indicates higher population density areas, while red indicates zero population density.

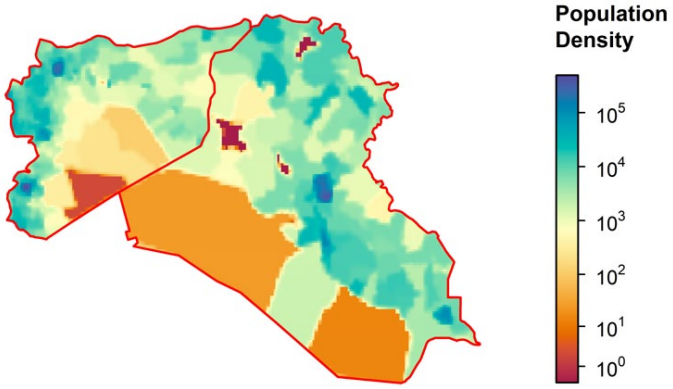

Figure 6. Population Density in Iraq and Syria

2. GDP per capita

This control variable, derived from the DRYAD-Gridded global datasets for the Gross Domestic Product and Human Development Index over the period 1990–2015, provides sub-national data on yearly GDP per capita at a resolution of 5 arc-minute (approximately 9.3-kilometers at the equator), to account for the effects of wealth and economic development.[95] Figure 7 displays the gridded GDP per capita in Iraq and Syria with high productive areas represented in yellow, while lower development areas are shown in black.

[95] Matti Kummu, Maija Taka, and Joseph H. A. Guillaume, "Gridded Global Datasets for Gross Domestic Product and Human Development Index over 1990–2015," *Scientific Data* 5, no. 1 (February 6, 2018): 180004, https://doi.org/10.1038/sdata.2018.4.

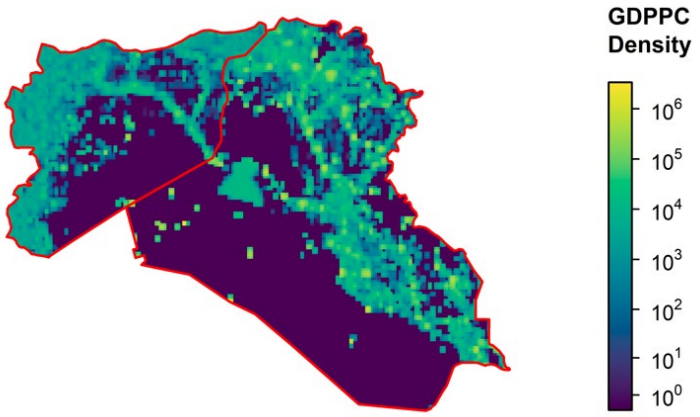

Figure 7. GDP Per Capita in Iraq and Syria

3. Road Density

Road density data, obtained from the Global Roads Inventory Project version 4, provides information on the density of all types of roads in Iraq and Syria at a resolution of 5 arc-minutes, to account for the effects of infrastructure on communication and violence.[96] Figure 8 illustrates the road density using a black-to-red color scale, with red representing areas with high road density and black representing areas with low road density.

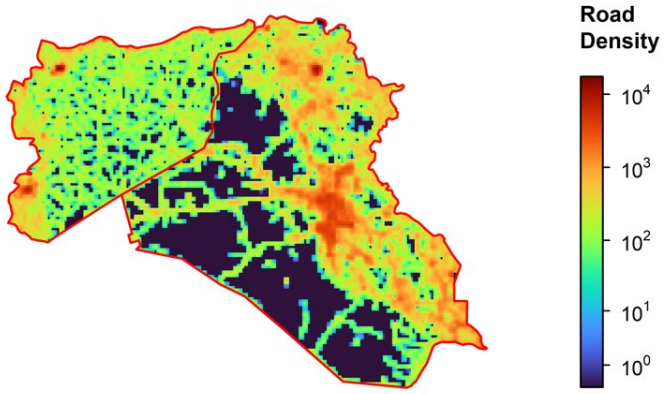

Figure 8. Road Density in Iraq and Syria

[96] Meijer et al., "Global Patterns of Current and Future Road Infrastructure – Supplementary Spatial Data" (Zenodo, May 23, 2018), https://doi.org/10.5281/ZENODO.6420961.

4. Violent Deaths

Two control variables were created using the UCDP GED dataset to account for the number of violent deaths in Iraq and Syria. The first variable, *Death History*, measures all violent deaths that occurred from April 1, 2004, to August 7, 2014. These dates were chosen because al Qaeda in Iraq (AQI), which eventually became ISIS, was founded in April 2004, and the U.S. military began airstrikes against ISIS in Iraq on August 7, 2014.[97] The second variable, *Death Current*, measures the number of violent deaths that occurred in the 7 days before and after each leaflet drop. This is identical to the third dependent variable described above, but is included as a control variable in the other models to account for overall differences in violent activity levels, which may influence social media outcomes separately from the leaflet drop operations.

5. Total Number of Messages

The *Total Message Count* variable referenced above as the first dependent variable, which measures the number of messages in the 7 days before and after each operation, is also included as a control variable in the other models. As with the controls for overall violence levels, this is intended to account for overall differences in communication volumes, to ensure that locations are not judged to be more positive or more violent simply because they are more socially active.

[97] Cameron Glenn et al., "Timeline: The Rise, Spread, and Fall of the Islamic State," Wilson Center, October 28, 2019, https://www.wilsoncenter.org/article/timeline-the-rise-spread-and-fall-the-islamic-state.

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V. RESULTS

Poisson regression was used to examine the relationship between the interaction of two independent variables: *Time* (pre- and post-leaflet drop) and treatment distance (*Raqqa Binary and Mosul Binary,* defined based on a radius of 65-kilometers from the city center) and three dependent variables: *Total Message Count, Positive Message Count,* and *Death Count* for each leaflet drop operation. Control variables for *Population Density, GDP per capita, Road Density*, previous and current violent deaths, and total message counts were included in each model to prevent spurious relationships, except where these were used as dependent variables. The control variables were log-transformed before regression analysis to account for skewed distributions. A regression table was created for each dependent variable, and each table contains six leaflet drop operations as events, assessed in six separate models. The events considered in these models were as follows:

- Event 1: Operation conducted on August 20, 2014, in Mosul, Iraq
- Event 2: Operation conducted on March 16, 2015, in Raqqa, Syria
- Event 3: Operation conducted on May 17, 2015, in Raqqa, Syria
- Event 4: Operation conducted on July 19, 2015, in Raqqa Syria
- Event 5: Operation conducted on February 08, 2016, in Raqqa, Syria
- Event 6: Operation conducted on March 10, 2016, in Mosul, Iraq

The first regression table (Table 1) displays the results when using the total number of Twitter messages as the dependent variable. The second regression table (Table 2) displays the results for the total number of positive sentiment Twitter messages as the dependent variable. The third regression table (Table 3) displays the results for the total number of violent deaths as the dependent variable. The results from these models produced three noteworthy findings as follows.

A. FINDING ONE: OPERATIONS ASSOCIATED WITH HIGHER RATES OF SOCIAL MEDIA COMMUNICATIONS

Table 1 presents the results of Poisson regression models with *Total Message Count* as the dependent variable. The independent variables include distance (represented by *Mosul Binary* and *Raqqa Binary*), *Time*, and their interaction terms (Mosul Binary x Time and Raqqa Binary x Time). Five control variables – *Population Density, GDP per capita, Road Density, Death History*, and *Death Current* – were also included for each leaflet drop operation. The analysis shows that the interaction terms of between time and distance are statistically significant (p-value < 0.01 or 0.05) in each model. The coefficient for the interaction term between time and distance indicates how much the volume of social media messages is expected to change after the leaflet drop within the treatment area, compared to how much it is expected to change in the areas outside the treatment area during the same time period.

For instance, except for Event 1, all other events exhibit positive coefficients for the interaction terms between time and distance. The positive coefficient suggests that the volume of social media messages within the treatment area is expected to be higher in the post-period compared to the areas outside the treatment area during the same time period. Additionally, a positive coefficient for the distance variable (e.g. *Raqqa Binary)* indicates that during the pre-operation period, the treatment area will have a higher volume of messages compared to the areas outside the treatment area. Finally, a positive coefficient for *Time* indicates that in the post-operation period, the areas outside the treatment area will have a higher volume of social media messages compared to the pre-operation period. This finding supports the first hypothesis, which is that leaflet drop operations are likely to result in an increased volume of social media messages in the operation's vicinity.

Figure 9 shows prediction plots for each leaflet drop operation, based on the models reported in Table 1. The y-axis in each figure shows the expected number of social media messages. The x-axis shows the time period, with '0' for before the leaflet drop and '1' for after the operation, including the operation day. The z-axis differentiates whether the location is within the treatment area defined by a 65-kilometer radius from the city center (blue line), or outside of the 65-kilometer radius from the city center (red line). The slope

of the lines indicates whether the relationship between the time variable (pre- and post-operation) and message volume is negative or positive for either the treatment area or the area outside the treatment area. A positive slope indicates an increase in messages as the line moves to the post-operation period, while a negative slope suggests a decrease. Also, if the blue line is above the red line for the same time period, it indicates a higher volume of messages in the treatment area compared to the area outside the treatment area. Conversely, if the red line is above the blue line, it indicates a higher volume of messages in the area outside the treatment area compared to the treatment area. The red and blue bands around each line represent the 95% confidence intervals of each effect. The confidence interval indicates the degree of uncertainty associated with the positive or negative direction of an effect.[98]

In the case of Event 1, a negative coefficient for the interaction terms between distance and time is observed, meaning that the volume of social media messages within the treatment area is expected to be lower in the post-period compared to the areas outside the treatment area during the same time period. However, for all other five events, an increase in the volume of messages is noted in the treatment areas in the post-operation period, relative to the areas outside the treatment area.

The timing of Event 1 may explain its negative coefficient, given the unique circumstances surrounding it. The timing of a leaflet operation, especially in a dangerous and uncertain environment like a war zone, can have an impact on its effectiveness. For instance, Event 1 took place in Mosul, Iraq, just two months after ISIS took control of the city.[99] During this initial period, the city was likely in chaos and people were uncertain about what the future held. This circumstance could have made people more receptive to the messages in the leaflets, but it may also have made them less likely to post on social media for fear of reprisals from ISIS. Additionally, there may have been more restrictions on internet access as ISIS was new to power in the area, and it could have affected how people reacted to the leaflets and how active they were on social media afterward.

[98] Rebecca Bevans, "Understanding Confidence Intervals | Easy Examples & Formulas," Scribbr, August 7, 2020, https://www.scribbr.com/statistics/confidence-interval/.

[99] Glenn et al., "Timeline."

Therefore, the unique circumstances surrounding the timing of Event 1 might explain why it was associated with a less of an increase in the total number of messages, compared to the later operations.

Table 1. Total Message Count Poisson Regression Results

	Total Message Count					
	Poisson (Event 1)	Poisson (Event 2)	Poisson (Event 3)	Poisson (Event 4)	Poisson (Event 5)	Poisson (Event 6)
Mosul Binary	-0.222***					-0.186***
	(0.008)					(0.009)
Raqqa Binary		0.279***	0.413***	-0.163***	0.428***	
		(0.015)	(0.018)	(0.023)	(0.016)	
Time	0.331***	-0.164***	-0.188***	-0.043*	-0.300***	-0.006
	(0.005)	(0.017)	(0.021)	(0.025)	(0.017)	(0.007)
Population Density	0.107***	0.564***	0.581***	0.781***	0.250***	0.213***
	(0.003)	(0.007)	(0.009)	(0.011)	(0.008)	(0.004)
GDP per capita	0.234***	0.039***	0.037***	0.021***	0.262***	0.497***
	(0.002)	(0.002)	(0.002)	(0.003)	(0.003)	(0.003)
Road Density	1.249***	0.263***	0.439***	0.405***	0.740***	0.595***
	(0.003)	(0.008)	(0.011)	(0.013)	(0.010)	(0.004)
Death History	0.345***	0.640***	0.629***	0.492***	0.565***	0.336***
	(0.001)	(0.002)	(0.003)	(0.004)	(0.002)	(0.001)
Death Current	-0.241***	-0.335***	0.760***	1.219***	0.231***	0.287***
	(0.015)	(0.035)	(0.014)	(0.009)	(0.013)	(0.003)
Mosul Binary x Time	-0.163***					0.277***
	(0.010)					(0.010)
Raqqa Binary x Time		0.197***	0.217***	1.064***	0.044**	
		(0.020)	(0.024)	(0.028)	(0.021)	
Constant	-7.417***	-3.847***	-5.314***	-6.965***	-5.499***	-6.784***
	(0.034)	(0.062)	(0.077)	(0.091)	(0.062)	(0.041)
Observations	2,528	2,442	2,442	2,442	2,442	2,528
MAE	148.770	29.741	21.903	17.263	27.145	76.685
RMSE	1,518.661	175.618	166.635	126.872	176.066	344.746
AIC	940,893	229,642	176,429	131,878	199,329	564,392
BIC	940,945	229,694	176,481	131,931	199,381	564,445
Log Likelihood	-470,437.312	-114,812.108	-88,205.449	-65,930.183	-99,655.452	-282,187.148

Note: *p < 0.1; **p < 0.05; ***p < 0.01

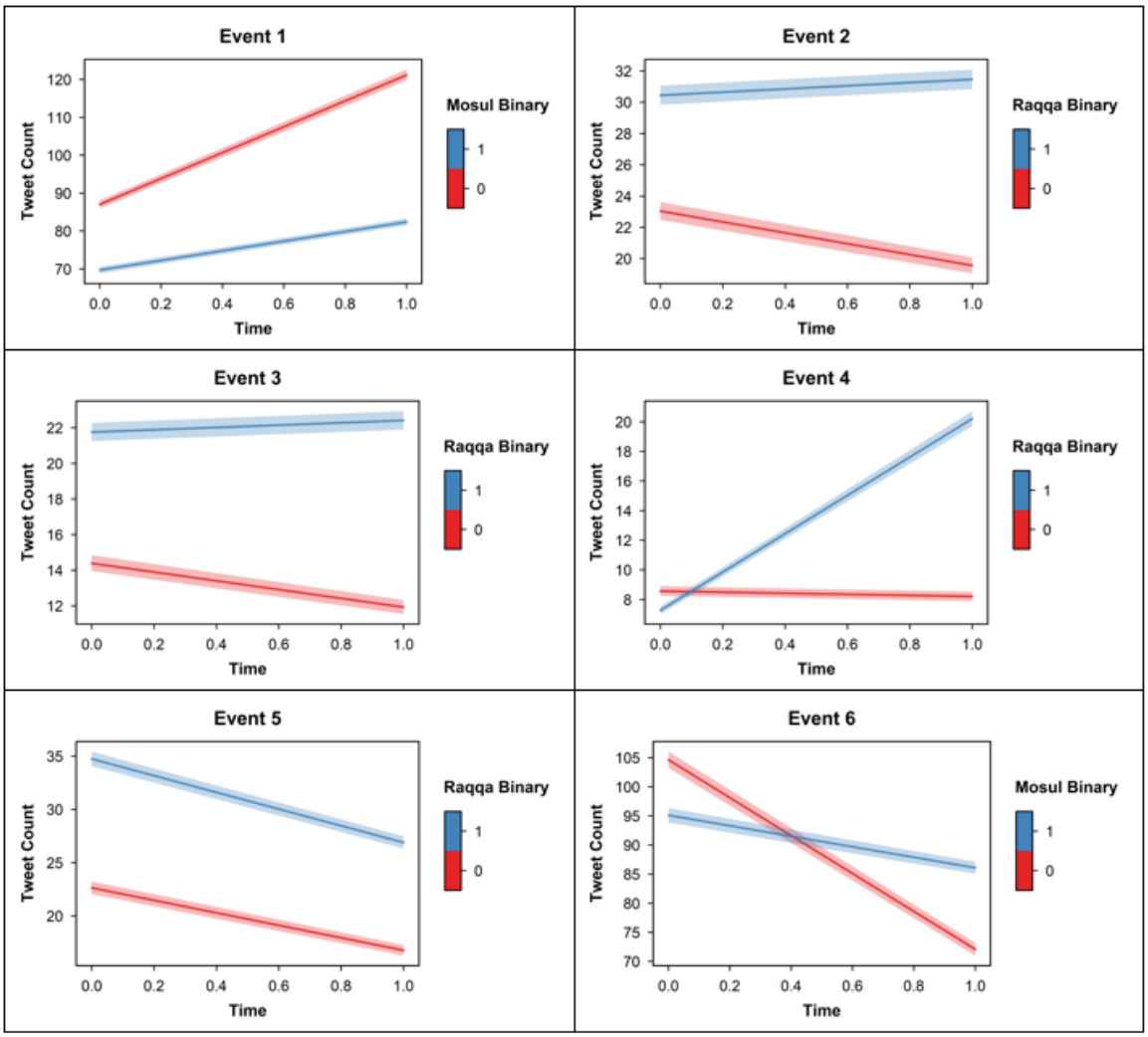

Figure 9. Predicted Effects on Total Message Count

B. FINDING TWO: OPERATIONS ASSOCIATED WITH A DECREASE IN EXPRESSIONS OF POSITIVE SENTIMENT

Table 2 presents the results of Poisson regression models with the number of positive sentiment social media messages as the dependent variable. The independent and control variables remain consistent with the previous model, with the addition of the *Total Message Count* as a control variable. The analysis reveals that the interaction term between time and distance is statistically significant (p-value < 0.01 or < 0.05) for all events except Event 5. The coefficient for the interaction term between time and distance indicates how much the volume of positive sentiment social media messages is expected to change after

the leaflet drop within the treatment area, compared to how much it changes in the areas outside the treatment area during the same time period. Among the five events demonstrating statistical significance, only Event 6 exhibits a positive coefficient for the interaction term. The remaining events display a negative coefficient for the interaction effect. These negative coefficients suggest that the volume of positive sentiment social media messages within the treatment area is expected to be lower in the post-period compared to the areas outside the treatment area during the same time period. This finding supports the second hypothesis that leaflet drop operations are likely to lead to a decrease in the expression of positive sentiments in social media messages.

Figure 10 shows prediction plots for each of the leaflet drop operations that demonstrated statistical significance for the number of positive messages. The y-axis represents the expected number of positive messages, while the x-axis shows the time period, with '0' for before the leaflet drop and '1' for after the operation, including the operation day. The z-axis differentiates whether the location is within 65-kilometers of the city center shown by a blue line or outside 65-kilometers from the city center shown by a red line. The slope of these lines reveals whether the relationship between the time variable (pre- and post-operation) and positive messages is negative or positive for either the treatment area or the area outside the treatment area. A positive slope indicates an increase in positive sentiment messages as the line moves closer to the post-operation period, while a negative slope suggests a decrease. Also, if the blue line is above the red line for the same time period, it indicates a higher volume of positive sentiment messages in the treatment area compared to the area outside the treatment area. Conversely, if the red line is above the blue line, it indicates a higher volume of positive sentiment messages in the area outside the treatment area compared to the treatment area.

In the case of Event 6, in contrast to the other events, a positive coefficient for the interaction term between time and distance is observed, meaning that the volume of positive sentiment messages within the treatment area is expected to be higher in the post-period compared to the areas outside the treatment area during the same time period. The positive coefficient observed for Event 6 could be attributed to the timing of the operation, which may have coincided with other positive developments or news events. Such events

could have influenced public sentiment, leading to an increase in positive messages. For instance, Event 6 took place just two weeks before the launch of Operation Conquest, a significant military campaign from the U.S. coalition forces aimed at retaking Mosul from ISIS.[100] This operation was a beacon of hope and marked a turning point in the fight against ISIS, potentially sparking a more positive outlook among the population. Therefore, the timing of Event 6 could have created a more receptive environment for the leaflet drop operation, leading to a more positive response from the population.

Table 2. Positive Message Count Poisson Regression Results

	Positive Message Count					
	Poisson (Event 1)	Poisson (Event 2)	Poisson (Event 3)	Poisson (Event 4)	Poisson (Event 5)	Poisson (Event 6)
Mosul Binary	0.030**					-0.035*
	(0.014)					(0.019)
Raqqa Binary		0.176***	0.049	0.556***	0.150***	
		(0.034)	(0.044)	(0.051)	(0.040)	
Time	-0.033***	0.095***	-0.006	0.017	0.068*	-0.015
	(0.009)	(0.035)	(0.042)	(0.052)	(0.037)	(0.015)
Population Density	0.056***	-0.052***	0.155***	-0.079**	0.205***	-0.039***
	(0.005)	(0.019)	(0.027)	(0.032)	(0.021)	(0.006)
GDP per capita	0.026***	-0.038***	0.034***	0.026***	0.033***	0.069***
	(0.004)	(0.005)	(0.007)	(0.007)	(0.006)	(0.005)
Road Density	-0.083***	0.076***	-0.196***	0.086**	-0.133***	-0.023***
	(0.006)	(0.023)	(0.030)	(0.036)	(0.020)	(0.006)
Tweet Count	1.108***	1.164***	1.149***	1.208***	1.136***	1.044***
	(0.003)	(0.008)	(0.008)	(0.011)	(0.009)	(0.005)
Death History	-0.007***	-0.039***	-0.066***	-0.019*	-0.118***	-0.049***
	(0.002)	(0.007)	(0.009)	(0.011)	(0.006)	(0.005)
Death Current	0.148***	-0.055	-0.287***	-0.462***	-0.064**	0.103***
	(0.013)	(0.068)	(0.041)	(0.028)	(0.030)	(0.010)
Mosul Binary x Time	-0.113***					0.124***
	(0.018)					(0.022)
Raqqa Binary x Time		-0.255***	-0.116**	-0.467***	-0.045	
		(0.041)	(0.054)	(0.058)	(0.044)	
Constant	-2.371***	-2.182***	-2.774***	-2.708***	-3.558***	-1.970***
	(0.050)	(0.162)	(0.201)	(0.211)	(0.158)	(0.052)
Observations	2,528	2,442	2,442	2,442	2,442	2,528
MAE	4.462	1.391	0.783	0.624	1.088	2.806
RMSE	36.123	14.377	7.857	5.208	10.127	18.185
AIC	6,738	2,888	1,717	1,500	2,183	5,127
BIC	6,796	2,946	1,775	1,558	2,241	5,186
Log Likelihood	-3,358.969	-1,433.821	-848.347	-740.073	-1,081.624	-2,553.737
Note:						*p < 0.1; **p < 0.05; ***p < 0.01

[100] Henry Austin and Sarah Burke, "Iraqi Forces Launch 'Operation Conquest' to Retake Mosul from ISIS," NBC News, March 24, 2016, https://www.nbcnews.com/storyline/isis-terror/iraqi-forces-launch-operation-conquest-retake-mosul-isis-n544826.

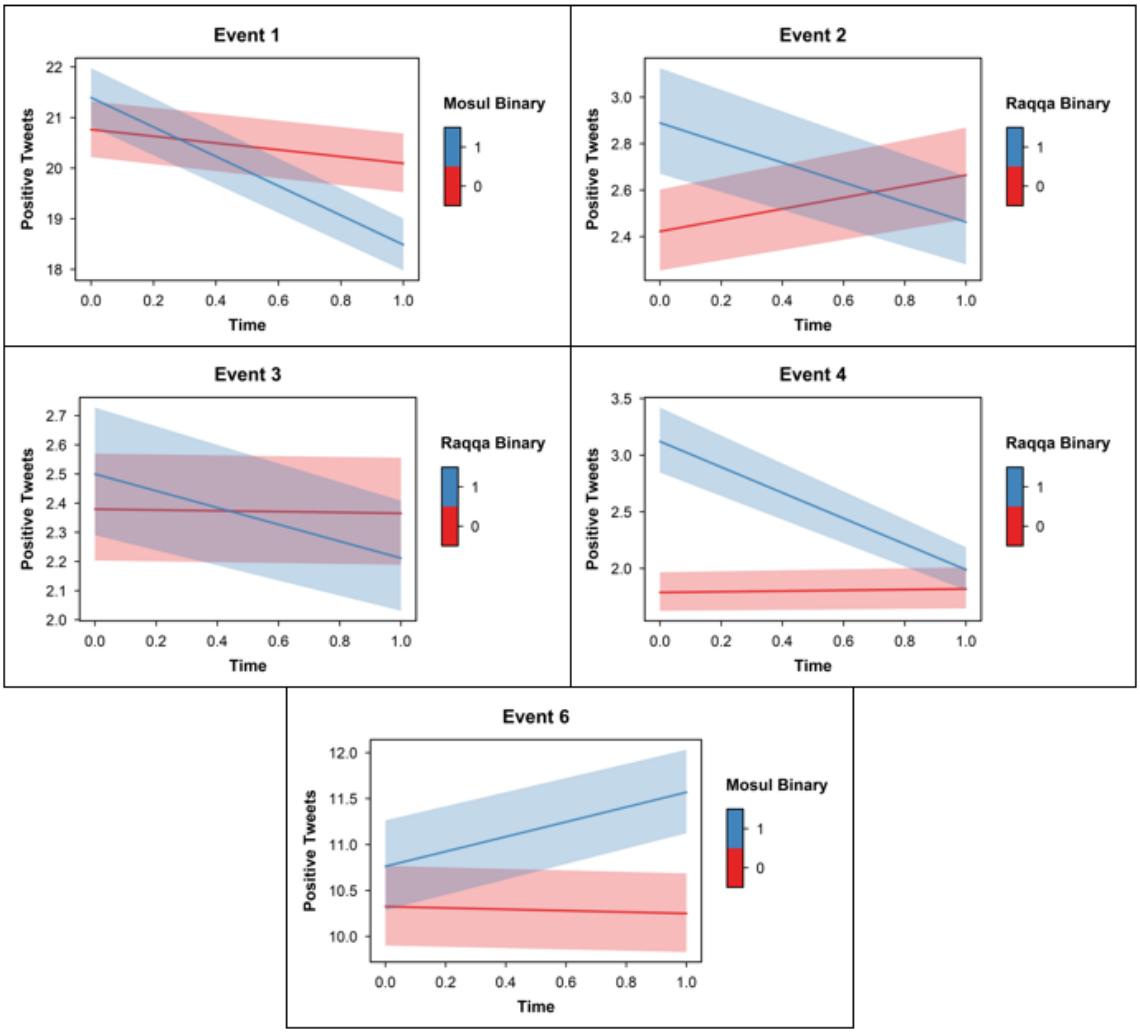

Figure 10. Predicted Effects on Positive Message Count

C. FINDING THREE: OPERATIONS ASSOCIATED WITH A DECREASE IN VIOLENT DEATHS

Table 3 presents the results of Poisson regression models with the number of violent deaths as the dependent variable. The independent and control variables remain consistent with the previous models. The analysis reveals that the interaction between time and distance is statistically significant (p-value < 0.01 to < 0.1) for four events: Events 1, 4, 5, and 6. The coefficient for the interaction term between time and distance indicates how much the volume of violent deaths is expected to change after the leaflet drop within the treatment area, compared to how much it is expected to change in the areas outside the

treatment area during the same time period. Except for Event 6, all three events demonstrating statistical significance exhibit a negative coefficient for the interaction term. The negative coefficients suggest that the volume of violent deaths within the treatment area is expected to be lower in the post-period compared to the areas outside the treatment area during the same time period. This finding is contrary to the third hypothesis which predicted that leaflet drop operations are likely to lead to an increase in the number of violent events in the surrounding area.

Figure 11 shows prediction plots for the leaflet drop operations that demonstrated statistical significance for the number of violent deaths. The y-axis represents the expected number of violent deaths, while the x-axis shows the time period, with "0" for before the leaflet drop and "1" for after the operation, including the operation day. The z-axis differentiates whether the location is within 65-kilometers of the city center shown by a blue line or outside 65-kilometers from the city center shown by a red line. The slope of these lines reveals the relationship between the time variable (pre- and post-operation) and the number of violent deaths. A positive slope indicates an increase in violent deaths as the line moves closer to the post-operation period, while a negative slope suggests a decrease. Also, if the blue line is above the red line for the same time period, it indicates a higher number of violent deaths in the treatment area compared to the area outside the treatment area. Conversely, if the red line is above the blue line, it indicates a higher number of violent deaths in the area outside the treatment area compared to the treatment area.

The negative coefficient observed in these events could be attributed to a combination of factors. First, the propaganda aspect of the leaflets might have been more effective than anticipated, sowing seeds of doubt and mistrust within ISIS and leading to disintegration or reduced group cohesion, and consequently, less violence. Second, the leaflet drops could have served as a warning sign for civilians and non-combatants, allowing them to take precautionary measures or evacuate the area, thereby reducing the number of potential victims. Third, the fear of retaliation from ISIS may have prompted civilians to remain cautious, leading to a decrease in potential targets for violence. Finally, ISIS fighters may have adopted a more cautious approach in response to the leaflet drops, temporarily reducing their violent activities as they anticipated retaliation.

Table 3. Death Count Poisson Regression Results

	Death Count					
	Poisson (Event 1)	Poisson (Event 2)	Poisson (Event 3)	Poisson (Event 4)	Poisson (Event 5)	Poisson (Event 6)
Mosul Binary	2.079***					0.474
	(0.128)					(0.338)
Raqqa Binary		-1.189***	-1.758***	1.254***	-0.435	
		(0.261)	(0.523)	(0.414)	(0.382)	
Time	0.547***	-0.742***	1.020***	1.805***	1.350***	-0.433
	(0.143)	(0.226)	(0.282)	(0.381)	(0.300)	(0.427)
Population Density	-0.308***	0.045	0.272*	-0.414***	0.179	0.051
	(0.025)	(0.108)	(0.146)	(0.110)	(0.130)	(0.145)
GDP per capita	0.287***	0.035	0.342***	0.047	0.088**	0.161*
	(0.022)	(0.032)	(0.067)	(0.040)	(0.041)	(0.085)
Road Density	-0.318***	0.499***	0.527***	0.753***	0.388**	-0.062
	(0.032)	(0.144)	(0.166)	(0.200)	(0.162)	(0.137)
Tweet Count	0.387***	0.069**	0.105**	0.075***	-0.008	0.354***
	(0.014)	(0.033)	(0.042)	(0.025)	(0.034)	(0.037)
Death History	0.268***	0.722***	0.577***	0.956***	0.842***	0.625***
	(0.015)	(0.053)	(0.066)	(0.058)	(0.057)	(0.040)
Mosul Binary x Time	-4.325***					0.911**
	(0.326)					(0.443)
Raqqa Binary x Time		-0.057	-0.018	-2.789***	-1.168***	
		(0.403)	(0.552)	(0.456)	(0.426)	
Constant	-1.287***	-5.922***	-11.433***	-6.305***	-8.361***	-6.740***
	(0.267)	(0.885)	(1.191)	(1.034)	(1.082)	(1.470)
Observations	2,528	2,442	2,442	2,442	2,442	2,528
MAE	0.488	0.099	0.062	0.074	0.078	0.051
RMSE	8.387	0.999	0.764	0.883	0.726	0.565
AIC	6,056	1,177	726	782	789	562
BIC	6,108	1,229	778	834	842	615
Log Likelihood	-3,018.939	-579.626	-354.084	-382.038	-385.692	-272.113

Note: $^{*}p < 0.1$; $^{**}p < 0.05$; $^{***}p < 0.01$

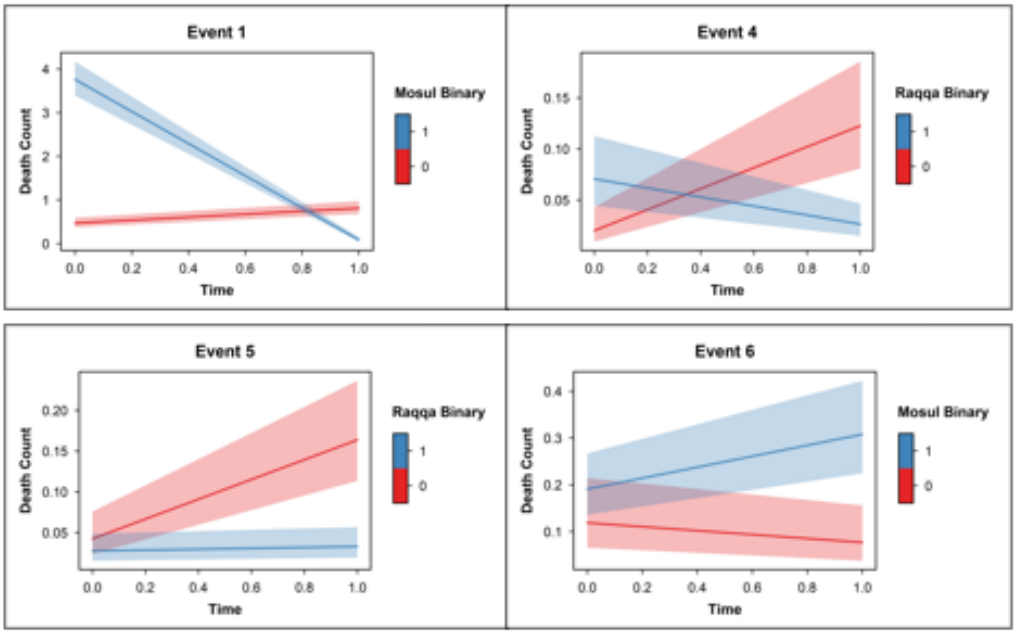

Figure 11. Predicted Effects on Death Count

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VI. CONCLUSION

This thesis explored the potential of utilizing open-source data to evaluate the impact of OIE, highlighting the power of data-driven methodologies in assessing OIE effectiveness. The study yielded three key findings: 1. Leaflet drop operations were associated with an increase in social media communications. 2. These operations also corresponded with a decline in expressions of positive sentiment. 3. A decrease in violent deaths was observed following leaflet drop operations. Based on the preliminary evidence presented here, it seems that these operations had a mixed overall effect as they stimulated social media discussions and reduced violent deaths but led to a decrease in positive sentiment expressions on social media. We also observed important differences between operations, for instance, in the operation on March 10, 2016, in Mosul, Iraq, we observed an increase in violence following the leaflet drop, rather than a decrease. These partially divergent outcomes seen in these cases point strongly towards the need for additional research to unpack the conditions under which operational approaches lead to different outcomes in different operations.

While these findings have provided a useful tool in assessing the OIE, the overarching message of this study is not merely the utility of social media or the specific outcomes of the operations, such as increased communication or decreased violence. Instead, it highlights how a data-driven, geospatial approach to operational assessment can yield more rigorous judgments by modeling the behavioral effects of operations.

In the broader context, the findings presented in this study have demonstrated the feasibility of employing data-driven approaches to evaluate the impact of OIE activities on both online and offline behaviors, including communication patterns and violent activities. This research provides a holistic understanding of OIE's impact on behaviors in both digital and physical spaces by integrating data from various sources, including publicly available information (PAI), social media, news outlets, and other open-source data. Additionally, the data-driven geospatial approach to operational assessment presented in this study could offer a promising framework for evaluating IO effectiveness across a broader spectrum of

activities, including traditional media campaigns, public opinion analysis, targeted messaging, and online counter-disinformation efforts.

The geospatial approach can also aid in producing clear results which can visually represent the impact and reach of OIE activities. These visualizations can provide a dynamic and concise representation of the data, making it easier to understand and interpret the effectiveness of OIE activities. This not only enhances our understanding of the IE, but also provides a practical tool for strategizing and optimizing future OIE activities.

Based on these findings, our core recommendation is that the joint force should adopt these data-driven geospatial approaches to the assessment of OIE. This would provide transformative capability leveraging ongoing open-source streams to dynamically assess operations and effects at scales that were previously impossible. In contrast to the current assessment approaches which tend to be ad-hoc and subjective, this new approach leverages cutting-edge statistical techniques to provide quantifiable metrics of actual behavioral impacts.

In addition, this research points to two secondary recommendations. The first recommendation emphasizes the importance of real-time data collection and analysis in an operational setting. While this study utilized historical archive data, the dynamic nature of IO hinges on real-time data collection and analysis. However, the collection and analysis of real-time data requires substantial investments in data infrastructure and personnel capable of continuously monitoring social media, news, and other sources of data. The second recommendation suggests early integration of assessment planning into the overall operation, which would facilitate establishing behavioral baselines before an operation begins by collecting data on key indicators like public sentiment or communication patterns. These baselines provide a clear comparison point, enabling a more precise assessment of OIE.

This study paves the way for future research by demonstrating the potential of data-driven, geospatial approaches in assessing the effectiveness of OIE. Future research should continue to explore the potential of open-source data by expanding the scope of data collection to encompass a wider range of sources to evaluate the impact of OIE.

Additionally, future research should focus on extending the application of this data-driven geospatial approach to a broader range of military operations assessment processes. The implications of this study should encourage further exploration and application of these methodologies in the field, thereby contributing to the advancement of our understanding of military operations.

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