SPATIAL RISK ANALYSIS OF OIL REFINERIES AND IMPACTS TO MILITARY OPERATIONS

Zachary L. Schiff, Department of Systems and Engineering Management, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433, 937-255-6565, Zachary.schiff@afit.edu
William E. Sitzabee, PhD, PE, Department of Systems and Engineering Management, Air Force Institute of Technology, Wright-Patterson AFB, OH 45433, 937-255-6565, William.sitzabee@afit.edu

ABSTRACT

Failures of critical infrastructure have become more commonplace due to advances in technology, terrorist threat, and coupling of infrastructures. Military operations are dependent on refined petroleum products to provide the ability to project forces worldwide. Oil refineries are critical to military readiness and tend to be co-located in relatively small geographic regions. This paper presents a methodology to statistically measure the increase in vulnerability due to clustering of the high-volume oil refineries.

INTRODUCTION

Over the past quarter century, technology advances have contributed to an increase connectedness, also known as coupling effects or interdependencies, between different critical infrastructure systems. Four general categories of coupling effects exist: physical, cyber, geographic, and logical [1]. As a result, natural disasters, aging infrastructure, human error, and terrorist attacks have the ability to cause disruptions to society in multiple different economic sectors and infrastructure systems at the same time. With multiple disruptions to critical infrastructure, the nation's ability to function properly is severely hampered and impacts the economy, government, and health sectors. Limits of money, time, and manpower require a management strategy to determine where resources should be applied to reduce the impacts of failure to critical infrastructure. This is typically completed in a two-step process: risk assessment and risk management. Risk assessment involves the collection and integration of threat, vulnerability, and consequence. Risk management determines which measures should be taken based on a risk reductions strategy [2].

BACKGROUND

The Homeland Security Act of 2002 established the Homeland Security Department (HSD) in order to protect key resources and infrastructure from disaster, ultimately to reduce the impact of terrorist attacks on the United States. Homeland Security Presidential Directive Number 7 (HSPD-7) stated the Secretary of Homeland security was responsible for coordinating the overall national effort to identify, prioritize, and protect critical infrastructure and resources. HSPD-7 also designated agencies responsible for conducting analyses and directed HSD to produce a comprehensive, integrated plan for critical infrastructure. The National Strategy for Homeland Security categorized critical infrastructure into 13 different sectors and the petroleum infrastructure falls within the energy sector [3]. The petroleum infrastructure and refineries are actively monitored by the Department of Homeland Security and Department of Energy. The relationship between government entities and private industry is complicated due to the fact that approximately 85 percent of the national infrastructure is owned by private industry [4]. Furthermore, the government acts as both a regulator and consumer [5].

Energy security is a key concern for military leaders within the Department of Defense (DoD) as privately and publicly operated commercial distributions systems provide energy in different forms to the bases. While short-term outages are routinely exercised, the impacts of long-term outages are not well understood [6]. Within the United States Air Force, infrastructure energy only accounts for a small portion of the overall energy consumption. Nearly 84 percent of the energy consumed by the Air Force is aviation fuel use, with 12 percent in facilities and 4 percent in vehicle and ground equipment. This indicates that a major disruption in fuel supply would have major mission impacts and could significantly disrupt operations and our national security.

The United States refining industry supplies over 50 percent of the jet fuel demand and the DoD has consumed as much as 145 million barrels annually [7]. Typical refineries yield a limited supply of jet fuel and diesel fuel depending on the type and quality of crude oil processed. Petroleum infrastructure has been identified as geographically concentrated in the past and different types of policy methods were evaluated to encourage dispersion [8]. Specifically, Texas and Louisiana refineries account for 43 percent of the total United States refining capacity. Of further concern, according to GAO-09-87, refineries are producing at a level very close to maximum capacity [9]. As a result, a disaster, either natural or man-made, could potentially result in large shortages for a time period.

Risk Analysis

The concept of risk and risk assessments have a long history, and date back more than 2,400 years ago when the Athenians utilized their risk assessment methods before making decisions in war [10]. Understanding and measuring risk against consequences has been one of the foundational pillars of western society. Risk analysis is commonly used to describe the uncertainty involved with events that affect the financial market, health industry, and critical infrastructure. In both business and government, leaders are faced with decisions and information that has uncertainty. Understanding the uncertainty provides the baseline for making better decisions [11].

Risk, a function of vulnerability, consequence, and threat, is typically used for computing risk and also discussions about risk. Lowrance [12] introduced risk as a measure of the probability and severity of adverse effects. Cox [13] provides generally-accepted definitions for each of these terms. Risk is defined as the potential for loss or harm due to the likelihood of an unwanted event and the consequences of the event. Consequence is the outcome of the event that includes any losses of capability or ability to operate normally. Threat is any indication, circumstance, or location that places an asset or event with the potential to cause damage. Vulnerability is any weakness in the asset or system infrastructure design that can be exploited [13].

In the United States Governments' Risk Assessment Methods, there have been three phases of formulas in the past decade [14]. In the first phase that spanned FY2001 to FY2003, the Department of Justice was responsible for handling risk and risk equated to population. In the second phase which spanned FY2004 to FY2005, risk was the sum of threat (T), critical infrastructure (CI), and population density. In the third phase, which is currently still in practice, the probability of events was systematically introduced into the formula. Equation 1 shows the current approach in which risk is a function of threat (T), vulnerability (V), and consequence (C) variables [2].

$$\text{Risk} = f\,(T, V, C) \tag{1}$$

In the review of this method by the national research council, multiplying the variables together produces acceptable natural disaster risk quantification [15].

Geographic Information Systems

Tobler [16] introduced the first law of geography which states that everything is related, but items that have smaller distances between them are more related than distant items. Spatial autocorrelation is the tool that was created as a result of this relationship and describes the relatedness of items and their relationships across space [17]. Several authors [18, 19] have used spatial tools to determine the relationship of infrastructure systems and evaluate the vulnerability of infrastructure systems. Geographic Information Systems provide a toolset to both statistically and visually identify trends in data with respect to both space and attributes.

RESEARCH

This research examines how the spatial relationship and coupling effect of oil refineries pose a threat to military readiness. A spatial analysis of oil refining data was conducted to determine how oil refineries are related to each other based on location and capacity. This will yield insight as to the type of threats and potential risk mitigation strategies that are available to minimize future disruptions.

Data Collection

Data were collected from public sources including the U.S. Department of Energy (DoE), Energy Information Administration (DoE), and the United States Census Bureau. The data pieces include refining capacity, refinery names, and United States boundaries. The refining capacity, name, and production characteristics are available from the Energy Information Administration. Refinery names were georeferenced with latitude and longitude coordinates in order to spatially connect the production characteristics with location.

Spatial Analysis

In order to determine if a correlation exists between location and capacity of the oil refineries, two statistical tools are available: Spatial Autocorrelation (Global Moran's I) and Cluster/Outlier Analysis (Local Anselin's I). Given a set of features and an associated attribute, these tools evaluate whether pattern exists that is clustered, dispersed, or random. Each of the tools returns four different values: Local/Global I value, z-score, p-value, and a code representing the cluster type. A large I-value (positive/negative) indicates a strong relation of the feature with a nearby feature. An I-value of zero indicates that there is not a relationship between location and the attribute. The p-value and z-score confirm statistically whether a correlation exists. Table 1 shows the results of the Moran's I analysis and Figure 1 shows the the spatial analysis with the high output refineries in a clustered region highlighted. The Moran's I analysis reveals that there is less than a 1% chance that the pattern is random and confirms a clustered pattern.

Table 1: Moran's I Analysis

	Moran's I	**z-score**	**p-value**
Oil Refinery Analysis	0.1582	11.1848	0.0000

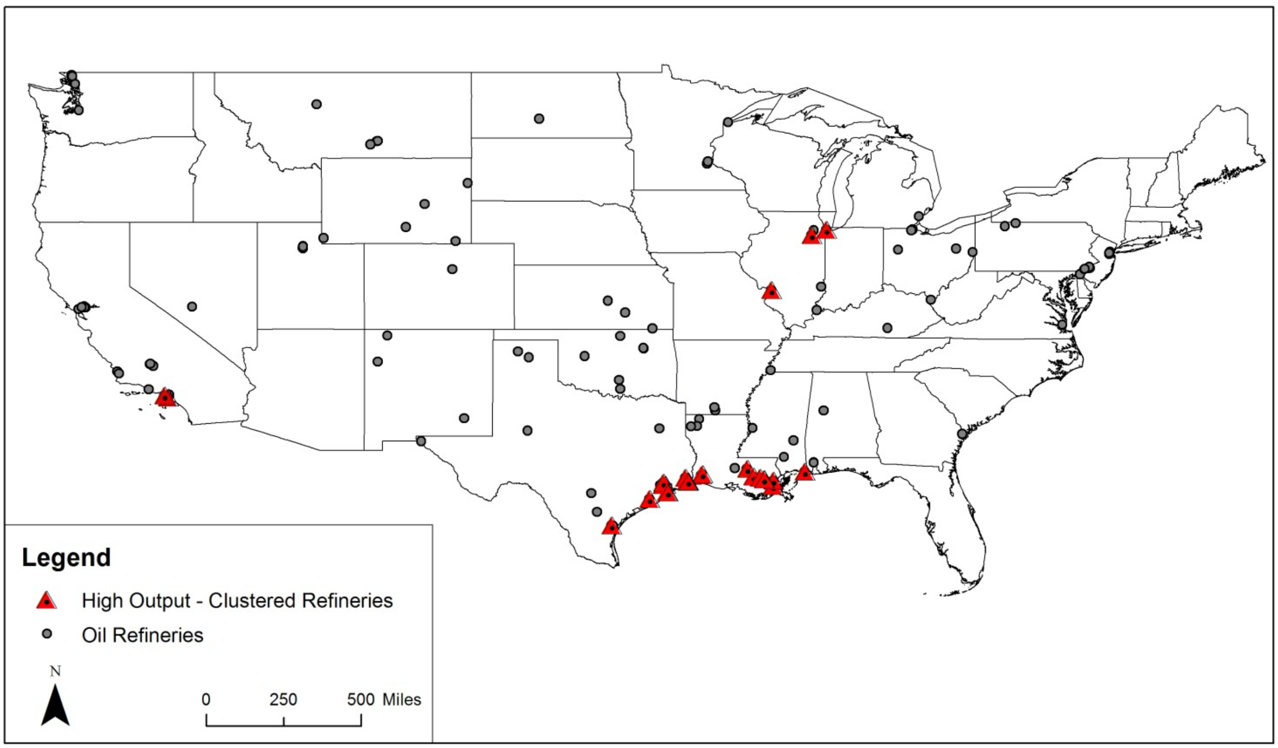

Figure 1: Oil Refinery Spatial Analysis

DISCUSSION

The spatial analysis compared oil refinery location and capacity which led to three key findings. First, the analysis showed that the Southeast Gulf Region has an area with high output, highly clustered refineries. Second, the analysis revealed that the Great Lakes Region also has a high output, clustered area with several refineries; this was an unexpected result. Finally, the West Coast Region had a high output cluster of refineries that was less significant than the first two regions, and was also unexpected.

This research effort shows visually and mathematically that high capacity refineries are co-located in a very small geographic area. While this was previously identified visually, this paper presents a method to use spatial statistics to quantify and validate previous research. Since vulnerability is directly tied to risk, several conclusions can be drawn. Oil refineries within the areas identified above should be protected against natural disasters (i.e. hurricanes, earthquakes, tsunamis). Furthermore, these are the refineries that should be considered for hardening in a man-made disaster scenario (i.e. terrorism).

As a result of the refineries operating at near full capacity, policy to encourage the construction of new refineries and more capacity should be proposed to reduce the vulnerability of a disruption to military readiness. Oil refined products play a key role in the military's ability to conduct operations across the world. A significant disruption to the oil refinery system could potentially have severe policy and military implications.

Finally, the tools in this research can be used to determine where to place future capacity and how to reduce the system impacts of location within the oil refinery system. Policy makers should shape and mold policy to protect existing refineries and look for ways to encourage dispersal in the construction of future refineries. The tools used in this research could visually and mathematically determine whether the new refinery reduces the vulnerability and thus the overall risk to the system.

DISCLAIMER

The views expressed in this article are those of the authors and do not reflect official policy or position of the United States Air Force, Department of Defense, or the United States Government.

BIBLIOGRAPHY

[1] S. Rinaldi, J. Peerenboom, and T. and Kelly, "Identifying, Understanding, and Analyzing Critical Infrastructure Interdependencies," *IEEE Control Systems Magazine*, pp. 11-25, 2001.

[2] John Moteff, "Risk Management and Critical Infrastructure Protection: Assessing, Integrating, and Managing Threats, Vulnerabilities, and Consequences," Congressional Research Service, Washington, DC, Report for Congress Order Code: RL32561, 2004.

[3] George W. Bush, "National Strategy for the Physical Protection of Critical Infrastructure," White House, Washington, D.C., 2003.

[4] C. Robinson, J. Woodard, and S. Varnado, "Critical Infrastructure: Interlinked and Vulnerable," *Issues in Science and Technology*, pp. 61-67, September 1999.

[5] J. Simonoff, C. Restrepo, R. Zimmerman, and Z. Naphtali, "Analysis of Electrical Power and Oil

and Gas Pipeline Failures," in *International Federation for Information Processing*, E. Goetz and S. Shenoi, Eds. Boston: Springer, 2008, vol. 253, pp. 381-294.

[6] "Air Force Energy Infrastructure Plan," 2010.

[7] Anthony Andrews, "Department of Defense Fuel Spending, Supply, Acquisition, and Policy," Washington, D.C., 2009.

[8] P. Parformak, "Vulnerability of Concentrated Critical Infrastructure: Background and Policy Options," Washington, D.C., 2007.

[9] F. Rusco, "Refinery Outages Can Impact Petroleum Product Prices, but No Federal Regulations to Report Outages Exist," 2008.

[10] Terje Aven, *Foundations of Risk Analysis*. Hoboken, NJ: John Wiley & Sons, Ltd., 2003.

[11] David Vose, *Risk Analysis: A Quantitative Guide (3rd Edition)*. Hoboken, NJ: John Wiley and Sons, Inc., 2008.

[12] William Lowrance, *Of Acceptable Risk*. Los Altos, CA: William Kaufmann, 1976.

[13] Jr., Anthony (Tony) Cox, "Limitations of "Risk = Threat x Vulnerability x Consequence" Risk Analysis," *Risk Analysis*, pp. 1749-1761, 2008.

[14] Todd Masse, Siobhan O'Neil, and John Rollins, "The Department of Homeland Security's Risk Assessment Methodology: Evolution, Issues, and Options for Congress," Washington, D.C., 2007.

[15] John Ahearne, "Review of the Deparment of Homeland Security's Approach to Risk Analysis," Washington, D.C., 2010.

[16] W.R. Tobler, "A computer movie simulating urban growth in the Detroit region.," *Economic Geography*, pp. 234-240, 1970.

[17] P. Longley, M. Goodchild, D. Maguire, and D. Rhind, *Geographic Information Systems and Science*. Hoboken, NJ: John Wiley & Sons, Inc., 2011.

[18] C.Y. Shih et al., "Data Management for Geospatial Vulnerability Assessment of Interdependencies of U.S. Power Generation," *Journal of Infrastructure Systems*, pp. 179-189, 2009.

[19] Peter Sabatowski, "Security Vulnerability Trends related to Electric Power Supplied at Military Installations," Wright-Patterson Air Force Base, 2010.

[20] Luc Anselin, "Local Indicators of Spatial Association," *Geographical Analysis*, pp. 27:93-115, 1995.

[21] Edward Feser and Stuart Sweeney, "Regional Industry Cluster Analysis Using Spatial Concepts," in *ACCRA 46th Annual Conference*, Charlotte, NC, 2006, pp. 1-37.