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Examining the Impact of Logistics on Military Strength among East Asian Nations Using Data Envelopment Analysis

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EXAMINING THE IMPACT OF LOGISTICS ON MILITARY STRENGTH AMONG EAST ASIAN NATIONS USING DATA ENVELOPMENT ANALYSIS

THESIS

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Abstract

The current narrative in logistics revolves around modernization and the rapid development and deployment of capabilities, which is a sentiment echoed across the Air Force and the DoD alike. However, the combination of intangible and tangible aspects of logistics can make it challenging to find a foundational place to start the process. The purpose of this study is to evaluate logistical factors to include land area, infrastructure, labor force, and GDP and their relationship to military power. This foundation will provide a baseline of areas for improvement and replication. Data Envelopment Analysis (DEA) and linear regression were leveraged to analyze countries in the East Asian hemisphere and the United States. Additionally, the weight of the relationship between logistical factors and military power was explored. This research concludes that while countries are not entirely efficient at achieving military power, targeted areas can be used to improve with promising results. Moreover, the selected logistical factors were shown to exercise a strong influence over military power.

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The logistics field requires constant vigilance and a personal sense of humility to seek, learn from, and add new areas to your individual flair and finesse for problem-solving when the unexpected is inevitably thrown your way. 2020 has certainly had its unexpected twists and turns, but I would like to thank my classmates for riding it out together with kindness, support, and in good humor. I would also like to thank my thesis advisor Dr. Seong-Jong-Joo for his positive and encouraging disposition, and my sponsor DLA Aviation, and Brigadier General David Sanford, for his mentorship and for allowing me to take on this topic. Finally, to my daughter, the toughest kid I know: everything I do is for you.

Meaghan E. Crandell, Capt, USAF

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EXAMINING THE IMPACT OF LOGISTICS ON MILITARY STRENGTH AMONG EAST ASIAN NATIONS USING DATA ENVELOPMENT ANALYSIS

I. Introduction

Background/Problem Statement

The world of logistics is rapidly transforming. With the advancement of technology and the refinement of shipment and delivery strategies throughout the globe, the ability to move assets efficiently, effectively, and with precision is no longer a luxury…but an expectation. More and more industries are trying to gain a competitive edge by developing their logistical processes, including foreign nations and near-peer adversaries (Wissler, 2018). Just as Jeff Bezos commercially redefined how to leverage the supply chain to meet consumer needs with overwhelming success (Haber, 2016), the Department of Defense (DoD) needs to begin considering how to transform the military supply pipeline to reach the level of flexibility, resilience, and lethality it aspires to attain in the realm of adaptive basing and future conflict (Mattis, 2018). The Air Force must begin to holistically consider evaluating the supply chains of both businesses and nations alike to identify potential benchmarks that can be explored and refined or, conversely, vulnerabilities that can be exploited and referenced in its own pursuits of restructuring the military value chain.

Before the process of refinement begins, however, in the case of large organizations such as the Air Force, DoD, or even an entire country in that of itself, a clear picture needs to be developed of current capabilities, as well as the level of efficiency in which those capabilities are being utilized. Additionally, a closer look at how these factors expressly contribute to the organization's overall effectiveness needs to

be pinpointed as a source of study and potential replication. In this case, the relationship between four logistical elements or metrics was evaluated with military power as a baseline.

Various factors affect and dictate the military power of a nation. Brooks (2007) argues that while material and human resources such as wealth, technology, and human capital are necessary pieces of the puzzle, how a nation leverages those resources is just as, if not more, pertinent in the cultivation of military effectiveness. Moreover, many outside entities shape how a nation uses its assets, such as cultural and societal factors, political institutions, and the international arena's landscape. Essentially, military power does not necessarily revolve solely on the amount of resources a nation has at its disposal but how efficiently it leverages these resources. This mismatch can be seen in the case of Russia and North Korea, both of which may not necessarily have all of the infrastructure, technology, or other elements that may dictate strength and modernization, but consistently rank highly in terms of military power because of how they work around and leverage their limited resources. In that vein, this study determined how well each of the four categories was utilized by their respective countries and how the efficient utilization of these resources contributed to their overall military power.

Purpose Statement

This study's primary purpose is to explore the efficiency of logistical factors and processes of nations within the United States Indo-Pacific Command (INDOPACOM) that contribute to strengths or weaknesses within each respective military. Logistics can be a broad term and is often coupled with intangible characteristics that are difficult to measure. Bridging this gap was done by focusing on four variables: Gross Domestic

Product (GDP), Total Land Area, Logistics Labor Force, and Infrastructure. Each of these components was then evaluated in their total contribution to military power for a specific country based on how efficiently these resources were utilized. The countries were then ranked by relative efficiency for each category. Through this research, Data Envelopment Analysis (DEA) was sought to identify and evaluate the critical drivers' contribution to military success by their efficiency. Once determined, linear regression was used to provide additional context and determine the weight each variable had on military power. While evaluating this body of research, the endeavor was to find which components offer the highest return on investment and simultaneously drive the most substantial impact by carefully managing their usage.

Research Questions

This study tries to answer the following two questions:

RQ1: How efficiently does each country achieve its military power?

RQ2: To what level, if any, does each variable affect military power?

Production theory was first observed to provide a framework for the inputs and outputs selected before performing DEA and garner an understanding of the relationship between decision-making entities and limited resources on a larger scale. The literature review revolved around the use of DEA in the areas of efficiency, logistics, economic growth, infrastructure, and potential military applications. Both DEA and linear regression models were fashioned as complements to determine the efficiency with which each country achieved its military power and the magnitude in which each factor played a role in that process. Finally, findings are presented with a discussion on research limitations and areas for future research.

Methodology

The methodology utilized to analyze the information in this research includes three unique DEA models: a Charnes-Cooper-Rhodes (CCR) model, a Banker-Charnes-Cooper (BCC) model, and a slack-based measure of efficiency (SBM) model. Linear Regression was then used to add context to the relationships among variables in each model. Finally, Production Theory was used as a framework to present the findings based primarily on the principles outlined in the text, *A Theory of Production* (Cobb & Douglas, 1928).

Assumptions

This thesis's primary assumption is that the data collected from Military Firepower and the Logistics Performance Index (LPI) are a correct and accurate representation of overall military strength and logistics performance for each country.

Limitations

This study derived information from sources that are subjective in nature. The military power indices published by Global Fire Power were used to convey a country's military standing on a global scale. These indices are rankings based on each nation's potential war-making capability across land, sea, and air fought by conventional means. Holistically, this information incorporates manpower, equipment, natural resources, finances, geography, and many other individual factors (Global Firepower, 2021). The data does not include immaterial aspects of military power such as strategy, doctrine, and the impact of voluntary versus involuntary military service and is heavily quantitative. The World Bank publishes both the Gross Domestic Product (GDP) and the Logistics

Performance Index (LPI). Although the logistics performance measures derived from the LPI are based on a combination of qualitative and quantitative measures, the qualitative assessments are based primarily on surveys and interviews from experts in the field of logistics and are potentially predisposed to personal biases. Despite these sources' subjectivity, they have been used as the foundation of various studies and are reputable. North Korea was excluded from this research due to a lack of available data for their logistics performance.

II. Literature Review

Chapter Overview

The purpose of this chapter is to provide the foundational knowledge used to support effective logistics practices in a militaristic or organizational context, based on the efficient use of resources. This chapter begins with an evaluation of production theory. This topic will provide the theoretical basis of manipulating inputs and outputs to achieve an ideal outcome, or in this case, an increase in military power. This literature review will then go through an overview of DEA's uses and measuring efficiency, then move into a synopsis of the relevant uses in logistics, economics, infrastructure, and military applications. There were no studies that did a targeted analysis on the influence of logistical factors in relation to military power within a country.

Production Theory

The theory of production is rooted in economics. It attempts to explain the methods by which a firm dictates how much of each commodity, or output, it sells and produces, as well as how many inputs such as labor or raw materials it will use to achieve that level of output (Dorfman, 2016). After exploring the ideal balance of inputs to outputs, Dorfman (2016) classified various productive activities to include determining the most profitable quantity of products and the best approaches to maximize profits within those parameters. This way of thinking created new ways to manipulate and optimize the selection of inputs and outputs that had a tangible effect on the bottom line of a firm by finding the “perfect” balance.

In *A Theory of Production*, Cobb and Douglas (1928) sought to understand the relationship between inputs and outputs based on the two entities' relative changes. The effect that transfers from input to output or the "relative influence" between these variables is measured in DEA as efficiency. Fully recognizing the correlative nature of the DEA variables in the same fashion as the theory of production allows one to pinpoint and adjust inputs and/or outputs to achieve better efficiency. This relationship has been translated and leveraged in several different studies to include an interesting adaptation on ecological efficiency.

Production theory was used alongside DEA to investigate the outcome of various polluting activities. While DEA was typically used to balance "good" variables to provide an ideal outcome, in the case of ecology, various "bads" or negative aspects were evaluated and weighed in terms of inputs and outputs to find an outcome that caused the least amount of environmental damage (Dyckhoff & Allen, 2001). Production theory was also used as the theoretical foundation to explore the relationship between quality and efficiency. DEA is almost exclusively used to study efficiency from a perspective that is internal to the firm, excluding outside factors that often go in conjunction with efficiency, such as quality of service. Using a quality-adjusted model developed by Sherman and Zhu (2006) and Zervopoulos and Palaskas (2001) further enhanced the model to balance high-quality and high-efficiency per service unit used in a selected sample. In the same vein, this paper's research uses production theory as a basis for a carefully selected series of inputs and outputs to showcase varying levels of logistical efficiencies to target and balance performance within countries in the East-Asian hemisphere.

DEA and Measuring Efficiency

Salas-Velasco (2019) and Fifekov (2019) used DEA to competitively rank countries based on efficiency linked to targeted variables. In other areas, DEA has been used to analyze efficiency involve healthcare, to include a breakdown of healthcare investment and relative competitiveness of healthcare practices throughout 34 countries in East Asia (Kim, 2020), as well as varying modes of transportation such as air (Cui & Li, 2017a, 2017b, 2017c; Oum et al., 2005) and freight (Chakhtoura & Pojani, 2016; Lovold Rodseth, 2017), environmental practices, logistics performance, economic growth, national security, and military strength, just to name a few. More of these studies will be discussed in the following literature.

Logistics Performance Index (LPI)

While the connection between logistical prowess and success may appear as a recent discovery with the commercial industry's logistics boom not far off in the distance, prioritizing logistics has long been touted as a recipe for military accomplishment. The Roman Army relied on a robust supply network to wage highly aggressive warfare at all times of the year (Roth, 1999). Moreover, Sun Tzu himself stated that the line between disorder and order lies in logistics (Tzu, 2018). The Logistics Performance Index (LPI) is a tool created and published every two years by the World Bank to assess challenges and opportunities that a series of 160 countries face in their performance concerning trade logistics (International LPI, 2020). A combination of field-related feedback and quantitative performance data is used to calculate the score in six categories, including infrastructure, shipping, customs, timeliness, tracking and tracing, and quality of logistical services to reach a composite score (International LPI, 2020). The score can

range anywhere from one to five, with one being the lowest performance level and five being the highest performance level. Elements of the LPI were used for the DEA model established in this study.

There are currently no direct studies linking the LPI, or specific portions of the LPI, to Military Strength. The LPI has frequently been used in conjunction with DEA to measure the logistical presentation and relative efficiency of a country or entity. Marti et al. (2017) computed and assessed a synthetic index of overall logistics performance, using LPI as the basis, with the intent to assist countries, governments, and corporations in furthering relationships with business partners and to effectively anticipate fluctuations that could harm their competitiveness. Though several factors were analyzed, it was found that income and geographical area were top drivers of logistics performance. The point was then made that this DEA-LPI model would be apt in presenting a realistic direction and intensity for efficiency improvement concerning logistics performance, making it a useful tool for planners implementing logistics programs. As an extension, it is possible to consider using the LPI as an input for military power to assess areas of improvement and potential contributions to military strength.

The efficiency of logistics activities is also recognized as a key factor in international freight transport. Therefore, assessing a country's logistics processes is pertinent for domestic and international logistics operators. Using the LPI, Andrejic and Kilibarda (2014) discovered that focusing on the logistics efficiency of a country provides a gateway to better trade flow and economics. Furthermore, they found that lower efficiency scores tended to indicate lower logistics quality and competence and a lower percentage of shipments meeting quality standards.

Yu and Hsiao (2016) examined the relationship between technology and logistics proficiency among countries. They divided countries into income groups and found that high-income groups tended to benefit more from logistics technology versus operational skill. Conversely, results from the low-income groups suggested an improvement in logistics technology and operational skills would provide the most return on efficiency.

In the environmental sphere, Lu et al. (2019) designed Environmental Logistics Performance Index (ELPI) by combining the traditional LPI with the transport sector's carbon dioxide emissions intensity and oil consumption intensity to determine which countries had better green logistics performance. In conjunction with DEA and an environment Range Adjusted Model (RAM), they evaluated the ELPI and found a significant relationship between income and region regarding impact to the environment through logistics, especially transportation. Low-income countries tended to have the worst ELPI, with an increasing gap between high and low-income groups. It is easy to see the LPI can be leveraged from various intents, as the field's breadth is vast and the opportunities to play with different variables are plenty.

Economic Growth Measures and Infrastructure

Countries with a booming economy are often perceived to be global powerhouses or, at the very least, are thought to have oriented themselves in the direction of success. Economic prosperity is measured via Gross Domestic Product (GDP), which is the value of all of the goods and services produced by a country in one year and then divided by a country's total population. When the GDP shows an increase year after year, it is known as economic growth (Roser, 2013). Stemming from increased access to resources and other commodities as an extension of economic expansion, countries can find themselves

better positioned to improve other conditions, such as infrastructure, social welfare, and even military strength.

The relationship between economic development and military strength was looked at specifically by Beckley (2010) to determine why certain countries could garner more military power than others. It was emphasized that while non-material factors such as political systems and standard of living undoubtedly contribute to economic development, a country's resources are the primary consideration for improvements in national defense and defense planning. By using variables including culture, democracy, and economic development, it was concluded that not only are military effectiveness and economic development positively correlated, but that economic development is a crucial piece of cultivating military power.

From a different perspective, Dumas (1990) articulated that economic power can be linked to a more diplomatic approach when influencing military strength and national security. While traditionally, the acquirement of weapons of mass destruction has been used as the foundation while considering global defense and posturing strategies, when economic strength was added to the equation, the results showcased the role that a robust economy has when settling conflicts versus other more violent alternatives that may have more destructive outcomes.

In Ross et al. (2012), a fundamental question of how to assess and improve the efficiency of economic systems has been around from the beginning of economics as a discipline, with the aim to improve living standards and quality of life. Multiple studies were consolidated for review, with the number of countries ranging from 16 to 130. The most common inputs used were GDP, capital, and labor, and the macroeconomic

performance of the countries was looked at over a period of one to fifty years from 1950-2010. The general consensus landed with increased economic efficiency linked to a spectrum of elements such as labor force, improved literacy rates, lower infant mortality, and the use of technology. Moreover, when it comes down to measuring economic growth and successful logistics strategies, physical infrastructure capabilities such as modes of transportation and communication may have noteworthy implications for strategic supply chain orientations, along with preserving the environment and the national trade policies of a country. This further emphasizes the relationships that exist between adequate supply chain infrastructure, sustainability, and economic growth. DEA was used to determine the link between productivity and infrastructure, resulting in 33 countries operating slower than their most productive scale. This discovery denotes an increase in infrastructure would improve these conditions and, by extension, its partners' sustainability and economic growth.

The World Bank estimated that the decision-making errors of China's infrastructure investments were around 30%, resulting in the loss of 500 billion Yuan (Zhen, 2006). An analysis of the efficiency of infrastructure investments in China showed that higher economic development areas such as the Yangtze River Delta and the Pearl River Delta Region tended to have the most growth in infrastructure and urbanization. The study also found that urbanization lags in the eastern provinces due to social, historical, and technological reasons. Further, inland transportation in European countries was targeted by Baran and Górecka (2019) using DEA through the lens of economic and environmental factors. This information led to the key finding that ineffective roads and rail transportation sectors were linked to economic and environmental concerns.

Military Applications and DEA

There are various uses and applications for Data Envelopment Analysis in a military setting that can be leveraged to glean inciteful information about efficiency and process improvement. For example, DEA was used in conjunction with Artificial Neural Networks (ANN) by Liu et al. (2009) to evaluate the performance of Military maneuver engineering support, a part of an engineering corps. Because there is a considerable breadth of roles, responsibilities, and projects within the maneuver engineering support element, analyzing performance was done primarily from a qualitative and subjective viewpoint in the past, focusing on only three criteria such as manpower, time, or outlay. The evaluation of these elements had even been dubbed as a "complex problem," a result of the many intricacies involved in rating performance. A hybrid two-stage model integrating neural networks and DEA was selected to analyze performance as analytically and objectively as possible. First, the maneuver engineering support projects were ranked, and efficiency scores were applied through DEA and given a "super-efficiency" score. Once the efficiency data was collected, it was then used to "train" the neural networks, also known as a teacher value. The objectivity obtained from the precursor DEA analysis was vital because it influenced the teacher value and the neural network when evaluating multiple criteria. Ultimately, this two-step evaluation method was successful.

In another study by Han and Sohn (2011), DEA was used to proactively group inventory management systems at existing air bases for the Republic of Korea Air Force (ROKAF) to increase efficiency and propose an optimal base-grouping scenario. The inputs used were factors affecting inventory management, such as the number of items

managed by item manager, the proportion of assigned item managers to authorized item managers, and the number of Not Operationally Ready Supply (NORS), representing the degradation of aircraft. The outputs used were asset management, item management, item management, error management, and equipment management. The results found that the average efficiency of grouping items by mission and aircraft type is much higher than by grouping according to location or individual airbases. However, issues arise when grouping airbases by mission, as a huge budget would be required to establish those systems, making the option of grouping by aircraft type much more viable (Han & Sohn, 2011).

Looking at the performance of military transportation units with the intent to decrease operating costs and increase productivity was done in Despic et al. (2019). DEA and Stochastic Frontier Analysis (SFA), a statistical technique used to estimate deviations in performance, were used in conjunction with one another to assess military vehicles expended for conducting cargo transportation tasks on behalf of supply and various military institutions. Efficiency was analyzed over three levels: efficiency of transport units, vehicle efficiency, and vehicle efficiency within defined classes. As a result, the study successfully identified and classified transportation units that were efficient and not efficient, with DEA producing the most useful efficiency data.

Summary

Production Theory is not only highly applicable with today's economic emphasis on resource allocation and consumption but the perfect pairing for evaluating the efficient usage of resources in conjunction with DEA in an assortment of scenarios. It is clear that although there has been an emphasis placed on modernizing and streamlining logistical

efforts worldwide, there is still room for systematic improvements in many countries. The application of DEA is tried and tested, as shown by recent business research and findings. In the next chapter, the methodology will describe the avenues for data collection and examination used to build the DEA and linear regression models for this thesis.

III. Methodology

Chapter Overview

The purpose of this chapter is to discuss the two methods and subsequent models performed to achieve the relative efficiency data and test the significance of variables relating to the East Asian countries included in this thesis. The model's purpose will describe the current situation and calculate relevant efficiency scores in infrastructure, total land area, labor force, and GDP to paint a picture of each country's current logistical landscape. The resulting data will then be utilized to show areas to target and replicate or improve upon.

Research Methodology

DEA and efficiency measures go hand-in-hand. This study's primary consideration was to measure how the efficient use of targeted resources affected military power in select countries. Therefore, DEA was a natural fit to use as the basis for this model. Farrell (1957) proposed the framework of production frontier analysis. While Farrell (1957) was able to lay the foundation, Charnes et al. (1978) was able to solve Farell's model by using linear programming and subsequently proposing the Charnes-Cooper-Rhodes (CCR) model. An alternative DEA model was fashioned by Banker et al. (1984): while the CCR model includes Constant-Return-to-Scale (CRS) measurements, the authors instead leveraged variable-return-to-scale (VRS). This technique is known as the Banker-Charnes-Cooper (BCC) model. VRS estimates whether an increase or decrease in input or outputs results in a variable change in the outputs or inputs, respectively, meaning it incorporates both increasing and decreasing returns to scale.

CRS include proportional change for input and output variables (Cooper, Seiford, & Zhu, 2011).

The third and final DEA model used in this study was designed by Tone (2001) and is known as the slack-based measure of efficiency (SBM) model. The SBM model focuses on the slack generated by variables when they are entirely efficient instead of constant or variable-returns-to-scale. Regardless of model intricacies, DEA holistically works to take inputs and outputs of a specified Decision-Making Unit (DMU) and yield the overall efficiency of a benchmarked DMU. A benchmark in this setting is a baseline DMU that is efficient in the model. To break down DEA's mathematics, we review a CCR model (Cooper et al., 2007: p.23). E_0 will be the efficiency score for DMU *0:*

Maximize
$$E_0 = \frac{\left\{\sum_{r=1}^{R} u_{r0} y_{r0}\right\}}{\left\{\sum_{i=1}^{I} v_{i0} x_{i0}\right\}}$$

subject to

$$\frac{\left\{\sum_{r=1}^{R} u_{r0} y_{rk}\right\}}{\left\{\sum_{i=1}^{I} v_{i0} x_{ik}\right\}} \leq 1 \quad \text{for all } k$$

u_{r0}, $v_{i0} \geq \delta$ for all r, i,

where

y_{rk}: the observed quantity of output r generated by unit $k = 1, 2, \ldots, N$,

x_{ik}: the observed quantity of input i consumed by unit $k = 1, 2, \ldots, N$,

u_{r0}: the weight to be computed given to output r by the base unit 0,

v_{i0}: the weight to be computed given to input i by the base unit 0,

δ: a very small positive number.

This fractional programming model can be converted into a linear programming model by moving the objective function's denominator to side constraints, then multiplying the denominator to both sides of the original side constraint. All three DEA models were used in this study to target different areas, account for gaps, and achieve a well-rounded view of efficiency for each DMU. First, the relative efficiency of DMUs was assessed using the CCR and BCC models. Next, the SBM model was used to showcase areas where an increase in military power relative to efficiency within the targeted variables would be possible. Finally, efficiency was compared across all models relative to the benchmarked country.

Specification of Data and Variables

22 DMUs or countries were selected from the targeted region of USINDOPACOM except for the United States (U.S.), which was added mainly to provide texture as a point of reference and comparison. Several variables were considered to determine how logistical and socio-economic factors affect military power, including logistics infrastructure, GDP, labor force, land area, and the Military Power Index (MPI).

Logistics infrastructure is a component of the LPI, discussed in detail in the review of the literature. The LPI is provided by the World Bank (2020). This metric determines the quality of a country's railroads, ports, highways, and roads, all of which play a role in the effective and agile movement of assets, a vital aspect of military effectiveness. GDP, also derived from the World Bank, weaves its way into and impacts almost every variable in this study. The GDP is a representation of all of the goods and

services produced within a country in a given year. When the GDP is higher, and an economy is performing better, there is more opportunity to acquire resources, enhance infrastructure, and increase the labor force. This combination is the perfect recipe for increasing logistical performance, if used diligently, and ultimately military performance as a by-product.

Data for the labor force is taken from the LPI, and the labor force alone has its implications for logistical and military presentation. The volume and skill-level of a country's labor force contribute to the type and quality of services being rendered to support wartime activities to include wartime materiel output as well as specialized services such as niche transportation, shipping, and analysis services among many other fundamental areas of the workforce (Global Fire Power, 2020). The last of the four inputs used in this study was the total land area taken from Global Fire Power. Total land area is the variable countries have the least amount of control over. However, it has an enormous impact on how a country designs its logistical structure and defends itself.

The sole output used in this study was the MPI. More specifically, an adjustment was made to use the reverse MPI because DEA operates under the assumption that the larger the index, the better the country. The traditional MPI weights the best countries with the smallest scores, so reversing the index by taking the reciprocal of the original MPI aligned the data to the DEA mechanics to produce an accurate efficiency score. Together these inputs were able to portray how efficient selected countries were able to achieve their MPI. Table 1 summarizes the descriptive statistics of these variables.

Table 1: Descriptive Statistics for Variables

	Labor Force	Land Area	GDP	LPI Infrastructure	R_MPI
Maximum	806,700,000.00	9,826,675.00	21,374,418,877,706.70	4.25	16.50
Minimum	1,240,000.00	697.00	13,852,850,259.49	1.99	0.29
Mean	95,110,863.64	1,746,559.09	2,335,917,861,903.57	3.06	3.83
Standard Deviation	189,336,352.70	3,018,020.97	5,151,752,494,836.35	0.74	4.44
Variable Type	Input	Input	Input	Input	Output

To reiterate, the LPI Infrastructure is an index based on multiple factors previously discussed, while total land area is measured in square kilometers and the GDP is measured in US dollars. The labor force consists of total able and working bodies in logistics-based professions. When mean and standard deviation are compared, R_MPI exhibits the highest variability. On the other hand, LPI Infrastructure shows the least variability.

Table 2 shows the degree of correlation between the variables used in this model.

Table 2: Correlation Matrix for Variables

	Labor Force	Land Area	GDP	LPI Infrastructure
Labor Force				
Land Area	0.6275			
GDP	0.5718	0.8286		
LPI Infrastructure	0.1849	0.4023	0.4643	
R_MPI	0.7436	0.7874	0.9022	0.4747

Essentially, because we want to understand how the inputs, the independent variables, affect the output, the dependent variable, the stronger the correlation between the independent and dependent variable, the better. However, the strong correlation among independent variables can raise an issue on discriminant validity of the variables. The correlation between the inputs and the output, the reverse MPI, was sufficiently high: this is desirable based on the theoretical framework in which production theory operates.

When exploring the relationship among inputs, the correlation between variables was sufficiently low based on the pre-established significance level of .9. It also appeared that multicollinearity may cause issues among the variables, however the Durbin-Watson test was conducted and levels were found to be in range.

Post Ad Hoc Analysis using Linear Regression

Simple and multiple linear regression were applied to determine the degree to which each input affects military power. Though there were many iterations throughout its infancy, linear regression was first created by Sir Francis Galton in the 1880s to determine how "co-related" the height of trees was to their parents. His method was known as "regression to the mean." Galton's colleague, Karl Pearson, carried the model forward by creating the "least squares method" and is the basis of what is used today (Kopf, 2015). Linear regression is used to quantitatively show the relationship between the independent and dependent variables in a model. Mathematically, linear regression in its basic form is shown as:

y= MX +c.

This equation most adequately demonstrates the relationship between the independent variable, X, and the dependent variable, Y (Kumari & Yadav, 2018). Moreover, included as a portion of the linear regression model is the R-squared value (R^2), otherwise known as the coefficient of determination. The R^2 value is the total variation in the dependent variable that can be explained by the independent variable. The closer the R^2 value is to 1, the stronger the linear relationship is between the X and Y variables, and vice-versa. The further the value is from 1, the weaker the connection between variables. For example, if the R^2 value is 1, then 100% of the change in the

dependent variable is explained by the change in the independent variable (Kumari & Yadav, 2018). In this particular model, linear regression was used to determine the extent to which labor, GDP, infrastructure, and land area each individually impacted military power via the reverse MPI. Ultimately, this provides more context while selecting and adjusting inputs when seeking to optimize military power.

Summary

DEA and linear regression were selected and used to best answer the research questions at the root of this thesis. Throughout the next chapter, the analysis and results will be discussed in detail. They will demonstrate how efficiently countries could achieve military power and which inputs significantly impact military power in isolation.

IV. Analysis and Results

Chapter Overview

The analysis and results section of this thesis will review the outcome of the data and methods introduced in the previous chapter. Completion of this review and interpretation of results will set up the final recommendation wherein potential areas of improvement among inputs, and the weight of individual inputs on military power will be discussed.

DEA Models and Results

As mentioned previously, the three input-oriented DEA models (CCR, BCC, and SBM) were leveraged to determine how efficiently each country could achieve its military power given its resources. Table 3 summarizes the DEA model results.

Table 3: Efficiency Scores by Three DEA Models

Countries	BCC-I Score	CCR-I Score	SBM-I-C Score	Scale Efficiency*	MIX efficiency**
China	1.00	0.99	0.77	0.99	0.78
India	1.00	1.00	1.00	1.00	1.00
Indonesia	0.75	0.63	0.45	0.84	0.71
Pakistan	1.00	1.00	1.00	1.00	1.00
Bangladesh	1.00	0.73	0.48	0.73	0.66
Japan	0.84	0.84	0.47	0.99	0.56
Philippines	0.82	0.43	0.32	0.53	0.74
Vietnam	1.00	1.00	1.00	1.00	1.00
Thailand	0.77	0.73	0.60	0.95	0.81
Myanmar	1.00	1.00	1.00	1.00	1.00
Korea, Rep.	1.00	1.00	1.00	1.00	1.00
Malaysia	0.77	0.73	0.47	0.95	0.64
Nepal	1.00	0.62	0.39	0.62	0.63
Australia	0.93	0.93	0.50	1.00	0.54
Taiwan	1.00	1.00	1.00	1.00	1.00
Sri Lanka	1.00	1.00	1.00	1.00	1.00
Cambodia	1.00	0.89	0.70	0.89	0.78

Laos	1.00	0.88	0.60	0.88	0.69
Singapore	1.00	1.00	1.00	1.00	1.00
New Zealand	1.00	0.90	0.57	0.90	0.64
Mongolia	1.00	1.00	1.00	1.00	1.00
United States	1.00	1.00	1.00	1.00	1.00
Mean	0.95	0.88	0.74	0.92	0.83

*: Scale Efficiency = CCR-I/BCC-I; **: MIX Efficiency = SBM-I-C/CCR-I

10 out of the 22 countries produced a 1.00, or 100 percent efficiency across all DEA models. These countries were used as a point of reference, also known as a benchmark, by which other countries can pace their efficiency adjustments and will be discussed further following table 4. The BCC input-oriented model measured Pure Technical Efficiency (PTE), otherwise known as "internal" or "local" factors. These are factors within each country and, therefore, within its control. Next, the SBM input-oriented model was calculated. This score is a combination of the BCC, SE (Scale Efficiency), and MIX (input mix in this study) scores. SE is indicative of the operating conditions or external factors affecting a country, such as market conditions, that may not be entirely within its control and is a value of CCR score divided by a BCC score or PTE. The CCR input-oriented model measured technical efficiency (TE) and is a multiplication of BCC and SE Finally, the MIX was used to determine the combination of inputs or "optimal mix" to achieve the desired output, or in this case, the desired military strength. The MIX score is attained by dividing the SBM by the total efficiency.

Looking at the average efficiencies for each category, BCC ranked the highest at .95, meaning collectively East Asian countries are internally efficient, with the S.E. ranking not too far behind at .92. Therefore, it was not a surprise to find that most countries are 100 percent efficient internally. Only three countries had a BCC score ranking below 80 percent to include Indonesia, Thailand, and Malaysia. The lowest

overall score is the SBM score at .74, indicating there could be combined improvements across multiple categories, as it is a merged score. Additionally, Japan and Australia had the lowest MIX score, meaning the mix of resources used to attain military strength was not optimal. Simultaneously, external conditions depressed the SE for the Philippines, lagging far behind other countries at .53. Because the CCR model is a composite score that uses internal and external factors (such as the SE) the Philippines' CCR also ranked the lowest for that category.

Going more in-depth with the listed composite scores (CCR and SBM), since SBM was the lowest overall, results in this column will first be explored. As mentioned previously, the SBM is multiplication of the MIX, PTE, and SE scores. Several countries ranked low, but Nepal and the Philippines were at the bottom with .39 and .32 respectively. These scores are in large part due to their low SE and MIX scores. This could result from a resource or infrastructure issue impacting efficiency due to no small amount of natural disasters and unforeseen circumstances in both regions. As for CCR scores, the SE heavily affected the results since the BCC scores were high, meaning external factors affect the efficiency rates in these countries. Finally, some interesting individual cases will be evaluated. New Zealand was able to boast 100 percent internal efficiency; however, its SBM efficiency clocked in at .57, mainly because its mix of resources used to achieve military power was not optimal, dropping the overall score. There is also China, which boasts a high MPI, but achieved a low MIX score, as well which means that even though it may have a large quantity of land, personnel, and other resources, they may not be leveraging them in a way that most improves their military strength.

Meanwhile, Table 3 provides top-level insight into the areas countries may or may not fully leverage with their resources to achieve military power, Table 4 takes it a step further by providing relative percentages to relay where a country could improve its inputs to achieve its current military power more efficiently. This table was completed using an SBM input-oriented model (SBMIC).

Table 4: Projections by the SBMIC Model

Countries	Score	(I) Labor Force	(I) Land Area	(I) GDP	(I) LPI Infrastructure	Benchmark
China	0.77	-51.77	-28.45	-13.50	0.00	India
India	1.00	0.00	0.00	0.00	0.00	N/A
Indonesia	0.45	-87.08	-96.89	-12.96	-23.71	India
Pakistan	1.00	0.00	0.00	0.00	0.00	N/A
Bangladesh	0.48	-88.06	-53.40	0.00	-67.14	Vietnam
Japan	0.47	-59.25	-73.47	-67.51	-11.77	India
Philippines	0.32	-88.13	-93.61	-16.23	-73.74	Pakistan
Vietnam	1.00	0.00	0.00	0.00	0.00	N/A
Thailand	0.60	-46.16	-63.92	0.00	-50.93	Pakistan
Myanmar	1.00	0.00	0.00	0.00	0.00	N/A
Korea, Rep.	1.00	0.00	0.00	0.00	0.00	N/A
Malaysia	0.47	-52.01	-89.02	0.00	-72.81	Myanmar
Nepal	0.39	-67.61	-57.22	-28.19	-92.06	Pakistan
Australia	0.50	-0.44	-99.40	-44.82	-56.02	Korea Rep.
Taiwan	1.00	0.00	0.00	0.00	0.00	N/A
Sri Lanka	1.00	0.00	0.00	0.00	0.00	N/A
Cambodia	0.70	-13.63	-25.69	0.00	-81.93	Pakistan
Laos	0.60	0.00	-54.67	-17.15	-86.81	Myanmar
Singapore	1.00	0.00	0.00	0.00	0.00	N/A
New Zealand	0.57	0.00	-97.55	-5.30	-69.21	Korea Rep.
Mongolia	1.00	0.00	0.00	0.00	0.00	N/A
United States	1.00	0.00	0.00	0.00	0.00	N/A
Mean	0.74	-25.19	-37.88	-9.35	-31.19	N/A

To reiterate, all of the percentages in table 4 are relative to one another. Negative percentages represent an underutilization of a resource in relation to its military power index in the context of other countries' practices as a comparison. Countries with 100%

efficiency did not display a need for improvement or areas of underutilization, as they were already found to be operating at maximum efficiency. In Nepal's case, the LPI infrastructure came to -92.06, the lowest rate for the category. This score means that relative to its 21 counterparts, Nepal could have better utilized or improved its infrastructure practices roughly 92 percent to achieve its Military Power Index. Essentially, at the MPI Nepal currently has, the infrastructure element is not up-to-par and could be improved vastly, not even taking into account raising the index itself. These results could be primarily due to the massive earthquake Nepal sustained in 2015 and then again in 2020. On the other hand, Japan needs to place more emphasis on its GDP by investing more in its military, as it is sitting at -67.51, a rate much higher than its counterparts within the GDP input category.

When looking at the labor force, it is curious but somewhat understandable that many countries with a larger labor force were also shown to be inefficient in this category. A higher resource count can make optimal usage harder to come by, as it takes more deliberation in the act of planning and execution. By extension, China, Indonesia, and Bangladesh, all with considerably-sized labor forces, were all shown to be underutilizing their labor force by more than 50 percent.

As we learned previously, the land area can dictate many defense and logistical support factors. It is also a factor that countries have little-to-no control over changing and effectively utilizing land area can pose many difficulties depending on the terrain and many other circumstances. For instance, Australia is geographically diverse, with many of its population centers focused on coastal regions of the country. This location preference is primarily because the interior outback makes a large portion of the country

difficult to occupy, which could at the very least partially explain its low utilization score for the land area at -99.4 percent. New Zealand and Indonesia followed closely with -97.55 and -96.89, respectively, further contributing to the lowest overall mean score of -37.88 for total land area.

The column on the far left was the SBM results taken from table 3: the efficient use of a combination of internal, external, and mix of inputs to produce an output. From the SBM model, in addition to the input evaluations, a benchmark was created. A benchmark is the lambda value found in the SBM output results, meaning it is the closest efficient country relevant to the original DMU. More simply, benchmark countries are used as a point of reference because they were shown to be operating at 100 percent efficiency. The countries that were not found to be entirely efficient may use the "benchmark country" that is most closely related to their own to model their efficiency improvements accordingly. For example, many of China's inputs are similar to those of India in terms of size and scale; additionally, India is 100 percent efficient with said resources. Therefore, India is China's performance benchmark for efficiency. Holistically, Pakistan and India were used most frequently as benchmarks for each of the countries.

The total efficiency score (SBM) across all countries came to .74, with input categories ranging from -9.35 in GDP to -37.88 in total land area. Though there are areas for improvement, many of the countries in East Asia are using their resources wisely, given that many of the countries are small and have geographical challenges, such as the case of Singapore, and still have high MPIs with maximum efficiency. Given that land area is more difficult to change, infrastructure is another area that could benefit from efficiency gains in the Eastern hemisphere, although there are natural phenomena that

may impact efforts to increase efficiency on this end, as well, such as typhoons, corrosive environments, earthquakes, tsunamis, tropical storms, and other natural disasters that pose threats to infrastructure reform.

Linear Regression Analysis and Results

Linear regression was performed to determine the strength of the relationship between each input and a country's military power index: essentially, how big of an impact does each resource category have on a particular country's overall strength? Correlation analysis was performed and interpreted using Table 2. China and the United States are considered outliers due to their high MPI in relation to other countries. To reduce these outliers' impact, the reverse military strength index was transformed by taking its square root. A model summary is shown in Table 5.

Table 5: Regression Results

	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Labor Force	.788***				.732***		.768***	.739**
LPI Infrastructure		.520**			.326**	.273*	.335**	.325
Land Area			.722***			.612***	-.052	-.059
GDP				.810***				.042*
F-Statistics	.000	.013	.000	.000	.001	.001	.001	.000
Adjusted R^2	.600	.234	.498	.639	.693	.540	.676	.656

*: significant at α=.1; **: significant at α=.05; ***: significant at α=.01

Model 1 consisted of labor force as the independent variable and the square root of the reverse MPI as the dependent variable, then so on and so forth to LPI Infrastructure, Land Area, and GDP in Models 2 through 4. Models 5 through 8 used different combinations of variables. The first number in this table is .788 under labor

force and model 1. This number is known as the standardized beta coefficient. As the standardized beta coefficient approaches 1, it represents the ability of the independent variable(s) to have a more substantial effect on the dependent variable. Next, the asterisks alongside the numbers represent the variable's level of significance, with the associated significance level listed below the table. The F-statistic represents the model's overall significance, or rather, the probability of an error in the model, and is considered significant at .001. Lastly, the bottom row is the adjusted R^2, which is the percentage of variation in Y that is explained by X. Therefore, in Model 1, 60 percent of the MPI can be explained by labor force. Now that the critical elements of interpretation have been discussed, holistically, Model 2 performed the worst, as the standard beta coefficient and R^2 values were low relative to the other models excluding land area in model 7, which will be discussed shortly. Model 2 also had the highest F-statistic. Together this shows that compared to its counterparts, Infrastructure and MPI have the least significant relationship out of the bunch. On the other end of the spectrum, Model 5 had the best overall score, indicating that labor force and infrastructure together carry the most weight when affecting the MPI. Land Area in Model 7 became negative due to collinearity, which also can inflate R^2. Due to collinearity symptoms such as a reversed leading sign of Land Area and reduced significant levels of LPI Infrastructure, Land Area, and GDP as shown in Model 8, the pooled effect of all independent variables is unknown. However, the Durbin-Watson test was conducted and the number was found to be in range.

As post-ad-hoc analysis, several scatter plots are constructed. Figure 1 shows a scatter plot with a trend line for the square root of the reversed MPI and labor force.

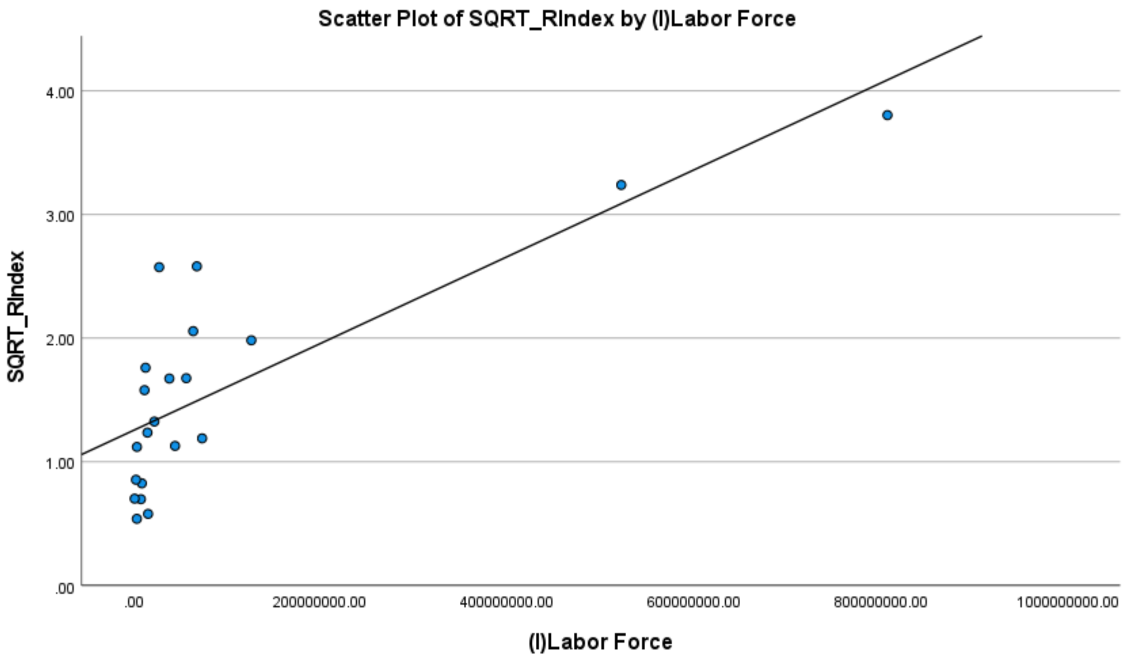

Figure 1: Scatter Plot for Square Root Reversed Power Index and Labor Force

Figure 1 showed a positive linear relationship between labor force and military power, meaning that if labor force were to increase, then military power would follow in-kind. As mentioned previously, China and the United States were the two outliers, and measures were taken to alleviate potential negative side-effects of including them in the model. Additionally, these variables were an important addition to gain the best understanding of how the variables operated and worked together in East Asia and relative to the United States. Figure 2 demonstrates the relationship between the square root of the reversed MPI and LPI infrastructure.

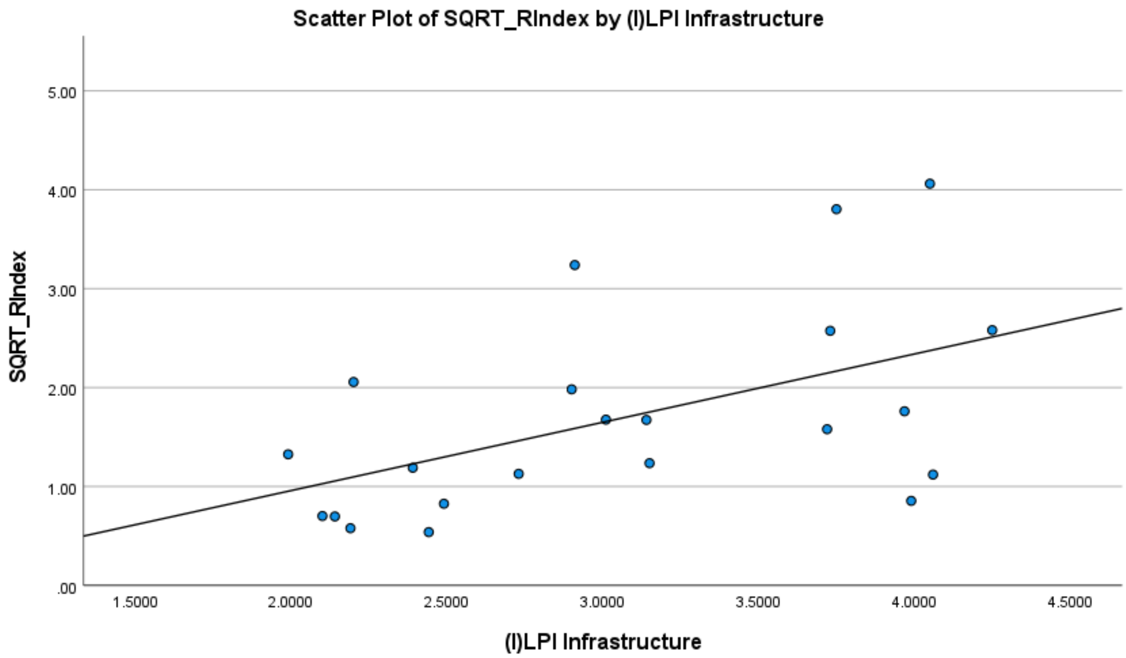

Figure 2: Scatter Plot for Square Root Reversed Power Index and Logistics Infrastructure

Figure 2 showed that there was a positive linear relationship between infrastructure and military power. As touched on previously, this demonstrates that as infrastructure increases or improves, so does military strength. This data also fits the linear trend line better and is more evenly dispersed than Figure 1. The next figure displays the relationship between land area and the square root of the reversed MPI.

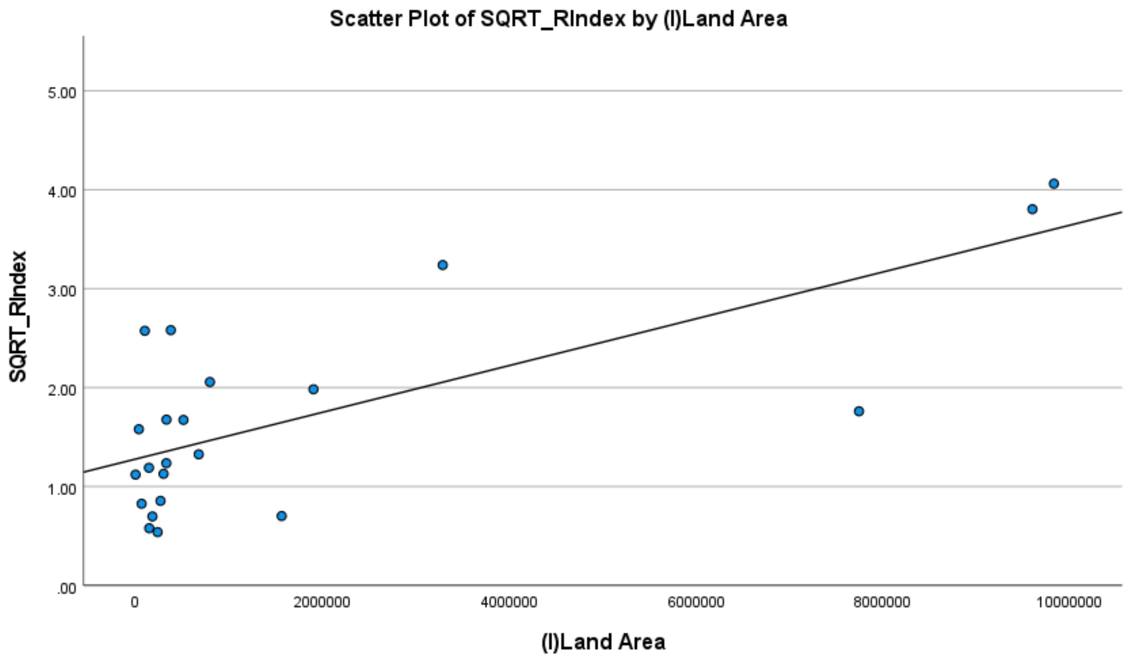

Figure 3: Scatter Plot for Squared Root Reversed Power Index and Land Area

Figure 3 shows that there is a positive linear relationship between land area and military power. Larger countries with greater landmass have a higher military power index. If a country were able to acquire more land, which is admittedly exceedingly difficult or impossible in most cases to do, their MPI would increase. The fit line is again skewed, as in figure 1, due to the United States and China being outliers. Lastly, figure 4 displays the relationship between GDP and the square root of the reversed MPI.

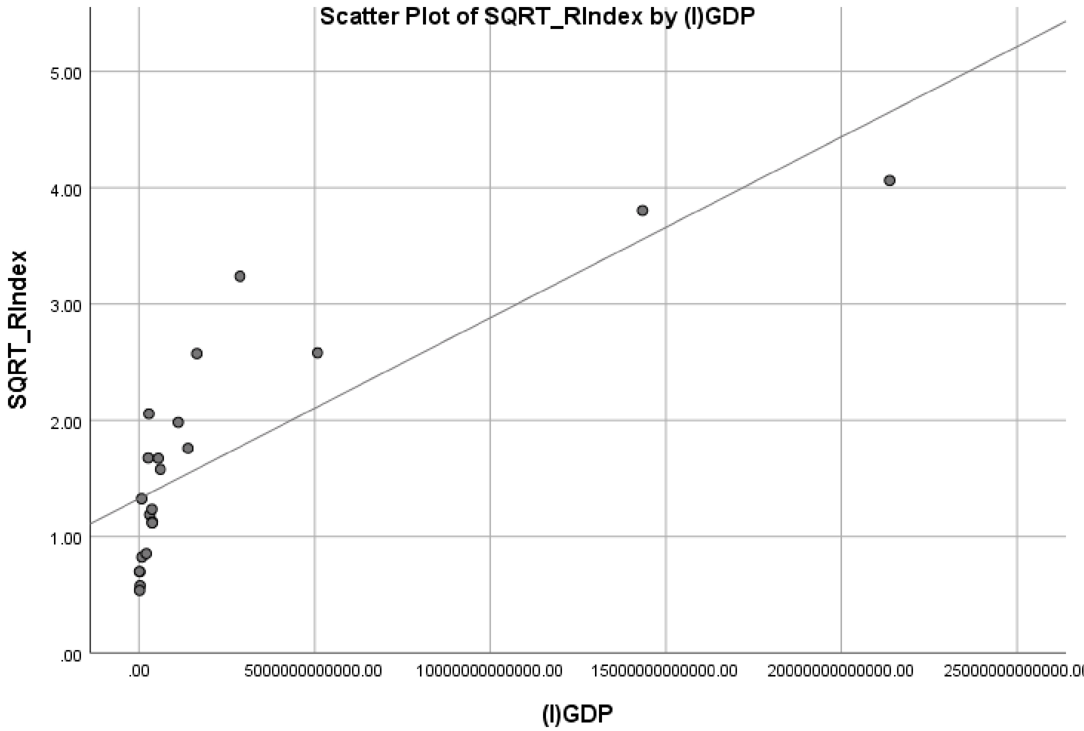

Figure 4: Scatter Plot for Squared Root Reversed Power Index and GDP

Figure 4 again shows that there is a positive linear relationship between GDP and military power. Therefore, as GDP increases, so does military power.

Summary

This analysis and results section is layered in a fashion that allows each method and model to build on itself and provide connections for a conclusive overall picture. First, DEA was leveraged to depict relative efficiency levels of individual countries and their achieved military power index. Internal operations ranked the highest in the East Asian hemisphere, while the SBM score had the lowest mean, resulting from the lower SE and MIX scores throughout. From this observation, we can deduce that a better mix of

resources and more ideal external circumstances would increase the SBM score. However, the total average mean scores for all categories were high.

Moving forward, projections from the SBM model were used to show relative snapshots of resource utilization for each country corresponding to their MPI. Essentially, the first model gave a top-level view of East Asia, while the second model broke the analysis down into bite-sized chunks. The second model gave a clear picture of how countries were operating and where efficiency adjustments could be made to specific variables to achieve a better outcome. This was also a good illustration or baseline of where vulnerabilities can be targeted, as well as potential key points of process replication. Land area and infrastructure had the lowest level of utilization.

Following both DEA models, linear regression was leveraged to show the relationship between the input variables and military power. Table 5 contained 8 model combinations. Model 5 proved to be the best overall, demonstrating that infrastructure and labor force together have the greatest influence on military strength. Lastly, a graphical representation of each input variable and the square root of the reverse MPI was conducted, showing that each variable had a positive linear relationship with the military power. Ultimately, this means that when one of these variables is improved, military strength will follow-suit.

V. Conclusion and Future Research

Conclusion

Logistics is undoubtedly transforming. While the common inclination is to progress and improve our organizations to embrace modernization, the simple question of "Where do I start?" can easily be overlooked in the process. We often look to continuous process improvements or the optimization of subsystems without knowing the impact on the entire system as a whole. The result of this angst and haste compounds itself in tepid growth and underwhelming efforts in the realm of rapid change and advancement in the Air Force and the civilian sector alike. However, this body of research provides a starting point for State Department and military panners o engage with nations in their areas of responsibility to illustrate ways to improve their own military power.

This research provides a roadmap to discovering the baseline of how an organization, or a country in this instance, is operating, as well as a prescriptive lens of where efforts can be concentrated to improve military strength as a whole. In this instance, labor force, GDP, infrastructure, and total land area were utilized, and their relationship to military power was evaluated, as many of these elements are foundational to logistical frameworks.

Future Research

This study mainly focused on the "*where"* by showcasing countries in their current state of efficiency among the given variables relative to military power, as well as the significance of each variable in relation to military power. It would be beneficial to build upon this foundation and explore the *"how"* to find targeted remedies in pursuit of

improving efficiency, and thus its overall military strength, given each country's own unique circumstances. Conversely, one could also seek to explain how a country achieved its rating when entirely efficient. This analysis also only focused on four variables under the umbrella of their contribution to logistics; there are many other areas that can be looked at as a component of militaristic success in the future.

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14. ABSTRACT The current narrative in logistics revolves around modernization and the rapid development and deployment of capabilities, which is a sentiment echoed across the Air Force and the DoD alike. However, the combination of intangible and tangible aspects of logistics can make it challenging to find a foundational place to start the process. The purpose of this study is to evaluate logistical factors to include land area, infrastructure, labor force, and GDP and their relationship to military power. This foundation will provide a baseline of areas for improvement and replication. Data Envelopment Analysis (DEA) and linear regression were leveraged to analyze countries in the East Asian hemisphere and the United States. Additionally, the weight of the relationship between logistical factors and military power was explored. This research concludes that while countries are not entirely efficient at achieving military power, targeted areas can be used to improve with promising results. Moreover, the selected logistical factors were shown to exercise a strong influence over military power.			
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