Total Landed Cost Model

by

Muhammad Sohaib Chaudhry
Master in Engineering Management, King Fahd University of Petroleum & Minerals, 2016

and

Kun-Zhe Lee
Master of Business Administration, National Taiwan University, 2016

SUBMITTED TO THE PROGRAM IN SUPPLY CHAIN MANAGEMENT
IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF APPLIED SCIENCE IN SUPPLY CHAIN MANAGEMENT
AT THE
MASSACHUSETTS INSTITUTE OF TECHNOLOGY

May 2022

Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

Signature of Author: ____
Department of Supply Chain Management
May 6, 2022

Certified by: ____
Mehdi H. Farahani
Postdoctoral Associate
Capstone Advisor

Certified by: ____
David Correll
Research Scientist
Capstone Co-Advisor

Accepted by: ____
Prof. Yossi Sheffi
Director, Center for Transportation and Logistics
Elisha Gray II Professor of Engineering Systems
Professor, Civil and Environmental Engineering

Total Landed Cost Model

by

Muhammad Sohaib Chaudhry

and

Kun-Zhe Lee

Submitted to the Program in Supply Chain Management
on May 6, 2022 in Partial Fulfillment of the
Requirements for the Degree of Master of Applied Science in Supply Chain Management

ABSTRACT

As more and more multinational companies are exploring low-cost countries to purchase commodities from, it has become critical for companies to calculate the total landed cost before making a purchasing decision. This capstone project establishes a model for the sourcing team of GE Gas Power to capture costs such as materials, labor, energy, transportation, even custom duty and tariffs for each country to optimize the total landed cost. Sensitivity analysis is also conducted on a sample part provided by GE to evaluate how changes in various cost factors impact the best-cost country ranking. A comparison is also made between the outcome of the model and the purchasing decision made by GE in the past. As a result, our recommended best-cost country based on the model matches with some of GE's existing sourcing countries. Our model also suggests some countries that GE never purchased from, which resulted in total landed cost difference of up to 17% compared with purchasing the sample commodity from current countries. This list would help GE further explore those countries with some examinations of qualitative measurement and standards before making the final purchasing decision.

Capstone Advisor: Mehdi H. Farahani
Title: Postdoctoral Associate
Capstone Co-Advisor: David Correll
Title: Research Scientist

ACKNOWLEDGEMENTS:

We would like to thank General Electric, especially our project sponsor Sarthak Prakash. This project was well defined and had a clear long-term vision. Sarthak was extremely supportive throughout the project and gave us the opportunity to learn, develop and implement the total landed cost model. We would also like to thank the commodity leaders at GE that participated in building the input variables in the model.

We would also like to thank our project advisors Dr. Mehdi H. Farhani and Dr. David Correll for their support and leadership throughout the year. Dr. Mehdi and Dr. David have continuously guided us and conducted brainstorm sessions. They always helped us look at total landed cost from different angles and showed us new methods of calculating.

We would also like to thank our writing coach and editor Toby Gooley who provided us with feedback throughout the year. Toby has been incredibly helpful and diligent and her past experience in logistics has helped us in this project.

Lastly, we would like thank our friends, colleagues and staff at MIT CTL and our families who always supported us throughout this journey.

Table of Contents

List of Tables

List of Figures

Chapter 1: Introduction

1.1 Company Background

The sponsor company for this capstone project, General Electric (GE), is a multinational conglomerate which was incorporated nearly 130 years ago and has developed its operations in different segments, including aviation, power, renewable energy, digital industry, additive manufacturing, locomotives, venture capital and finance. Starting from 2021, GE is putting more focus on aviation, healthcare, power, and renewable energy, and this project will focus on the sourcing issue that GE Gas Power has encountered.

GE Gas Power is a world leader in natural gas power technology, service, and solutions. It not only sells a variety of gas turbine products but also provides power plant solutions as well as equipment services and upgrades. Examples include power plants, steam turbines, generators, heat-recovery steam generators (HRSG), digital and cybersecurity solutions. According to an interview with our sponsor in GE (S. Prakash, personal communication, September 28, 2021), in 2021, GE Gas Power had more than 50% of the market share in gas power generation, which accounts for over 30% of the world's total power.

In regards to procurement, in accordance with GE Gas Power's strategic priorities for operational transformation, they not only consider purchasing costs, but also pursue a leaner supply chain with shorter lead times that have high levels of product safety and quality. After all, employee safety and product quality are critical for their business continuity, and quality is the key to maintaining customer satisfaction. In addition, customer-centric, on-time delivery and industry-best lead time are also metrics they focus on.

1.2 Motivation

It has become a common practice for many multinational companies to optimize their supplier portfolio by shifting suppliers from the Americas and Europe to low-cost countries such as China and India, and regions such as the Middle East, Africa, and other areas of Asia Pacific.

As a result of the GE sourcing team's efforts to optimize the sourcing portfolio, which included shifting some suppliers to low-cost countries, GE Gas Power has increased commodity purchases from these areas by three to four times in the past three years (S. Prakash, personal communication, September 28, 2021).

While GE Gas Power has already reduced its commodities costs by moving their spend to competitive countries or regions, the company also considers it is important to purchase from the "best-cost country." The assessment is based on a consideration of many different cost factors. As GE Gas Power seeks to source and deliver products and materials in a wider range of countries, the distances between sourcing countries and destination countries, as well as the relevant cost factors, have become more varied. Therefore, the company needs a "total landed cost" (TLC) model to accommodate this trend.

According to the discussions with GE Gas Power's Best-Cost Country (BCC) team, in addition to purchase price, total landed cost also considers transportation cost and storage cost, as well as the underlying costs associated with risks in the supply chain.

1.3 Problem Statement

This capstone project establishes a model that GE Gas Power's sourcing team can use to capture the costs and factors needed to optimize its purchasing decisions in terms of total landed cost. Specifically, we identify which countries are best for a particular commodity for the gas turbines and power plant solutions. The commodities include, but are not limited to, engineered systems, HGP (Hot Gas Inspection) and combustions, forgings, airfoils, structures, small parts, and raw materials.

For the methodology, after we conducted literature reviews on low-cost country, total landed cost, and cost of risk implication, we initiated interviews with commodity leaders of GE Gas Power to understand the cost structure of the commodities. We further discussed with GE BCC team to understand the internal and external data sources to be leveraged to build our model. Incorporating web-scraping techniques, our Excel-based total landed cost model factors the parameters input by the users and prices of cost drivers that either synchronized with the public data source or manually plugged in by users. It can conclude the recommended list of best-cost countries for GE's sourcing team to explore and make purchasing decisions eventually. To evaluate the model's efficacy and the impact of individual cost driver's variance, we conducted comparison analysis using historical purchase order data and sensitivity analysis using the example commodity provided by GE.

Chapter 2: Literature Review

To create a model to capture total landed cost for optimizing purchasing decisions, this project needs to identify, quantify, and verify the key metrics that align with GE Gas Power's strategic priorities to be fed into the model. We have conducted a literature review—including case studies of previous BCC projects, and interviews with GE sourcing and logistics leaders—regarding purchasing decision-making criteria , such as labor rate, supplier capability, political stability, safety and quality indicators, and logistics lead-time, as well as cost variables of materials, logistics, packaging, customs, tariffs, insurance, carrying cost of good in transit, and so on. Ideally, with the total landed cost model, we can determine which country is optimal for purchasing a commodity and how much the cost saving would be from this sourcing decision.

2.1 Low-Cost Country

According to a study identifying the best-cost countries for sourcing direct materials (Vu & More, 2017), the point of BCC is not only to consider low material cost or low labor cost, which has been discussed in many studies about low-cost country (LCC) sourcing. Indeed, firms have searched the whole world for the places with the advantage of lower production cost to manufacture and source (Siegfried, 2013). Nevertheless, BCC should also consider the assessment of other factors associated with geopolitical, macroeconomic, socio-demographics, sustainability, etc.

According to Kusaba et al. (2011), LCC focuses on countries with relatively lower production cost and a culturally or geographically substantial distance from buyer's location. To react to the increase in foreign competition in domestic markets, firms sought global sourcing as a reactive strategy. However, as prices increase, it has become important to build up a firm's competitive advantage in low-cost countries for their manufacturing and sourcing.

Sawhney and Sumukadas (2005) also concluded that LCC has become inevitable to formulate supply chain networks of sourcing, production, and distribution in developing countries. It was again reinforced by Lockström (2006), who emphasized that during the globalization phenomenon, LCC is the way for foreign companies to take advantage of economies of scale and comparative advantages in order to improve competitive advantage.

A study conducted by Bain & Co. showed that sourcing in low-cost countries may provide material cost savings of 10-35%, while the additional cost incurred from lead time variability and operational delays may offset that savings (Crone, 2006). This encourages more studies to shift the focus from LLC to total landed cost (TLC) and the costs of risk implications.

2.2 Total Landed Cost

According to Howell (2017), total landed cost (TLC) includes all costs to procure or produce the commodity or product and transport it from the supplier to the buyer. This includes not only material pricing, labor cost and overhead, but also packaging, freight, import duty, customs clearance fees, taxes, insurance, inventory holding and currency conversion, and so on. Therefore, the total landed cost model can capture both nominal and hidden costs within the supply chain from end to end corresponding to each sourcing activity.

From a division of labor perspective, Howell (2017) states that the responsibility for cost management is often distributed among different departments with disparate goals and incentives. The Procurement function focuses on working with suppliers to reduce product-related costs like materials, packaging, qualification of materials and suppliers, etc. The logistics function is tasked with working with service providers to reduce transportation costs and customs fees. On the other hand, supply or demand planners are directly or indirectly responsible for reducing inventory. However, the true total landed cost can only be understood when a comprehensive TLC analysis is conducted and used as the guidance for different departments.

Many studies also propose different methods as part of the total landed cost framework. They range from graphical methods, rating or linear weighting methods, standard cost allocations (Kumar et al., 2010) and classification approaches (Zeng & Rossetti, 2003), to mathematical algorithms, and different process costing methods (Meinke, 2007). These methods have different levels of accuracy and complexity, and the higher level of accuracy normally implies greater complexity of the method. However, although several cost drivers, frameworks, and methods have been proposed, the perceived performance has not been satisfactory in the past (Pumpe, 2015).

A total landed cost model combined with supply chain risks assessment was built per the research conducted by Feller (2008), in which more variables were listed and factored into the optimization model that delivers the suppliers suggestions for the supply chain of a biotech company. Feller (2008) identified the components of the total landed cost model into five categories: purchasing, inventory, logistics, trade compliance and finance for further analysis as shown in Table 1. According to Feller (2008), whichever company considers all five of these costs in the sourcing decision model would be at an excellent position through global sourcing to outperform the cost structures of their competitors.

Table 1*:*
Components of the Total Landed Cost Model (Feller, 2008)

Purchasing	**Inventory**	**Logistics**	**Trade Compliance**	**Finance**
Material	Average Inventory	Freight	Duty	Tooling
Packaging	Safety Stock	Fuel Surcharge	Tariffs	Payment Terms
Qualification	Pipeline Inventory	Accessorial	Customs Fees	Discounts
One-time	Warehousing	Hazmat		

2.3 Cost of Risk Implication

The key to the research on the risk implication of supply chain is how to identify and quantify the risks in terms of costs that could be accommodated into the total landed cost model. A growing number of international companies have shifted their sourcing priorities toward low-cost countries where they can enjoy the materials and labor with lower costs. However, the invisible supply chain risks may incur hidden costs and subsequently offset cost saving opportunities. Examples of such risks include long lead time, volatile foreign currency exchange, customs duties, regulatory restrictions, damage or loss during transit, communication barriers, and lax quality standards (Min, 2011). Vincent (2010) concluded that a cost and risk assessment that weighs costs, risks and variables in a single sourcing strategy decision model could ensure delivery of the lowest total landed cost.

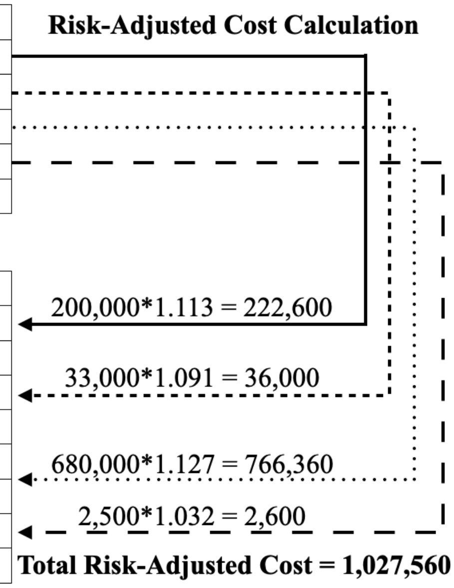
When it comes to implementation of the model that could help businesses make decisions on the sourcing suggestions, qualification of these risks is critical yet difficult. According to the research on incorporating risks and costs into global sourcing decisions (Sharma et al., 2019), the Data Envelopment Analysis (DEA) approach can be used to calculate the weighted sums of inputs and outputs and hence the cost efficiency. This approach avoids calculating how much of the cost would be affected by the risk factors. Instead, it focuses on the cost efficiency analysis that is associated with different risks and identifies the most beneficial supplier.

Alternatively, other research tried to calculate risk-adjusted cost based on the computed risk index of different risks identified (Feller, 2008). The Failure Mode Effects Analysis (FMEA) (Crow, 2008) process can be used to quantify the potential risk. To calculate the risk-adjusted cost for a supplier, the landed cost by category and the risk index by category are used with the risk index becoming a multiplier of cost. The risk-adjusted cost would be derived by multiplying the risk index multiplier by the cost associated with each corresponding supply chain activities as shown in Figure 1.

Figure 1:
Components of the Total Landed Cost Model (Crow, 2008)

Risk Category	Computed Risk Index
Logistics/Trade Compliance	11.3
Inventory/Quality	9.1
Purchasing/Organization	12.7
Finance/R&D	3.2
Total Risk Index	36.3

Cost Category	Landed Cost (USD)
Freight	200,000
Inventory Carrying Cost	18,000
Packaging	5,000
Warehousing	10,000
Material	650,000
Tooling	30,000
Finance	2,500
Total Landed Cost	915,500



2.4 Literature Review Summary

After the literature reviews on many sources about low-cost country, total landed cost, and cost of risk implication, a common theme has emerged on how to develop a sourcing decision model for GE Gas Power. The model or communication framework will help to suggest which countries to choose for different commodities and how different teams could collaborate with each other to drive the best total landed cost.

This capstone project will build a model to identify the low-cost countries using a total landed cost model which captures different supply chain costs. However, every company using these models must establish their own variables and processes for making sourcing decisions given the wide variety of business natures and organizational structures in supply chain.

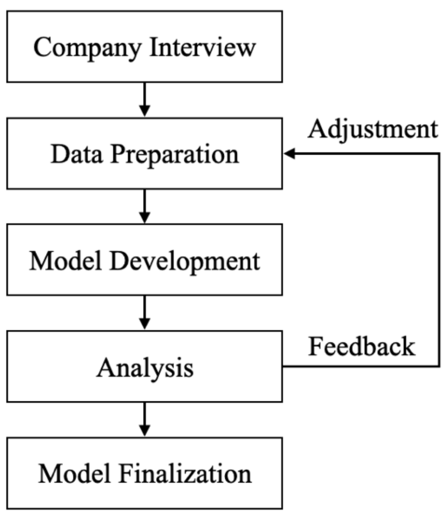
By assigning costs associated with the various components or activities of the supply chain, a company can tailor their total landed cost model for its industry to run the product-specific simulations that identify the optimal sourcing countries, rationalize the supply chain networks and mitigate the risks. Eventually, this capstone project will enable companies to run practical cost models that enhance profit margins and improve cash flows from the standpoint of procuring decision-making. It will also provide insights and drive actions that create value for both GE Gas Power and its suppliers.

Chapter 3: Data and Methodology

GE is seeking a dynamic model that ranks countries to purchase from using a total landed cost model. In this chapter, we describe the general approach to methodology, the cost elements that will be used in our model and the data sources. We then provide an overview of how the model was developed and the sample data that was used to test and analyze.

3.1 Methodology

Figure 2:
Methodology flow chart



This project starts with literature review focusing on low-cost country, total landed cost, and cost of risk implication. Therefore, we would have to better understand the cost elements and the framework of how they relate to each other in a global sourcing network. In addition, we conducted interviews with GE's Best-Cost Country team and the commodity leaders to better understand their commodity procurement in terms of SKU classifications, composition of raw materials, labor requirements, utilities and energy needed, as well as other special procurement requirements. Hence, when we sculpture the model, we could break down the cost structure in the way that more aligned with GE's procurement strategies and tactics.

For data preparation, we have several steps in terms of data collection and data cleaning. For data collection, with the understanding from the interviews and focus group with GE Best-Cost Country Team and commodity leaders, we would get a better sense of what kind of data we could collect from the public data source or GE internal data source as indicated in Sections 3.3 and 3.4.

As for data cleaning, we eliminated those commodities beyond the scope from the 2020 purchase orders dataset. Hence, we narrowed down the scope for model development and scale to the other commodities in the future by GE themselves. In addition, we removed outliers, for example, data from countries for which the economic, labor, and material data are not available from public data sources, or the purchase order price per PO quantity is extremely high or low within the same category.

In consideration of the model roll-out to GE BCC Team, we decided to use Excel incorporated with web-scraping techniques to develop the total landed cost model. This model will be fed by public data sources in real time like prices of raw materials or labor rate as well as data plugged in by GE internal data source like transportation freight and custom duties. With users' input of commodity, destination, shipment weight, and different weights of raw materials or components, the model can conclude the best-cost country from a total landed cost perspective.

For analysis, we requested the commodity leader of GE to provide one example commodity with weights of different materials and types of costs, shipment weight (in kilogram), destination country, HS code (Harmonized Commodity Description and Coding System), and energy consumption (in kilowatt hour). We conducted sensitivity analysis to examine the impact of the best-cost country ranking subject to the incremental change in price factors. We also compared the best-cost country recommendation with the historical decision and further discussed with GE to see if further adjustments are needed in the model in terms of our parameters and structures of cost breakdown. After the loop of feedback and adjustments, we were able to finalize the model and handed over to GE's BCC Team.

3.2 Cost Elements

GE is diversifying to work with best-in-class suppliers that meet safety, quality, delivery, and cost (SQDC) expectations. However, with global supply chain challenges and hyper-inflationary market, GE is looking into new geographies which offer better total landed cost outcomes while meeting safety, quality, and delivery requirements. As highlighted in the literature review in section 2.2, there are multiple cost elements that can be categorized under Low-Cost Country and Total Landed Cost. These elements were shown in Table 1 and will be discussed in detail in the following sections.

3.2.1 Low-Cost Country

For GE's sourcing department, the focus for model creation is only on components where there is a cost element. Variables that are not related to costs, such as climate risk, war risk, and corruption indices, will not be incorporated into the model for identifying the Best-Cost Country. After multiple interviews, the cost elements were identified as shown in Table 2 and these cost elements are subset of the Total Landed Cost.

Table 2:
Cost Components Used in Identifying LCC

Economical	Labor	Material
Energy price	Factory worker wages	Metal exchange prices
	Engineering wages	

3.2.2 Total Landed Cost

During initial interviews with GE (S. Prakash, personal communication, December 14, 2021), over 20 cost elements were discussed as possible components of the model. Many cost elements on the initial list could not be quantified for the purposes of a Total Landed Cost model. To gather data on which costs were most relevant to the business, focus groups and data/literature reviews were conducted. Some cost elements were more significant to the organization and were therefore used as the primary sources for the Total Landed Cost. The specific areas that were included in the cost elements were transportation, materials, labor and overheads. As cost components were identified, data sources were identified to understand what historical data, real-time data, or estimates can be used in the model.

The cost elements identified and used in the model are listed below in Table 3.

Table 3:
Cost Components Used in Total Landed Cost Model

Transportation	Materials	Labor	Overhead
Freight cost	Steel price	Factory worker wages	Energy price
Tariffs	Aluminum price	Engineering wages	
Custom fees	Copper price		
	Carbon steel price		
	Nickel price		
	Cobalt price		

3.3 Data Description from GE

In this section, the data provided by GE will be described in details. This includes the purchasing data, logistics data, and how materials were selected based on interviews with commodity leaders.

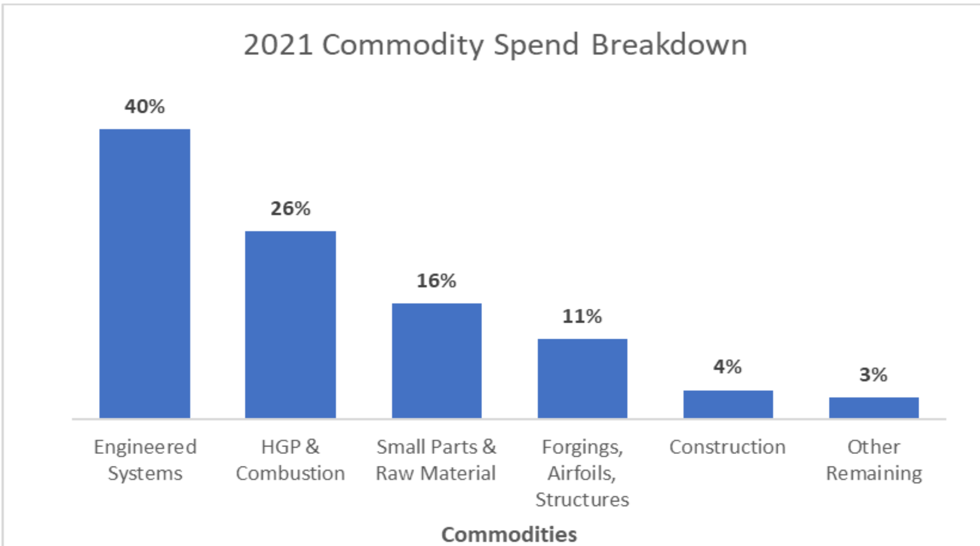
3.3.1 Purchasing Data

The data provided by GE was for a period of 12 months and consisted of all the purchases that were conducted in the year 2020. The data included item description, price of item, quantity purchased, supplier location, destination location and commodity breakdown. There are 5 main commodities in which materials are classified:

i) Small Parts and Raw Material;
ii) HGP & Combustion;
iii) Engineering Systems;
iv) Forgings, Airfoils, Structures, Fabrication and
v) Construction.

The five commodities are considered as Tier 1 commodities which consist of sub-commodities that are considered as Tier 2. The Tier 2 commodities are then broken into Tier 3 and Tier 4. Figure 3 below shows a histogram of Tier 1 commodities which represent USD 4 Billion of annual spend.

Figure 3:
Breakdown of Commodity Tier 1 of GE Purchasing Data



Note: The figure was made using GE 2021 purchasing data

3.3.2 Logistics Data

Logistics cost comprises two types of cost. First is the transportation cost, which is paid to the freight forwarders and is usually under an annual contract with fixed rates. The second cost is the customs compliance cost, which is paid to the government and consists of duty and tariffs.

Customs compliance costs depend on the type of product being transported and which country it is transported to. To determine the customs duty, every product is categorized into a Harmonized System (HS) code. The HS code is a standardized numerical method of classifying traded products and is commonly used in many countries for import and export process of goods. It is used by customs authorities around the world to identify products when assessing duties and taxes. (U.S. International Trade Administration, n.d.).

This research project includes the transportation cost only and there is opportunity for further research in customs compliance cost. Since GE operates and imports in several countries, the customs duty data and tariffs data can be extracted from their third-party partners and be incorporated in this model in future.

After the alignment with GE and project advisors, we derived the estimation of transportation cost from the multiplication of:

i) Distance (in kilometer);
ii) Average air freight rate (in ton-kilometer);
iii) Shipment weight (in ton)

For distance data, first, we collected coordinates of 950 cities around the world from bactchgeo.com. Second, since the total landed cost is calculated at country level, we only kept the coordinate of one city to present each country. For most of the countries we used capital city as the representative city, whereas for countries with wider territories, to reduce the bias, we used the geographically-central city to present the country. For example, we used the coordinate of Wichita, Kansas, to present the coordinate of United States of America instead of Washington D.C. Finally, as shown in Table 4, we derived the mileage chart in kilometer for country-to-country distances based on the Excel ACOS formula with the coordinates of every combinations of given two countries:

```
= ACOS [(sin(Latitude_Origin * PI() / 180) * sin(Latitude_Destination * PI() / 180) +
cos(Latitude_Origin * PI() / 180) * cos(Latitude_Destination * PI() / 180) *
cos(Longitude_Destination * PI() / 180 - Longitude_Origin * PI() / 180)) ] * 6357
```

Table 4:
Country-to-Country Distance Mileage Chart

Distance - km										
	Afghanistan	Albania	Algeria	Andorra	Angola	Antigua and Barbuda	Argentina	Armenia	Australia	Austria
Afghanistan	-	4,358	5,851	5,813	7,549	12,248	15,203	2,274	11,313	4,570
Albania	4,358	-	1,506	1,508	5,552	8,009	11,524	2,086	15,586	811
Algeria	5,851	1,506	-	667	5,096	6,630	10,095	3,577	16,920	1,678
Andorra	5,813	1,508	667	-	5,763	6,504	10,432	3,560	17,091	1,330
Angola	7,549	5,552	5,096	5,763	-	8,661	7,752	6,268	13,282	6,290
Antigua and Barbuda	12,248	8,009	6,630	6,504	8,661	-	5,717	10,050	16,346	7,684
Argentina	15,203	11,524	10,095	10,432	7,752	5,717	-	13,319	11,753	11,741
Armenia	2,274	2,086	3,577	3,560	6,268	10,050	13,319	-	13,540	2,391
Australia	11,313	15,586	16,920	17,091	13,282	16,346	11,753	13,540	-	15,881
Austria	4,570	811	1,678	1,330	6,290	7,684	11,741	2,391	15,881	-

For average air freight rate, we assumed the same rate between different regions or carriers due to the limited access to worldwide real-time freights information and the consideration to reduce the complexity of the model. Hence, we referred to the National Transportation Statistics table as of April 2020 from U.S. Department of Transportation, Bureau of Transportation Statistics for the average air freight revenue per ton-mile and applied it to the worldwide rate. According to the report, the latest rate $137.5 per ton-mile was from 2018, and we assumed the same for our model. We then converted that into $0.000854 per kg-km and multiplied this coefficient by the distances on the mileage chart in Table 4. Accordingly, we derived the country-to-country air freight chart as shown in Table 5 in below.

Table 5:
Country-to-Country Air Freight Chart

Transportation Prices (Air) - USD / kg										
	Afghanistan	Albania	Algeria	Andorra	Angola	Antigua and Barbuda	Argentina	Armenia	Australia	Austria
Afghanistan	0.000	3.724	4.999	4.966	6.450	10.464	12.989	1.943	9.666	3.905
Albania	3.724	0.000	1.287	1.288	4.744	6.843	9.846	1.782	13.316	0.693
Algeria	4.999	1.287	0.000	0.570	4.354	5.664	8.625	3.056	14.456	1.433
Andorra	4.966	1.288	0.570	0.000	4.924	5.557	8.913	3.042	14.603	1.137
Angola	6.450	4.744	4.354	4.924	0.000	7.400	6.623	5.356	11.348	5.374
Antigua and Barbuda	10.464	6.843	5.664	5.557	7.400	0.000	4.884	8.587	13.966	6.565
Argentina	12.989	9.846	8.625	8.913	6.623	4.884	0.000	11.380	10.041	10.031
Armenia	1.943	1.782	3.056	3.042	5.356	8.587	11.380	0.000	11.568	2.043
Australia	9.666	13.316	14.456	14.603	11.348	13.966	10.041	11.568	0.000	13.568
Austria	3.905	0.693	1.433	1.137	5.374	6.565	10.031	2.043	13.568	0.000

Regarding the calculation of the transportation cost out of total landed cost for each country-to-country combination, we multiplied the origin-to-destination air freight by the shipment weight that input by the user, which for example would be the weight of one unit of the example commodity to be discussed in Chapter 4.

3.3.3 Sample Scope

To build the initial model, GE decided to narrow the scope and provided a sample of parts from two Tier 2 commodities. The commodities are Fabrication and Casting/Combustion. We interviewed each of the commodity leader to obtain the cost breakdown of the sampled parts. Table 6 below shows the material and labor composition of the selected parts. These compositions were then used to identify the remaining sources of data required. For example, if the commodity leader mentioned that Part X was bought from Country A and requires 5 KG of steel, aluminum and copper, we then researched publicly available sources to obtain pricing levels of these materials in that country. The same is applicable for labor hours and cost. If the commodity leader mentioned that Part X required 100 hours of labor and was bought from Country A, we then researched public resources for Country A and identified the factory wages and engineering labor wages.

Table 6:
Interview Questions for Commodity Leaders

Interview Questions	Answers
Item description of sampled part	
Commodity Name	
Material 1 Name	
Material 1 Unit of Measure	
Material 1 estimate Quantity	
Material 2 Name	
Material 2 Unit of Measure	
Material 2 estimate Quantity	
Material 3 Name	
Material 3 Unit of Measure	
Material 3 estimate Quantity	
Estimate Labor Hours	
Supplier country	
Destination country	
Weight of item (KG)	
Estimate dimensions	
Any additional cost associated in making this part	
Transportation cost from supplier to destination	

3.4 Public Data Sources

This part will present all the data collected from external sources for the parameters according to the results from the interview questions in the previous Section 3.3.3.

Empirical data and statistics at the country level related to these parameters were collected from external sources such as Tradingeconomics.com, Theglobaleconomy.com, Salaryexpert.com, Salaryexplorer.com, These statistical data were collected for all countries with publicly available information. From the interviews, commodity leaders also suggested some statistical data from external sources which provided information related to steel production process, steel price and the production volume of steel raw materials such as lme.com, cmegroup.com, sunsirs.com, markets.businessinsider.com and Mepsinternational.com. The data collected will be presented in the following sections.

3.4.1 Labor Cost

There are two types of data collected in this section: i) Factory worker wages and ii) Engineering wages. Factory worker wages were obtained by searching average salaries of factory workers, welders or fabricators in a country. Engineering wages were obtained by researching the 50^{th} to 75^{th} percentile of salaries of mechanical engineers in a country. The data was collected from online sources such as salaryexpert.com, tradingeconomics.com, salaryexplorer.com, and theaveragesalarysurvey.com for the years 2021 and 2022. All wages were converted to USD and were obtained from top 107 countries that represent 99.6% of worlds manufacturing output. Top 15 countries are highlighted in Table 7 below in alphabetical order.

Table 7:
Wages Data for Factory Workers and Mechanical Engineers

Region	Country name	Factory labor USD Rate / Hour	Mech Engineer USD Rate / Hour
Africa	Algeria	$ 1.65	$ 6.51
Africa	Angola	$ 1.36	$ 4.19
South America	Argentina	$ 2.12	$ 6.42
Oceania	Australia	$ 17.41	$ 45.39
Europe	Austria	$ 16.11	$ 34.83
Caribbean	Bahamas	$ 10.09	$ 34.00
Middle East	Bahrain	$ 8.77	$ 26.02
Asia	Bangladesh	$ 0.49	$ 2.38
Central America	Belarus	$ 0.82	$ 2.15
Europe	Belgium	$ 16.22	$ 37.01
North America	Bermuda	$ 13.99	$ 48.00
South America	Bolivia	$ 3.12	$ 8.05
Europe	Bosnia and Herzegovina	$ 1.97	$ 6.11
South America	Brazil	$ 3.57	$ 14.47
Europe	Bulgaria	$ 2.67	$ 12.80

3.4.2 Metal prices

For metal prices, online resources used were lme.com, cmegroup.com, price.metal.com, sunsirs.com, markets.businessinsider.com and mepsinternational.com herein referred to as MEPS.

The two commodities which GE selected to build the base model were Fabrication and Casting/Combustion. The raw materials selected by GE commodity leaders for these commodities are shown in Table 8 below:

Table 8:
Raw Materials Selected by GE in Model Development

Raw Material	Commodities
Carbon Steel	Fabrication & Casting/Combustion
Stainless Steel	Fabrication & Casting/Combustion
Nickel	Fabrication & Casting/Combustion
Copper	Fabrication
Aluminum	Fabrication
Cobalt	Casting/Combustion

For majority of the data, web-scraping techniques were used to synchronize the real time data of metal prices into our model. Using this method, manual updates required by GE users will be limited. Table 9 summarizes the price of metals in USD per KG and displays the sources of information.

Table 9:
Materials Summary of Web Inputs

Materials Summary of Web Inputs								
Region	Stainless Steel 304 (As of Nov 2021)	Hot Rolled Coil Steel (April 2022)	Copper (April 2022)	Aluminum (April 2022)	Nickel (April 2022)	Cobalt (April 2022)	Source	Input Type
Asia	$ 3.46	$ 0.82	$ 11.58	$ 3.42	$ 34.54	$ 88.14	metal.com sunsirs.com mepsinternational.com	Web Scrape
Europe	$ 4.06	$ 1.32	$ 10.33	$ 3.38	$ 33.85	$ 82.35	lme.com mepsinternational.com	Hard Coded + Web Scrape
Americas	$ 4.28	$ 1.48	$ 10.39	$ 3.38	$ 34.10	$ 82.00	https://markets.businessinsider.com/ www.cmegroup.com https://agmetalminer.com/ mepsinternational.com	Hard Coded + Web Scrape
Africa	$ 4.47	$ 1.45	$ 11.36	$ 3.71	$ 37.24	$ 90.59	See assumptions table	
Oceania	$ 4.15	$ 0.82	$ 11.58	$ 3.42	$ 34.54	$ 88.14	See assumptions table	

All prices are in ***USD/KG***

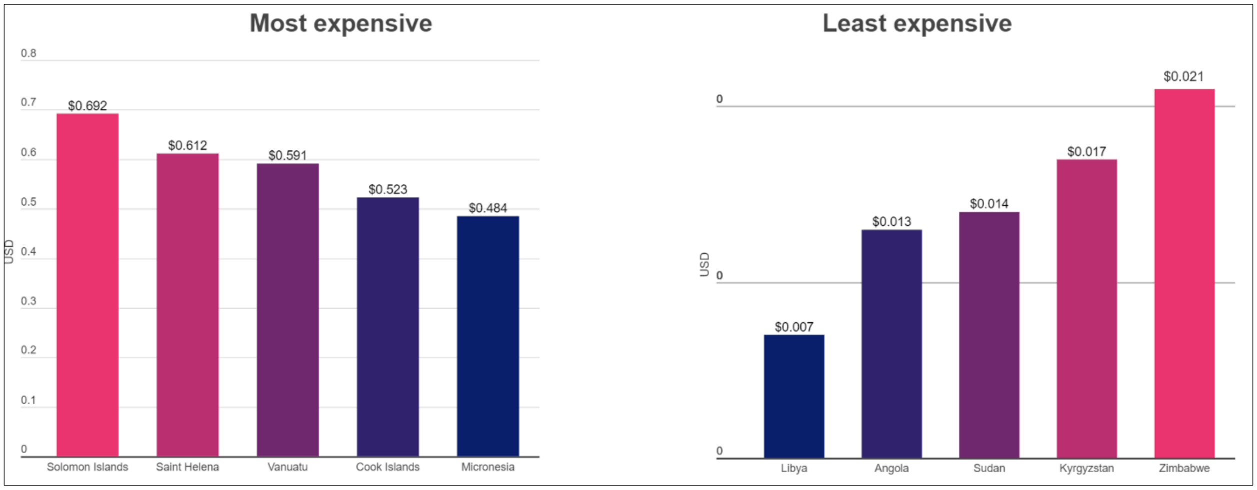
The green highlighted regions are where data was obtained from online sources and the yellow highlighted rows are regions where assumptions were made on the metal prices. These assumptions are a multiplier factor which can be modified by the user.

All data obtained for metals was from April 2022 apart from stainless steel. For stainless steel, the data will be four months old on a rolling basis due to access limitation. In our case, the data was extracted as of November 2021. For North American, MEPS uses regional average steel prices which are computed from a weighted average of prices in USA and Canada. For Asia, MEPS uses regional average steel prices from Japan, China, Taiwan and South Korea. For Europe, MEPS uses regional average steel prices from Spain, Germany, Italy, France, and the United Kingdom.

3.4.3 Energy Cost

The price of electricity will be used to factor for the overhead costs a supplier can face in a particular country. The data is obtained from cable.co.uk which has gathered data of 230 countries from more than 3000 energy tariffs across the globe. The below Figure 4 shows the most and least expensive countries for one kwh (Kilowatt-hour)

Figure 4:
The Most and Least Expensive Countries in the World for One KWH



Note. World wide electricity pricing in KWh, n.d. (https://www.cable.co.uk/energy/worldwide-pricing/#pricing).

As shown in Figure 4, the five cheapest countries for electricity are Libya, Angola, Sudan, Kyrgyzstan, and Zimbabwe. The five most expensive countries for electricity are Solomon Islands, St Helena, Vanuatu, the Cook Islands and Micronesia. To compare with the United States, the price of one kwh is averaged at $0.109 and is ranked in 82nd place in terms of having the cheapest electricity price. Whereas China is ranked in 56th place with a price of $0.08 per one kwh.

The commodity leaders in GE will estimate the kwh a supplier may require either to operate or to produce a component. The data from cable.co.uk will then be used to multiply the price by the estimated amount of kwh required to calculate an estimate cost for each country.

3.5 Model Development

Microsoft Excel was used to build the total landed cost and low-cost country model. There were several other platforms under discussion but Microsoft Excel was the final decision due to the ease of use by the different members of the GE team.

The excel file contains three main sections which are the input section, data section, and output section. In the input section, the user enters the quantity of the various materials required, labor hours, weight of product, and destination country where product needs to be shipped. Section 3.5.1 includes detailed explanation of the input section. The data section includes all the prices of materials, labor, logistics, and overheads which has been extracted either from GE or from public sources using web scraping or manual inputs from the website. These data inputs were explained previously in Section 3.3 and 3.4. The output section calculates the total cost by multiplying the data entered in input variables with the unit prices in data section. The final cost of each country is then calculated by adding the total cost of materials, labor, transportation and overheads.

$$Total\ Landed\ Cost = \sum_i Material\ Price_i \times Quantity_i + Labor\ Cost + Logistics\ Cost + Overheads$$

$$where\ i\ represents\ differnt\ materials$$

The cost buckets in Equation 1 are at a high level and consist of several variables which are explained in Section 3.5.1.

3.5.1 Input Variables

The input variable section can be broken down into four categories as highlighted in the formula above. The categories are materials, labor, logistics and other miscellaneous cost.

Figure 5 shows a screenshot from the excel model that includes all the variables included within each category of the input section.

Figure 5:
Input Variables Screenshot from Excel Model

Input Section

Material Inputs	Input	UOM
Stainless Steel	1000	KG
Carbon Steel	0	KG
Copper	200	KG
Aluminum	0	KG
Nickel	0	KG
Cobalt	0	KG

Labor Inputs	Input	UOM
Factory Labor Hours	300	Hours
Engineering Labor Hours	100	Hours

Logistics Inputs	Input	UOM
Destination Country	Argentina	
Shipment Weight	20000	KG
HS Code ?	NA	

Overhead Cost	Input	UOM
Energy Consumption	0	KWH

In the materials section, users will input the quantity of the different metals required to manufacture a commodity or product they are seeking to purchase. The six metals were identified in Section

3.4.2 and the user is expected to estimate the quantity of each of the metals required. If a metal is not required to manufacture a product or commodity, the user can simply input zero. It is important to note the UOM (Unit of Measure) being used which is KG (Kilograms) in this excel model.

These inputs will then be used to multiply by the price which is being extracted for each country or region through web scraping and manual inputs.

In the labor section, users estimate and input the factory labor hours required to manufacture a commodity or product. Furthermore, some products may require design and engineering work and therefore, there is another category called engineering or professional labor hours. In this section, users will estimate the engineering hours required which will then be used to multiply by the cost of labor in each country to calculate the total labor cost.

In the logistics section, users input the destination country where the final product needs to be delivered, estimated weight of the product and HS code if known. The weight of the shipment is multiplied by the pricing data provided by GE to calculate the freight cost from all countries to the destination country. The HS code can be used to identify the import duties in the destination country but due to the lack of availability of data, this section was determined by GE to be included at a later stage after model deployment.

In overhead cost section, users will input the estimate amount of energy in KWH required to either run the facility of manufacture a product. Utilities is a major factor of overhead cost and differentiates from country to country and therefore it was included as part of the excel model.

3.5.2 Output Section

The output section calculates the sum of all materials, labor, overhead and transportation. This section also ranks countries having the lowest total cost based on the input variables. The final results from this section are then displayed to the user showing the top 10 low-cost countries where they can buy this particular product from. Figure 6 shows a sample screenshot from the excel model.

Figure 6:
Final Output Results of Total Landed Cost

Final Output of Total Landed Cost																
				Materials							Labor			Overheads	Transportation	
Country code	Region	Country name	Continental region	Stainless Steel (USD)	Carbon Steel (USD)	Copper (USD)	Aluminum (USD)	Nickel (USD)	Cobalt (USD)	Total Materials Cost USD	Total Labor Cost (Factory	Total Labor Cost (Engineerin	Total Labor Cost USD	Total Energy Cost USD	Total Logistics Cost USD	Total Landed Cost USD
DZ	Africa	Algeria	NORTHERN AFRICA	$ 4,471	$ 145	$ -	$ -	$ 3,724	$ -	$ 8,340	$ 1,323	$ 1,303	$ 2,626	$ 328	$ 14,358	$ 25,652
AO	Africa	Angola	SUB-SAHARAN AFRICA	$ 4,471	$ 145	$ -	$ -	$ 3,724	$ -	$ 8,340	$ 1,084	$ 839	$ 1,923	$ 127	$ 21,097	$ 31,487
AR	South America	Argentina	SOUTH AMERICA	$ 4,277	$ 148	$ -	$ -	$ 3,410	$ -	$ 7,835	$ 1,698	$ 1,285	$ 2,982	$ 527	$ 15,241	$ 26,585

Chapter 4: Results and Analysis

The model in this project considers different parameters of input factors and price information with different weights assigned to them by the commodity leader for individual commodities. The model will conclude different results in terms of best-cost countries depending on these independent variables, since there are many different factors involved in the total landed cost when it comes to purchasing decisions for the sourcing country. Our analysis focused not only on the model's outcome, but also on how the individual variables change the outcome of total landed cost ranking.

We used one commodity example that was provided by GE Gas Power to run the model with the weights that were configured by the commodity leader. We then compared our model output against the actuals selected by GE. Furthermore, in order to quantify the impact of the change of any given single variable, we continued with the same example commodity to conduct sensitivity analysis on different price factors – metal price, labor rate, energy cost, and transportation price.

4.1 Example Data

The example selected by GE was a steel casing casting for turbines which is under the Tier 1 commodity called Forgings, Airfoils, Structures, Fabrication. This is a 30,000 KG part which is made of 26,000 KG of stainless steel and requires more than 800 labor hours. The estimate electricity consumption was 100,000 KWH and the destination country selected by GE was Italy. The current suppliers of GE for steel casing casting are from Poland, China and Italy. Figure 7 below shows the screenshot of the input variables from the excel model.

Figure 7:
Input Variables of Sample Part Selected by GE

Input Section

Material Inputs	Input	UOM
Stainless Steel	26030	KG
Carbon Steel	0	KG
Copper	0	KG
Aluminum	0	KG
Nickel	0	KG
Cobalt	0	KG

Labor Inputs	Input	UOM
Factory Labor Hours	880	Hours
Engineering Labor Hours	50	Hours

Logistics Inputs	Input	UOM
Destination Country	Italy	
Shipment Weight	30250	KG
HS Code ?	NA	

Overhead Cost	Input	UOM
Energy Consumption	100000	KWH

4.2 Model Outcome of the Example Data

Based on the input variables, the excel model calculated the total landed cost for all 107 countries and ranked them based on the countries having the lowest cost. Figure 8 shows the top 10 countries having the lowest total landed cost.

Figure 8:
Total Landed Cost Output of Sample Part elected by GE

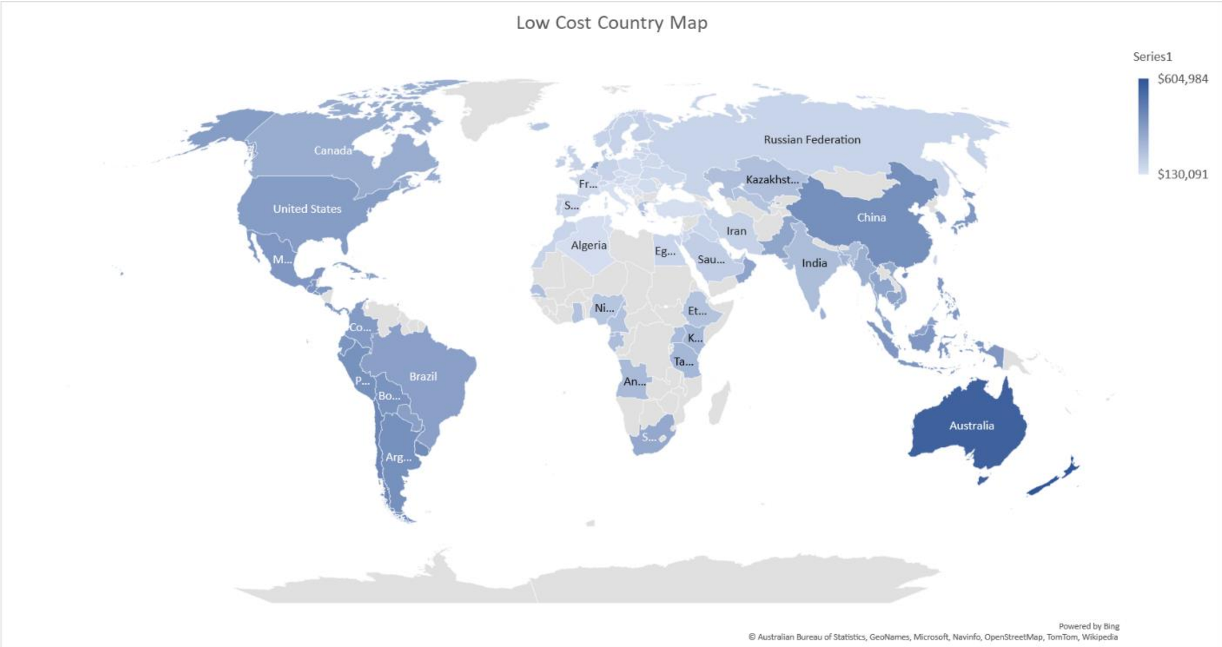
Final Output of Total Landed Cost

			Materials	Labor	Overhead	Transportation	
Country code	Region	Country name	Total Materials Cost USD	Total Labor Cost	Total Energy Cost USD	Total Logistics Cost USD	Total Landed Cost USD
BA	Europe	Bosnia and Herzego	$ 105,801.80	$ 2,036.22	$ 8,549	$ 13,703.61	$ 130,091
HR	Europe	Croatia	$ 105,801.80	$ 4,048.36	$ 9,855	$ 13,229.87	$ 132,935
RS	Europe	Serbia	$ 105,801.80	$ 2,754.02	$ 6,141	$ 18,736.78	$ 133,433
IT	Europe	Italy	$ 105,801.80	$ 11,284.64	$ 20,092	$ -	$ 137,178
TN	Africa	Tunisia	$ 116,381.98	$ 3,075.13	$ 6,102	$ 15,306.79	$ 140,865
HU	Europe	Hungary	$ 105,801.80	$ 3,788.63	$ 10,031	$ 21,453.43	$ 141,075
SK	Europe	Slovakia	$ 105,801.80	$ 6,055.95	$ 9,981	$ 21,130.44	$ 142,970
TR	Middle East	Turkey	$ 90,115.86	$ 1,641.82	$ 7,091	$ 44,317.68	$ 143,167
SI	Europe	Slovenia	$ 105,801.80	$ 9,758.89	$ 17,273	$ 13,529.71	$ 146,363
DZ	Africa	Algeria	$ 116,381.98	$ 1,781.17	$ 3,279	$ 25,072.66	$ 146,515

It is important to note that the total landed cost value is not for should-cost purposes but it is only to differentiate countries from one another. Bosnia and Herzegovina was ranked as the top country followed by Italy and Croatia. It is also shown in Figure 9 that Italy does not have any logistics cost which is due to the destination being Italy and therefore, there will be no need to air freight this product.

Figure 9 displays the world heat map of countries which are colored from light blue to dark blue. The lighter the color, the lower the total landed cost is. It can be noticed that the countries that are farther from Italy, have a darker color which is due to having a higher transportation cost which increases the total landed cost.

Figure 9*:*
World Heat Map of Total Landed Cost



4.3 Sensitivity Analysis

In this section, sensitivity analysis is conducted by changing the materials price, labor price, energy price, and transportation price. For each sensitivity analysis scenario, we only change one cost driver at one time while holding the remaining cost drivers unchanged. The change will be increasing and decreasing by 20%, 40%, and 60% to examine how the output results change and whether a country's rank is affected. The analysis will focus on the ranking of top 5 countries only.

4.3.1 Sensitivity of Material Cost

The outcome of country ranking with changes in stainless steel price is shown in Table 10. The middle column which has heading of "100% (No change)" is the base case where material price has not been changed. The "120%" column represents a 20% increase in material price and "80%" column represents a 20% decrease in material price.

Bosnia and Herzegovina remained as the best-cost country regardless of the change in price from 20% to 60%. Croatia and Serbia remained as the second and third best-cost country. Italy was the fourth best-cost country at the base case and remained fourth lowest with a +-20% change. However, when there was more than 20% change in stainless steel price, Italy moved from fourth to fifth best-cost country. As stainless steel price decreases by more than 20%, Tunisia is added into the top 5 ranking list. When stainless steel price increases by more than 20%, Turkey is added into the top 5 ranking list. This occurs since stainless steel price varies from region to region and a percentage increase in price causes a higher impact in some countries vs. the other.

Table 10:
Sensitivity Analysis of Stainless-Steel Price on Country Ranking

	Sensitivity of Stainless Steel Price						
BCC	**40%**	**60%**	**80%**	**100% (No change)**	**120%**	**140%**	**160%**
1	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina
2	Croatia	Croatia	Croatia	Croatia	Croatia	Croatia	Croatia
3	Serbia	Serbia	Serbia	Serbia	Serbia	Serbia	Serbia
4	Tunisia	Tunisia	Italy	Italy	Italy	Turkey	Turkey
5	Italy	Italy	Tunisia	Tunisia	Turkey	Italy	Italy

4.3.2 Sensitivity of Labor Cost

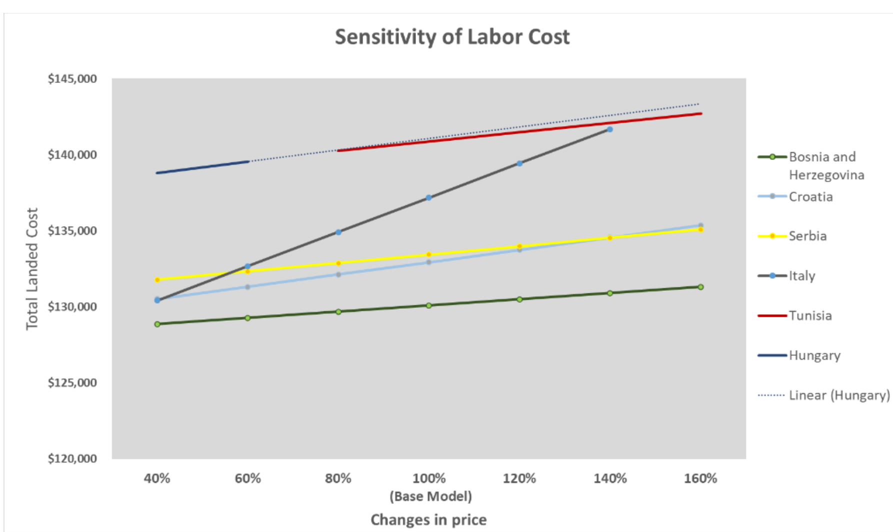
Labor prices do not fluctuate on a regular basis as materials price do. They usually change on an annual basis in a country based on market dynamics and country's economic performance.

Bosnia and Herzegovina remained as the best-cost country regardless of the change in price up to 60%. Croatia is the second best-cost country in the base case and becomes the third best-cost country when labor prices decrease by 60%. An increase in labor price by more than 40% also causes Croatia to move from second to third best-cost country. The complete summary of rankings is shown in Table 11 and Figure 10 shows the line graph with total landed cost values.

Table 11:
Sensitivity Analysis of Labor Cost on Country Ranking

	Sensitivity of Labor Cost						
BCC	**40%**	**60%**	**80%**	**100% (No change)**	**120%**	**140%**	**160%**
1	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina
2	Italy	Croatia	Croatia	Croatia	Croatia	Serbia	Serbia
3	Croatia	Serbia	Serbia	Serbia	Serbia	Croatia	Croatia
4	Serbia	Italy	Italy	Italy	Italy	Italy	Tunisia
5	Hungary	Hungary	Tunisia	Tunisia	Tunisia	Tunisia	Hungary

Figure 10:
Sensitivity Analysis of Labor Cost on Total Landed Cost



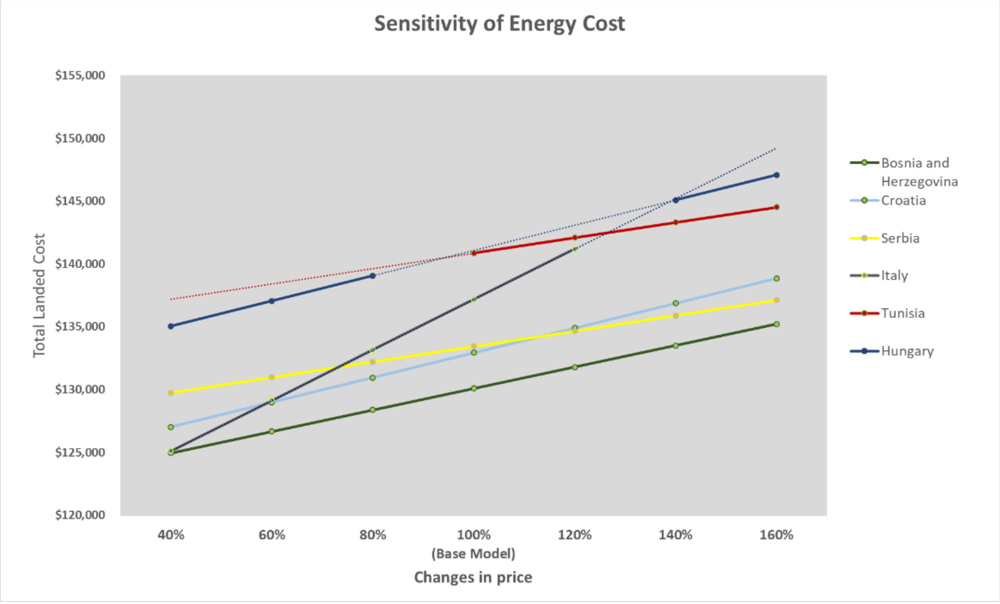
4.3.3 Sensitivity of Energy Cost

Bosnia and Herzegovina remained as the best-cost country regardless of the change in price from 20% to 60%. Croatia remained the second best-cost country with a 20% and 40% decrease in electricity price but moved to third best-cost country when there was more than 40% decrease in electricity price. An increase in electricity price also caused Croatia to move to third ranked country. The complete summary of country rankings are shown in Table 12 and Figure 11 shows the line graph with total landed cost values.

Table 12:
Sensitivity Analysis of Energy Cost on Country Ranking

	Sensitivity of Energy Cost						
BCC	40%	60%	80%	100% (No change)	120%	140%	160%
1	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina
2	Italy	Croatia	Croatia	Croatia	Serbia	Serbia	Serbia
3	Croatia	Italy	Serbia	Serbia	Croatia	Croatia	Croatia
4	Serbia	Serbia	Italy	Italy	Italy	Tunisia	Tunisia
5	Hungary	Hungary	Hungary	Tunisia	Tunisia	Hungary	Hungary

Figure 11:
Sensitivity Analysis of Electricity Prices on Total Landed Cost



4.3.4 Sensitivity of Transportation Price

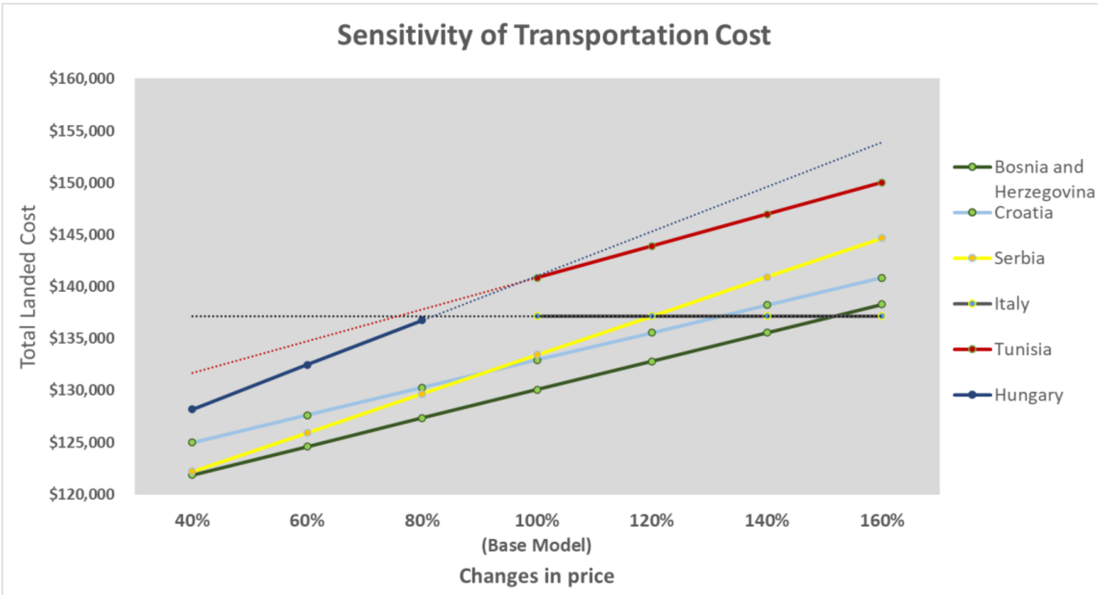
Bosnia and Herzegovina remained as the best-cost country when there was up to 40% change in transportation price. However, a change of more than 40% caused it to move to second best-cost country. Changes in transportation price seem to be a major factor in deciding the best-cost country and the dynamics can be seen in Table 13. The rankings are constantly changing when there is a change in price by 20%. An important observation is that as transportation prices increase, the ranking of Italy improves. Italy was the fourth best-cost country supplier in the base case and was ranked third when there was a 20% increase in price. With a 40% increase in price, Italy was ranked second and was finally ranked first when there was a 60% increase in transportation price. This occurred since transportation cost from Bosnia and Herzegovina increased significantly and its total landed cost became higher than Italy.

The line graph in Figure 12 shows how Italy's total landed cost remained constant while other countries had an increase in their total landed cost. This is due to the destination being Italy and hence there is no impact of transportation price on Italy.

Table 13:
Sensitivity Analysis of Transportation Cost on Country Ranking

	Sensitivity of Transportation Cost						
BCC	**40%**	**60%**	**80%**	**100% (No change)**	**120%**	**140%**	**160%**
1	Turkey	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Bosnia and Herzegovina	Italy
2	Bosnia and Herzegovina	Turkey	Serbia	Croatia	Croatia	Italy	Bosnia and Herzegovina
3	Lebanon	Serbia	Croatia	Serbia	Italy	Croatia	Croatia
4	Serbia	Croatia	Turkey	Italy	Serbia	Serbia	Serbia
5	Croatia	Hungary	Hungary	Tunisia	Tunisia	Tunisia	Tunisia

Figure 12:
Sensitivity Analysis of Transportation Cost on Total Landed Cost



4.4 Discussion

After conducting sensitivity analyses on material, labor, electricity, and transportation prices with the selected sample commodity, we found that total landed cost is the most sensitive to changes in transportation price and electricity price.

The most changes in country ranking of 5 lowest cost countries can be noticed by looking at the number of times the line graph has intersected in Figure 11 and Figure 12. Each intersection represents a change in country ranking and this is how the volatility was calculated.

According to the historical purchase order data provided by GE, the current suppliers of steel casing casting are from Poland, China and Italy. The excel model created and shown in Figure 8 in this project suggests that the best-cost country is Bosnia and Herzegovina, Croatia as second lowest, Serbia as third, Italy as fourth, and Tunisia as fifth best-cost country.

The current supply countries of GE, Italy and Poland, are ranked as 4th and 13th best-cost country based on our model. This proves our model's efficacy by cross-verifying the purchase decision that GE made in the past. Where destination is Italy for this particular product, our recommendation to GE is to find alternative sources in the best-cost country which is Bosnia and Herzegovina or the second lowest country which is Croatia. However, rapid increases in transportation cost may require to build strong relationships with suppliers in Italy.

In addition to the sensitivity analysis on material, labor, transportation and energy costs, we also researched impact of oil prices. There is a high correlation between the price of oil and price of metals such as steel. When there is an increase in oil price, the market price of metals also increases which increases the total material cost. The oil industry is a consumer of steel and the price of oil impacts transportation cost of these metals (Yunda, 2020). With regards to electricity prices, an increase in oil price does not have a major impact. Petroleum is not a major source of fuel in electricity generation since most of electricity comes from coal and natural gas followed by renewables (Fares, 2015). Therefore, procurement professionals should also monitor oil price as it directly impacts transportation cost and metal prices.

4.5 Research Limitations

Building a model using Excel offers a straight-forward user interface for GE to modify, since this tool will be handed over to the sponsor company's procurement professionals and they are familiar with the cost breakdown of different cost drivers. In addition, with the flexibility of the user input, they are also able to see how the suggested best-cost country ranking changes when they configure different parameters of the cost drivers in real time.

The first major limitation comes from data accuracy of the prices of cost drivers in the total landed cost formula in terms of accessibility, granularity, and timeliness.

For data accessibility, we encountered difficulties in collecting logistics data and labor rates of different countries. Unlike the electricity price that we could refer to the single source and use web-scraping technique to keep feed the real time data into our model, there is no single website that includes the labor rates of all countries. Hence, we would need to manually collect the data from different sources and it will not be updated by itself whenever the model is refreshed. Furthermore, we estimated transportation and did not include custom duty and tariffs for the moment. GE plans to accommodate these two pieces of costs into the model at the later stage.

Country level granularity is limited in the model as we found out the metal prices could only be derived by regions instead of specific countries. For example, for all European countries, we derived the same price of stainless steel, hot rolled coil steel, copper, aluminum, nickel, and cobalt from the London Metal Exchange (LME). Likewise for all the Asian countries, we leveraged price information from SMM Information & Technology Co., Ltd. This has decreased the level of sensitivity in differentiating the best-cost country ranking when it comes to different countries within the same region.

As for data timeliness, sometimes we were not able to obtain the most up-to-date snapshot of the price information and it requires users to manually check and update. For instance, the latest snapshot of the average air freight revenue per ton-mile provided by the National Transportation Statistics table of U.S. Department of Transportation, Bureau of Transportation Statistics was 2018. We could only assume the same to calculate for 2022. Another example is stainless steel since the latest price we could obtain was as of November 2021 while the prices of other metals can be up-to-date. These factors reduce the accuracy of the model in terms of having the most up to date information.

Chapter 5: Conclusion

Through our analysis using one example commodity provided by GE based on the outcome of our total landed cost model, we concluded a country that GE has not been sourcing from, Bosnia and Herzegovina. This has been a great insight for GE's BCC team to further explore and evaluate if it would be a good candidate country to source from after considering other factors such as safety, quality, delivery, and cost. From there, GE will also do risk assessment on aspects like geopolitics, economics, infrastructures, legal, and compliance before making the purchasing decision.

From the other angle, Italy and Poland are two of the countries that GE is currently purchasing from. According to our model, they are ranked as 4^{th} and 13^{th} amongst 107 candidate countries, which has also provided a certain level of confidence for both GE and this capstone project that the gap is not too significant between GE's purchasing decision in the past and the model's suggestion on best-cost country. In terms of total landed cost, the difference between Italy and

Bosnia and Herzegovina is 5.4% and the difference between Poland and Bosnia and Herzegovina is 17.5%.

We could also draw a conclusion from the example commodity analysis and sensitivity analysis that the transportation and energy costs play a key role in determining the ranking of total landed cost and best-cost country. Like the example commodity analysis section along with Figure 9 the world heat map of total landed cost has pointed out how distance impacts the total landed cost. Furthermore, the sensitivity analysis on transportation has shown the most drastic changes in best-cost country ranking happen in relation to transportation cost changes, in comparison to the changes on all the other cost drivers. However, if we also incorporate the other transportation mode options like truck, railway, and ocean, the result might change significantly and it will be beneficial to explore this in future studies.

5.1 Future Research

Initially, for the purchasing cost piece of total landed cost, we were evaluating two methods. The first method was to develop the regression model to estimate the should-cost leveraging the historical purchase order data. The second method was to rely on GE's procurement professionals to decide the parameters of cost drivers for the calculation of should-cost along with real time prices information web-scraped from the internal and external source. The former has the advantage of being more accurate because it could be automated, whereas the latter may be less accurate but provides the procurement team with more flexibility.

If we chose the first method, the regression model, for a product's should cost estimation, it would have been able to simulate the weights of different cost drivers. For example, if GE's 2021 purchase order data indicates they procured Product A only from China, Vietnam, and Germany before. We could have used the historical purchase order price and each cost driver's price corresponding to the country and time as the training data to train the regression model. After the model was trained and tested, we could have plugged in the price of each cost driver of the other countries to get the estimate of the should cost for other countries that GE never sourced from. Adding up with the other cost drivers like transportation, custom duty, and tariffs with our total landed cost model, we might have concluded the best-cost country to be Country Y to procure Product A.

However, the second method was used, which is based on Excel calculations with the parameters input by the user due to the consideration of user acceptance and project direction advised by the sponsor company (S. Prakash, weekly meeting, February 2, 2022). With that being said, this model relies more on the human judgment and the weights assigned to the inputs by the users. However, sometimes how much weights were assigned for different parameters would differ from one user to another due to different user's experiences and understanding of the commodity. That is to say, the outcome of the best-cost country would change depending on different users even if the same commodity, shipping destination, and shipment weight are assigned. At a certain level, this has increased the variability of the outcome and decreased the accuracy of the model, which we considered to be the first major limitation of the research.

To counter the limitations on model accuracy discussed in Section 4.5, there are two focus areas for the model to improve in the future – model structure and data accuracy. Future research can be done to explore a regression model which can increase automation with higher accuracy and reduce human errors of judgement for should cost estimation. If the model users still need a certain level of flexibility of tuning different parameters of cost drivers, a future total landed cost project could explore the possibility to incorporate a regression model into a user-friendly interface that users can customize the parameters.

On the other hand, for data accuracy, normally a company would reach out to consulting firm or third-party market research agency to derive the data, such as metal prices or labor rates of different countries for the higher level of data granularity and timeliness, instead of relying on public sources like the London Metal Exchange. They would also have in-house teams for a certain type of information. For example, after GE BCC team derives the transportation, custom duty, tariffs data from their logistics team, they can further augment the model. This will enable GE to enhance the accuracy of the model's conclusion on which country is the best-cost country that they should go explore for sourcing.

When it comes to procurement decisions especially when evaluating which country to source a commodity from given a destination country, the procurement professionals would not only take into account the monetary factors like what has been discussed in this total landed cost model project, but also the risks implications that may lead to further direct or indirect cost accruals in the short term or long term. Though in the beginning we've clarified the project scope with GE that we would only factor monetary cost drivers into our model, for future researchers of total landed cost studies, more attention could be paid on risk implications and how these implications could be converted into monetary calculations. Alternatively, a scorecard or filtering criteria for sourcing countries can also be developed for procurement professionals to factor in risk implications in purchasing decisions.

References

Batchgeo (n.d.). Cities by Latitude & Longitude
Retrieved April 16, 2022, from https://batchgeo.com/map/latitude-longitude

Cable.co.uk World wide electricity pricing in KWh. (n.d.)
Retrieved March 07, 2022 from https://www.cable.co.uk/energy/worldwide-pricing/#pricing

Career Explorer (n.d.).
Retrieved April 10, 2022, from https://www.careerexplorer.com

CME Group (n.d.).
Retrieved April 08, 2022, from https://www.cmegroup.com

Crone, M. (2006). Are Global Supply Chains Too Risky? A Practitioner's Perspective. Supply Chain Management Review.

Crow, Kenneth (2008). Failure Modes and Effects Analysis (FMEA). DRM Associates. Available at: htto://www.npd-solutions.com/finea.html

Fares, R. (2015, February 12). Low Oil Prices Could Be Good for Electricity and Renewables. https://blogs.scientificamerican.com/plugged-in/low-oil-prices-could-be-good-for-electricity-and-renewables/#:~:text=Therefore%2C%20the%20price%20of%20oil,%2C%20wind%2C%20and%20other%20renewables.

Feller, B. (2008). Development of A Total Landed Cost and Risk Analysis Model for Global Strategic Sourcing. Available at: https://dspace.mit.edu/handle/1721.1/43828

Howell, G. (2017). Total Landed Cost Analysis: Identifying Hidden Costs in Global Supply Chains. EPS News. Available at: https://www.ebnonline.com/author.asp?section_id=3911&doc_id=283172

Kumar, N., Andersson, D. and Rehme, J. (2010). Logistics Of Low Cost Country Sourcing. International Journal Of Logistics Research And Applications, 13(2), pp. 143–160.

Kusaba, K., Moser, R. and Rodrigues, A.M. (2011). Low-Cost Country Sourcing Competence: A Conceptual Framework and Empirical. Journal of Supply Chain Management, 47(4), pp.73-93.

Lockström, M. (2006). Low-Cost Country Sourcing. Trends and Implications. Springer Science & Business Media.

London Metals Exchange (n.d.).
Retrieved April 08, 2022, from https://www.lme.com

Markets Insider. (n.d.). Commodity Prices
Retrieved April 10, 2022, from https://markets.businessinsider.com

Meinke, A. (2007). Cost Oriented Supply Chain Management And Supply Chain Controlling. Combination and configuration of instruments. Aachen: Shaker Verl.

MEPS International Ltd (n.d.).
Retrieved April 08, 2022, from https://www.mepsinternational.com

Metal Miner (n.d.).
Retrieved April 08, 2022, from https://www.agmetalminer.com

Min, H. (2011). Measuring The Risk Of Sourcing From Low Cost Countries: A Macro Perspective, International Journal of Services and Operations Management. Available at: https://www.researchgate.net/publication/264821745_Measuring_the_risk_of_sourcing_from_low_cost_countries_A_macro_perspective

Pumpe, A. and Vallée, F. (2015). The Total Landed Cost Concept. Begging for Answers, In: Blecker, Thorsten Kersten, Wolfgang Ringle, Christian M. (Ed.): Operational Excellence in Logistics and Supply Chains: Optimization Methods, Data-driven Approaches and Security Insights. Proceedings of the Hamburg International Conference of Logistics (HICL), Vol. 22, ISBN 978-3-7375-4058-2, epubli GmbH, Berlin, pp. 31-54.

Salary Expert (n.d.).
Retrieved April 10, 2022, from https://www.salaryexpert.com

Salary Explorer (n.d.).
Retrieved April 10, 2022, from https://www.salaryexplorer.com

Sawhney, R. and Sumukadas (2005). Coping with Customs Clearance Uncertainties in Global Sourcing. International Journal of Physical Distribution & Logistics Management, 35(3-4), pp.278-295.

Shanghai Metals Market (n.d.).
Retrieved April 08, 2022, from https://www.price.metal.com

Sharma, S.K., Singh, R. and Matai, R. (2019). Incorporating Risks And Costs Into Global Sourcing Decisions. Available at: https://www.inderscienceonline.com/doi/pdf/10.1504/IJPM.2019.102947
Siegfried, M. (2013). A Shift in Sourcing Strategy. Inside Supply Management, 24(2), pp.26.

SunSirs China Commodity Data Group (n.d.).
Retrieved April 08, 2022, from https://www.sunsirs.com

The Average Salary Survey (n.d.).
Retrieved April 10, 2022, from https://www.theaveragesalarysurvey.com

Trading Economics (n.d.).
Retrieved April 08, 2022, from https://www.tradingeconomics.com

U.S. Department of Transportation, Bureau of Transportation Statistics, National Transportation Statistics. Explore.dot.gov. (2020, April 20). Retrieved April 16, 2022, from https://explore.dot.gov/views/AverageFreightRevenueperTon-mile/Chart?%3Aincrement_view_count=no

U.S. International Trade Administration. (n.d.).
Retrieved March 07, 2022, from https://www.trade.gov/harmonized-system-hs-codes

Vincent, K.M. (2010). Costs, Risks and Variables to Consider in Sourcing Decision Models for Globally Dispersed Manufacturers. Available at: https://ctl.mit.edu/pub/thesis/costs-risks-and-variables-consider-sourcing-decision-models-globally-dispersed

Vu, T.T.M. and More, P.R. (2017). Identifying the Best-Cost Countries for Sourcing SKF's Direct Materials. Chalmers University of Technology. Available at: https://odr.chalmers.se/handle/20.500.12380/254136

Yunda, A. (2020, July 09). Do oil prices still correlate with scrap and steel? Fastmarkerts. https://www.metalbulletin.com/Article/3940953/Do-oil-prices-still-correlate-with-scrap-and-steel.html

Zeng, A. Z. and Rossetti, C. (2003). Developing A Framework for Evaluating the Logistics Costs in Global Sourcing Processes: An Implementation and Insights. International Journal of Physical Distribution & Logistics Management, 33(9), pp. 785–803.