DC site selection from both quantitative and qualitative perspectives: A case study of Logitech Asia Pacific logistics network

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Abstract

Logitech management team needs to decide which location in India should be selected for the new Logitech distribution center. Costs and service level improvements are not the only motives. There are other concerns about labor, tax, access to customers and so on, which are qualitative and cannot be quantified. For the site location decision, the present study attempts to quantify the qualitative variables and combine both quantitative and qualitative aspects. In addition to the cost and lead time simulation model, the AHP model is adopted to evaluate possible locations over qualitative criteria. Results suggest that there is no significant reason that Logitech should move to India. However, there are opportunities worth exploring. Results also show that the approach of the present study could bring benefits to businesses, which helps to combine business performance measures with the internal hierarchy of business functions.
Preface

This report has been written after six months of research at Logitech Nijmegen. As my graduation project, the research is conducted for the two-year program of Operations Management & Logistics at Technical University Eindhoven.

I would like to thank to a few people at Logitech. My supervisor, Ron van der Wegen, Senior Director of Global Logistics, who gave me this opportunity to do my research at Logitech, is a true visionary and is always inspiring. His visions, although not captured in this report, extend my understanding of logistics. My program manager, Martijn Cillessen, who have helped me through the entire study and who have helped me to develop soft skills, is open-minded and helpful. My colleague, Lennart Nederpel, who likes to do sports and do even more sports, always has patience for me and has shared every bit of knowledge he has very generously. Without his help, my study cannot be finished without a lot of struggles. Last but not the least, Victor Giesen, who demonstrates German humor exists and can work out on a Chinese, is a fun person to work with. The workplace can become very dull without his presence.

Furthermore, I would like to thank my university mentor, Dr. Zümüül Atan. She has been supporting me all the way since the very beginning of my search for a project. As a person, I am goal-oriented and can become stubborn at times. I appreciate that she has faith in me, gives me the freedom to explore and always sets a high standard to keep me motivated. I also would like to thank my second mentor, Prof. Ton de Kok. I am honored to have him as my mentor and appreciate his comments.

As I am writing this, which marks the end of 7 years in the Netherlands, I cannot feel calm. Once, I was lost in life and could not find my path. Now, after years of development, I am confident about the future and look forward to it. Logitech allows me to learn much more than the study itself. I am thankful to have this opportunity.

Being very serious, I want to mention the indirect contribution from Deadmau5, Markus Schulz, the Beatles, Bob Marley and an infinite list of musicians. It is unfortunate I cannot include their inputs in this report.

Last but not the least, I want to give my special thanks to my parents, who have supported me to study abroad through all these years. The last time when I saw them face to face was in 2008. I cannot wait to reunite with my family in February. Also, I want to give my special thanks to my girlfriend, hopefully to be my fiancée very soon. She helps me to stay focused, share my happiness and is always by my side when I am down. Nonetheleast, I want to thank all my friends and relatives for the good wishes.

Jing Luo
Nijmegen Dukenburg, Jan 2013
Management Summary

Current situation

Logitech is a global company with consumers all over the world, supported by a global supply chain network. Its suppliers are mainly located in Asia. There are distribution centers that spread over EMEA (Europe, the Middle East and Africa), APAC (Asia Pacific), the US and Latin America. Five types of end customers are categorized in the following:

1. Distributors who help us distribute our products to store chains.
2. Retailers like Wal-Mart, Best Buy and Dixons etc.
3. Large manufacturers that assemble our products with PC’s and laptops.
4. B2B that are businesses and organizations that buy devices for their offices.
5. Consumers who buy our products directly with us through the Internet.

Traditionally speaking, Logitech provided mainly to distributors and large manufacturers. In the US, retailers have been an important customer type for a time as well.

Change environment

Times are changing, however. To stay competitive and to enable growth, Logitech needs to accommodate the other customers/markets more and more as well. Especially, Logitech will increasingly focus on the so-called emerging markets to increment market share in geographical areas, like India. To adapt to these changes, the supply chain needs to make sure it can support the new requirements. But what does this exactly mean for the current logistics network? The present study will elaborate on this question and present a case study of Logitech logistics network for Indian market.

Objectives of the present study

The present study aims to use a theoretical framework to jointly evaluate quantitative outputs (cost and lead time) from the simulation model and qualitative opinions held by the global directors and the local Sales team, in order to decide if Logitech should serve the Indian customers from a new warehouse in India.

The present study is interested in the following scenarios: Stay with the current DC in Singapore, go to Mumbai and set up a bonded/non-bonded warehouse or go to Chennai and set up a bonded/non-bonded warehouse.

Potential benefits

The benefits of the present study are the following:
The present study helps Logitech to gain an understanding of changes in terms of cost and lead time if a new DC is set up in India.

In addition to a quantitative perspective, the present study uses opinions of Logitech business functions (represented by director/manager) as qualitative criteria.

For academic interests, the present study aims to experiment the AHP model at Logitech and investigate what benefits it can bring to companies.

Conclusions and recommendations

The major findings of the present study are the following:

- **Cost analysis:**
  - A reduction in end-to-end logistics cost but not significant, if Logitech moves to Mumbai/Chennai.
  - Import duty is worth investigating.
  - Non-bonded warehouse does not meet the MRP labeling requirement although it is more cost efficient.

- **Lead time analysis:**
  - The total lead time, and especially DC to customers lead time can be improved when there is a DC in India.

- **AHP site selection analysis:**
  - Most Logitech functions prefer to stay with Singapore DC.
  - Between Mumbai and Chennai, Chennai is more preferred.

Based on the findings, Logitech is recommended to do the following:

- Adjust product mix for Indian market.
- Research on the possibility and cost to do MRP labeling in China.
- Negotiate sea shipment rates with the regional forwarder.
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1 Introduction

Logitech management team needs to decide which location in India should be selected for the new Logitech distribution center (DC). Location candidates have already been suggested by reliable sources. The aim is to create and compare relevant scenarios and perform a quantitative analysis to see the benefits of having this location. Costs and service level improvements are not the only motives. There are other concerns about labor, tax, access to customers and so on. Moreover, it is a question if there should be a new DC in India in the first place. For this reason, it is necessary to include the current situation in the analysis. Furthermore, it is interesting to revisit the logistics network (concerning neighboring DC’s and related sales regions) under the assumption that a new DC in India has been decided. The management team needs to know whether or not relevant DC’s should serve different markets. Last but not least, the final decision should be a mutual agreement among different stakeholders at Logitech. Not only the Global Logistics department, but Sales, Logistics, Customer Replenishment, Supply Chain Planning, After Sales and Contracts & Trade Compliance functions should support it too.

The remaining of this report is organized in the following way. In the next section, the research subject and contexts are firstly introduced. It provides readers with necessary and relevant background information. Section 3 identifies the most relevant problem that needs to be studied. With a central problem recognized, the section continues with a literature review on DC location analysis. Next, Section 4 explains the research methodology and generates a list of research questions. Section 5 is about all scenarios in the scope of this study. Section 6 is an important part of this report, which describes the models used and explains how data is collected. The final results are presented in Section 7. In Section 8, conclusions are drawn and recommendations are given. Section 9 shows the limitations of the present study and finally a theoretical discussion is given in Section 10.

2 Research Subject and Contexts

In this section, background and problem-related information is given. It begins with a description of Logitech, such as its history, types of customers and future visions. In the second part, data management tools which are observed in Logitech practice will be introduced. This part provides information about possible ways to collect data. For the purpose of the present study, it describes different functions of software and gives an indication of the most useful and reliable data source. The third part of this section details Logitech supply chain at two levels. At the higher level, global locations, basic functions and features of Logitech DC’s are described. It gives an overall understanding of Logitech supply chain. At the lower level, information directly relevant to the present study and the Logitech problem is given. The emphasis is placed upon Indian market and current logistics practices of Logitech in India. In addition, several Logitech DC’s in Asia-Pacific (APAC) are introduced, which are subject to functional change when a new DC is established in India. The fourth part introduces an ongoing Logitech project and the role of the present study on its project agenda.
2.1 Company Background

Logitech is a world leader that connects people to the digital experiences they care about. Across multiple platforms (computing, communication and entertainment), Logitech combines hardware and software to enhance gaming, video security, digital navigation, social networking, online communication, and entertainment (home, music and video).

Founded in 1981, Logitech International is a Swiss public company listed on the SIX Swiss Exchange and on the Nasdaq Global Select Market.

Logitech offers a wide range of products including keyboards, mice, microphones, game controllers, webcams, PC speakers, headphones, and audio devices. These products are distributed in more than 100 countries worldwide.

Logitech has five types of end customer: a) Distributors who help Logitech to distribute Logitech products to store chains; b) Retailers like Wal-Mart, Best Buy, Dixons and so on; c) Large OEM (Original Equipment Manufacturer) that assemble Logitech products with PC’s and laptops; d) Businesses and organizations that buy Logitech devices for their offices (Business To Business, B2B); e) Consumers who purchase Logitech products directly through Internet.

Traditionally speaking, Logitech provides mainly to distributors and large OEM manufacturers. And in the United States, retailers have been an important customer type as well. But times are changing. To stay competitive and be able to grow, Logitech needs to adapt to other types of end customers as well. In addition, Logitech needs to increase its focus on emerging markets, including Brazil, Russia, India and China. By doing so, Logitech will expand its market shares in these geographical areas.

2.2 Data Management

At Logitech, there are 4 types of software existing in practice: Oracle Database (OD), Cube, Cyclops, and Tableau. Cyclops and Cube are relatively new and have been used only for 1 or 2 years.

Both OD and Cube are database management tools.

OD is a popular database management tool for enterprise. Essentially, it is an information center where information is retrieved and stored. At Logitech, OD contains every piece of information about different business activities, which include sales and marketing, replenishment, warehouse management, logistics and supply planning. Cube is basically a lighter and customized version of OD. Its level of technical complexity is much lower. But it meets the special needs of Sales and Marketing Department (SMD).

In theory, OD and Cube should contain the same information. However, it is found in practice that inconsistency exists. Based upon interviews with planners and analysts, it may be because Cube is new and is likely to have errors.

Cyclops is used by Global Planning Team (GPT), whose main task is to order from suppliers. As an aiding tool, Cyclops helps GPT decide on the optimal order quantities. Cyclops requires demand forecast from OD. It also requires inputs from planners, for
example, safety stock planning. Then, Cyclops is able to output a so-called Build Plan (BP), which gives optimal order quantities for particular times in a given planning period.

Tableau is a data visualization tool. It functions as an interface between users and database management software, such as Oracle and Cyclops. Tableau can extract information from Oracle or Cyclops and then represent data in graphic formats.

An important note is that OD is the most essential and pervasive system at Logitech. Besides, it has been used and tested for a long period. Therefore, Oracle is the most preferred and the most reliable source of data.

2.3 Logitech Supply Chain

2.3.1 Background Information

Logitech has suppliers mainly from Eastern Asia. The vast majority of them are Original Design Manufacturer supplier (ODM). ODM’s design and manufacture products. But eventually, those products will be specified and branded by Logitech for sale. The only factory that Logitech owns is in Suzhou, which is very close to Shanghai (The internal codename of this factory is referred to as ‘SZM’).

Before sending to customers, finished goods are first shipped to Logitech DC’s. It is noted that only DC’s for retail are included in the scope. As depicted in Figure 7 in the Appendix there are DC’s across the globe. They scatter over EMEA (Europe, the Middle East and Africa), Asia, the US and Latin America. There are some notable facts about Logitech DC’s:

1. Proximity to most customers. Most DC’s are close to the majority of customers in their sales regions (Olive Branch, Oostrum, Shenzhen, Taoyuan, Tokyo, Mexico and Dubai). The average lead time from a Logitech DC to customers is no longer than days.

2. Cost effective. Most DC’s are close to a sea port and benefit from local labor situation (local labor costs are lower than neighboring areas).

3. Favorable tax and duty treatment. Logitech DC’s take advantage of local tax and duty rates. It has two aspects. One is that Logitech DC’s enjoy local tax and duty rates directly. The other one is an indirect tax and duty advantage. For example, Hong Kong U-Turn. Speakers and webcams manufactured in China receive percent less duty if percent of the products cross dock via Hong Kong DC.

4. Predictable and controllable inbound supply chain costs. Manufacturing logistics costs are kept under control and can be expected.

2.3.2 Indian Market and Logitech DC’s in APAC

By Logitech definition, APAC includes East Asia, South Asia, Southeast Asia and Australia. China and Japan are excluded and treated as separate markets.
In APAC, Logitech does not manage DC and transportation by itself. Instead, these tasks are outsourced to regional Third-party Logistics (3PL) service providers and forwarders. 3PL service providers are responsible for warehouse management and forwarders arrange logistics activities.

India is an emerging market with a high potential. It is expected that the gross revenue of Indian market will grow from □ million now to □ million dollars in the fiscal year of 2015.

Figure 8 in the Appendix gives a global understanding of supply chain operations for Logitech Indian market. It can be seen that Logitech has no DC in India at this moment. The importing and distribution of Logitech products are done by 4 national distributors. To ship products to India, Singapore DC (SGP) receives products from suppliers, manages them and resells them to Indian distributors. It is noted that in this case the Freight On Board (FOB) point is right before a shipment is finalized in Singapore. It means that Logitech is no longer responsible for any cost incurred once products are shipped from Singapore to India. It is indicated by the ‘Costs’ Row, which shows only shipment and warehousing costs for Logitech in the ‘Before Customs’ Column. After that point, distributors become fully responsible. It is also noted that Logitech and Indian distributors close an invoice at FOB point. An invoice is an itemized bill of all shipped goods. The invoice prices will have an impact later when shipped goods wait to be cleared at India Customs. As indicated in Figure 8, it is estimated that □ percent of invoice prices needs to be paid by Indian distributors. From the distributor perspective, customs duty is the largest cost component. Basically, it influences how much local distributors are willing to agree on retail prices in favor of Logitech. Logitech wants retail prices to be low. It is good for competition and market development. Right now, however, Indian local distributors need to raise retail prices to offset high clearance cost. Therefore, clearance cost has a great impact on retail prices for the Indian market and should be a crucial element to consider in the redesign.

There are 3 Logitech DC’s in APAC. Taiwan DC (TWN) is sited in Taoyuan. It serves only Taiwan market. Hong Kong DC (HKG) serves multiple areas, including Hong Kong, South Korea, Australia, and New Zealand. The third DC has been previously mentioned, which is SGP in Singapore. It serves South and Southeast Asia, including Singapore, India, Malaysia, Philippine, Vietnam, Thailand, and Indonesia. When there is a new DC in India, the management team expects changes in the role of SGP, TWN, and HKG. For example, SGP would have more capacity to serve Asian markets because of free capacity saved from India.

2.4 Logitech Network Optimization Study

Logitech Network Optimization Study is an ongoing project initiated by the Global Logistics department. In 2011, Logitech conducted a qualitative research on logistics network improvement. In the study, several things were done: a) An overview of Logitech logistics network was described; b) key costs drivers were identified; c) a SWOT analysis of current logistics network was made; d) future development of emerging markets was considered. The study came to many conclusions. One key finding is that: Transportation cost is the major cost driver for logistics network redesign (See Table 11 in the Appendix). In
relevance to the present study that focuses on India, two hypotheses are presented below:

**Hypothesis 1** A local warehouse in India will reduce end-to-end supply chain costs and meet customer expectations of service lead time.

**Hypothesis 2** Assuming that there is a local warehouse in India, the current logistics network in APAC needs to be redesigned.

The structure of this subsection is as the following. First of all, it is necessary to introduce the present project, which is the follow-up of Network Optimization Study 2011 and the reason why Logitech asks the author of the present study to participate. Second, the organization of the present project is described. It clarifies what types of decision the author of the present study can make. Next, system scope, strategic objectives, project objectives and general assumptions of the present project are provided one by one. This information is clearly defined by Logitech, which helps to understand what Logitech searches for and what the present study can make a contribution to.

### 2.4.1 Purpose of the Present Project

Network Optimization Study 2011 was the Phase I of the project. It was concluded from a qualitative approach that the current network design could be improved. On the basis of the conclusions, simulation scenarios have been created.

Phase I is followed by Phase II that aims to verify or falsify Phase I hypotheses from a quantitative perspective. To be specific, validation is done by simulating and comparing scenarios regarding total costs and service level. This method is required by Logitech. In addition, redesign solutions should be provided, if necessary.

The present study is part of Phase II.

### 2.4.2 Organization

The organization chart for this project is displayed in Figure 1. On the top, the Steering Committee (SC) will be fully involved and make key decisions on modeling assumptions. The Extended Team (ET) shares the same function but plays a supporting role to SC.

Core Team (CT) consists of supply chain analysts who actualize models and then analyze model outcomes. They are guided by SC and ET when crucial modeling assumptions need to be made. The author of the present study functions as a supply chain analyst in the CT.

**Company supervisor** Ron van der Wegen  
**University supervisors** Zümbül Atan, Ton de Kok  
**Steering Committee** Michele Hermann, Ron van der Wegen, Lance Solomon  
**Project Manager** Martijn Cillessen  
**Core Team** Victor Giesen, Lennart Nederpel, Ramana Nareddy, Jing Luo, Holly Lin
2.4.3 System Scope

The system scope of this project is shown in Figure 2. First of all, it needs to be emphasized that the end customers are local distributors only, which is specifically decided by the management team. The chart draws a picture of the traditional Logitech business model, in which products are shipped from suppliers, via a Logitech DC, and finally imported by local distributors. There exist other types of business model but they are not considered in this research.

Another note is on the system scope contents. It is seen in Figure 2 that the contents of the system scope are about a) if there should be a new DC in India; b) and if so, where the Logitech DC should be sited in India. The choice is based on available options. SC is in charge of DC site candidate selection. In the dashed lines, it is seen that multiple blocks are considered and each one is specified with a predefined location. Location differences do not only spell out differences in distance, but also ones in sales, tax, law and trade
compliance and so on. These qualitative aspects are evaluated by SC, global directors, and local managers, while quantitative aspects are being examined by the simulation model designed by CT.

2.4.4 Strategic Objectives of Logistics Network Design

The following strategic goals provide guidance to decision making and are described in the following:

- Support growth in emerging markets.
- Strive to more customer centric organization: Support new sales channels and increase customer satisfaction.
- Keep costs under control and improve margins.
- Review new tax & import regulations (especially for emerging markets).

The present study should consider and align with Logitech strategic objectives.

2.4.5 Project Objectives

The following outcomes are expected to be delivered in the end:

- Make a list of assumptions used for modeling.
- Create a model manual so that the analytical model can be understood and reused in the future by the analytics team.
- Represent selected scenarios graphically and quantitatively.
- Create a business case per scenario with costs and service level calculated.
- Evaluate model by checking it with real input data after model is implemented.

These deliverables are required by Logitech. Depending on how the research problem is finally defined, the present study may need to deliver more results than the original ones.

2.4.6 General Assumptions of the Present Project

General assumptions are used to create a basic setup for the project. For individual assignments within the project, specific assumptions still need to be made. A list of general assumptions has been made at the beginning of the project as the following:

- Current global inventory strategy is used and no change is required.
- For ordering and replenishment, frequencies and quantities are based on fiscal year 2012 (FY 2012), which is from the 1st of April 2011 to the 31st of March 2012.
- Existing cost structures are used for transportation and warehousing.
- Input data, such as customer orders, are from FY 2012.
• SC will provide guidance to determine setup costs and target service levels for non-existent lanes and sites.

3 Problem Statement

This section begins with cause and effect analysis. Logitech thinks the current supply chain for Indian market as inefficient. Cause and effect analysis helps to identify possible causes and to choose one that is both significant and practical. The central problem is that there needs to be a Logitech DC within India. The selection of this problem shows a clear indication of the purpose of the present study and the area of literature to focus. They will be described in the following sub-sections. In the literature review section, the analytic hierarchy process (AHP) is paid with special attention.

3.1 Cause and Effect Analysis

Based upon the study of Network Optimization Study 2011 and the interview with Senior Director Global Logistics Ron van der Wegen, a cause and effect tree for the Indian case has been created, which is seen in Figure 3.

As indicated by the diagram, ‘Supply chain inefficiency’ is the symptom of Logitech business performance. The immediate causes are ‘High retail price’, ‘Low service level’ and ‘High total supply chain costs’. For these variables, it is noted that there is no exact scale of measurement at Logitech yet. Retail price, service level and total supply chain costs are expected to have rooms for improvement based upon the analysis of Network Optimization Study 2011. In relation to strategic objectives described previously (in Section 2.4.4), the first two items are relevant to become a more customer centric organization, and the last one is about keeping costs under control and increasing profit margin as a result. So they are regarded as key performance indicators. Another note is total supply chain costs has two aspects: Logitech and distributors. The rationale is that retail prices can be lowered if logistics costs for distributors are reduced, which is aligned with Logitech strategy.

‘Indian market served by DC outside India’ (which is made bold in Figure 3) has indirect effects on all of key performance indicators. Although the item is on the far left side of the diagram, which in theory means solving it as a problem may not be necessarily relevant to supply chain efficiency improvements, the interview with Mr. van der Wegen shows a new DC in India can give Logitech great advantages and open the access to costs reduction and service level improvement.

Therefore, finding the optimal location of a new Logitech DC in India is proposed to be the central problem of this study.

One major advantage of having a DC in India is a significant reduction in clearance cost. At Indian Customs, it is estimated that importers need to pay percent of invoice prices for clearance. Right now, Indian distributors import Logitech products from SGP and quoted prices are higher than original manufacturing prices. It is because SGP buys from product suppliers first and has orders sent to Singapore. This intermediate step, however, increases invoice prices due to additional costs involved. A new DC in
India helps to reduce the invoice prices to original manufacturing prices with a markup percentage, which is still lower than the price that customers are paying. Therefore, the total supply chain costs as well as retail prices can be reduced. Second, it helps Logitech to develop a relationship with local government and port authority. This improvement will reduce waiting time at customs, which currently accounts for 50 percent of total lead time. Third, a DC inside India decreases shipping time to distributors. Right now, it takes about 3 weeks to ship from SGP to India. A DC in India will shorten distances to distributors and give Logitech room for supply chain flexibility. Sequentially, service level can be improved. Fourth, a local presence grants Logitech tax reduction, which contributes to cost saving in total supply chain costs.

The cause and effect tree presents other potential problems. One problem can be that Indian market needs to be further developed. Another problem is closely related to the ultimate goal, which is that inventory and replenishment policies need optimization. Nonetheless, these problems may not be valid given the contexts. A market development may increase potential consumers in India. However, the growth of sales is likely to be inhibited by the current logistics infrastructure. In addition, Logitech outsources DC operations to 3PL service providers in APAC. So, there is limited room left for operational excellence. An important note is the above statements are not claimed to be correct. Those are logically deduced from available information and need to be validated by the present study.

The cause and effect tree should be interpreted carefully but with a high level of confidence. First, Network Optimization Study 2011 takes a qualitative perspective and has validated the lack of DC presence in India as a cause to the problem. Second, the senior director Ron van der Wegen, who has reliable and incoming reports from regional managers in APAC, supports the diagnosis. These two sources of information are aligned with the cause and effect tree. Still, there is no guarantee that the items and their relations in the diagram are valid and reliable. Also, it should not be taken for granted that the focus on a new DC in India must be valid, nor that other possible problems have been invalidated. But, the cause-and-effect tree helps to provide a promising direction to reach the ultimate target.

In relation to strategic objectives of Logistics Network Design, a new Indian DC promises lower retail price due to cost reduction for distributors, higher service level due to proximity to consumers, better tax scheme due to local presence in India, and growing profit margin due to expected sales growth. Hence, our problem definition is aligned with company strategies.
Figure 3: Cause-and-effect diagram, based on the format created by Ishikawa (1990). The purpose of developing this diagram is to define all relevant problems and identify the most central problem. An arrow represents a cause-and-effect relationship. All textual items are factual information about Logitech or India. When an item is placed on the right hand side of an arrow, it is the effect of the item on the left hand side of the arrow. ‘Supply chain inefficiency’ is made bold as the ultimate aim of problem solving. ‘Indian market served by DC outside India’ is made bold and regarded as the central problem, whose area of influence is highlighted by bold-faced arrows.
3.2 Purpose of the Present Study

Unlike other areas of OR, the challenge of site location analysis is to consider multiple objectives and support complex enterprise decision process. It is unfortunate that traditional approach focuses excessively on academic interests (Brandeau and Chiu, 1989; Klose and Drexl, 2005); and, thus has a limited capacity of solving real life problems. Therefore, one of the benefits of the present study should help to bridge the gap between theory and practice.

In addition, this study aims to formulate a general theoretical framework that benefits similar real life cases. To be specific, the framework would be interesting to managers of a complex organization, who work on an international site location problem, or need to evaluate and redesign current logistics network. In this way, the present study may make a contribution to the knowledge and understanding of site location and logistics network redesign.

3.3 Literature on DC Location Analysis

3.3.1 Background and Previous Work

Since Weber’s work, numerous studies have been done to solve site location problems. Aikens (1985) reviewed some of the most notable work on the subject, and made a special contribution by developing the taxonomy to classify models. Although Aikens’ taxonomy helps to distinguish models, it looks at specific attributes only, like the number of sites, or patterns of demand. In contrast, Klose and Drexl (2005) based categorization upon the general contents of site location problems; according to which, 9 types of models were recognized and listed below:

1. The shape of the set of potential sites yields models in the plane (which is a continuous solution space where every point is a possible solution), network location models (in which distances are assumed to be the shortest paths in a graph), and discrete location or mixed-integer programming models (in which potential site candidates are explicitly given and the rest is similar to network location models), respectively. For each of the subclasses mentioned here, distances are calculated using some metric.

2. Objectives may be either of the minsum or the minmax type. Minsum models are designed to minimize average distances while minmax models have to minimize maximum distances.

3. For models without capacity constraints, demand allocation is not restricted. If capacity constraints for the potential sites exist, demand allocation has to obey the rules. In the latter case, single-sourcing or multiple-sourcing becomes a question.

4. Single-stage models focus on distribution for one stage only. In multi-stage models, the hierarchy of the supply chain is at multiple levels.

5. Single-product models deal with a single homogeneous product. If products are not homogeneous and not able to be aggregated into one product, multiple-product models have to be used.
6. Many times, location models are based upon the assumption that demand is independent of spatial decisions, for example, customers are assumed to spread out equally in the space regardless of the DC and customer distances. If demand is elastic, on the other hand, the relationship between demand and distance needs to be considered explicitly.

7. Static models optimize system performance for one period. Dynamic models, on the other hand, deal with a given planning horizon. In the latter case, input data vary over time.

8. Deterministic models assume input is known with certainty, whereas probabilistic models are the opposite. For the latter case, probability patterns are used to represent input uncertainty.

9. Classical models assume that the quality of demand allocation is measured for each pair of supply and demand points. Combined location/routing models look at the interrelationship between pairs of supply and demand points.

This classification shows that academics are primarily interested in mathematical models that emphasize the use of heuristics or optimization. Although considerable work has been done using simulation, classic review papers intentionally neglect them (Aikens, 1985; Brandeau and Chiu, 1989; Revelle and Laporte, 1996; Hamacher and Nickel, 1998; Klose and Drexl, 2005; Melo et al., 2009). For illustration purpose, a simple uncapacitated site location model is extracted from (Aikens, 1985) and presented below:

\[
\begin{align*}
\text{Minimize} & \quad \sum_{i \in I} \sum_{j \in J} c_{ij} x_{ij} + \sum_{i \in I} f_i z_i, \\
\text{subject to} & \quad \sum_{i \in I} x_{ij} = 1, \ j \in J, \\
& \quad z_i - x_{ij} \geq 0, \ i \in I, \ j \in J, \\
& \quad x_{ij} \geq 0, \\
& \quad z_i \in 0, 1,
\end{align*}
\]  

(3.3.1)

(3.3.2)

(3.3.3)

(3.3.4)

where

\(x_{ij}\) = the proportion of customer \(j\)’s demand satisfied by facility \(i\).

\(z_i\) = 1 if facility \(i\) is established, 0 otherwise.

\(c_{ij}\) = the total production and distribution costs for supplying all of customer \(j\)’s demand from facility \(i\).

\(f_i\) = fixed cost of establishing facility \(i\).

\(I, J\) = the sets of candidate site locations and customer zones respectively.

Constraint (3.3.1) ensures that each customer’s demand is exactly satisfied and constraint (3.3.2) makes sure that customers receive shipment only from established site. Constraint (3.3.3) and (3.3.4) are boundary conditions that set limits to the solution space. Altogether, these constraints help to find the single best solution to the minimization function.
In this case, the objective is to minimize costs in production, distribution and site investment. Critical decisions are the number of customer zones and the selection of candidate site locations. In other cases, objectives and decisions can be different. Depending on the difficulty level of the specific problem, more advanced mathematics techniques may be needed.

Nowadays, there is software especially designed for linear programming problems, such as LINDO Systems, AIMMS, and Excel Solver. For a problem like the example, it takes a short time to have a solution. For difficult problems, however, linear programming approach may lead to a long or infinite calculation time.

Numerous authors have made a contribution to the heuristics or optimization approach. We will mention a few notable works here. Geoffrion and Graves (1974) formulated a mixed integer linear program for a capacitated and multi-product DC network design. With the help of Benders Decomposition technique, the program required a short amount of time to find the best solution. The study was successfully applied to a major food firm with 17 product classes, 14 production sites, 45 possible DC locations, and 121 customer zones. Another study made an attempt to solve the dynamic site location problem (Khumawala and Whybark, 1975). It examined a situation in which a company faced a growing or changing market or when costs were changing over time. Essentially, it is a difficult problem. Combinations of candidate locations have to be completely enumerated to find out the best one. In practice, calculation becomes impossible because of a large number of combinations. Therefore, the authors proposed solution procedures to substantially reduce the total number of combinations at first, and then find an optimal (exact) or a close-to-optimal (heuristic) solution. Ghost and Craig (1983) proposed a model that helped retailers to make a strategic location plan in a dynamic environment. The model took into account possible competitive and demographic changes. By implementing the strategy, retailers could expect maximized profits. Tcha and Lee (1984) studied the problem of locating sites in a multi-level distribution system, in which different levels of intermediate DC’s were concerned. Although the model produced superior results, it could perform at best for two-level cases. For more than that, computational tractability required attention. In the area of network location theory, Chen et al. (1998) proposed a d.-c. programming to solve multi-source Weber and conditional Weber problems, which is an optimization technique that expresses objectives functions and the left hand side of constraints as differences of convex functions. Multi-source Weber and conditional Weber problems were formulated as d.-c. functions and results showed it was more efficient solution procedures. In another example, repeated matching algorithm was used to solve the single-source capacitated location problem (Rõnnqvist et al., 1999). In the problem formulation, each customer could only be supplied by one capacitated DC. The repeated matching algorithm solved a succession of cost matching problems until certain convergence conditions were met. The approach was proven to be time robust and yield high quality solutions.

In recent literature, Fleischmann et al. (2006) developed an optimization planning model for BMW’s allocation of multiple products to global production sites over a long term planning period. The model included both the supply of materials and the distribution of finished goods. The early tests showed a reduction in investments and operational expenses of about 5% to 7%. Chakravarty (2005) used fast solution procedures to determine simultaneously site location, production quantities and export/import quantities.
Investment costs were used as overhead absorbed by products produced. The model was used to study the impacts of costs, demand, and import tariff on site investment, production quantities, overhead, local taxes, size of the market and long-term exchange rates. Dias et al. (2007) discussed a dynamic locating problem in which a site could open, close and reopen with costs associated over a planning horizon. The model used an efficient primal-dual heuristics that could determine both upper and lower limits to the optimal solution. This method could generate high-quality solutions and solve large instances of problems in a reasonable time. Sourirajan et al. (2007) studied a single-product network design problem with lead time and service level requirements. The model used a Lagrangian heuristic to obtain a near optimal solution with reasonable computation time. A scenario analysis showed the number of DC’s and their utilization depended on the priorities assigned to performance metrics. Snyder et al. (2007) considered a site location problem with uncertain customer demands. But the probabilistic pattern is assumed to be certain. The model minimized total costs by implementing a Lagrangian-relaxation-based algorithm. It proved to be very effective. For problems with up to 150 sites and 9 scenarios, it took less than 2 minutes to find a solution. Numerous studies have also contributed to multiple stage problems. For example, Hinojosa et al. (2008) considered a site location problem with two different distribution levels, in which new sites could be built and existing ones could be closed down over a planning period. The model used a Lagrangian approach to minimize total costs, including transportation, inventory holding costs, investment and operational expenses for sites. Lee and Dong (2008) discussed a multi-echelon forward and reverse logistics network. Due to the complexity and large number of variables and constraints, a two-stage heuristic approach was proposed to decompose the original problem into a location-allocation problem and a revised network flow problem. Tests showed the heuristic performed well with respect to solution quality and computation time.

As discussed in Section 1, mathematical models experience problems with model applications. Nowadays, many companies become multinational. Most of the previous studies, however, have been domestic-oriented and focus on developed countries (Brandeau and Chiu, 1989). To cope with today’s business world, international factors need to be included and developing countries, like China and India, should be paid with special attention. Also, supply chain managers need to think strategically in these days to stay competitive (Bechtel and Jayaram, 1997). Unfortunately, mathematical models cannot evaluate the above mentioned qualitative criteria and are incapable of dealing with multi-objectives. The reality is: A site location decision, unlike other areas of OR, requires human judgment; in addition, a single objective, like cost minimization, oversimplifies enterprise concerns. With these aspects missing, enterprise strategy cannot be fully realized in a site location decision. Therefore, it is the purpose of this chapter to consider qualitative criteria explicitly. Last but not least, the field of site location analysis has been overly occupied with mathematical complexity, assumptions and techniques. Nonetheless, simulation studies have contributed to problem solving in practice (Connors et al., 1972; Bowersox, 1972) and should be given more attention.

### 3.3.2 AHP

Several interviews have been conducted with senior director and manager at Logitech. It shows that enterprises take a different approach to site location problems. A typical way of
doing is to use a two-stage process (Society of Manufacturing Engineers, 1993). The first stage is to establish site requirements and their relative importance. Site requirements are specific desired characteristics of a site. The characteristics can also be referred to as site location factors. In Table 1, major site location factors are listed. In the second stage, managers use established location factors as selection criteria and assess candidate site locations individually. If the profile of a location shows criteria are satisfied, the location is selected; otherwise, it is eliminated from the list. This iterative selection process continues until there is only one candidate left. It can be observed that an enterprise approach has two distinguishing characteristics:

**Complex** The enterprise approach involves multiple decision makers. Essentially, it is a process of compromising conflicting interests and qualitative measurements.

**Multi-criteria** For enterprise, site location problems have multiple objectives. In mathematical modeling, one or two criteria help with a decision. In practice, many criteria are under consideration.

In recent literature, the AHP has been suggested as a good solution to real world decision-making problems. It is simple, easy to use and very suitable for dynamic and multi-criteria decision making. The program was originally developed by Saaty (1980). It was designed for military contingency planning, scarce resources allocation, and political participation in disarmament agreements. All these problems ask for intangible measurement in a multi-criteria setting. In other words, decision variables are not subject to quantification due to physical absence, like relationship with local government, and decision makers need to consider multiple criteria, like selecting the best DC location in terms of costs, service level, closeness to customers, tax and legal incentives and so on.

The applications of the AHP are widespread. Vaidya and Kumar (2006) reviewed 150 applications. They discovered that AHP was predominantly used for Selection and Evaluation (38%), followed by Decision Making (14%), Prioritizing Items (13%), Development (12%), and some minor themes. Regarding application areas, the AHP was mainly applied to problems in the area of Personal (18%), Engineering (17%) and Social (15%). It was also observed that the AHP gained academic attention considerably over the years. Prior to 1990, 12% of review papers on the AHP (before 2003) was published. Between 1991 and 1997, it became 30%. And from 1998 to 2003, the number increased to 58%. An important note is the AHP is a flexible tool and has been combined with other techniques, such as mathematical programming and simulation (see aslo Ho (2008) for a review; Badri (1999) for a goal programming extension; Kahraman et al. (2004) and Kaboli et al. (2007) for a fuzzy extension of the AHP; Shang and Sueyoshi (1995) for a simulation extension, unified with Data Envelopment Analysis).

Some recent literature will be presented. Korpela et al. (2002) discussed a problem in which customer service requirements and suppliers strategies were included in production capacity allocation and supply chain design. The aim of the study was to prioritize customers based upon their strategic importance, requirements and risks associated. The model used the AHP for prioritization and mixed integer programming for optimization. Kuo et al. (2002) took a fuzzy AHP approach to locate a new convenience store. It showed the proposal approach performed better than the regression model. Wang et al. (2005) presented a decision tool for managers to select suppliers. The method used a combination of the AHP and Preemptive Goal Programming (PGP). The AHP was used
to process qualitative factors. And PGP was used to handle the quantitative aspects of decision making. Partovi (2006) discussed a strategic solution to site location problems by combining both external (customer demands, status of competition, profile of locations) and internal criteria (critical internal business processes) in decision making. The model was based upon Quality Function Deployment (QFD) incorporated with the AHP and Analytic Network Process (ANP). The AHP was used to measure the relationship intensity between factors in the model and their dependencies. Shinno et al. (2006) examined the case of the machine tool industry in Japan. It expanded the conventional Strengths, Weaknesses, Opportunities and Threats (SWOT) by using the AHP to determine the importance of each SWOT factor.

<table>
<thead>
<tr>
<th>1 Access to markets/distribution centres</th>
<th>6 Labor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cost of serving markets</td>
<td>Prevailing wage rates</td>
</tr>
<tr>
<td>Trends in sales by areas</td>
<td>Extent and militancy of unions in the area</td>
</tr>
<tr>
<td>Ability to penetrate local market by plan presence</td>
<td>Productivity</td>
</tr>
<tr>
<td></td>
<td>Availability</td>
</tr>
<tr>
<td></td>
<td>Skill levels available</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>2 Access to supplies/resources</th>
<th>7 Taxes and financing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transportation costs</td>
<td>State income tax/local property and income taxes</td>
</tr>
<tr>
<td>Trends in supplier by area</td>
<td>Unemployment and compensation premiums</td>
</tr>
<tr>
<td></td>
<td>Tax incentive concessions</td>
</tr>
<tr>
<td></td>
<td>Industrial pollution control revenue bonds</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 Community/government access</th>
<th>8 Transportation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambience/cost of living</td>
<td>Trucking service</td>
</tr>
<tr>
<td>Co-operation with established local industry</td>
<td>Rail service</td>
</tr>
<tr>
<td>Community pride</td>
<td>Air freight service</td>
</tr>
<tr>
<td>Housing/churches</td>
<td></td>
</tr>
<tr>
<td>Schools and colleges</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>4 Competitive considerations</th>
<th>9 Utilities services</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location of competitors</td>
<td>Quality and price of water and sewerage</td>
</tr>
<tr>
<td>Likely reaction to the new site</td>
<td>Availability and price of electric and natural gas</td>
</tr>
<tr>
<td></td>
<td>Quality of police, fire, medical services</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>5 Environmental factors</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Community attitude</td>
<td></td>
</tr>
<tr>
<td>State/local government regulations</td>
<td></td>
</tr>
</tbody>
</table>

Table 1: A review of major site location factors (Yang and Lee, 1997).

4 Research Methodology and Questions

In this section, the regulative cycle is firstly introduced and used as the guiding methodology for this study. It is an excellent tool to define the project scope from a research design point of view. Moreover, it helps to understand necessary research stages, their contents, sequence and relationship. Based upon this methodology, main research questions are defined. Furthermore, sub-questions are developed to help create an action plan.

4.1 Methodology

The regulative cycle (displayed in Figure 4) is recommended by Aken et al. (2007), which focuses on Business Problem Solving (BPS) projects. As explained, the purpose of BPS
is to

“...solve a business performance problem in the material world of actions; it
is aimed at actual change and improvement in this material world.”

Figure 4: The problem solving process of the present study, based upon the regulative cycle (Van Strien, 1997).

As seen in Figure 4, the regulative cycle begins with ‘problem mess’, which means undefined and ambiguous problems within the business organization. Among potential problems, ‘problem definition’ is to select the most important one that should contribute significantly to performance but requires only reasonable efforts in time. Next, ‘analysis and diagnosis’ is followed. The purpose is to create specific knowledge about the problem and help to find possible solutions. The most redesign suitable solution is then specified into a plan at the next stage, which is ‘plan of action’.

The actual redesign is not part of the project. So, ‘intervention’ and ‘evaluation’ are out of the scope of the present study (In Figure 4, both items are displayed in dotted lines).

As understood from the description, the regulative cycle is suitable for BPS projects in the sense that it also focuses on making change and improvement. In Section 3, the cause-and-effect tree is used to identify the central problem as the lack of Logitech DC presence in India. At the ‘analysis and diagnosis’ stage, we plan to take a design-oriented approach so that we will use a limited diagnosis. The rationale is that Logitech asks explicitly for an analysis on site location in India. There is no need to explore other potential problems or attempt to validate them. However, a justification of the defined problem is still necessary. Accordingly, the current level of supply chain performance in India needs to be included. It is regarded as the performance baseline and used as the basis for scenario comparison. In other words, if a suggested scenario outperforms the baseline, the problem definition is validated. If all suggested scenarios fail to perform
better than the baseline, the problem definition is invalidated. At last, literature is consulted, a redesign solution is proposed and a specific action plan is created.

4.2 Research Questions

Originally, Logitech defines the objective as the following:

“Given the current logistics environment and predefined scenarios, by considering the number of DC’s and their locations (as the independent variables), develop a generic model that simulates costs and service level (as the dependent variables), in order to improve Logitech network in APAC.”

In addition, this study is interested in assisting the SC with their decision process. A standalone simulation model takes into account only total costs and service level. As equally important, the other qualitative factors need to be considered too. The challenge is to help the management team to evaluate simultaneously all relevant factors and make sure the solution procedures are intuitive, practical and easy to understand.

Therefore, the following objective is proposed and added:

Use a theoretical framework to jointly evaluate quantitative outputs from the simulation model and qualitative opinions held by the global directors and Indian Sales team, in order to make the best DC location and logistics network redesign decisions.

In summary, this study has two major research questions.

• What are the total costs and service level of present and hypothetical scenarios, concerning the current logistics environment and Logitech logistics network for India?

• How can decision makers make the best decisions on DC location and logistics network redesign problems, given that both quantitative and qualitative location factors need to be considered?

In the next step, research questions can be further decomposed into concrete sub-questions as the following:

• What costs components are relevant and should be taken into account?

• What data or information is needed to measure the identified costs components?

• How should the total costs of Logitech supply chain be modeled with data available?

• How should be the service level of Logitech supply chain measured?

• What information is available to calculate the defined service level of Logitech supply chain?

• What simulation scenarios should be created in relevance to DC location and logistics network redesign decisions?
• What is the baseline performance in terms of cost, service level and lead time and how is it in comparison with hypothetical scenarios?

• What qualitative factors should be considered in relevance to DC location and logistics network redesign decisions?

• How can be qualitative factors quantified in relevance to DC location and logistics network redesign decisions?

• By what method should be all factors compared simultaneously?

• By what method should be all factor comparisons synthesized to make a decision on the best DC location or a logistics network redesign decision?

On the basis of the regulative cycle and research questions formulated above, the following assignments are planned:

• Investigate site location literature, explore alternative solutions and develop a framework to help with decision making.

  The main purpose is to search for possible solutions in theory but only apply those that are suitable for Logitech in terms of project objectives and team communication. A framework should accommodate present Logitech assignments and additional ones that can enhance project performance. The proposed framework needs to be approved by Logitech and communicated in the project team.

• Validate the hypothesis that a new DC in India improves Logitech supply chain efficiency.

  Logitech has a clear objective that the option to have a new DC in India is the only potential cause to be investigated. Therefore, a limited diagnosis is planned, which compares the current situation with hypothetical scenarios in terms of costs and service level.

• Use the proposed framework to aid Logitech decision making so that the best site location candidate is selected in India.

  Scenarios are specified by the management team. The proposed framework is used to compare scenarios in terms of relevant location factors. Both qualitative and quantitative factors need to be considered.

• If a new DC in India is presumably decided, use the proposed framework to optimize the roles of SGP, HKG, and TWN.

  A new DC in India affects neighboring DC’s in the Indian realm, such as SGP, HKG, and TWN. Costs and service level analyses are performed to investigate whether Logitech needs to change the dedicated markets of those DC’s.

5 Scenarios

In total, there are 5 scenarios. One is the current situation. The other ones are possible options. In the rest of this report, the current situation will be referred to as the baseline scenario. The possible options will be referred to as the simulation scenarios. The inclusion of these scenarios is determined by the Steering Committee. For an overview, please have a look at Table 12 in the Appendix.
Before moving on to the next section, two important concepts need to be discussed first. As seen later in this report, these two concepts play a key role in scenario evaluation. It is noted that these concepts are learnt during the period of this study. The major source of information is interviews with local logistics managers.

The first one is the difference between a bonded and a non-bonded warehouse. A bonded warehouse is customs-controlled. Until duty is paid, goods belong to the customs. But the goods can be placed in the warehouse. It implies the possibility that goods are moved to the intended DC location without regular clearance procedures, like duty payment. On the contrary, a non-bonded warehouse cannot receive goods that have not cleared customs yet.

The second concept is MRP labeling, which is closely related to the first one. A MRP label is a small piece of paper adhered to the retail package of imported goods at a unit level. It contains information of importer of record, the maximum retail price and etc. MRP labeling is required and authorized by Indian customs. Without a MRP label attached, goods can only stay in the port.

Combining these two concepts, several implications can be made. First, regarding the MRP labeling requirement only, a bonded warehouse is the better option. The cost of setting up MRP labeling processes can be expected to be lower in India than in the origin country (which is China). The rationale is MRP labeling requirement is a special requirement only seen in India. The locals are familiar with the processes. If it is done either in origin factories or in origin ports, the cost impact of implementing MRP labeling may be huge. Second, there is a cost advantage to have goods consolidated at one place and then have MRP labeling done once for all. This is only possible with the Indian bonded warehouse option. If it is done either in origin factories or in origin ports, it can be speculated that dedicated resources need to be allocated, due to the fact that Indian goods are only a relatively small portion of the total inventory. Therefore, incremental costs, such as additional labor and management cost, are accrued. Third, the installation cost of having a bonded warehouse is approximately twice as much as having a non-bonded warehouse. Therefore, it may be too early to jump to the conclusion that a bonded warehouse must be better. Besides, cost is an important but not the only factor in the decision making. Other quantitative factors, such as total lead time, qualitative factors, such as closeness to customers, and the company logistics strategy, which is to stimulate market growth in India, may give a completely different direction.

It is noted that there is an advantage of port proximity in all scenarios. Singapore DC is close to the Singapore port. In simulation, the Mumbai DC site is close to the Mumbai port and the Chennai DC site is close to the Chennai port.

6 Modeling and Data Collection

This section is divided into two parts. Part I is about the cost and lead time model, which Logitech is majorly interested in. Part I begins with a background introduction. Then, the cost analysis is explained in details, such as the general approach and the major modeling steps. Part I ends with a brief description of data collection. Part II is about the AHP site selection model, which supplements the cost and lead time analysis with
a qualitative aspect. Part II follows the same structure of Part I. Modeling building is explained. Then, there are successive discussions on modeling issues, such as consistency check, application and the power method. In the end, a detailed discussion on data collection is presented.

It is noted that one of the original assignments is to calculate service level. During the project, the service level analysis is replaced with a lead time analysis. Scenarios are evaluated and compared with respect to total lead time. Experts from other functions are involved in this assignment. They provide support to measure the standard lead times of relevant logistics processes, which are estimated to meet the targeted service level.

6.1 The Cost and Lead Time Model

6.1.1 Modeling Building

Background As mentioned in Section 4.2, the cost and lead time analysis is the original Logitech assignment. In the organization, the present author functions as a junior analyst and is responsible for part of the group assignment. One of the team objectives is to create a general model, which should be a model template in Excel. Therefore, it is crucial to have a shared agreement on modeling approach and assumptions. For this part of the present study, the modeling approach and primary assumptions are determined by the Steering Committee and experienced analysts.

Cost analysis

The volume approach In logistics business, companies need to negotiate contract rates with forwarders and 3PL service providers. For example, Logitech needs to discuss with a forwarder the price of shipping a 40-foot container from Port A to Port B. Another example is to discuss with a 3PL service provider the price of packing imported goods into one standard pallet. To continue with, if the number of containers or pallets is known, the cost amount of shipping a 40-foot container from Port A to Port B or packing imported goods into one standard pallet becomes known as well. Therefore, the key is existing cost structures specified in the contracts with forwarders and 3PL service providers.

On an underlying basis, volume is one variable that has the common presence. This physical attribute is the most essential characteristic to describe different types of logistics unit, such as container, pallet, shipper carton, and so on. The implication is: Once the total shipment volume is known, the total number of different logistics units can be calculated accordingly by dividing unit volume. Next, contract rates can be applied to calculate the total shipment cost. For warehousing and some other cost elements, the same logic is applied.

In summary, the volume approach provides great insights into cost calculation. Later, it will be seen in more details how this approach supports the cost analysis.

Major modeling procedures The cost analysis consists of 3 major steps:
1. Choose data sources.

2. Create an overview of modeling considerations.

3. For each cost element, describe cost calculation steps in details.

An overview of all data sources is available in the Table 13 in the Appendix. Two most fundamental data sources are shipment details report (SDR) and Agile. SDR gives a detailed description of outbound shipments from Logitech DC’s to customers. A typical entry contains ship-to customer, shipment date, quantity, SKU, sell price and etc. SDR is regarded as the basis for total shipment volume calculation. Here, an important assumption is that the total inbound shipment is equal to the total outbound shipment over the same length of time. Agile specifies standard quantities of a particular SKU in types of containers, pallets and cartons. Based on Agile, unit dimensions of a particular SKU can be deduced. In combination with SDR, it is therefore possible to know the total volume of a shipment by multiplying shipment quantity with unit dimensions. Together with shipment date information in SDR, it is possible to calculate the total shipment volume in any given time period.

In the Appendix, an overview of logistics processes, cost elements and corresponding modeling considerations are presented in Table 14. The structure of the table attempts to draw a picture of the complete logistics processes without omitting important modeling details. Several remarks need to be addressed. First of all, the model evaluates scenarios on an end-to-end basis. For baseline scenario, although Logitech is not responsible for any cost after FOB point, it makes sense to include them for an equal comparison with simulation scenarios, in which Logitech is responsible for delivering to customers. The motivation is about the future position of Logitech in the Indian market other than any short-term benefits. Second, for processes like warehouse in, warehousing and warehouse out, some cost elements are not independently calculated in the simulation scenarios. Instead, they are calculated by multiplying constant factor(s) with corresponding baseline results. There are two types of constant factors. One is called regional comparison factor. Mumbai to Singapore is 88%, Chennai to Singapore is 81%. For example, if we want to know the handling in cost in Mumbai, we need to multiply 88% with the amount of handling in cost for the baseline. The other one is called non-bonded to bonded comparison factor with a value of 150%. For bonded simulation scenarios, the factor should be applied to the non-bonded simulation scenario of the same region. For example, if the total handling in cost is known for the Mumbai Non-bonded scenario, we should apply the 150% to calculate the total handling in cost for the Mumbai Bonded scenario. The data source can be found in Table 13. Third, the dynamics of having multiple DC’s are not concerned in the simulation scenarios. If there is a new DC established in India, it will not have any interaction with the Singapore DC.

In the following, exact calculation steps are detailed for every cost element. Important notes will be supplemented when needed. It needs to be emphasized: Unless there is a special note, all calculations are on a quarterly basis.

- Inbound shipment cost:

  \[
  \text{Inbound shipment cost} = \sum_{\text{1}} \text{Number of lanes} \\
  (\text{Total inbound shipment CBM} \times \text{Dollar price per CBM})
  \]
### Table 2: Relationships between factory origins and Singapore DC, provided by APAC supply chain specialist; for inbound shipment of retail products.

<table>
<thead>
<tr>
<th>Factory origin</th>
<th>Singapore DC</th>
</tr>
</thead>
<tbody>
<tr>
<td>SZ</td>
<td>Palletized</td>
</tr>
<tr>
<td>CM (Hank)</td>
<td>Palletized</td>
</tr>
<tr>
<td>ODM Suppliers</td>
<td>Loose Carton</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Input devices</th>
<th>Non-input devices</th>
</tr>
</thead>
<tbody>
<tr>
<td>Customs Value (CV)</td>
<td></td>
</tr>
<tr>
<td>Basic Customs Duty</td>
<td>0</td>
</tr>
<tr>
<td>Countervailing Duty</td>
<td>MRP price x</td>
</tr>
<tr>
<td>(CVD)</td>
<td>Quantity x 80%</td>
</tr>
<tr>
<td></td>
<td>10%</td>
</tr>
<tr>
<td>Education Cess on CVD/Secondary &amp; Higher Education Cess on CVD (EC)</td>
<td>CVD x 2% +</td>
</tr>
<tr>
<td></td>
<td>CVD x 1%</td>
</tr>
<tr>
<td>Customs Cess on CVD/Secondary &amp; Higher Education Cess on CVD (EC)</td>
<td>0</td>
</tr>
<tr>
<td></td>
<td></td>
</tr>
</tbody>
</table>

### Table 3: Indian duties calculations. Input devices are defined as mouse and keyboard products, non-input devices are defined as all other types of products, including speakers, webcams and gaming devices. In this table, one type of duty namely SAD is excluded. SAD is not applicable when MRP labeling requirement is met, which is presumed in the analysis.

- Dollar price per CBM is different per lane. In this study, two lanes are relevant. One is originated from Shanghai port and the other one is originated from Hong Kong port. SDR does not indicate port origin. Each shipment, however, is SKU-dependent. By reference to SKU part number, port origin can be looked up in WW Item Master (WWIM).

- For the same lane, dollar price per CBM is different with trade incoterm. As already presented in Table 14 in the Appendix, each scenario is associated with trade incoterms. A trade incoterm intends to communicate the tasks, costs, and risks associated with the transportation and delivery of goods. And it specifies a contractual relation between a seller and a buyer in international trade. The present study has introduced FOB in the beginning. The other incoterms include port to door (PTD) and door to door (DTD), in which PTD covers the distance from origin port to customer DC and DTD covers the distance from factory origin to customer DC.

- For the same lane and incoterm, dollar price per CBM is different with each
Figure 5: The functional relationship between truck rate multiplier and pallet number. The vertical axis is for truck rate multiplier and the horizontal axis is for pallet number. The curve in red displays the average cost scheme of Dutch forwarders. The curve in blue displays the attempt to adopt the original pattern to India. The invention of the blue curve is a matter of guess work. Initially, a basic reverse function formula is chosen. Gradually, new parameters are added to close the gap between two curves. Eventually, it is decided to use $\frac{ax}{c+b}$ with $a = 3.77$, $b = -0.355$, and $c = 0.97$. The raw data is available in Appendix G.
Total inbound shipment CBM ÷ Unit CBM of a pallet ÷ Utilization rate of a pallet

- The above formulas do not distinguish types of containers (floor load or palletized). One difference is: For a floor load container, loosely loaded goods need to be palletized. So there is an additional cost element involved. But it will be listed separately to align with accounting classification. The other difference is each type of container has a different utilization rate, which has been discussed.

- Utilization rate of a pallet is an approximation of the actual usage of a pallet. Unlike a container, a pallet seems not to have visible boundaries. However, there is a regulation on height in practice. In addition, size differences of cartons can waste space.

- Prices are predetermined contract rates signed with 3PL service provider.

  - Material cost:
    
    \[
    \text{Material cost} = \frac{\text{Number of pallets} \times \text{Provision of Re-cycled Pallets}}{\text{Floor load inbound shipment CBM} \div \text{Unit CBM of a pallet} \div \text{Utilization rate of a pallet}}
    \]

    Provision of Re-cycled Pallets is charged per pallet, which is to have empty pallets ready for use. It is a predetermined contract rate signed with 3PL service provider.

    - In the present study, only retail products are considered. Table 2 specifies types of shipment distinguished by factory origin. SDR does not indicate factory origin. However, it is port-dependent. By reference to the port origin of a shipment, factory origin can be looked up. Therefore, all floor load shipments can be identified.

  - Storage cost:
    
    \[
    \text{Storage cost} = \sum_{1}^{\text{Number of weeks}} (\text{Weekly price of pallet storage} \times \text{Pallet quantity at the end of the week})
    \]

    Officially speaking, a quarter has 13 weeks at Logitech.

    - Weekly price is a predetermined contract rate signed with 3PL service provider. The value depends on pallet quantity at the end of the week. If it is in the lower range, a higher value is applied; and vice versa.

    - Pallet quantity is not calculated. The 3PL service provider sends APAC logistics specialists a billing report every week. In the report, the exact number of pallets in storage is available.

- Total handling out:
- Total handling out cost = 
  Stuffing cost + Handling out cost

- Stuffing cost = 
  Number of containers × Price of stuffing a container

- Handling out cost = 
  Number of shipments × Price of handling out a shipment

- Number of containers = 
  Total outbound shipment CBM ÷ Unit CBM of a container 
  ÷ Utilization rate of a container

- The above formulas do not distinguish types of containers (floor load or palletized). The difference is each type of container has a different utilization rate. The type of containers depends on customer preference. And it can be found in SDR for which customer a shipment is arranged.

- Prices are predetermined contract rates signed with 3PL service provider.

- Goods are either placed in a pallet or in a master shipper carton. A master shipper carton is a package box, different with each SKU. Agile has a record of carton sizes and the assumption is one carton is for a single SKU only. This assumption is aligned with practice. In the formula, the variable shipment may be confused with the general understanding of a shipment. In this context, it is defined as the quantity for a SKU that is ready for shipment and is recorded as an entry in SDR. If the quantity of the shipment is less than 4 master shipper cartons, the price of handling out is the multiplication of carton numbers and a predetermined unit price agreed with 3PL service provider. If the quantity of the shipment is more than 4 master shipper cartons or the SKU is in pallets, the price is a fixed rate.

  • MRP labeling cost:

  - MRP labeling cost = \( \sum_{1}^{\text{Number of months}} \) 
    \((\text{Price of MRP labeling per piece} \times \text{Product quantity at the end of the month})\)

  - Each quarter consists of 3 months.

  - Price of MRP labeling per piece is a predetermined contract rate signed with 3PL service provider. The value depends on total product quantity at the end of the month. If it is in the lower range, a higher value is applied; and vice versa. Price of MRP labeling per piece is applied to each retail package.

  - Total product quantity is available in SDR and is the total number of retail pieces of all traded goods.

  • Serialization cost:

  - Serialization cost =
    \( \text{Price of serialization per carton} \times \text{Number of cartons} \)

  - Price of serialization per carton is a predetermined contract rate signed with 3PL service provider. Currently, Singapore DC does not practice serialization.
but Hong Kong DC does. In the future, Logitech plans to achieve serialization. It is therefore included in the cost analysis. Because Hong Kong is in the same region, the price of serialization per carton at Hong Kong DC is used.

- As already discussed previously, the total number of carton can be obtained using the volume approach. And data is available in SDR and Agile.

- Duty and VAT:
  - Table 3 shows how exactly Indian duties are calculated for different product groups. The information is provided by local logistics manager and confirmed by global Trade & Compliance director.
  - Customs Value (CV) is defined as the sum of total shipment value, insurance, freight cost and loading. Total shipment value will be discussed separately because it is an important point in this analysis. The values of insurance and freight cost are based on the suggestions of the local logistics manager. Loading is calculated as 1% of the total shipment value.
  - Total shipment value is the total value of goods shipped. For internal logistics, in which goods are shipped from suppliers to Logitech DC, a percentage is added to the original unit production cost. This markup is called markup and its value depends on the destination country. The unit cost with the markup applied determines the total shipment value. For external logistics, in which customers are responsible for ordering, shipping and collecting, sell price is used to determine the total shipment value. Because Logitech has already made an investment in transportation, the sell price for customers has to be higher. Therefore, it can be speculated that a new DC in India should reduce the amount of import duty. When Logitech becomes the importer of record, the total shipment value reduces because customers sell price is replaced with unit cost with a markup.
  - SDR is suitable for duty calculation, because the report structure is shipment-based and duty calculation is also shipment-based.

- Sea shipment to customers:
  - Sea shipment to customers cost = \( \text{Number of total product quantity} \times \text{Freight cost per unit quantity} \)
  - Logitech is not responsible for the cost at this time. And there is no access to the financial data of Indian customers. The average freight cost per unit quantity is based on the past experience of Indian logistics manager.
  - Number of shipment quantity is detailed in SDR. Therefore, total product quantity is the summation of all shipment quantities in a given period.

- Inland transport to customers cost:
  - Inland transport to customers cost = \( \sum_{1}^{\text{Number of customers}} (\text{Full truck load cost} + \text{Less than full truck load cost}) \)
– Full truck load cost =
  \[ \text{rounddown(} \frac{\text{Total shipment CBM}}{\text{Unit CBM of a full truck}} \text{)} \]
  \( \div \) Utilization rate of a full truck \( \times \) Price of a full truck load

– Less than full truck load cost =
  \( \frac{\text{Remaining shipment CBM}}{\text{Unit CBM of a pallet} \times \text{Truck rate multiplier}} \]
  \( \times \) Price of a full truck load

– Remaining shipment CBM =
  \( \frac{\text{Total shipment CBM}}{(\text{Unit CBM of a full truck}} \times \text{rounddown}(\frac{\text{Total shipment CBM}}{\text{Unit CBM of a full truck}})) \)

– Truck transport cost is calculated on a daily basis for each customer.

– In practice, forwarders offer 2 types of prices. One is for full truck load (FTL); the other one is for less than a full truck load (LTL). Because there is a cost advantage, forwarders give a discount on FTL. So, the cost structure in terms of pallet number is not linear. Instead, it can be described by a reverse function. In daily language, as the number of pallets increase, the unit price of truck transportation decreases at a rate of acceleration.

– At this moment, Logitech is not responsible for inland transportation in India. So the local logistics manager does not have the knowledge of a proper cost scheme. In the analysis, we assume that Indian forwarders use the same cost scheme in India as in the Netherlands. Because the unit CBM of a standard pallet in APAC is slightly smaller, the maximum number of pallets is greater. An extension of the original scale is attempted (which can be seen in Figure 5).

– The truck rate multiplier is a factor to be multiplied with unit pallet price of FTL. And the result is the unit pallet price corresponding to a given pallet number. The unit pallet price of FTL is obtained by dividing the FTL price with the maximum number of pallets of FTL.

– The FTL price and the maximum truck load in India are provided by Purchasing & Compliance director.

• Other costs:
  – Clearance cost:
    * Clearance cost =
      \[ \text{Total customs broker fee + Total port transportation cost} \]
    * Total customs broker fee =
      \[ \text{Number of clearance} \times \text{Customs broker fee per time} \]
    * Total port transportation cost =
      \[ \text{Number of clearance} \times \text{Port transportation cost per time} \]
    * Clearance cost includes broker fee and port transportation. Broker fee is paid for the service of a customs broker who helps importers and exporters
to clear goods through customs borders. Port transportation is the cost
to move goods from port to the destination DC.

- At this moment, Logitech is not responsible for clearance in Indian ports.
Only Indian customers know about it. Based on interviews with the World
Wide Trade & Compliance manager, it is suggested to use the above for-
mulas, which is based on past experience. Also, the value of customs
broker fee per time and port transportation cost per time are not based
on any existing contract but purely on estimation.

- One time of clearance is defined as an aggregation of shipments under the
name of the same customer and in the same day. In reality, this definition
may be a bit optimistic. However, the World Wide Trade & Compliance
manager supports the definition for the modeling purpose. To calculate
the total number of clearance, SDR is used to group shipments by customer
and by day.

  - Cross state tax:

    - \( \text{Cross state tax} = \)
      \[1\% \times (\text{Customs value} + \text{Clearance costs} + \text{Import duty})\]

    - Cross state tax is applicable when traded goods enter the destination state.
      Two out of 4 Indian customers have their parent DC in the Mumbai state;
      the other two, in the Chennai state. In terms of volume, \( \boxed{2} \) of the total
      shipment CBM goes to Mumbai and the rest goes to Chennai.

    - At this moment, Logitech does not pay for cross state tax. Only Indian
      customers know about it. Based on interviews with the local logistics
      manager, it is suggested to use the above formula, which is based on past
      experience.

    - For baseline scenario, it is not known with certainty which port customers
      would choose. For this reason, it is assumed that there is an equal chance
      of choosing Mumbai or Chennai as the destination port. Therefore, the
      chance of entering the Mumbai or Chennai state is equal. Sequentially,
      the average of the Mumbai and Chennai scenario is treated as a proper
      estimation for the baseline. In the Mumbai scenario, only goods that need
      to enter Chennai are charged. In the Chennai scenario, only goods that
      need to enter Mumbai are charged.

**Lead time analysis** The lead time analysis is not complex. Once logistics processes are
clearly defined, the standard lead time for a logistics process is available through experts.
Although service level is not explicitly expressed, the standard lead time aims to meet
customer expectations. Therefore, all scenarios are assumed to satisfy customers, but
with a different total lead time. The aim of this analysis is therefore to evaluate scenarios
in terms of total lead time. The shorter it is, the less goods are there in the pipeline, which
is good for Logitech. DC to customers lead time is another criterion. If a scenario has
a short DC to customers lead time, it means great lead time flexibility with customers,
which is an advantage for Logitech.
6.1.2 Data Collection

The cost analysis requires data of fiscal year 2012, which becomes available with help of an experienced analyst. The data is contained in SDR and only retail products for India are relevant and included. The lead time analysis does not require any raw data.

6.2 The AHP Site Selection Model

6.2.1 Modeling Building

Major modeling procedures The AHP approach has three major steps (Saaty, 1994a):

1. **Problem decomposition.** An arbitrary decision problem is decomposed into factors. Each factor is further decomposed to sub-factors. A chain of hierarchy is formed by grouping the problems into multiple levels. For example, a manager needs to make a site location decision and select the best one among alternatives. The decision problem can, for example, be decomposed into two factors by using Table 1: access to supplier/resources, and community/government access. The manager can continue to expand the hierarchy until all necessary factors are included.

2. **Comparative.** One distinguishing feature of the AHP is pairwise comparison. For example, two location factors cost of serving markets and trucking service are compared and their relative importance to each other is rated. Decision makers provide numerical values for the priority of each factor using a standard rating scale Table 4. This information will be used to assess the relative importance of each relevant factor against all the rest at a particular level.

3. **Synthesis of priorities.** Using special mathematical techniques, the priority weight of a factor at each level is computed. From one level to one below, the composite priority weight of a factor is calculated by multiplying the priority weight of the factor at its own level with its parent factor at one level above. Composite priority weights are calculated repeatedly. This is an iterative process across all levels of the hierarchy until all factors are prioritized and ranked in a clear order.

The solution process of the AHP location decision is depicted in Figure 6.

Pairwise comparison is the key step of the AHP location model for two reasons: a) It determines priority weights of location factors; b) it rates location candidates based upon qualitative factors. Two factors are compared each time. So is their relation to each other. The relative importance of each factor against another is placed on a measurement scale to convert verbal judgments into numerical judgments. As indicated by Table 4, the scale ranges from 1 to 9 and the meaning of each score is provided with a description. The relative importances of factors in the same factor group (a cluster in which all factors belong to the same parent factor) are then presented in a matrix form, which will be referred to as priority weights matrix (which is abbreviated as PWM; a mathematical expression is displayed in Equation 6.2.1). It can be observed that PWM is symmetric because of the reciprocal rule described in Table 4. It can also be deduced that PWM has only one non-zero eigenvalue. By doing matrix row operations, a typical PWM can be transformed into a matrix, whose rows except the first one contain no other values but
### Table 4: The fundamental scale (Saaty, 1994b)

The first six rows explain which number is assigned to a factor equally important to or more important than another factor. The Row ‘Reciprocals of above’ explains which number is assigned to a factor if it is less important. It explains, for example, if one factor is extreme important compared to another factor. The factor is assigned with 9. For the less important factor, it is assigned with the reciprocal of 9.

<table>
<thead>
<tr>
<th>Intensity of importance</th>
<th>Definition</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Equal importance</td>
<td>Two activities contribute equally to the objective.</td>
</tr>
<tr>
<td>3</td>
<td>Moderate importance</td>
<td>Experience and judgment slightly favor one activity over another.</td>
</tr>
<tr>
<td>5</td>
<td>Strong importance</td>
<td>Experience and judgment strongly favor one activity over another.</td>
</tr>
<tr>
<td>7</td>
<td>Very strong on demonstrated importance</td>
<td>An activity is favored very strongly over another; its dominance demonstrated in practice.</td>
</tr>
<tr>
<td>9</td>
<td>Extreme importance</td>
<td>The evidence favoring one activity over another is of the highest possible order of affirmation.</td>
</tr>
<tr>
<td>2, 4, 6, 8</td>
<td>For compromise between the above values</td>
<td>Sometimes one needs to interpolate a compromise judgment numerically because there is no good word to describe it.</td>
</tr>
</tbody>
</table>

If activity $i$ has one of the above nonzero numbers assigned to it when compared with activity $j$, then $j$ has the reciprocal value when compared with $i$.

| Reciprocals of above | | A comparison mandated by choosing the smaller element as the unit to estimate the larger one as a multiple of that unit |

### Equation 6.2.1

$$A = \begin{pmatrix} \frac{w_1}{w_1} & \frac{w_1}{w_2} & \cdots & \frac{w_1}{w_n} \\ \frac{w_2}{w_1} & \frac{w_2}{w_2} & \cdots & \frac{w_2}{w_n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{w_n}{w_1} & \frac{w_n}{w_2} & \cdots & \frac{w_n}{w_n} \end{pmatrix}$$

In the next step, priority weights of factors need to be calculated, which involves factor normalization based upon the relative scale of measurement. Eigenvalues Method (EM) is recommended by Saaty, especially when data are not entirely consistent (Saaty and Vargas, 1984). Priority weight is calculated in 3 steps:  

1. Find the eigenvalue of the PWM, which is the trace of the matrix and is the *only and largest* eigenvalue; 
2. accordingly, solve the equation $(A - \lambda_{max}I)q = 0$ to obtain the eigenvector, where $I$ is the identity matrix, $\lambda_{max}$ is the identity matrix, and $q$ is the desired eigenvector; 
3. normalize each element of the eigenvector through dividing each of them by the total sum of all elements in the eigenvector. 

In the structured hierarchy, the priority weights of factors at the highest level are first computed. The weight of a higher level element is then used to weight its child factors below at the next level (composite weights). The procedures repeat itself downward along the hierarchy, until the lowest level is reached.

Candidate locations are rated with regard to each location factor at the lowest level of the hierarchy. Location factors can be quantitative or qualitative. Quantitative factors are their corresponding values, and the qualitative factors are measured by the provided scale instrument from 1 to 9. Before quantitative factors are compared, they must be first normalized. The final priority score for each location is obtained by multiplying the rating score regarding a given factor by the priority weight of the corresponding factor.
Two features of the AHP approach make it unique. One is that human judgment is involved, quantified and utilized. It is especially valuable when an international site location is under consideration, in which international factors are complex and qualitative. With the help of the AHP, these factors can now be converted into numbers for comparison. Confusion and disagreement among decision makers are then able to be clearly expressed and easily compared. The other one is an arbitrary problem is decomposed into multiple specific problems. Miller (1956) found that people became confused if they had to process a lot of information simultaneously. International site location is concerned about many factors and a large amount of information. Therefore, information processing and communication make decision making challenging. It becomes even more when decision makers have different perspectives. The AHP can help to decompose a general problem into specific problems that decision makers find easier to discuss. Eventually, a succession of agreements leads to the final consensus.

Some illustrative examples are available (Saaty, 1990; Yang and Lee, 1997), in which simple cases help to demonstrate the solution procedures and effectiveness of the AHP.

**Consistency check** Consistency check is to detect if decisions are made by a constant logic. For example, there are three fruits on the table. An apple, a pear and a banana. A decision maker needs to compare the fruits pair by pair. Given that apple is preferred to pear and pear is preferred to banana, a consistent comparison should be that apple is preferred to banana. Otherwise, it becomes illogical as the decision contradicts other decisions.

In case of AHP model, the consistency issue is more complicated. As already shown in Table 4, a number is assigned each time when a comparison is made. In contrast with

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<table>
<thead>
<tr>
<th>Step 0: Plant location project (plant need identified and justified)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Identify relevant plant location factors</td>
</tr>
<tr>
<td>Step 2: Develop priority weights</td>
</tr>
<tr>
<td>Step 3: Collect data and rank each potential location</td>
</tr>
<tr>
<td>Step 4: Analyze comparative results</td>
</tr>
<tr>
<td>Step 5: Identify preferred site(s)</td>
</tr>
<tr>
<td>Step 6: Final recommendations</td>
</tr>
</tbody>
</table>

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Figure 6: Solution process of the AHP site location model (Yang and Lee, 1997)
the fruit example, it is more difficult in this case to tell if all comparisons are consistent. The degree of confusion is much higher when dealing with a matrix of numbers. This statement contains more truth, as the number of items increases. Fortunately, Saaty (1990) has proven that PWM is consistent if and only if \( \lambda_{\text{max}} = n \), in which \( n \) is the size of the PWM. Based on this theorem, Saaty recommends the following consistency check method for a given PWM (Saaty, 1990):

1. Calculate the consistency index (CI). The mathematical expression is \( (\lambda_{\text{max}} - n)/(n - 1) \). It measures the consistency difference between \( \lambda_{\text{max}} \) and \( n \). If \( CI = 0 \), the given PWM is perfectly consistent.

2. Look up in the random index (RI) (Table 5). For a particular index, or the size of a PWM, the table refers to the average CI of a large number of random reciprocal matrices.

3. Calculate the consistency ratio (CR), which is CI divided by RI. If CR is around or less than 10%, the consistency check is a pass. Otherwise, some ratings need to be changed slightly to make an improvement.

<table>
<thead>
<tr>
<th>n</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>.52</td>
<td>.89</td>
<td>1.11</td>
<td>1.25</td>
<td>1.35</td>
<td>1.40</td>
<td>1.45</td>
</tr>
</tbody>
</table>

Table 5: The table of random index(Saaty, 1994b). The scale of the index is ranged from 1 to 9. For practical purpose, if the size of the PWM is greater than 9, the matrix should be broken into separate groups. Otherwise, there is too much information under consideration. It is also noticeable that for \( n = 1 \) and \( n = 2 \), random consistency index is 0. It is because inconsistency cannot happen in those two cases.

**Application** The application of the AHP model uses Visual Basics for Applications Excel (VBA Excel). The codes of the program are included in Appendix H. The advantages and the reasons of using VBA Excel are the following:

- Excel is a popular platform. A VBA Excel application can be shared with and opened by any user who has Excel installed.
- VBA Excel can create a user interface in Excel. AHP model requires both textual (e.g. a factor or a location name) and numerical (e.g. a rating score or the level of the hierarchy) inputs. For this problem, VBA Excel can offer an easy solution by creating a dialogue environment.
- VBA Excel is a great tool for task automation. Not only does it help to save time from labor, but also enables the program to be used in most cases without a long period of preparation.
- VBA Excel has sufficient programming power. AHP model needs matrix operations. The build-in functions are capable of doing required matrix operations within a short amount of time.

**The power method** One of the difficulties with the AHP model is to find the dominant eigenvalue \( \lambda_{\text{max}} \), which is required for the consistency check. To solve the problem in a
direct way, the eigenvalues of an $n \times n$ matrix $A$ are given by the following equation

$$\lambda^n + c_{n-1}\lambda^{n-1} + \ldots + c_0 = 0.$$  \hfill (6.2.2)

It can be seen that the equation becomes more and more difficult to solve, as the value of $n$ increases. Fortunately, the power method is available in linear algebra. It is a fast approximating technique that calculates the largest eigenvalue of a $n \times n$ matrix in absolute value.

In Larson and Falvo (2012), the power method has been well-explained.

This approximation method requires an iterative process. The sequence is shown below.

First of all, it is assumed that the matrix $A$ has a dominant eigenvalue (the largest in absolute value) with its corresponding dominant eigenvectors. Next, the sequence starts with choosing an initial approximation $x_0$. It has to be a non-zero vector and can be any non-zero vector. For instance, if the size of $A$ is 2, $x_0$ can be chosen to be $(1 \ 1)$.

$$x_1 = Ax_0$$
$$x_2 = Ax_1 = A(Ax_0) = A^2x_0$$
$$x_3 = Ax_2 = A(Ax_2) = A^3x_0$$
$$\vdots$$
$$x_k = Ax_{k-1} = A(Ax_0^{k-1}) = A^kx_0$$

There is no strict rule about the value of $k$. The idea is: By properly scaling, $x_1$, $x_2$, $x_3$, \ldots and $x_k$ converge to the dominant eigenvector gradually. As the value of $k$ is large enough, a good approximation should be obtained. In this study, the value of $k$ is assigned with a very large number. Given the size of matrices ($n$ is no greater than 9), a successful conversion is always ensured.

After that, its corresponding eigenvalue is given by

$$\lambda = \frac{Ax \cdot x}{x \cdot x}.$$ \hfill (6.2.3)

The quotient is called the Rayleigh quotient. It helps to calculate the dominant eigenvalue corresponding to the eigenvector obtained by the power method.

An important note is a PWM always has a positive dominant eigenvalue. It is because the rating scale in AHP model contains positive numbers only. Therefore, a PWM always has positive entries. It means that the largest $\lambda$ of a PWM is equal to the exact value of the dominant eigenvalue, not its absolute value.

6.2.2 Data Collection

As explained previously, a DC site selection is often a joint decision. Stakeholders from different areas share the same interest, because the final decision can have an impact on each of them.

In this study, 5 global (senior) directors have made a contribution from 5 different functions, including Replenishment, Trade & Compliance, Logistics, After Sales and Supply...
Chain Planning. All of them have years of experience and knowledge about their function. Two local managers are also invited, who are in the Sales function and have a good understanding at an operational level.

Global directors have a general understanding of the most important issues about India. They are also able to align their preference with the company strategy. This means they are less motivated by the short term interests, such as profit margin. Local managers are exactly the opposite. They are mostly concerned about immediate impacts on business performance. With help of the company supervisor and the program manager, it is finally decided on the list of participants. For a detailed description of all functions, please have a look at Table 16 in the Appendix.

With each participant, three meetings are planned. The first meeting is an orientation session. The Network Optimization Study 2011, the present project (Network Optimization Study Phase II), the role and the purpose of AHP model are introduced. More importantly, the participant is informed of the plan, which includes three steps: a) Before the next meeting, the participant will send a list of factors that capture the major concerns when selecting a DC site; b) The first follow-up meeting is to do factor ranking. The participant needs to compare factors. In the end, a rank of factors is created; c) The second follow-up meeting is to do location ranking. Concerning each factor, the participant needs to compare site locations. In the end, a rank of site locations is created for every decision making factor.

Sessions took place in a structured and controlled environment. The participant gave answers to questions that were based on the list of decision making factors received. Also, the participant needed to give his or her reasoning behind each preference. The participant could ask for guidance when it was needed. For example, when there was confusion related to AHP model, like the rating scale, he or she was provided with an explanation so that the participant understood and was able to proceed.

A sample of the decision factor inquiry form can be found in Appendix J. A sample of the ranking questionnaire can be found in Appendix K. Before the first follow-up meetings, the decision factor inquiry form was sent to all participants by email, together with a short explanation about the usage of the form. The ranking questionnaire was only used later with local managers. The development was based on the experience with global directors, who were interviewed first. The purpose of using the form was to create an easy and better structured environment.

It can be seen in the ranking questionnaire that a shortened rating scale is used. If a participant really needs more options, we write down a note and will use the in-between number afterwards. For example, if a participant thinks 5 is too high and 3 is too low, we will use 4 as the model input. Also, a participant is not asked to use the numerical scale. We did try it with global directors in the first follow-up meeting, but the results convinced us of not using it. Our observation was the textual scale appeared to be natural and friendly. In summary, both changes serve the purpose to reduce learning time for participants and are based on our experience of implementation.
7 Results

In this section, results are presented in two parts. The first part is results of the cost and lead time analysis. It starts with an overview of total logistics cost of the baseline and simulation scenarios. Then, results for each cost element is provided. Part I ends with a short paragraph of the lead time analysis. The second part shows the results of the AHP site selection model. The texts structure follows the same order of the AHP decision making processes. It is noted that raw outputs are available in the Appendix but the aim is to gain insights from the results. Therefore, raw outputs are summarized by function.

7.1 Results of the Cost Analysis

7.1.1 Overview

In Figure 9, a comparison of end-to-end logistics cost between scenarios is displayed. All results are on a yearly basis. The immediate impression is that there is a cost reduction between the baseline scenario and the simulation scenarios. In Table 6, the ratio differences between the baseline and the simulation scenarios are summarized. For either location, a bonded option is always more expensive. And the difference between a bonded DC in Mumbai and in Chennai is 0.33%, with Mumbai being more expensive. Regarding the non-bonded option, a DC in Chennai is more expensive than in Mumbai, with a difference of 0.74%. These differences will be explained and become clear when results are analyzed at a detailed level.

<table>
<thead>
<tr>
<th>Baseline</th>
<th>Mumbai Bonded</th>
<th>Mumbai Non-bonded</th>
<th>Chennai Bonded</th>
<th>Chennai Non-bonded</th>
</tr>
</thead>
<tbody>
<tr>
<td>100.00%</td>
<td>96.88%</td>
<td>88.65%</td>
<td>96.55%</td>
<td>89.39%</td>
</tr>
</tbody>
</table>

Table 6: Ratio differences between the baseline and the simulation scenarios. Instead of showing rounded numbers, there are two digits to the right of the decimal point. The reasoning behind is that the numerical scale of the end-to-end logistics cost is at a million dollar level. So, a tiny ratio difference can result in a significant gap.

7.1.2 A Detailed Analysis of Results

The complete results of the cost analysis can be found in Appendix L. In the following, results are analyzed concerning each of the cost elements.

**Shipment cost to DC** The baseline scenario has a significant lower cost than any of the simulation scenarios. The cost differences can be explained by two things. The first thing is the fact that | of the total volume is shipped from Hong Kong to Singapore PTD and the contract rate for this lane is relatively low. For the same lane (Hong Kong to the destination DC, PTD) the average rate of simulation scenarios is approximately 3 times as much as the baseline. The second thing is another fact that the remaining
volume is shipped from Shanghai at relatively lower rates. Although these rates are still much higher than the one for the Hong Kong lane, they help to narrow the gap between the baseline and the simulation scenarios. In Table 17, we can see the final results are aligned with the rate differences.

Between Mumbai and Chennai scenarios, the shipment cost is lower for Chennai. It is because the contract rates of Chennai lanes are comparatively lower.

Finally, it can be observed that shipment cost to DC shows no difference between bonded and non-bonded options for the same location.

**Total handling in** For the baseline only, calculation is based on real life data. As already mentioned in Table 14, regional comparison factor (see Table 7) and non-bonded to bonded factor (see Table 8) are applied to know the cost for simulation scenarios. Because the baseline scenario deals with a non-bonded DC in Singapore, the regional comparison factor is firstly used to calculate the costs for Mumbai Non-bonded and Chennai Non-bonded. Subsequently, the non-bonded to bonded factor is multiplied with to know the cost for Mumbai Bonded and Chennai Bonded.

As can be seen in the final results, bonded simulation scenarios have the highest costs, followed by the Singapore scenario. And the most cost efficient options are non-bonded simulation scenarios.

**Material cost, storage cost, total handling out, serialization** Please refer to the ‘Total handling in’ paragraph. To calculate for different scenarios, the same approach is used. The final results follow the same pattern.

**MRP labeling** For MRP labeling cost calculation, the approach is the same as above mentioned warehouse-related cost elements. But there is one major difference.

For non-bonded scenarios, it is not possible to do MRP labeling in India. Therefore, it is assumed in the analysis that MRP labeling is operated in China, where most products are manufactured. Likewise, a regional comparison factor is multiplied with the baseline result. In this case, China is chosen because doing business is cheaper in China than in Singapore or India. In the final results, it can be seen that non-bonded options are considerably cheaper than the baseline.

For this reason, the final results display a different but still similar pattern with the other warehouse-related cost elements. As can be seen, the non-bonded options have the same amount of cost regardless of the site location, which is different from other warehouse-related cost elements. Another point is: MRP labeling cost is the key factor that makes Chennai Non-bonded more favorable than Mumbai Non-bonded. It is worth discussing because Chennai Bonded and Mumbai Bonded show a reversed relationship. By looking at other cost elements, some of which have been discussed and some will be seen later, the relationship of Mumbai Bonded with Chennai Bonded tends to be less cost effective regarding inbound shipment and warehousing, be the same regarding import duty and clearance, be more effective regarding freight cost and cross state tax. The relationship of Mumbai Non-bonded with Chennai Non-bonded share the same pattern except for MRP labeling. In terms of MRP labeling cost, there is no difference between non-bonded
options but there is a difference of less than $100,000 between the bonded ones. This explains why we see that Mumbai Non-bonded and Chennai Non-bonded are surprisingly different from the bonded counterpart.

**Duty and VAT** As seen in Table 9, Duty and VAT accounts for the vast majority of the total cost. Also, the difference between the baseline and the simulation scenarios in terms of duty and VAT is more than $500,000. Among simulation scenarios, duty and VAT does not have a difference because the same duty and VAT regulations are required no matter which port Logitech selects.

The reason for the cost reduction is because the customer sell price in the baseline scenario will be replaced with an internal measure of unit cost in simulation. However, an important note is the cost reduction does not only depend on the price difference, which has been explained several times throughout this report. The product mix is another important factor. In Table 3, products are classified into two groups. It can be seen in the ‘Input devices’ column that the total duty does not depend at all on CV. It means that the shipment value is not influenced by either sell price or internal unit cost. Instead, it has a dependent relationship with MRP price in the Row CVD. So the key question is at what percentage of the input devices takes account of the total shipment volume. Table 10 shows that the majority of shipments into India is input devices. Non-input devices, which help to reduce import duty, is a bit more than \[ \text{of the total shipments.} \] Therefore, it can be expected that import duty will reduce as the Indian product mix changes towards non-input devices, assuming the total shipment volume remains the same.

<table>
<thead>
<tr>
<th>Country</th>
<th>Singapore</th>
<th>Mumbai</th>
<th>Chennai</th>
</tr>
</thead>
<tbody>
<tr>
<td>Relative cost comparison</td>
<td>100.00%</td>
<td>87.50%</td>
<td>81.25%</td>
</tr>
</tbody>
</table>

Table 7: Regional comparison percentage, which is based on the information shared by the global director of Purchasing & Compliance.

<table>
<thead>
<tr>
<th>Types of warehouse</th>
<th>Non-bonded</th>
<th>Bonded</th>
</tr>
</thead>
<tbody>
<tr>
<td>Comparison factor</td>
<td>100%</td>
<td>150%</td>
</tr>
</tbody>
</table>

Table 8: Non-bonded to bonded comparison factor for India, which is based on the information shared by the global director of Purchasing & Compliance.

**Sea shipment to customers** Sea shipment to customers is only applicable to the baseline scenario in which customers pick up orders in Singapore and arrange shipments to India. Based on the method shared by the Indian logistics manager, the final result is surprisingly high. Compared to ‘shipment cost to DC’ for the baseline, which measures lanes from Shanghai/Hong Kong to Singapore, the calculation result seems suspicious. It is because the geographical distance of Shanghai/Hong Kong to Singapore and Singapore
<table>
<thead>
<tr>
<th>Cost element</th>
<th>Average percentage of the total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment cost to DC</td>
<td>7.38%</td>
</tr>
<tr>
<td>Total handling in</td>
<td>0.68%</td>
</tr>
<tr>
<td>Material cost</td>
<td>0.35%</td>
</tr>
<tr>
<td>Storage cost</td>
<td>3.68%</td>
</tr>
<tr>
<td>Total handling out</td>
<td>0.44%</td>
</tr>
<tr>
<td>MRP labeling</td>
<td>10.05%</td>
</tr>
<tr>
<td>Serialization</td>
<td>0.95%</td>
</tr>
<tr>
<td>Duty and VAT</td>
<td>69.04%</td>
</tr>
<tr>
<td>Sea shipment to customers</td>
<td>1.94%</td>
</tr>
<tr>
<td>Inland transport to customers</td>
<td>0.93%</td>
</tr>
<tr>
<td>Clearance</td>
<td>0.55%</td>
</tr>
<tr>
<td>Cross state tax</td>
<td>4.00%</td>
</tr>
</tbody>
</table>

Table 9: The average cost structure with respect to each cost element. The ‘Average percentage of the total’ column calculates the percentage of the average costs of all baseline and simulation scenarios in the average total of all scenarios. It is noted that Duty and VAT accounts for almost 70% of the total.

<table>
<thead>
<tr>
<th>Product group</th>
<th>Volume percentage</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input devices</td>
<td></td>
</tr>
<tr>
<td>Non-input devices</td>
<td></td>
</tr>
</tbody>
</table>

Table 10: Volume percentage of input devices and non-input devices. The calculation is done by dividing the total CBM of one product group by the grand total of both product groups.

to Mumbai/Chennai are very close. Therefore, the calculation result holds against common sense. However, the simulation rate requested from senior APAC logistics manager shows the result might make sense. For unknown reasons, the lanes from Singapore to India are not cost effective. This may explain why the calculation result is very high.

Another perspective is to compare the calculation result with simulated inbound shipment costs. As discussed earlier, direct shipments from factory origins to India are also expensive compared to the current situation. In comparison, it can be seen that the calculation result lies in the range of direct inbound shipment costs. Still, it does not make sense that a shipment from Singapore to India costs more than a shipment from factory origins to India. It is obvious that the latter covers a much greater distance.

**Inland transport to customers** The cost of inland transport to customers is only concerned with simulation scenarios. It can be seen that Chennai-based scenarios have a slightly higher cost than Mumbai-based scenarios. The rationale is that most traded goods are delivered to the Mumbai area. Therefore, a greater distance needs to be covered if the new Logitech DC is located in Chennai.

**Clearance** The calculation results of clearance have been confirmed by the World Wide Trade & Compliance manager. Based on the past experience, the results lie in the possible range. However, in no way can this analysis give a definite answer.

For bonded scenarios, no broker fee is paid for the reason that bonded warehouse grants
an access into India without customs clearance. Therefore, a minor amount of cost saving is seen in the results.

**Cross state tax**  As explained earlier, cross state tax is only applicable when the final destination of trades goods is in a different state other than the warehouse location and when the traded goods have arrived in the destination state. Moreover, it is important to emphasize that the present analysis does not distribute goods to every customer DC location. The distribution model is predetermined to ship traded goods *only* to the parent DC of a customer. As can be seen in the formula, cross state tax depends on the shipment volume. Because almost all of the total volume flows to Mumbai area, it makes sense that the amount of tax is higher if the Logitech DC is based in Chennai. And the calculation results support this logic. As can be seen in the final results, cross state tax for Chennai-based scenarios are significantly higher than Mumbai-based scenarios.

### 7.2 Results of the Lead Time Analysis

In the Appendix, Table 18 contains the results of the lead time analysis. The logistics processes are classified into 4 broad processes. The contents are not done by the present author but experts in logistics or other functions at Logitech.

Compared to the baseline, lead time reduction in simulation scenarios is very significant. For baseline, it takes about more than 4 weeks to ship goods to Singapore and additional 2 weeks for customers to have goods cleared in Indian ports. The presence of Logitech in India can help to reduce that time to 29 days in total. It is also seen that there is a great improvement on DC to customers lead time. In simulation scenarios, it takes only 2 days to deliver goods to customers. For baseline, as mentioned above, it takes 2 weeks in total.

### 7.3 Results of the AHP Site Selection Model

As can be seen in Figure 10 in the Appendix, the present study has included in total 24 decision making factors that are placed at the bottom of the tree. Based on their functions and definitions (See Table 19, 20, 21, 22, 23, and 24), a hierarchy is created for the AHP model. It is noticed that some functions have more decision making factors and some have less. But it does not mean the function with more factors has more influence. The AHP modeling processes begin with factor ranking at the top level. Suppose that the Trade & Compliance factor at top has a low ranking position and accounts for only 5% of the total priority weight. Even though it has many factors and much more than some of the other functions, the summation of its children factors will not exceed 5% in terms of priority weight. In this way, the AHP model makes sure the final results do not depend on the number of children factors. In the present analysis, this characteristic of the AHP allows a strategic expression from the very beginning. In this case, the Steering Committee can determine the relative importances of every function. And the experts contribute to the ranking within their own function. In combination, a balance of vision and collective decision making is reached.
The results of factor ranking is summarized in Table 26 and Figure 11 in the Appendix. First of all, local concerns, which are expressed by Sales function, account for 2/3 of the total weight. If the present study is implemented, the cooperation of local Sales team is required. So, their interests need to be well-addressed. Secondly, Trade & Compliance is regarded as the most important aspect of the global functions (Replenishment, Trade & Compliance, Logistics, After Sales and Planning). It is because India is notorious for customs clearance being very difficult. The other factors play a minor role and contribute equally to the final decision.

Next, the results of site location ranking is summarized in Table 25 and Figure 12. It can be seen that Singapore DC location is more favorable in terms of Replenishment, Trade & Compliance, Logistics and Planning. It should be emphasized first that the definition of ‘location’ is broader than only a place where a DC is situated. Although it is a generic term often seen in AHP site location theory, the word has a much broader definition. In the case of the present study, the interest is in selecting the best scenario associated with a DC location. Based on our experience, participants could be misguided without this concept being clarified. For example, Replenishment is concerned with predictability. By definition, it is predictable when an agreement can be reached with a customer about delivery lead time. For the baseline (Singapore DC), Logitech does not deliver to Indian customers. With the restricted understanding of location, a participant would rate Singapore DC worse than DC’s inside India. It is because sea shipment between Singapore and India could add lead time variability and therefore instablizes delivery lead time. From a scenario-based perspective, however, Singapore DC is the best choice. Because Logitech is not responsible for delivery, customer satisfaction is always better, if not the best. From now on, the word ‘scenario’ will be used to clear the confusion.

To continue with the analysis, Singapore scenario is more favorable with respect to Replenishment. One reason, which has been mentioned in the example, is that Logitech does not need to do delivery. Concerning ‘Logitech field support’, the team based in Singapore has rich experience with regional customers and is rated excellent by the global director. With respect to Trade & Compliance, Singapore is a free trade zone. Overall, it is much more competent than India. One exception is ‘RMA processing difficulty’. Indian customs does not support returned goods to be exported. For this reason, Singapore is less preferred than Indian DC’s. For Logistics, Singapore port conditions and workforce are rated higher. As an intenrtional trade hub, Singapore is one of the best ports in the world. The educational level of labor and the availability of managers and blue-colar workers in logistics are both excellent. The advantage of Indian DC’s is DC to customers logistics. Because the distance is short and shipment is within India, the logistics lead-time and reliability are better in India than in Singapore. The last one is Planning, which is concerned with DC transit time and reliability and additional complexity to planning. For the first concern, the global director puts an emphasis on reliability, with which Singapore is more competent. With the second concern, Singapore is also better because an additional DC means the planning team has to invest more resources to cope with the change.

For After Sales, Indian DC’s are more preferred. As mentioned above, Indian customs does not support returned goods to be shipped out of India. Also, Mumbai and Chennai are close to Indian customers. Therefore, After Sales rates Indian scenarios higher than
the Singapore scenario.

The local Sales team has a mixed view. On the one hand, a DC inside India is thought to help with tax reduction. Although it means an additional running cost to have a dedicated tax team, the benefits are greater in the end. On the other hand, a DC in India means additional DC operation costs. Sales are driven by profit margin and less motivated by activities that involve any form of costs and expenses. For this reason, it is seen that Sales prefers to stay with the current Singapore DC. Globally speaking, the tax benefits may help to offset the added DC operation costs. Therefore, Singapore scenario is highly rated but slightly behind the Chennai scenario.

Between Mumbai and Chennai, there is a clear preference with Chennai over Mumbai. One exception is After Sales. It is mainly due to the fact that most Indian customers are located in the Mumbai area. Therefore, the distance to customers is shorter. Still, most functions show a clear preference to Chennai. The major reasons are the following. First, the Chennai customs is easier to be dealt with. The local Sales team maintain a good relationship with the port authority, which implicates that clearance processes will become faster and smoother. Second, the Mumbai port is one of the most congested port in the world. In contrary, the Chennai port has better port access and infrastructure. Third, Chennai is more cost effective. The local Sales team says Chennai is 50% more cost effective than Mumbai in terms of DC operations. Also, labor is cheaper in Chennai. Last but not the least, the availability of logistics professionals is better in Chennai than in Mumbai.

Finally, the final scores of 3 scenarios are displayed in Figure 13. It is seen that Singapore is the best choice with a score of 52%.

In the Appendix, raw outputs from the AHP model can be found in Table 27.

8 Conclusions and Recommendations

The major findings of the present study are the following:

- Cost analysis:
  - The cost analysis suggests that the end-to-end logistics cost will reduce if Indian market is served by a DC within India. However, the extent to which the total cost reduces is rather limited. The cost analysis does not show any significant saving in any of the 3 simulation scenarios.
  - The cost analysis shows that import duty accounts for the largest portion in total cost and also plays a major role in cost reduction. However, the analysis shows that import duty has a potential to reduce the total cost to a even greater extent. And the key is product mix.
  - Although bonded warehouse is much more expensive in terms of setup and operations, non-bonded warehouse does not meet the MRP labeling requirement. Unless factory origins can adapt to this requirement, non-bonded warehouse is not an option.

- Lead time analysis:
- The leadtime analysis supports the idea to have a DC in India. The total lead time, and especially DC to customers lead time are expected to drop significantly.

- **AHP site selection analysis:**
  - The AHP site selection model shows most Logitech functions prefer Singapore over Mumbai or Chennai, such as Replenishment, Trade & Compliance, Logistics, and Planning.
  - After Sales is the only function that has a strong preference for India.
  - If there has to be a new DC in India, almost all functions support Chennai.

Based on the findings, Logitech is recommended to do the following:

- Adjust product mix for Indian market. On the one hand, the AHP model shows that the local Sales are interested in having a DC in India. However, they are concerned about a reduction in profit margin due to added DC operation costs. On the other hand, the cost analysis shows there is an opportunity to increase profit margin. The key is import duty. To combine the results of both analysis, it is suggested to communicate with the local Sales team and create a plan together to set up a DC in Chennai, increase the percentage of non-input devices, reduce import duty and increase profit margin.

- Research on the possibility and cost to do MRP labeling in China. MRP labeling is the second highest cost element in the total cost. Because China is more competitive in terms of labor cost, it means a significant cost reduction on the long run. With this option enabled, a non-bonded warehouse becomes a practical solution. Therefore, the benefits are two fold and have a great impact.

- Negotiate sea shipment rates with the regional forwarder. It is expensive to ship to India directly or indirectly. If Logitech can quote a better rate, a significant cost reduction can be expected.

9 Limitations

Due to the time constraint, it is unfortunate that the present study has not been able to investigate the following topics:

- Cost analysis model validation with available financial data.
- A sensitivity analysis on key decision and constant variables, such as sea shipment rates, regional comparison factor, non-bonded to bonded factor and so on.
- A what-if analysis on the effect of product mix towards non-input devices.

One of the original assignments is to review APAC logistics network. Unfortunately, only a preliminary analysis has been done so far. Because it is not yet finalized, the outcome will not be included in this report.

Regarding the AHP model, a major lesson learnt is about soft skills. The AHP model uses human judgment as a source of inputs, therefore good communication skills are required.
to interview people. It is also important to observe what may or may not a participant understand. If necessary, confusion needs to be clarified as soon as there is a chance. But the challenge is whether or not the confusion can be observed easily. Moreover, organization is important especially when the participants are asked to follow a series of interviews. As the present author are still developing these skills, the benefits of the AHP model may not be fully explored in this study.

10 Theoretical Discussion

In practice, it is observed that a business decision is an internal negotiation of business functions. Although a quantitative analysis is objective, it does not address directly the interpretations of business functions on the outcome of the quantitative analysis. It is argued here that what really affects business decision making is the interests of business functions and their reaction to the quantitative analysis. Therefore, a quantitative analysis alone is not enough. A qualitative analysis, like the AHP, is needed to know the interests and concerns of business functions. With the knowledge provided by the AHP model, it becomes clear what may and what may not be relevant in the quantitative analysis. It is good for companies that the AHP model can lead through the complex and chaotic decision making processes.

For companies, the AHP theory certainly has a value. Site selection is one type of application. The scope is much wider, as seen in the literature. But one missing aspect, at least in the AHP application to site selection, is not to focus on internal business hierarchy. Based on the experience of the present study, instead of focusing on the external environment (external variables that describe the outside world, like taxation, local business culture, government, education and so on), the internal organization structure should be emphasized. The argument is: If modern businesses are based on a performance-driven scheme, it is unconvincing that business functions welcome any decision that damages their interest.

And the AHP model could be an excellent tool to bridge this gap. In the present study, for example, internal business hierarchy is placed inside the AHP model. At top levels of the decision making factor hierarchy, business functions are represented as decision making factors and help to express respective function interests. Because the AHP begins with the top levels, the interests of business functions become expressed at an early stage. In doing so, interests of business functions can either be autonomously balanced among functions or be intentionally aligned with the strategy of a higher function. At bottom levels, external variables provide the actual contents for comparison and spell out measures of candidates. External variables take into account business reality but they do not interfere the internal business processes. With such a hierarchy, both the internal and external interests are integrated into one decision making system, which could help companies with decision making.
References


Appendices

Appendix A  The map of Logitech DC’s

*Information is removed for confidential reasons.*

Figure 7: An overview of Logitech DC’s in the world.
Appendix B  Logistics network for Indian market

<table>
<thead>
<tr>
<th>Suppliers</th>
<th>Before FOB</th>
<th>Before Customs</th>
<th>At Customs</th>
<th>After Customs</th>
<th>Distributors &amp; Customers</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2M</td>
<td></td>
<td>SGP (FOB)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>ODM</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td>For Logitech</td>
</tr>
<tr>
<td>Shipments</td>
</tr>
<tr>
<td>Warehousing</td>
</tr>
<tr>
<td>For distributors</td>
</tr>
<tr>
<td>Shipments</td>
</tr>
<tr>
<td>Clearance (25% Invoice price)</td>
</tr>
<tr>
<td>Transportation</td>
</tr>
<tr>
<td>Transportation</td>
</tr>
<tr>
<td>Warehousing</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Lead Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 Weeks, 50% at Custom House</td>
</tr>
</tbody>
</table>

Figure 8: A graphical representation of current Logitech supply chain for Indian market. It is noted that major but not all cost components are listed in the figure.
Appendix C  Total logistics costs by Network Optimization Study 2011

Information is removed for confidential reasons.

Table 11: Worldwide logistics costs (estimated for fiscal year 2012). Total transport costs account for 72% of the total logistics costs, which is higher than the average industry ratio of 40% to 60% according to consultancy.
Appendix D  An overview of baseline and simulation scenarios

<table>
<thead>
<tr>
<th>Scenario name</th>
<th>Site location</th>
<th>Types of warehouse</th>
<th>Importation</th>
<th>MRP labeling</th>
</tr>
</thead>
<tbody>
<tr>
<td>Baseline</td>
<td>Singapore</td>
<td>Non-bonded</td>
<td>Free trade zone</td>
<td>Since the middle of 2012, MRP labeling has taken place at Singapore DC.</td>
</tr>
<tr>
<td>Mumbai Bonded</td>
<td>Mumbai</td>
<td>Bonded</td>
<td>Import duty required</td>
<td>With a bonded warehouse, goods can be shipped to the warehouse location and then have MRP labeling attached.</td>
</tr>
<tr>
<td>Mumbai Non-bonded</td>
<td>Mumbai</td>
<td>Non-bonded</td>
<td>Import duty required</td>
<td>With a non-bonded warehouse, goods cannot enter the Indian borders. Although MRP labeling could happen in the destination port, the efficiency is very limited due to port regulations. So, this option is necessary but not appealing. Another and perhaps the only option left is to do MRP labeling at factory origins. However, the setup cost is unclear.</td>
</tr>
<tr>
<td>Chennai Bonded</td>
<td>Chennai</td>
<td>Bonded</td>
<td>Import duty required</td>
<td>With a bonded warehouse, goods can be shipped to the warehouse location and then have MRP labeling attached.</td>
</tr>
<tr>
<td>Chennai Non-bonded</td>
<td>Chennai</td>
<td>Non-bonded</td>
<td>Import duty required</td>
<td>With a non-bonded warehouse, goods cannot enter the Indian borders. Although MRP labeling could happen in the destination port, the efficiency is very limited due to port regulations. So, this option is necessary but not appealing. Another and perhaps the only option left is to do MRP labeling at factory origins. However, the setup cost is unclear.</td>
</tr>
</tbody>
</table>

Table 12: An overview of five scenarios. The last column ‘MRP labeling’ is not part of any scenario description other than the baseline. It is included because MRP labeling is an important requirement for all simulation scenarios.
## Appendix E  Data sources of the cost and lead time analysis

<table>
<thead>
<tr>
<th>Datasources</th>
<th>Purpose</th>
<th>Instruction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shipment details report (SDR)</td>
<td>Outbound shipment details per Org-SKU, which is basis for all calculations; inbound freight, inbound handling, outbound handling, outbound freight and duties (also contains sell price for duty calculations)</td>
<td>Run the SDR in Oracle under responsibility OM Inquiry per region</td>
</tr>
<tr>
<td>Agile</td>
<td>Product characteristics, to calculate weight, CBM, carton quantity, pallet quantity, container quantity per SKU for the SDR, so it can be translated into measures over which the rates can be applied</td>
<td>Run the 8 and 9 level Packaging Data Report in Agile, that will contain all required information</td>
</tr>
<tr>
<td>WW Item Master</td>
<td>Product information, used to find information like factory (to find port of origin), duty information (HS code), material cost, product family per Org-SKU combination</td>
<td>Get latest version on the sharedrive</td>
</tr>
<tr>
<td>Freight rates</td>
<td>LSA bid rates, for inbound and outbound freight calculations, missing rates should be added</td>
<td>Request LSA bid rates at Lennart Nederpel (EMEA and AMR), Holly Lin (APJC)/ Request missing rates at Patrick Lanzing</td>
</tr>
<tr>
<td>WHS rates</td>
<td>Rates for inbound handling, serialization, material costs, outbound handling and fixed costs</td>
<td>Request at warehouse manager in region latest financial statement</td>
</tr>
<tr>
<td>Storage levels</td>
<td>Actual storage levels to define which percentage of total warehouse is dedicated for the first layer taken into consideration in simulation</td>
<td>Request period overview at warehouse manager in region</td>
</tr>
<tr>
<td>Exchange rates</td>
<td>Exchange rates, to calculate everything to US dollars if rates are specified in different currency</td>
<td>Balance sheet exchange rates on the Logitech Exchange</td>
</tr>
<tr>
<td>Supplier master</td>
<td>Document with all supplier names and ports of origin, to check what the port of origin is for each SKU shipped</td>
<td>Request at Lennart Nederpel or Victor Giesen</td>
</tr>
<tr>
<td>HS codes-duty percentages</td>
<td>Document per region that contains the duty percentage per HS code</td>
<td>On the Logitech Exchange in Contracts &amp; Trade Compliance Services</td>
</tr>
<tr>
<td>Markup</td>
<td>Document that shows markup per region, as well as freight insurance</td>
<td>Request at Lennart Nederpel or DJ Garner</td>
</tr>
<tr>
<td>ISO standard container type sea</td>
<td>Container maximum volumes, to calculate the CBM rates for inbound sea</td>
<td>Divide the rate per container with the CBM per container (20ft to 32.12 m³; 40ft to 65.7 m³; 40ft HC 74.23 m³)</td>
</tr>
<tr>
<td>Other rates</td>
<td>VAS rates, MRP rates or rates for miscellaneous if applicable</td>
<td>Request at warehouse or freight manager in region</td>
</tr>
<tr>
<td>Serialization information</td>
<td>Can be either exact per part number or estimate of warehouse manager, to check which part of inbound/outbound handling is serialized</td>
<td>Request at warehouse manager in region</td>
</tr>
<tr>
<td>Parameter settings</td>
<td>Settings for warehouse comparison to define difference in costs for regions, multiple DCs between baseline and simulations</td>
<td>Request at Patrick Lanzing</td>
</tr>
<tr>
<td>Expert opinions</td>
<td>There are types of costs that Logitech does not pay currently. But for calculation purposes, it is interesting to investigate the possible impacts. Without real life data, expert opinions are used as the basis of calculation</td>
<td>Request at experts (World Wide Trade &amp; Compliance Manager, Indian National Distribution Manager, and Senior APJ Logistics Manager)</td>
</tr>
</tbody>
</table>

Table 13: An overview of data sources, created by an experienced analyst in the team. The ‘Datasources’ column gives the names of datasources. The ‘Purpose’ column shows why the data sources are used in the model. The ‘Instruction’ column explains how to create the data sources. ‘CBM’ stands for cubic meters. LSA bid rates are the contract rates agreed with the forwarder. The ‘HS code’ stands for the Harmonized Commodity Description and Coding System code. It is an internationally standardized system for classifying traded products. The above mentioned markup is the costs added to the unit production cost. The additional costs cover the internal logistics costs to have traded products shipped from a factory origin to a destination DC.
Appendix F  An overview of modeling considerations in the cost analysis

Information is removed for confidential reasons.

Table 14: Processes, costs and respective modeling considerations for baseline and simulation scenarios. The symbol '-' means the cost element is not relevant to the corresponding scenario. ‘OTD’ stands for open to discussion. For example, non-bonded warehouse scenarios require MRP labeling to be complete before reaching Indian borders. Both factory origin or origin/destination port during the inbound shipment are possible options. But it is not yet clear which one is better. It is noted that Singapore DC is in a free trade zone. Therefore, bonded/non-bonded is not a relevant factor.
Appendix G  Raw data of truck rate multiplier approximation

*Information is removed for confidential reasons.*

Table 15: A comparison of original and approximation with respect to the same pallet number. In the approximation, FTL is 35 pallets, 2 pallets more than the original case.
Appendix H   VBA codes of the AHP model

Option Explicit
Public i As Integer
Public j As Integer
Public k As Integer
Public Const Iteration As Integer = 100
Public Const RightBound As Integer = 16

' MAIN PROGRAM THAT DEFINES THE STRUCTURE; THE FOLLOWING STEPS AIM TO HELP CREATE A USER INTERFACE
Private Sub Main1()
' Step 1 is basic setup that asks for initial inputs
Dim Msg As String
On Error GoTo BadEntry
MsgBox "The program will begin with Step 1, which is to setup the model. Please answer the following questions."
Call NextQueDec
Application.ScreenUpdating = False
Call PairwiseComp
Call DataArea
Exit Sub
BadEntry :
Msg = "An error occurred."
Msg = Msg & vbCrLf & vbCrLf
Msg = Msg & "Make sure you follow the instruction correctly."
Msg = MsgBox Msg, vbCritical
Exit Sub
End Sub

Private Sub Main2()
' Step 2 begins with EM calculation and the output gives a rank of decision making factors
Dim Msg As String
On Error GoTo BadEntry
Application.ScreenUpdating = False
Sheets("DecisionFactors").Activate
Call FactorPW
Call CompositePW
Application.ScreenUpdating = True
Sheets("PairwiseComp").Activate
MsgBox "Calculation is done. Please have a look. When you are ready, go back to 'Interface' and proceed with 'Step 3'."
Exit Sub
BadEntry :
Msg = "An error occurred."
Msg = MsgBox Msg, vbCritical
Exit Sub
End Sub

Private Sub Main3()
' Step 3 distinguishes quantifiable factors and then display matrices
Dim Msg As String
On Error GoTo BadEntry
Call CanComp
Exit Sub
BadEntry :
Msg = "An error occurred."
Msg = MsgBox Msg, vbCritical
Exit Sub
End Sub

Private Sub Main4()
' Step 4 does EM calculations for location comparison
Dim Msg As String
On Error GoTo BadEntry
Call CanPW
MsgBox "Calculation is done. Please have a look. When you are ready, go back to 'Interface' and finalize the program with 'Report'."
Exit Sub
BadEntry :
Msg = "An error occurred."
Msg = MsgBox Msg, vbCritical
Exit Sub
End Sub
Private Sub Fin()
    'The finishing step creates a report that summarizes all important information.
    Dim Msg As String
    On Error GoTo BadEntry
    Call Report
    MsgBox "The final report has been generated. Please have a look at the final conclusion."
    Exit Sub
    BadEntry:
    Msg = "An error occurred."
    MsgBox Msg & "Please go back to 'Interface', click on 'Report' to restart."
    Exit Sub
End Sub

'These sub functions below contain the actual contents to actualize a particular design. The main program above uses call function to use the following functions:

Private Sub Report()
    'This function generates a report that contains the results from decision factors comparison and location comparison. In addition, it writes the final conclusion regarding the most chosen candidate and its score. It also produces a comparison chart.
    Dim Sum As Integer
    Dim QualSum As Integer
    Dim QuanSum As Integer
    Dim Grd As Variant
    Dim List() As Variant
    Dim Count As Integer
    Dim Factor As String
    Dim TotScore As Double
    Dim BestCandy As String
    Dim TotRng As Variant
    Dim Rng1 As Variant
    Dim Rng2 As Variant
    Dim LScore As Double
    Dim CanChart As Chart
    Application.DisplayAlerts = False
    Application.ScreenUpdating = False
    For i = ActiveWorkbook.Worksheets.Count To 1 Step -1
        If Worksheets(i).Name = "FinalReport" Then
            Worksheets(i).Delete
        End If
    Next i
    Application.Worksheets.Add(Before:=Worksheets("RatingScale")).Name = "FinalReport"
    Sheets("FinalReport").Tab.ColorIndex = 8
    Range(Cells(1, 1), Cells(1, RightBound - 1)).Interior.Color = RGB(255, 255, 204)
    Cells(1, 1).Value = "Factor"
    Cells(1, 3).Value = "Composite priority weight"
    Cells(1, 6).Value = "|
    Cells(1, 7).Value = "Candidates:"
    Cells(1, 1).Font.Bold = True
    Cells(1, 3).Font.Bold = True
    Cells(1, 6).Font.Bold = True
    Cells(1, 7).Font.Bold = True
    Sheets("Candidates").Activate
    Range("A1").Activate
    'Copy candidate names to final report
    For i = 2 To RightBound
        If Cells(i, 1) <> "|
            Count = Count + 1
        Else:
            i = RightBound
        End If
    Next i
    ReDim List(1 To Count)
    Sheets("Candidates").Activate
    For i = 1 To Count
        List(i) = Cells(i + 1, 1).Value
    Next i
    Sheets("FinalReport").Activate
    Cells(1, 8).Select
    For i = 1 To Count
        Cells(i, 8 + i).Value = List(i)
        Cells(i, 8 + i).Font.Bold = True
    Next i
    'The main code of writing the final report
    Sum = Sheets("DecisionFactors").Range("A:A").Count
    Grd = ActiveWorkbook.Sheets("DecisionFactors").Cells(Sum, 1).Value
    Sheets("DecisionFactors").Activate
    'Copy the lowest level factors from 'DecisionFactors' sheet and their CW
    For i = 2 To Sum
        If Cells(i, 1).Value = Grd Then
            Cells(i, 3).Select
            Selection.Copy
            Sheets("FinalReport").Activate
            If IsEmpty(Cells(2, 1)) = True Then
                Cells(2, 1).Select
                ActiveCell.PasteSpecial(xlPasteValues)
            Else
                Cells(1, 1).Select
                Selection.End(xlDown).Offset(1, 0).Select
                ActiveCell.PasteSpecial(xlPasteValues)
            End If
        End If
    Next i
End Sub
Sheets("DecisionFactors").Activate
If Cells(i, 1).Value = Grd Then
    Cells(i, 7).Select
Selection.Copy
Sheets("FinalReport").Activate
If IsEmpty(Cells(2, 3)) = True Then
    Cells(2, 3).Select
    Selection.End(xlDown).Offset(1, 0).Select
    ActiveCell.PasteSpecial(xlPasteValues)
Else
    Cells(1, 3).Select
    Selection.End(xlDown).Offset(1, 0).Select
    ActiveCell.PasteSpecial(xlPasteValues)
End If
End If
Sheets("DecisionFactors").Activate
Next i
'Copy candidates ratings WRT decision factors
Sheets("Candidates").Activate
QualSum = Sheets("Candidates").Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
QuanSum = Sheets("Candidates").Range("Q:Q").Cells.SpecialCells(xlCellTypeConstants).Count
For i = 1 To Sum
    Sheets("FinalReport").Select
    Factor = Cells(i, 1).Value
    For j = 1 To QualSum
        Sheets("Candidates").Activate
        If Cells(j, 1) = Factor And Cells(j, 1).Font.Bold = True Then
            For k = 1 To Count
                Cells(j, 1).Activate
                ActiveCell.Offset(k, Count + 2).Copy
            End If
        End If
    Next j
    Sheets("Candidates").Select
Next k
End If
Next i
For i = 1 To QuanSum
    Sheets("FinalReport").Select
    Factor = Cells(i, 1).Value
    For j = 1 To Count
        Sheets("Candidates").Activate
        If Cells(j, 17) = Factor And Cells(j, 17).Font.Bold = True Then
            For k = 1 To Count
                Cells(j, 17).Activate
                ActiveCell.Offset(k, 3).Copy
            End If
        End If
    Next j
    Sheets("Candidates").Select
Next k
End If
Next i
'Now, the program begins to calculate the final score for each candidate
Cells(Sum + 1, 6).Value = "Total score"
Cells(Sum + 1, 6).Font.Bold = True
For i = 1 To Count
    TotScore = 0
    For j = 2 To Sum
        TotScore = TotScore + Cells(j, 3).Value * Cells(j, 8 + i).Value
    Next j
    Cells(Sum + 1, 8).Offset(0, i).Value = TotScore
    Cells(Sum + 1, 8).Offset(0, i).Interior.Color = RGB(219, 229, 241)
    Cells(Sum + 1, 8).Offset(0, i).Font.Bold = True
Next i
Set Rng1 = Range(Cells(Sum + 1, 9), Cells(Sum + 1, 9 + Count - 1))
LScore = WorksheetFunction.Max(Rng1)
For i = 1 To Count
    If Cells(Sum + 1, 8 + i).Value = LScore Then
        BestCandy = Cells(1, 8 + i).Value
        End If
Next i
Cells(Sum + 5, 3).Value = "Summary"
Cells(Sum + 8, 3).Value = "The best candidate is:"
Cells(Sum + 9, 3).Value = "With a preference score of:"
Cells(Sum + 9, 10).Value = LScore
Cells(Sum + 9, 10).NumberFormat = "0%"
'Bold
Cells(Sum + 5, 3).Font.Bold = True
Cells(Sum + 8, 3).Font.Bold = True
Cells(Sum + 8, 10).Font.Bold = True
Cells(Sum + 9, 3).Font.Bold = True
Cells(Sum + 9, 10).Font.Bold = True
'Italic
Cells(Sum + 5, 3).Font.Italic = True
Cells(Sum + 8, 3).Font.Italic = True
Cells(Sum + 8, 10).Font.Italic = True
Cells(Sum + 9, 3).Font.Italic = True
Cells(Sum + 9, 10).Font.Italic = True
'Font size
Cells(Sum + 5, 3).Font.Size = 40
Cells(Sum + 8, 3).Font.Size = 20
Cells(Sum + 8, 10).Font.Size = 20
Cells(Sum + 9, 3).Font.Size = 20
Cells(Sum + 9, 10). Font.Size = 20
'underline
Cells(Sum + 5, 3). Font.Underline = True
For i = 1 To 4
   Cells(Sum + 5, 2 + i). Interior.Color = RGB(255, 255, 204)
Next i

Application.ScreenUpdating = False
Set Rng2 = Range(Cells(1, 9). Cells(1, 9 + Count - 1))
Set TotRng = Union(Rng1, Rng2)
Set CanChart = ActiveSheet.Shapes.AddChart.Chart
With CanChart
   .SetSourceData TotRng
   .ChartType = xl3DBarClustered
   .Legend.Delete
   .PlotBy = xlRows
   .HasTitle = True
   .ChartTitle.Text = "The final scores of all candidates"
End With

CanChart.Parent.Height = 550
ActiveSheet.ChartObjects(1).Left = ActiveSheet.Columns(3).Left
ActiveSheet.ChartObjects(1).Top = ActiveSheet.Rows(Sum + 10).Top
Application.ScreenUpdating = True
Sheets("FinalReport"). Activate

'React to the original , which is defined below
Private Sub ResetAfterStep3()
   Application.DisplayAlerts = False
   Application.ScreenUpdating = False
   For i = ActiveWorkbook.Worksheets.Count To 1 Step -1
      If Worksheets(i).Name <> "Interface" And Worksheets(i).Name <> "RatingScale" Then
         Worksheets(i).Delete
      Next i
   Application.DisplayAlerts = True
   Application.ScreenUpdating = True
   Sheets("DecisionFactors"). Activate
   Call DataArea
   Exit Sub
Next i
Call PairwiseComp
Call FactorPW
Call CompositePW
Sheets("FinalReport"). Activate
MsgBox "Calculation has been re-done. Please check if all matrices are consistent. If not, review your decision.
If everything is OK, please continue with the next step." & vbNewLine & vbNewLine
Msg = "An error occurred."
Msg = MsgBox(Msg & " Make sure you follow the instruction correctly. " & vbNewLine & vbNewLine
   "Please go back to 'Interface', 'Restart' with Step 2."
MsgBox Msg, vbCritical
End Sub
Private Sub RecalculateAfterStep1()
   Application.ScreenUpdating = True
   Sheets("DecisionFactors"). Activate
   Call PairwiseComp
   Exit Sub
End Sub

Dim Mag As String
On Error GoTo BadEntry
Sheets("DecisionFactors"). Activate
MsgBox "Calculation has been re-done. Please check if all matrices are consistent. If not, review your decision.
If everything is OK, please continue with the next step." & vbNewLine & vbNewLine
Msg = "An error occurred."
Msg = MsgBox(Msg & " Make sure you follow the instruction correctly. " & vbNewLine & vbNewLine
   "Please go back to 'Interface', 'Restart' with Step 2."
MsgBox Msg, vbCritical
End Sub
Private Sub RecalculateAfterStep1()
   Application.ScreenUpdating = True
   Sheets("DecisionFactors"). Activate
   Call PairwiseComp
   Exit Sub
End Sub

Dim Mag As String
On Error GoTo BadEntry
Application.ScreenUpdating = False
Call FactorPW
Call CompositePW
Sheets("FinalReport"). Activate
MsgBox "Calculation has been re-done. Please check if all matrices are consistent. If not, review your decision.
If everything is OK, please continue with the next step." & vbNewLine & vbNewLine
Msg = "An error occurred."
Msg = MsgBox(Msg & " Make sure you follow the instruction correctly. " & vbNewLine & vbNewLine
   "Please go back to 'Interface', 'Restart' with Step 2."
MsgBox Msg, vbCritical
End Sub
Private Sub ResetAfterStep3()
   Application.ScreenUpdating = False
   Sheets("FinalReport"). Activate
   Call DataArea
   Exit Sub
End Sub

Dim Mag As String
On Error GoTo BadEntry
Sheets("DecisionFactors"). Activate
Application.DisplayAlerts = False
58
Application.ScreenUpdating = False
For i = ActiveWorkbook.Worksheets.Count To 1 Step -1
  If Worksheets(i).Name = "Candidates" Then _
    Worksheets(i).Delete
Next i
Call CanComp
Application.DisplayAlerts = True
Application.ScreenUpdating = True
Exit Sub

BadEntry:
  Msg = "An error occurred." & vbCrLf & vbCrLf & "Make sure you follow the instruction correctly." & vbCrLf & vbCrLf
  MsgBox Msg, vbCritical
End Sub

Private Sub RecalculateAfterStep3()
  ' # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
  ' # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # Recalculate PW's of decision factors # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
  ' # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
  Dim Msg As String
  On Error GoTo BadEntry
  Application.ScreenUpdating = False
  Call CanPW
  Sheets("Candidates").Activate
  MsgBox "Calculation has been re-done. Please check if all matrices are consistent. If not, review your decision(s). If everything is OK, please continue with the next step."
  Exit Sub
BadEntry:
  MsgBox Msg, vbCritical
End Sub

Private Sub NextQueDec()
  ' # # # # # # # # # # # # # # # # # #Generates new questions based on the results of earlier questions# # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # # #
  Dim Ans As Integer
  Dim TotLevel As Integer
  Dim TotFactor As Integer
  Dim FirstRow As Integer
  Dim Sum As Integer
  Dim MemoryList() As Variant
  Dim Msg As String
  Dim sh As Worksheet
  'The following lines check if the intended worksheet already exists. If not, create one.
  For Each sh In ActiveWorkbook.Worksheets
    Application.DisplayAlerts = False
    If sh.Name = "DecisionFactors" Then sh.Delete
  Next sh
  Application.DisplayAlerts = True
  Application.Worksheets.Add(after:=Worksheets("Interface")).Name = "DecisionFactors"
  ActiveWindow.DisplayGridlines = False
  Sheets("DecisionFactors").Activate
  Range(Cells(1, 1), Cells(1, RightBound - 1)).Interior.Color = RGB(255, 255, 204)
  Cells(1, 1).Value = "Level"
  Cells(1, 3).Value = "Factor"
  Cells(1, 5).Value = "Parent factor"
  Cells(1, 7).Value = "Composite priority weight"
  Cells(1, 1).Font.Bold = True
  Cells(1, 3).Font.Bold = True
  Cells(1, 5).Font.Bold = True
  Cells(1, 7).Font.Bold = True
  'The essential code
  FirstRow = 1
  Sum = 0
  TotLevel = InputBox("How many levels are there in total?"")
  For i = 1 To TotLevel
    TotFactor = InputBox("How many factors are there in Level " & i & " ?")
    ReDim MemoryList(1 To TotFactor)
    For j = 1 To TotFactor
      Cells(FirstRow + j, 1).Value = i
      Cells(FirstRow + j, 3).Value = InputBox("What is the name of Factor " & j & " ?")
      Cells(FirstRow + j, 5).Value = "Root"
    Next j
    Else
      TotFactor = InputBox("How many factors are there in Level " & i & " ?")
      For j = 1 To TotFactor
        Cells(FirstRow + j, 1).Value = i
        Cells(FirstRow + j, 3).Value = InputBox("What is the name of Factor " & j & " ?")
      Next j
    End If
  Next i
  MagBox = "Next, the system will ask some more questions to clarify the relationship between factors."
  For i = 1 To Sum
    FirstRow = 1
    If Cells(FirstRow + i, 1).Value <> 1 Then
      For j = FirstRow + i To 2 Step -1
        If Cells(j, 1).Value = Cells(FirstRow + i, 1) - 1 Then
          If IsEmpty(Cells(FirstRow + i, 5)) = True Then
            Ans = MagBox("Is " & Cells(j, 3).Value & " the parent factor of " & Cells(j, 5).Value & "?"
          End If
        End If
      Next j
    End If
  Next i
End Sub
This algorithm creates a number of matrices according to parent-sub factor relationship.

Dim Sum As Integer
Dim Parent() As Variant
Dim OldParent As Variant
Dim NumParent As Integer
Dim NextEmptyRow As Integer
Dim FirstRow As Integer
Dim UberCol As Integer
Dim Rng As Variant
Dim sh As Worksheet

For Each sh In ActiveWorkbook.Worksheets
    Application.DisplayAlerts = False
    If sh.Name = "PairwiseComp" Then sh.Delete
    Application.DisplayAlerts = True
Next sh

' The following lines check if the intended worksheet already exists. If not, create one.
For Each sh In ActiveWorkbook.Worksheets
    Application.DisplayAlerts = False
    If sh.Name = "PairwiseComp" Then sh.Delete
    Application.DisplayAlerts = True
Next sh

Sheets("DecisionFactors").Activate

For i = 1 To NumParent
    If i = 1 Then
        ActiveCell.Offset(1, 0).Select
    Else
        UberCol = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
        OldParent = "Nothing"
        ReDim Parent(1 To NumParent)
    End If
    Next i

For i = 2 To NumParent
    Parent(i - 1) = Cells(i, 5).Value
    For j = NumParent - 1 To 1
        If Parent(j + k) = Parent(j) Then
            Parent(j + k) = Cells(i, 5).Value
            k = NumParent - j
        ElseIf Parent(j + k) = Cells(i, 5).Value Then
            k = NumParent - j
        End If
    Next k
    Next j

For i = 1 To NumParent
    Sheets("PairwiseComp").Activate
    If IsEmpty(ActiveCell) Then
        UberCol = 0
    Else
        UberCol = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
    End If
    If i = 1 Then
        ActiveCell.Offset(1, 0).Select
    Else
        ActiveCell.Offset(2, 0).Select
    End If
    Selection.Copy
    Sheets("DecisionFactors").Activate
    For j = 1 To NumParent
        If Cells(j, 5) = Parent(i) Then
            Cells(j, 3).Select
        End If
    Next j
    sheets("PairwiseComp").activate
    If IsEmpty(ActiveCell) = True Then
        ActiveSheet.Paste
    Else
        NextEmptyRow = Range("A:A").End(xlDown).Row + 1
        Cells(NextEmptyRow - 1).Select
        ActiveSheet.Paste
    End If
    OldParent = Parent(i)
Next i
Cells(1, RightBound).Value = " Note: Before you continue, please make sure all consistency tests on 'PairwiseComp' are positive (indicated by green)."
Cells(2, RightBound).Value = When everything is OK, please go to 'Interface' and click on 'Step 3'."
Cells(3, RightBound).Font.Bold = True
Cells(3, RightBound).Font.Italic = True
Cells(3, RightBound).Font.Bold = True
Cells(3, RightBound).Font.Bold = True
Sheets("PairwiseComp").Activate

Private Sub CanComp()
    'This is used to create a profile of all candidates.
The following lines check if the intended worksheet already exists. If not, create one.
Dim Grd As Variant
Dim Sum As Integer
Dim sh As Worksheet
Dim Count As Integer
Dim FacList() As Variant
Dim CanList() As Variant
Dim Ans As String
Dim NumCandy As Integer
Dim FirstRowQuan As Integer
Dim Rng As Variant
For Each sh In ActiveWorkbook.Worksheets
    Application.DisplayAlerts = False
    If sh.Name = "Candidates" Then sh.Delete
    Application.DisplayAlerts = True
Next sh
Application.Worksheets.Add(after:=Worksheets("PairwiseComp")).Name = "Candidates"
ActiveWindow.DisplayGridlines = False
Sheets("Candidates").Activate
'Here, the program should secretly create final report and put down the outline.
For i = 1 To ActiveWorkbook.Worksheets.Count To 1 Step -1
    Application.DisplayAlerts = False
    If Worksheets(i).Name = "FinalReport" Then
        Worksheets(i).Delete
    End If
Next i
Application.Worksheets.Add(before:=Worksheets("RatingScale")).Name = "FinalReport"
Sheets("FinalReport").Tab.ColorIndex = 8
ActiveWindow.DisplayGridlines = False
Range(Cells(1, 1), Cells(1, RightBound - 1)).Interior.Color = RGB(255, 255, 204)
Cells(1, 1).Value = "Factor"
Cells(1, 3).Value = "Composite priority weight"
Cells(1, 6).Value = "|
Cells(1, 7).Value = "Candidates:"
Cells(1, 1).Font.Bold = True
Cells(1, 3).Font.Bold = True
Cells(1, 6).Font.Bold = True
Cells(1, 7).Font.Bold = True

The essential code
Application.ScreenUpdating = True
Sheets("Candidates").Activate
MsgBox "Step 3 begins with requiring information about the number of candidates and their names."
NumCandy = InputBox("How many candidates are there under consideration?")
ReDim CanList(1 To NumCandy)
For i = 1 To NumCandy
    CanList(i) = InputBox("Please type in the name of Candidate " & i & ", 
    If IsEmpty(Cells(1, RightBound + 1)) = True Then
        FirstRowQuan = 1
    Else
        FirstRowQuan = FirstRowQuan + NumCandy + 1
    End If
Next i
MsgBox "Now the program will ask if a decision factor is quantifiable. Please answer all questions."
Sum = Sheets("DecisionFactors").Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
Count = 0
'Look up the lowest level
Grd = ActiveWorkbook.Sheets("DecisionFactors").Cells(Sum, 1).Value
'Count the number of elements at the lowest level
For i = 2 To Sum
    If ActiveWorkbook.Sheets("DecisionFactors").Cells(i, 1).Value = Grd Then
        Count = Count + 1
    End If
Next i
'Create a list of decision factors at the lowest level
ReDim FacList(1 To Count)
For i = 1 To Count
    FacList(i) = ActiveWorkbook.Sheets("DecisionFactors").Cells(Sum - Count + i, 3).Value
Next i
For i = 1 To Count
    Ans = MsgBox("Is " & FacList(i) & " quantifiable?", vbYesNo)
Sub DataAreaCan ( ByVal NumCandy As Integer )
Dim Ans As String
Dim RowRef As Integer
Dim Sum As Integer
Dim MatrixSize As Integer
Dim DataAreaCan (NumCandy)
End Sub

Private Sub DataAreaCan ( ByVal NumCandy As Integer )
Dim Rng As Range
Dim RowRef As Integer
Dim Sum As Integer
Dim MatrixSize As Integer
Dim Ans As String
End Sub

' This function is designed for the decision factors page.
ActiveWindow.DisplayGridlines = False
Dim MatrixSize As Integer
Dim Sum As Integer
Dim RowRef As Integer
Dim Rng As Range
Sheets("PairwiseComp").Range("A1").Select
Dim FacList As Variant
For i = 1 To Sum
Cells(FacList(i), 1).Select
Cells(FacList(i), 1).Value = FacList(i)
Cells(FacList(i), 1).Font.Bold = True
Cells(FacList(i), 1).Font.Italic = True
MatrixSize = FacList(i)
Set Rng = Range(Cells(ActiveCell.Row, 1), Cells(ActiveCell.Row, RightBound + 1))
Rng.Interior.Color = RGB(255, 255, 204)
End For

For k = 1 To MatrixSize
ActiveCell.Offset(k, 0).Value = CanList(k)
End Sub

Private Sub DataAreaCan(ByVal NumCandy As Integer)
Dim Ans As String
Dim RowRef As Integer
Dim Sum As Integer
Dim MatrixSize As Integer
Dim DataAreaCan (NumCandy)
End Sub
Else If j > k Then
    ActiveCell.Offset(j, k).Formula = "=if(" & ActiveCell.Offset(k, j).Address & ")")
Else
    ActiveCell.Offset(1, 0).Select
End If
Next k

Next j
ActiveCell.Offset(1, 0).Select

Else: ActiveCell.Offset(1, 0).Select
End If
Next i

'For quantitative factors
Sheets("Candidates").Range("Q1").Select
Sum = Range("Q:Q").Cells.SpecialCells(xlCellTypeConstants).Count
For i = 1 To Sum
    If ActiveCell.Font.Bold = True Then
        Ans = MsgBox("Is " & ActiveCell.Value & " more favorable if its value is greater?", vbYesNo)
        Select Case Ans
        Case vbYes
            For j = 1 To MatrixSize
                For k = 1 To 3
                    If k = 1 Then
                        ActiveCell.Offset(j, k).Interior.Color = 65535
                    Else
                        ActiveCell.Offset(j, k).Formula = "/SUM(" & ActiveCell.Offset(j, 1).Address & ")")
                    End If
                Next k
            Next j
        Case vbNo
            For j = 1 To MatrixSize
                For k = 1 To 3
                    If k = 1 Then
                        ActiveCell.Offset(j, k).Interior.Color = 65535
                    Else
                        ActiveCell.Offset(j, k).Formula = "/SUM(" & ActiveCell.Offset(j, k - 1).Address & ")")
                    End If
                Next k
            Next j
        End Select
    End If: ActiveCell.Offset(1, 0).Select
End If
Next i

Cells(1, RightBound + 5).Value = "Note: There are two major columns. The one on the left contains qualitative factors. The one on the right contains quantitative factors."
Cells(2, RightBound + 5).Value = "The program has finished with information collection based on quantitative analysis."
Cells(3, RightBound + 5).Value = "Only when rating is complete, please go to 'Interface' and click on 'Step 4'.
Attention: Only the yellow cells require inputs!!"

Private Sub FactorPW()
    Dim MSize As Integer
    Dim CurRow As Integer
    'Dim Iteration As Integer
    Dim Sum As Integer
    Dim Rng As Variant
    Dim RunTime As Integer

    Iteration = 100
    Sum = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
    For RunTime = 1 To Sum
        If ActiveCell.Font.Bold = True Then
            For k = 1 To RightBound + 1
                If Cells(RunTime, k).Value = "|" Then
                    Set Rng = Range(Cells(ActiveCell.Row, 1), Cells(ActiveCell.Row, k))
                    MSize = k - 2
                    CurRow = ActiveCell.Row + 1
                    Call PowerIter(MSize, CurRow, Iteration)
                    ActiveCell.Offset(1, 0).Select
                End If
            Next k
        End If
    Next RunTime
End Sub

End Sub

'Important note: this program does not work if contents extend over the right limit; but the limit can be resized if necessary.
Private Sub FactorPW()
Dim MSize As Integer
Dim CurRow As Integer
'Dim Iteration As Integer
Dim Sum As Integer
Dim Rng As Variant
Dim RunTime As Integer

'Iteration = 100
Sheets("PairwiseComp").Activate
Sheets("PairwiseComp").Range("A1").Select
Sum = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
For RunTime = 1 To Sum
    If ActiveCell.Font.Bold = True Then
        For k = 1 To RightBound + 1
            If Cells(RunTime, k).Value = "|" Then
                Set Rng = Range(Cells(ActiveCell.Row, 1), Cells(ActiveCell.Row, k))
                MSize = k - 2
                CurRow = ActiveCell.Row + 1
                Call PowerIter(MSize, CurRow, Iteration)
                ActiveCell.Offset(1, 0).Select
            End If
        Next k
    End If
End If
Next RunTime
End Sub
'Calculate priority weights of candidates WRT decision factors

# Important note: this program does not work if contents extend over the right limit; but the limit
' can be resized if necessary.
Private Sub CanPW()
Dim MSize As Integer
Dim CurRow As Integer
'Dim Iteration As Integer
Dim Sum As Integer
Dim Rng As Variant
Dim RunTime As Integer
' Iteration = 100
Sheets("Candidates").Activate
Sheets("Candidates").Range("A1").Select
Sum = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
For RunTime = 1 To Sum
If ActiveCell.Font.Bold = True Then
    For k = 1 To RightBound + 1
        If Cells(RunTime, k).Value = "|" Then
            Set Rng = Range(ActiveCell.Row, 1), Cells(ActiveCell.Row, k)
            MSize = k - 2
            CurRow = ActiveCell.Row + 1
            Call PowerIter(MSize, CurRow, Iteration)
            ActiveCell.Offset(1, 0).Select
        End If
    Next k
Else: ActiveCell.Offset(1, 0).Select
End If
Next RunTime
End Sub

Power method

The first section is to establish the basic variables and define the A and x matrix.
Private Sub PowerIter(ByVal MSize, ByVal CurRow, ByVal Iteration)
Dim AMatrix() As Variant
Dim xMatrix() As Variant
Dim BLamb As Double
Dim Sum As Integer
Dim Row As Integer
Dim Col As Integer
ReDim AMatrix(1 To MSize, 1 To MSize)
ReDim xMatrix(1 To MSize)
' Here the AMatrix is defined
For Row = 1 To MSize
    For Col = 1 To MSize
        AMatrix(Row, Col) = Cells(CurRow + Col - 1, Row + 1)
    Next Col
Next Row
' Here the xMatrix is defined
For Row = 1 To MSize
    xMatrix(Row) = 1
Next Row
' In this section, Power method is performed once
Dim xNewMatrix As Variant
xNewMatrix = WorksheetFunction.MMult(xMatrix, AMatrix)
' Iteration begins; power method is performed repeatedly for given times
For i = 1 To Iteration - 1
    For j = 1 To MSize
        xMatrix(j) = xNewMatrix(j)
    Next j
    xNewMatrix = WorksheetFunction.MMult(xMatrix, AMatrix)
Next i
' Print out the JW results
Dim SumVector As Double
Cells(CurRow - 1, MSize + 3).Value = "IW"
Cells(CurRow - 1, MSize + 3).Font.Bold = True
For i = 1 To MSize
    SumVector = SumVector + xNewMatrix(i) / xNewMatrix(MSize)
Next i
For i = 1 To MSize
    Cells(i + CurRow - 1, MSize + 3).Value = (xNewMatrix(i) / xNewMatrix(MSize)) / SumVector
    Cells(i + CurRow - 1, MSize + 3).Font.Bold = True
    Cells(i + CurRow - 1, MSize + 3).Interior.Color = 8421504
Next i
' Calculate the biggest lambda
Dim MatForLam As Variant
MatForLam = WorksheetFunction.MMult(xNewMatrix, AMatrix)
BLamb = WorksheetFunction.SumProduct(MatForLam, xNewMatrix) / WorksheetFunction.SumProduct(xNewMatrix, xNewMatrix)
' Print out the biggest lambda
Cells(CurRow - 1, MSize + 4).Value = "EigenV"
Cells(CurRow - 1, MSize + 4).Font.Bold = True
Cells(CurRow, MSize + 4) = BLamb
Cells(CurRow - 1, MSize + 4).Font.Bold = True
Cells(CurRow, MSize + 4).Interior.Color = 8421504
ActiveCell.Offset(200, 200).Value = "Programmer Jing Luo TU/e student while doing internship at Logitech, Fall 2012"
' Calculate the CI and consistency
Dim CI As Double
Dim ConRatio As Double
Dim n As Integer
n = MSize
Cells(CurRow - 1, MSize + 5).Value = "CI"
' Important note: this program does not work if contents extend over 30 columns; but the limit can be increased if needed.

Private Function PWLookUp(Fac As String) As Double
Dim Sum As Integer
Dim PWCount As Integer
For PWCount = 1 To Sum
If Cells(PWCount, 1).Font.Bold = False And Fac = Cells(PWCount, 1).Value Then
For k = 1 To 30
PWLookUp = Worksheets(“PairwiseComp”).Cells(PWCount, k).Value
End If
Next k
Else
PWLookUp = 0
End If
End If
Next PWCount
End Function

Private Function RILookUp(Num As Integer) As Double
Dim Sum As Integer
Dim RICount As Integer
For RICount = 1 To Sum
If Cells(RICount, 1).Font.Bold = False And Num = Cells(RICount, 1).Value Then
For n = 1 To 10
If n = 1 Then
RILookUp = 1.49
Else If n = 2 Then
RILookUp = 1.45
Else If n = 3 Then
RILookUp = 1.41
Else If n = 4 Then
RILookUp = 1.37
Else If n = 5 Then
RILookUp = 1.12
Else If n = 6 Then
RILookUp = 0.9
Else If n = 7 Then
RILookUp = 0.8
Else If n = 8 Then
RILookUp = 0.58
Else If n = 9 Then
RILookUp = 0.45
Else If n = 10 Then
RILookUp = 0
End If
End If
Next n
End If
End If
Next RICount
End Function

Private Function PFLookUp(Fac As String) As String
Dim Sum As Integer
Dim PFCount As Integer
For PFCount = 1 To Sum
If Cells(PFCount, 1).Font.Bold = False And Fac = Cells(PFCount, 1).Value Then
For k = 1 To 30
For i = PFCount - 1 To 1 Step -1
Cells(CurRow, MSize + 6).Value = “Yes”
Cells(CurRow, MSize + 6).Interior.Color = 65280
Else
Cells(CurRow, MSize + 6).Value = “No”
Cells(CurRow, MSize + 6).Interior.Color = 255
End If
End For
Else
Cells(CurRow, MSize + 6).Value = “If consistent?”
Cells(CurRow, MSize + 6).Interior.Color = 8421504
End If
End For
Next i
Next k
Else
Cells(CurRow, MSize + 5).Value = “If consistent?”
Cells(CurRow, MSize + 5).Interior.Color = 8421504
End If
End If
End If
Next PFCount
End Function

Private Function LLookUp(Fac As String) As Integer
Dim Sum As Integer
Dim LCount As Integer
For LCount = 1 To Sum
If Cells(LCount, 1).Font.Bold = False And Fac = Cells(LCount, 1).Value Then
ConRatio = 0
Else
ConRatio = CI / RILookUp(n)
End If
If ConRatio <= 0.1 Then
Cells(CurRow, MSize + 5).Value = “Yes”
Cells(CurRow, MSize + 5).Interior.Color = 65280
Else
Cells(CurRow, MSize + 5).Value = “No”
Cells(CurRow, MSize + 5).Interior.Color = 255
End If
End If
End Sub

Private Function LLookUp(Fac As String) As Integer
Dim Sum As Integer
Dim LCount As Integer
For LCount = 1 To Sum
If Cells(LCount, 1).Font.Bold = False And Fac = Cells(LCount, 1).Value Then
For k = 1 To 30
If Worksheets(“DecisionFactors”).Cells(j, k).Font.Bold = True Then
Cells(CurRow, MSize + 6) = CI
Cells(CurRow, MSize + 6).Interior.Color = 8421504
Cells(CurRow, MSize + 6).Font.Bold = True
Else
Cells(CurRow, MSize + 6).Value = “If consistent?”
Cells(CurRow, MSize + 6).Interior.Color = 8421504
End If
End For
Next k
Else
Cells(CurRow, MSize + 5).Value = “If consistent?”
Cells(CurRow, MSize + 5).Interior.Color = 8421504
End If
End If
End If
Next LCount
End Function

Private Function PFLookUp(Fac As String) As String
Dim Sum As Integer
Dim PFCount As Integer
For PFCount = 1 To Sum
If Cells(PFCount, 1).Font.Bold = False And Fac = Cells(PFCount, 1).Value Then
For k = 1 To 30
Cells(CurRow, MSize + 5).Value = “Yes”
Cells(CurRow, MSize + 5).Interior.Color = 65280
Else
Cells(CurRow, MSize + 5).Value = “No”
Cells(CurRow, MSize + 5).Interior.Color = 255
End If
End For
Next k
Else
Cells(CurRow, MSize + 5).Value = “If consistent?”
Cells(CurRow, MSize + 5).Interior.Color = 8421504
End If
End If
End If
Next PFCount
End Function

Private Function PWLookUp(Fac As String) As Double
Dim Sum As Integer
Dim PWCount As Integer
For PWCount = 1 To Sum
If Cells(PWCount, 1).Font.Bold = False And Fac = Cells(PWCount, 1).Value Then
For k = 1 To 30
If Worksheets(“PairwiseComp”).Cells(j, k).Font.Bold = True Then
PWLookUp = Worksheets(“PairwiseComp”).Cells(PWCount, k).Value
End If
Next k
Else
PWLookUp = 0
End If
End If
Next PWCount
End Function

Private Function RILookUp(Num As Integer) As Double
Dim Sum As Integer
Dim RICount As Integer
For RICount = 1 To Sum
If Cells(RICount, 1).Font.Bold = False And Num = Cells(RICount, 1).Value Then
For n = 1 To 10
If n = 1 Then
RILookUp = 1.49
Else If n = 2 Then
RILookUp = 1.45
Else If n = 3 Then
RILookUp = 1.41
Else If n = 4 Then
RILookUp = 1.37
Else If n = 5 Then
RILookUp = 1.12
Else If n = 6 Then
RILookUp = 0.9
Else If n = 7 Then
RILookUp = 0.8
Else If n = 8 Then
RILookUp = 0.58
Else If n = 9 Then
RILookUp = 0.45
Else If n = 10 Then
RILookUp = 0
End If
End If
End If
Next n
End If
End If
Next RICount
End Function

Private Function LLookUp(Fac As String) As Integer
Dim Sum As Integer
Dim LCount As Integer
For LCount = 1 To Sum
If Cells(LCount, 1).Font.Bold = False And Fac = Cells(LCount, 1).Value Then
ConRatio = 0
Else
ConRatio = CI / RILookUp(n)
End If
If ConRatio <= 0.1 Then
Cells(CurRow, MSize + 5).Value = “Yes”
Cells(CurRow, MSize + 5).Interior.Color = 65280
Else
Cells(CurRow, MSize + 5).Value = “No”
Cells(CurRow, MSize + 5).Interior.Color = 255
End If
End If
End If
End If
Next LCount
End Function

Private Function PFLookUp(Fac As String) As String
Dim Sum As Integer
Dim PFCount As Integer
For PFCount = 1 To Sum
If Cells(PFCount, 1).Font.Bold = False And Fac = Cells(PFCount, 1).Value Then
For k = 1 To 30
If Worksheets(“DecisionFactors”).Cells(j, k).Font.Bold = True Then
Cells(CurRow, MSize + 5) = CI
Cells(CurRow, MSize + 5).Interior.Color = 8421504
Cells(CurRow, MSize + 5).Font.Bold = True
Else
Cells(CurRow, MSize + 5).Value = “If consistent?”
Cells(CurRow, MSize + 5).Interior.Color = 8421504
End If
End For
Next k
Else
Cells(CurRow, MSize + 5).Value = “If consistent?”
Cells(CurRow, MSize + 5).Interior.Color = 8421504
End If
End If
End If
Next PFCount
End Function

65
If Cells(PFCount, 1).Font.Bold = False And Fac = Worksheets("DecisionFactors").Cells(PFCount, 3).Value Then
    PFLookUp = Worksheets("DecisionFactors").Cells(PFCount, 5).Value
End If
Next PFCount
End Function

Private Function CPWLookUp(Fac As String) As Double
    Sheets("DecisionFactors").Activate
    Dim Sum As Integer
    Dim CPWCount As Integer
    Sum = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
    For CPWCount = 1 To Sum
        If Cells(CPWCount, 1).Font.Bold = False And Fac = Cells(CPWCount, 3).Value Then
            CPWLookUp = Cells(CPWCount, 7).Value
        End If
    Next CPWCount
End Function

Private Sub CompositePW()
    Dim Factor As String
    Dim Sum As Integer
    Sheets("DecisionFactors").Activate
    Sum = Range("A:A").Cells.SpecialCells(xlCellTypeConstants).Count
    For i = 2 To Sum
        Factor = Cells(i, 3).Value
        If LLookUp(Factor) = 1 Then
            Worksheets("DecisionFactors").Cells(i, 7).Value = PWLookUp(Factor)
        Else: Worksheets("DecisionFactors").Cells(i, 7).Value = PWLookUp(Factor) * (CPWLookUp(PFLookUp(Factor))
        End If
    Next i
    For i = 2 To Sum
        Cells(i, 7).Interior.Color = 10040115
        Cells(i, 7).Font.Color = 16777215
    Next i
End Sub
## Appendix I Logitech functions

<table>
<thead>
<tr>
<th>Participant</th>
<th>Global/Local</th>
<th>Description of department function</th>
</tr>
</thead>
<tbody>
<tr>
<td>Senior Director, Global Customer Replenishment</td>
<td>Global</td>
<td>Global Customer Replenishment department is responsible for communicating with customers, negotiating and maintaining a desired service level, and placing customer orders to suppliers.</td>
</tr>
<tr>
<td>Director, World Wide Trade &amp; Compliance Services</td>
<td>Global</td>
<td>World Wide Trade &amp; Compliance Services department has a good knowledge of customs clearance. They understand the customs regulation of the destination country and the relevant costs to do customs clearance.</td>
</tr>
<tr>
<td>Senior Director, Global Logistics</td>
<td>Global</td>
<td>Global Logistics department is responsible for delivering customer orders from factories to customers. Its top priorities include logistics capabilities management, logistics policy making, processes and metrics definition, logistics service providers management, and logistics network development.</td>
</tr>
<tr>
<td>Director, Global After Sales</td>
<td>Global</td>
<td>Global After Sales department is responsible for managing returned goods. They have a good knowledge of laws and regulations regarding returned goods.</td>
</tr>
<tr>
<td>Director, Global Supply Planning</td>
<td>Global</td>
<td>Global Supply Planning department is responsible for demand forecasting, inventory monitoring and making production plans with suppliers.</td>
</tr>
<tr>
<td>Country Manager/-National Distribution Manager, Logitech Electronic India Pvt</td>
<td>Local</td>
<td>Logitech Electronic India Pvt is the current Logitech presence in India. The organization is responsible for sales, finance, distribution and etc. within the country.</td>
</tr>
</tbody>
</table>

Table 16: A brief description of all Logitech functions that have participated in the present study. The ‘Global/Local’ column indicates if the participant is from a global or a local position. The ‘Description of department function’ column describes the basic department function corresponding to a participant.
Appendix J  A sample of the decision factor inquiry form

<table>
<thead>
<tr>
<th>Ranking factor</th>
<th>Definition</th>
<th>Impact (Opportunities/risks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Port congestion</td>
<td>A high number of vessels exceeds the number of available docks of the port. This leads to port congestion and causes delays.</td>
<td>Low level of congestion means a short lead time; high level of congestion might lead to longer and less predictable lead time.</td>
</tr>
</tbody>
</table>

*Note: Please add additional row if there are more factors you want to include.*
Appendix K  A sample of the ranking questionnaire

<table>
<thead>
<tr>
<th>Ranking factor</th>
<th>Definition</th>
<th>Impact (Opportunities/risks)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Government Taxation Regulation (ST, CST, VAT)</td>
<td>For any commercial activity done in the country, taxation would become applicable to be paid to govt</td>
<td>To manage commercial activities we would need dedicated team in filing taxes, claims etc</td>
</tr>
<tr>
<td>Local Warehousing</td>
<td>Central warehousing facility where we can stock up our product and do despatches to distributor against their orders. This would also be billing point</td>
<td>Manpower, insurance etc for the warehouse</td>
</tr>
</tbody>
</table>

**Questionnaire**

The questionnaire consists of two parts. Part I is factor ranking. Given a pair of factors, please give your opinion about their relative importance to the final decision. An example will be provided. Part II is location ranking. Regarding a ranking factor, please give your opinions about the relative importance between scenario’s. An example will be provided.
**Part I**

The scale is provided as the following. To find the better DC location, two factors are:

<table>
<thead>
<tr>
<th>Equally important</th>
<th>Two activities contribute equally to the objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly more important</td>
<td>Experience and judgment slightly favor one activity over another</td>
</tr>
<tr>
<td>Much more important</td>
<td>An activity is favored very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>Slightly less important</td>
<td>Experience and judgment slightly disfavor one activity over another</td>
</tr>
<tr>
<td>Much less important</td>
<td>An activity is disfavored very strongly over another; its dominance demonstrated in practice</td>
</tr>
</tbody>
</table>

**Example**

How do you compare Trade Compliance with Replenishment?

**Result:** Much less important

**Reasoning:** For the market, Trade Compliance is not a difficult issue. Replenishment, on the other hand, can give rise to problems. It is because there is little flexibility with customers. Therefore, Trade Compliance is much less important.

**Part I consists of 1 question.**

Q1. How do you compare "Government Taxation Regulation (ST, CST, VAT)" with "Local Warehousing"?

**Result:**

**Reasoning:**

---

**Part II**

The scale is provided as the following. Regarding the same factor, two location candidates are:

<table>
<thead>
<tr>
<th>Equally important</th>
<th>Two candidates contribute equally to the objective</th>
</tr>
</thead>
<tbody>
<tr>
<td>Slightly more important</td>
<td>Experience and judgment slightly favor one candidate over another</td>
</tr>
<tr>
<td>Much more important</td>
<td>One candidate is favored very strongly over another; its dominance demonstrated in practice</td>
</tr>
<tr>
<td>Slightly less important</td>
<td>Experience and judgment slightly disfavor one candidate over another</td>
</tr>
<tr>
<td>Much less important</td>
<td>One candidate is disfavored very strongly over another; its dominance demonstrated in practice</td>
</tr>
</tbody>
</table>

**Example**

Regarding Trade Compliance, how do you compare Mumbai with Chennai?

**Result:** Slightly less important

**Reasoning:** Mumbai clearance process is slightly worse than Chennai. It takes more time and is less predictable.
Part II consists of 6 questions.

Q1. Regarding "Government Taxation Regulation (ST, CST, VAT)", how do you compare Singapore with Mumbai?
   Result:
   Reasoning:

Q2. Regarding "Government Taxation Regulation (ST, CST, VAT)", how do you compare Singapore with Chennai?
   Result:
   Reasoning:

Q3. Regarding "Government Taxation Regulation (ST, CST, VAT)", how do you compare Mumbai with Chennai?
   Result:
   Reasoning:

Q4. Regarding "Local Warehousing", how do you compare Singapore with Mumbai?
   Result:
   Reasoning:

Q5. Regarding "Local Warehousing", how do you compare Singapore with Chennai?
   Result:
   Reasoning:

Q6. Regarding "Local Warehousing", how do you compare Mumbai with Chennai?
   Result:
   Reasoning:
Appendix L  Final results of the cost and lead time analysis

*Information is removed for confidential reasons.*

Figure 9: A graphical overview of end-to-end logistics cost across all scenarios.

*Information is removed for confidential reasons.*

Table 17: Results of the cost analysis specified by cost elements. ‘-’ shows the cost element is not relevant to a scenario. The list of cost elements match Table 14 in the Appendix. The only difference is some items are separated into multiple ones in this table. For example, ‘Clearance’ and ‘Cross state tax’ are listed separately but are in the same group in the other table.

*Information is removed for confidential reasons.*

Table 18: Results of the lead time analysis in days. For warehouse-related processes, they are presented at a higher level than what have been shown previously. Warehousing corresponds to the combination of ‘Warehouse in’, ‘Warehousing’, ‘Warehouse out’. In addition, VAS corresponds to ‘MRP labeling’.
Appendix M  Final results of the AHP site selection model

Information is removed for confidential reasons.

Table 19: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the Trade & Compliance function.

Information is removed for confidential reasons.

Table 20: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the Logistics function.

Information is removed for confidential reasons.

Table 21: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the After Sales function.
Table 22: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the Replenishment function.

Table 23: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the Planning function.

Table 24: The complete table of decision making factor names, definitions, and impact (opportunities/risks) for the Sales function.
Information is removed for confidential reasons.

Figure 10: A tree view of decision making factors based on expert opinions.
Table 25: Priority weights of site locations sorted by function. The numbers are the average ratings of a location candidate with respect to a function.

Table 26: Priority weight of decision making factors sorted by function. The results are the summation of composite priority weights of all children factors at the bottom level only.

Figure 11: A graphical representation of priority weights of decision making factors by function. The vertical axis is priority weight and the horizontal axis is Logitech functions.
Figure 12: A graphical representation of priority weights of site locations by function. The vertical axis is priority weight and the horizontal axis is Logitech functions.

Figure 13: A graphical representation of final scores of candidate scenarios. The results are processes and calculated by the AHP model. The vertical axis represents 3 scenarios; and, the horizontal axis represents percentage of preference on a 100% scale.

Table 27: Raw outputs from the AHP model. ‘Composite priority weight’ is the outcome of factor ranking. The ‘Location candidate’ column shows the outcome of location ranking.