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Integration of competitiveness indicators in the modeling of international logistics networks

Par

Fatma Khadija Ben Mustapha

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Abstract

In recent years, researchers have embraced the supply chain design problem and tried to design decision-making tools for managers to rely on when designing a production / distribution network. Tools proposed to companies mainly aim at minimizing costs while ensuring the resilience of the developed network. These tools integrate decisions on the selection of suppliers, the location of manufacturing plants and warehouses, choice of inventory control policies and the choice of transportation modes. Working in the same vein, this master thesis aims at proposing a comprehensive logistics network design model that integrates relevant economic competitiveness indicators of countries. By integrating some of the competitiveness indicators issued by the “World Economic Forum” in their “Global Competitiveness Report”, this new model intends to reinforce the robustness of the solutions proposed to decision makers.

Using the example of BIC, a French company founded in 1945 which has a distribution network spread over five continents, we will present how this model can help shaping the global supply chain. Each year, BIC sells over 10 billion disposable consumer products such as pens, lighters and shavers. Based on a virtual but realistic case study around BIC and using the GLPK solver to test the methodology, this master thesis intends to confirm that when designing their logistics network, companies can obtain a more robust supply chain configuration if they not only base their decisions on costs but also on the competitive advantages of countries. The main purpose is to acknowledge the relative weights that are attributed by a specific company to each factor in order to enable the company to make consistent choices for future changes in its logistics network.

The results we obtained using inverse optimization prove that the logistics network we found while integrating some competitiveness indicators is more robust as it better reflects BIC’s prior choices. Based on our analysis we are able to propose a two-step approach that provides decision makers with weights that will guide them towards a network configuration that minimizes their costs while reasonably integrating their competitiveness preferences.

The first step of the approach uses inverse optimization to deduce the weights that have been unconsciously attributed by a company to each competitiveness factor. The second step integrates these weights into the mathematical model presented here. By accepting these weights as guidance and then slightly altering them, decision makers will be able to choose a robust network configuration that minimizes their costs while reflecting their preferences in terms of their competitive environment.

Key words: Global supply chain; Logistics network design problem (LNDP); economic competitiveness indicators; inverse optimization.

Sommaire

Dans les dernières décennies, la recherche autour des problèmes de modélisation de réseaux logistique s'est accentuée. Plusieurs modèles et outils permettent ainsi aux multinationales de prendre des décisions plus éclairées concernant la sélection des fournisseurs, la localisation des centres de distribution et des usines, le choix des politiques de gestion des stocks, le choix des modes de transport… Ces outils ont pour but de permettre aux gestionnaires de modéliser des réseaux logistiques minimisant les coûts tout en assurant la robustesse du réseau. Ce mémoire va dans le même sens en proposant d'intégrer des indicateurs de compétitivité économique pertinents aux modèles. En effet, en intégrant quelques uns des indicateurs de compétitivité recensés par le Forum Économique Mondial, le modèle proposé ici permet de renforcer la robustesse des réseaux logistiques proposés aux gestionnaires.

À l'aide de l'exemple de BIC, une compagnie française qui a été fondée en 1945 et dont le réseau logistique s'étend aujourd'hui sur cinq continents, nous comptons démontrer comment le modèle proposé affecte la modélisation des réseaux logistiques. Tous les ans, BIC vend plus de 10 milliards de produits jetables à travers le monde : stylos, rasoirs et briquets. Ce mémoire se base sur une étude de cas virtuelle mais réaliste s'articulant autour de l'entreprise BIC. En utilisant les données publiques de cette compagnie et en simulant le réseau à l'aide du solveur GLPK, ce travail cherche à prouver qu'en modélisant leurs réseaux logistiques, les compagnies peuvent obtenir une meilleur configuration de leur chaine d'approvisionnement en basant non seulement leurs décisions sur des aspects financiers mais aussi sur des aspects touchant la compétitivité des pays.

En utilisant la méthode de l'optimisation inverse et en intégrant les poids se rapprochant des poids que BIC attribue actuellement aux facteurs de compétitivité des pays, nous avons pu démontrer que le réseau logistique obtenu est plus robuste puisqu'il reflète mieux les choix antérieurs de BIC. En nous basant sur cette observation, nous proposons ici une méthodologie en deux étapes qui permettra de guider les gestionnaires d'autres entreprises dans la recherche des pondérations qui leur permettront de modéliser un réseau logistique qui diminue leurs coûts et qui intègre leurs préférences en matière de compétitivité des pays.

La première étape de cette approche utilise l’optimisation inverse pour déduire les poids qui ont été attribués inconsciemment par l’entreprise aux différents facteurs de compétitivité. La deuxième étape permet ensuite aux décideurs d’intégrer ces poids au modèle mathématique que nous présentons, de les ajuster au besoin et d’étudier les alternatives possibles et leurs impacts sur les coûts et la performance en termes de compétitivité du nouveau réseau proposé.

Mots Clés: Chaîne d’approvisionnement internationale; problème de modélisation de réseaux logistiques (LNDP); indicateur de compétitivité économique; optimisation inverse.

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Because there is always a solution,

Because there are always ways to improve,

And because there are always people to remind you of these facts,

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Chapter 1 – Introduction

1.1 Overview

Since the 90's, many local firms have boosted their international presence by taking advantage of the improvements in transportation modes, the evolution of communication technologies and the lowering of trade barriers. These firms represent today's Multinational Enterprises (MNEs). In order to settle closer to customers, and to minimize their operating costs by taking advantage of lower labour costs, these companies are establishing manufacturing plants and distribution centers across the globe. By doing so, these firms are gradually designing their Global Supply Chains (GSC).

A GSC, as shown in Figure 1, can be seen as a network composed of: suppliers, manufacturing plants, distribution centers and customers.

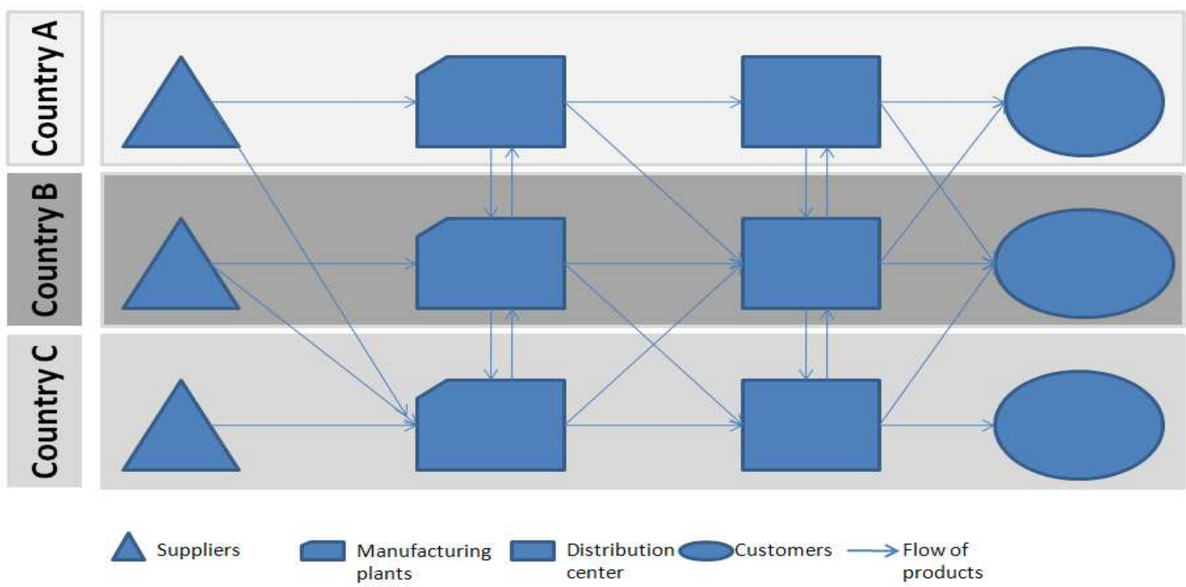

Figure 1: Global supply chain network

According to Christopher (2005, p.18): "*Leading-edge companies have realized that the real competition is not company against company but rather supply chain against supply chain*". Coordination between national and international players of a supply chain thus constitutes a competitive advantage when designing or modifying firms' logistics activities. Researchers have embraced the supply chain design problem and tried to design decision-making tools for managers to rely on when designing a production / distribution network.

In fact, while designing their logistics network, managers take into account many of the following input variables: volume and location of the demand, production costs, transportation costs, holding costs, raw material prices, etc. According to Cordeau et al. (2006), the integration of these variables in a Logistics Network Design Problem (LNDP), in order to minimize the whole network's fixed and variable costs while satisfying the demand, allows deciding on:

- The number, location, technologies and capacities of manufacturing plants and distribution centers,
- The selection of suppliers,
- The inventory control policies at each site,
- The transportation modes and the distribution channels,
- The flow of raw materials and finished products within the network.

Because some of the above decisions are strategic decisions which have repercussions on the long term and which necessitate significant investments, the mathematical models used to solve a LNDP, seek to ensure robust solutions by integrating, as much as possible, the external factors that could impact the input variables.

On a multinational level, factors that Operations Research (OR) theorists have taken into account to better evaluate the input variables of production costs are mainly quantitative factors. These factors include: exchange rates, local content rules, transfer prices, border crossing costs and income taxes in different countries. On the other hand, theorists of the international business field also intended to understand how an international firm can be competitive by exploiting the competitive advantages of the countries it settles in (Lee and Wilhelm, 2010).

The main difference between both approaches is that in evaluating a country's competitiveness, theorists of international business also take into account the qualitative factors that define the countries' environments. These qualitative factors can include for each country: political risks, ease of doing business, infrastructure quality, labour regulations, etc.

1.2 Problem definition

Acknowledging the fact that many international entities such as the "World Economic Forum" and "The institute for Management Development" are annually assessing the economic competitiveness of more than 130 countries around the world, researchers such as Lee and Wilhelm (2010) have urged to improve the actual logistics network designing models used in OR by incorporating the relevant economic competitiveness indicators provided by these institutions. The incorporation of these indicators would generate more comprehensive models that would better reflect the impact of the economic reality of different countries and improve the strategic planning of firms.

This work aims at reconciling these fields by addressing the following research question: How can one integrate the economic competitiveness indicators into logistics network design models?

In order to answer this broad subject, we will advance step by step by answering the following sub-questions:

- Which qualitative indicators related to the economic competitiveness of countries can be relevant in the design of logistics networks?
- How can these indicators be incorporated into the mathematical modeling of logistics network design?

The first objective of this thesis is to demonstrate how the integration of the competitiveness indicators affects the network design. The second objective is to minimize companies' costs while ensuring that the competitiveness performance of the proposed distribution networks remains robust.

1.3 Solution methodology

This research aims at identifying the economic competitiveness indicators that are relevant to the design of logistics networks. Then, the objective is to introduce a general formulation integrating these indicators in a multi-country, single-period, linear mixed-integer program and to assign a proper weight to each indicator using an inverse optimization approach. Finally, using GLPK, we will compare the performance of the new model and the performance of former models by testing them on the same data set. This data will represent a realistic enterprise network to which a deterministic and static demand will be applied.

1.4 Outline

The first chapter of this research has already introduced the subject and the research questions of this work. The second chapter will provide a literature review of actual models for international logistics network design problems. The third and fourth chapter will define the relevant economic competitiveness indicators and then propose a mathematical model that integrates them. Chapter five will present the data of a specific case on which the model will be tested. The sixth chapter will examine the performance of the new approach after providing a comparison between the results of the new model and those of a standard model. The final chapter will highlight the contribution of this work and provide directions for future research.

Chapter 2 - Literature review

2.1 Supply chains

In order to accomplish its mission, a company has to deliver to its customers the products it manufactures at the right place and at the right time. To be able to produce and also to distribute their products, companies surround themselves by a network that comprises suppliers, distribution centers, manufacturing plants and selling points. This network constitutes the supply chain of companies.

2.1.1 Definition of supply chains

From the 1990s, the interest of the scientific community towards the management of the supply chain has been constantly increasing. This increase is on one hand explained by the infatuation created by the subject and on the other hand by the fact that the definitions of supply chain vary a lot. These definitions concentrate sometimes on production and distribution activities and other times on the need of collaboration between producers and customers (Stock and Boyer, 2009). In this work, we will use the definition of Lummus et al. (2001, p.429) as it includes the important processes and players implicated in the supply chain:

> *"Supply chain includes all activities involved in delivering a product from raw material to the customer, including sourcing raw materials and parts, manufacturing and assembly, warehousing and inventory tracking, order entry and order management, distribution across all channels, delivery to the customer, and the information system necessary to monitor all of these activities."*

2.1.2 Global supply chains

Improvements in transportation modes, the evolution of communication technologies and the lowering / vanishing of trade barriers in many sectors of the industry have all made international exchanges easier. Having stores and suppliers located around the globe or producing in various lower wage countries is part of today's MNEs reality.

This geographic dispersion of activities complicates the management of the supply chain in many ways (Sheu, 2004). In fact, some features that were irrelevant to the success of a domestic supply chain have become highly important for the design of a GSC. Exchange rates, import and export tariffs, import and export quotas, transfer prices, longer transportation lead times, border crossing regulations are all relevant features to evaluate the profitability of a GSC and must thus be taken into account by supply chain managers. Furthermore, cultural differences, language barriers, political risks, worker skills can all affect the performance of business processes and should also be factored in when deciding on a global logistics network (Meixell and Gargeya, 2005).

Ultimately, GSCs have opened a world of possibilities but have also complicated the decision making process for MNEs.

2.2 Modeling of global supply chains problems

2.2.1 The Logistics Networks Design Problem

While instinctively modeling their supply chains, most companies' objective is to remain competitive on the international market by ensuring low production costs and a highly productive flow of products across their network. These objectives translate in financial terms by the minimization of total operating costs or the maximization of profits. These same objectives are used in mathematical models of OR to design optimal and robust logistics networks.

In order to achieve these objectives, the local optimization of each production stage of the logistics network is a plausible solution that is often used. However, to achieve better overall performance, both researchers and enterprises are now considering the logistics network as a whole and are trying to optimize it from the point of origin to the point of consumption. To do so, strategic, tactical and operational decisions must be harmonized with all actors of the logistics network. On the strategic level, these decisions affect: the number, capacity and location of manufacturing plants and warehouses. These decisions necessitate large investments and have a long-lasting effect on the logistics network. The second decision level is the tactical level. The selection of suppliers, the determination of the transportation modes and the assignment to manufacturing plants and warehouses of the products and the quantities to be produced are all decisions highly dependent on the strategic level but which can be modified yearly or even half-yearly as the investment required to implement the changes is lesser. Finally, decisions considering the flow of materials and products across the network are operational decisions (Balou, 2001; Cordeau et al., 2006). Achieving optimality in the design of a logistics network to satisfy customer demand and maximize profits by making simultaneous decisions on the three decisions levels described above is known in the literature as the Logistics Network Design Problem (LNDP).

The LNDP is a complex problem as it requires taking decisions on many components at the same time: location, capacity, procurement, transport, technology, etc. To better tackle the problem, researchers have often decomposed it into smaller and more easily treatable problems. We thus find an abundant literature treating the facility location problem and the distribution network design problem which are both integral parts of the LNDP.

The facility location problem is answering the strategic decision of plant or warehouse location. The most common objective of the facility location problem is to minimize the transportation costs and the fixed costs of the selected sites while satisfying customers' demand. Distance minimization, service level satisfaction or network coverage can also be used as objectives for the problem (Farahani et al., 2009). The capacitated Facility Location Problem and the Uncapacitated Facility Location Problem have largely been studied in continuous, discrete, deterministic, stochastic, static, dynamic, single and multiple product environments (Aikens, 1985; Sridharan, 1995; Owen and Daskin, 1998).

The distribution network design problem is an extension of the facility location problem as it allows deciding on multistage facility locations, on the assignment of products to plants and warehouses and on the selection of distribution channels (Melo, 2009). In the work of Geoffrion and Graves (1974), the objective is to minimize distribution costs in the network by deciding on the distribution centers

(DCs) to be opened, on the allocation of products to DCs and on the customers to be served from each DC. Further papers (Chandra and Fisher, 1994; Pirkul and Jayaraman, 1996) have added to the warehousing and distribution channel selection, the decision making on production scheduling and production allocation across opened manufacturing plants. Vidal and Goetschalckx (1997) and also Klose and Drexl (2005) provide a broad list of the various model formulations of the distribution network design problem and its multiple solutions' approaches.

Finally, the LNDP problem should be seen as the natural extension of the distribution network design problem as it adds the transportation modes selection and the procurement components to the production and distribution problem. According to Vidal and Goetschalckx (2001), the work of Arntzen et al. (1995) is one of the most comprehensive and complete models of LNDP that can be found in the literature. The article of Arntzen et al. (1995) describes the use of a Global Supply Chain Model developed for the international logistics network of Digital Equipment Corporation. The model has an objective function of minimizing a weighted combination of total operating costs and activity days. The total costs include production costs, transportation costs, inventory costs, procurements costs, duty costs, duty drawbacks and taxes. The model also takes into consideration local content rules limitations and offset trade constraints. Based on the BOM of all products, the mixed-integer linear program uses, in its optimization for multiple time periods, a non-traditional solution approach based on elastic constraints, row factorization, cascaded problem solution and constraint-branching.

Dogan and Goetschalckx (1999) provide a formulation of a LNDP in a domestic, multi-period, multi-commodity model. The model allows the simultaneous determination of supplier selection, manufacturing plants and warehouses locations and capacities, inventory location and sizing, customer demand allocation and distribution channels. The authors describe a primal decomposition solution methodology and compare it to a standard branch and bound method, proving the time effectiveness of the solution method they offer.

Cordeau et al. (2006) proposed two different approaches, one based on Benders decomposition and the other based on a simplex-based branch and bound method to solve a domestic, single-period and deterministic formulation of the LNDP. The formulation proposed in their article allows making simultaneous decisions on supplier selection, transportation modes, number and location of warehouses and manufacturing plants to be opened and flow of materials between manufacturing plants, warehouses and customers' demand points. These decisions aim at minimizing the sum of all fixed and variable costs within the network. The proposed model assumes a single manufacturing and a single distribution stage and also a single period environment but the flexible formulation proposed allows an easy extension of the formulation if needed. In fact, Monteiro et al. (2010) have extended Cordeau's (2006) model to consider the stochastic demand of customers and have added a decision variable to decide on the inventory levels in the warehouses. They have shown that integrating inventory level decisions to facility location, production levels and supplier selection decisions can enable the reduction of total logistics costs.

The article of Klibi et al. (2010) points out the shortfalls of the literature in addressing the Supply Chain Network (SCN) problem under uncertainty. Klibi, Mattel and Guitouni indicate that the SCN in its deterministic formulation has been extensively studied. However, looking into the optimization models proposed in the literature, the authors reveal that most of the available models make significant assumptions and simplifications that do not reflect the reality of the business environment. In fact, the future business environment in which the supply chain network will manoeuvre is unknown. Many available models allow integrating uncertainty related to standard business factors by integrating stochastic variable for: raw material costs, prices, currency rates, demand, etc... Inversely, the authors argue that few OR models propose a methodology that integrates major disruptive events. Major disruptive events such as: earthquakes, terrorist attacks, epidemics, etc. are all sources of uncertainty which can highly impact the effectiveness of the SCN. The article suggests developing a comprehensive SCN design methodology, which allows the integration of these sources of uncertainty. While the objective of the optimization models is often to minimize costs, the authors stress the fact that this minimization should not be done at the expense of a sustainable value creation. By motivating researchers to developing methodologies that integrate the uncertainty related to catastrophic events, the authors' goal is to erect the foundations of robust value-creating SCNs. A robust SCN is thus a network that minimizes costs and at the same time has the ability to remain functional in numerous and probable future scenarios.

2.2.2 Integration of quantitative factors of Global LNDP

"*Manufacturers establish foreign plants to benefit from tariff and trade concessions, cheap labor, capital subsidies, and reduced logistics costs "* (Ferdows, 1997).

The above citation explains the reasons why the design of a GSC requires taking into account additional features when comparing to domestic supply chains. As demonstrated in the work of Arntzen et al. (1995): taxes, duty drawbacks, local content rules and offset trade constraints can highly impact the solution and should be integrated in the model formulation.

Transfer prices also constitute a determinant feature of GSCs. As opposed to Arntzen's work that considers transfer prices of products as being an addition of incremental prices for each manufacturing or distribution step, Vidal and Goetschalckx (2001) have developed a formulation where transfer prices of products are decision variables. Actually, transfer prices are constrained by legal restrictions and even if the variation bracket of transfer pricing is getting smaller year after year (because of better laws and regulations) firms still have the opportunity to slightly vary transfer prices of their products. Because both transfer prices and the allocation of transportation costs to the sender or the receiver may represent substantial savings regarding global profits, Vidal and Goetschalckx (2001) added these decision variables to the selection model of facility location, the flow of materials between manufacturing plants, warehouses and customers' demand points and the transportation modes. To maximize after tax profits and to solve the formulated problem which takes into account fixed corporate income taxes for each country, currency exchange rates, tariffs and duties, Vidal and Goetschalckx use a heuristic algorithm that applies iterative linear programming based on the reformulation and the relaxation of the original problem until an optimal solution is found. We note however that the selection of suppliers was not integrated in the authors' model.

Wilhelm et al. (2005) provide a comprehensive model for the design of a US-Mexico supply chain under the North American Free Trade Agreement (NAFTA). In order to maximize after tax profits, the formulation allows making decisions on: manufacturing plants and warehouse location and capacity, technology selection at facilities, material flow, inventory levels at manufacturing plants and warehouses, suppliers selection, transportation modes, allocation of transportation costs and transfer prices. In this deterministic and multi-period Mixed-Integer Problem which relies on BOM constraints, the following global considerations are integrated: local content rules, exchange rate fluctuations, government investment incentives (safe harbour rule), border-crossing costs and graduated income tax rates. The authors provide a what-if analysis that demonstrates how the model can be used by managers to compare opportunities and to take decisions on the strategic and tactical level.

Reviews of the major formulations describing the mixed integer programming models for the design of GSCs are proposed by Vidal and Goetschalckx (1997) and Melo et al. (2009).

2.2.3 Integration of qualitative factors in global LNDP

The article of Meixell and Gargeya (2005) provides a review of the main articles tackling the problem of GSCs modelling. For what they consider as the relevant articles published between 1982 and 2005, the authors note that when taking manufacturing and sourcing decisions on the global level, the main globalization effects taken into account are tax, tariff, currency exchange rates, local content and local incentives. All these effects are quantitative features. The authors point out that some managing issues that arise with GSC such as cultural differences, reliability of infrastructure, political risks are difficult to represent mathematically and have generally been occulted by researchers.

More recently, Lee and Wilhelm (2010) also pointed out the lack of integration of qualitative factors in supply chain and facility location problems. Lee and Wilhelm's article discusses the evolution of international economics theories. The objective of Ricardo's comparative advantage theory, Porter's competitive advantage theory and the competitiveness theory is to explain the competitiveness forces that are shaping the global business environment. Even if competitiveness is a qualitative aspect that can be difficult to quantify, the authors present two reports: the "Global Competitiveness Report" and the "World Competitiveness Yearbook", benchmarking competitiveness. These reports offer a set of quantitative measures assessing countries' competitiveness in terms of: infrastructure, business environment, corruption, etc. Lee and Wilhelm claim that some of these competitiveness indicators should be used by the OR community to enhance strategic supply chain network planning. The authors argue that by integrating the relevant competitiveness indicators, as parameters, as variables or as constraints, the OR community should be able to find networks that are more robust. Even if the authors succeed in demonstrating the potential gains in integrating competitiveness indicators in OR problems, they do not suggest any methodology that would actually allow doing it.

Though Meixell and Gargeya (2005) and Lee and Wilhelm (2010) emphasize the fact that qualitative factors have been overlooked, we here describe some articles that have tried to propose different alternatives to integrate qualitative considerations when designing GSCs.

In his work, Haug (1992) aims at developing a mathematical model allowing high technology firms to take decisions on the transfer of production of a single commodity between international plants in order to decrease their overall cost function over a specific time horizon. The author includes in the cost function: material costs, labour costs, transportation costs and utilities' costs. Fixed costs of plant opening are not taken into account because the author assumes that the transfer of production will only take place between already established facilities. As the article is concentrating on high tech firms, where shelf lives and cycle times of products are short, including the learning curve effect was essential to building a thorough model. The prime contribution of this paper is thus the fact that it includes the learning curve effect on both material use and labour hours over time. By affecting different learning curves to different international countries the author attempts at quantifying the impact of worker's abilities. The author uses the learning curves data provided by Business International Corporation which was an advisory US agency specialized in the evaluation of economic and political risks in 50 countries around the globe.

In their paper, Bartmes and Cerny (1993) suggest a "capability-focused approach" instead of the "traditional approach" when deciding on location issues. The traditional approach, by definition, is a short term and tactical approach aiming to decrease the total cost function of the network only by taking advantage of lower labour wages in the manufacturing sector. This traditional approach consists of two steps. The first step concentrates on the qualitative features of countries as managers apply a subjective weight to the economical risks, the union activity, and the infrastructure quality of each country. Only countries with the highest scores are used for the second step. This second step consists of a simulation and a comparison between the Return on Investment (ROI) of each candidate country considering exchange rates, taxes, transfer prices, worker productivity ratios and production/distribution costs. The traditional approach ultimately relies on subjective weighing and short term ROI analysis. On the other hand, the capability focused approach proposed by Bartmes and Cerny depends on the core capabilities of the company. Instead of building a network of facilities and basing the decisions on a short term ROI analysis, their approach identifies the core capabilities or competitive advantages of the company and builds a network of capabilities. The co-location of these core activities is seen as a valuable asset for the firm. There is no mathematical model proposed by the authors, only a decision tree where: customer value, critical capabilities and requirement for co-location determine which countries are potential sites depending on the degree of proximity needed. Then a classic ROI analysis is done to compare and choose between the final countries.

The paper of MacCormack et al. (1994), also proposes a multiple phase decision making process for global location issues. The first phase consists in defining to which extent cost, quality, flexibility and innovation will contribute to the future success of the firm on the global market. Phase 2 allows accessing the economic conditions of different marketplaces. Tariffs, duties and local content rules of each country are the constraining conditions for manufacturing plant implementation. Phase 3 links the managing vision defined in the first phase to the qualitative attributes of the countries derived from phase 2. In this phase, transport infrastructure, communications systems, education level of the work force and suppliers' quality are assessed to decide whether or not they can support the firm's competitive advantages. The final phase consists in a quantitative analysis enabling the comparison between the cost effectiveness of the remaining options. The solution maximizing the profits is then chosen.

Hoffman and Schinderjens (1994) have proposed a two-step model to structure facility location selection in a global environment. The first step allows the selection of a country and the second step determines the site location. To select the most attractive countries, the authors determine the Optimal Performance Factors (OPF). OPFs are critical country attributes allowing the firm to maintain its competitive advantages. These attributes are both quantitative (tax, tariff, currency exchange rate...) and qualitative (education level, political risks, criminal rates, infrastructure's quality...). The OPFs of each country are given a grade from 1 (unattractive) to 5 (attractive). The result of step 1 is a ranking of countries according to their overall attractiveness. Step 2 integrates the ranking of countries in a classic minimizing costs function that enables facility selection.

Recently, Dogan (2012) proposed an integrated approach combining a Bayesian network and a Total Cost of Ownership analysis when selecting a manufacturing plant in an international environment. The proposed procedure allows the use of a probabilistic approach to approximate the effect of qualitative features on the cost function. Dogan's Total Cost of Ownership encloses: quality related costs, labor costs, construction and land costs, overhead costs, development costs, financial costs, manufacturing costs, energy costs, system and integration costs, transportation costs, taxes, tariffs and insurances. The basic assumption in this article is that each of these cost elements is assumed to be a continuous variable following a Gaussian distribution whose mean and variance are known. Each cost element is also assumed to be influenced by 12 factors which depend on 36 criteria. The following table explains the relation between factors and criteria as depicted by Dogan:

Factors	Criteria
Quality of labor	Labor skill Motivation of workforce Availability of workforce
Quality of suppliers	Technological capability of suppliers Alternatives Suppliers' reliability and responsiveness
Demographics	Population Language skills Unemployment rate
Geographical location	Land availability and price Quality and availability of raw materials Climate
Quality of life	Standard of living Education system Health system
Financial efficiency	Banking and financial services Credit Financial risk level
Quality of transportation	Quality of air/water transportation Quality of railway/road transportation Quality of distribution infrastructure
Government efficiency	Political Bureaucracy Business legislation
Quality of infrastructure	Technological Scientific Basic infrastructure
Regulatory	Environmental regulations Tax Custom duties
Social and cultural factors	Cultural barriers Community attitudes towards business and Unionization
Economic performance	Currency stability Economic growth Inflation

Table 1: Factors and Criteria used in Dogan's cost function

Firm experts wishing to locate an international facility will use international reviews accessing countries competitiveness such as the Global Competitiveness Report, The Central Intelligence Agency, The Index Mundi and Human Development Report to determine the probabilities for each criterion to be either high or low in each country. When no data from international reviews is available, the attribution of probabilities is subjective and only depends on the experts' point of view. In the proposed model, a high probability value represents the high degree of certainty of the occurrence of an event. A Bayesian network representing the probabilities of factors to be high or low (good / bad) depending on the probabilities of the criteria and the probabilities of cost factors to be high or low depending on the probabilities of the factors is then constructed. The outcome of the combined use of the Bayesian network and the Gaussian distribution of each cost element is a function describing the cumulative probabilities of the total costs. Ultimately, the proposed model allows comparing different alternatives by considering not only quantitative but also qualitative aspects while using a systematic approach.

Chapter 3 – Economic Competitiveness Indicators

Each year since 1979, the World Economic Forum releases The Global Competitiveness Report (GCR) (Schwab, 2012). The GCR aims at providing a comprehensive assessment of countries' competitiveness drivers. The report defines competitiveness as being "*the set of institutions, policies, and factors that determine the level of productivity of a country*". In recent years, the GCR has standardized its approach of competitiveness assessment by basing its analysis on the Global Competitiveness Index (GCI).

The GCI is a measuring system integrating both macroeconomic and microeconomic foundations of countries' competitiveness. The GCI is based on the following pillars: Institutions, Infrastructure, Macro Economic Environment, Health and Primary Education, Higher Education and Training, Goods Market Efficiency, Labor Market Efficiency, Financial Market Development, Technological Readiness, Market Size, Business Sophistication and finally Innovation.

These twelve pillars define a country's competitiveness and productivity by assessing its economic, social and environmental conditions. Each one of the pillars relies on 5 to 20 components, measuring a specific aspect of competitiveness. Unless a specific scale is defined in the report, the evaluation system used in the GCI assigns a score between 1 and 7 to each pillar's components. A mark of 1 is given for poor results and a mark of 7 is given to highlight a very strong performance.

The objective of this master thesis being the integration of relevant competitiveness indicators in the design of logistics networks, not all pillars neither all components of pillars given by the GCI are appropriate. We will here present a brief description of the components of pillars and the pillars that are assumed to be relevant. The pillars and some of their components that have been excluded from this work are critical for describing countries' competitiveness. Nonetheless, in this work they have been neglected based on the following assumptions:

- When designing a logistics network, companies are aiming at locating manufacturing plants and warehouses – not headquarters and research centers;
- When designing a logistics network, companies are aiming at minimizing their operating costs not at finding the best ways of financing their investments;
- When designing a logistics network, companies are aiming at minimizing their distribution costs not at settling in countries based on their market size.

The above assumptions allow us to disregard all pillars and components that are concerned with the macroeconomic environment, the financial market, the technological readiness, the innovation system and the market size of countries. Further work, based on different assumptions, might integrate these components to better suit the targeted objective.

In this work, seven pillars are used: Institutions, Infrastructure, Health and Primary Education, Higher Education and Training, Goods Market Efficiency, Labor Market Efficiency and Business Sophistication. The relevant components used to asses each one of these pillars are described in the following sections.

3.1 Institutions

The institutional framework represents the legal environment in which companies will expand and compete. A country providing a fair and reliable judiciary system and preserving corporate property rights is more likely to attract and retain foreign companies than a country where extreme bureaucracy delays companies' actions. For this first pillar, the following eight components are assumed to be relevant for the design of a logistics network:

- **Property rights:** legal protection of firms' property rights
- **Irregular payments and bribe:** extent to which bribery is necessary in obtaining public contracts or obtaining favourable judicial decisions

- **Favouritism in decisions of government officials:** extent to which government officials favour well-connected firms when voting policies
- **Burden of government regulation:** extent to which administrative requirements are easy to comply with
- **Efficiency of legal framework in settling disputes:** effectiveness of the legal framework for settling private business disputes
- **Business costs of terrorism:** extent to which terrorism threatens everyday business
- **Business costs of crime and violence:** extent to which organized crime threatens everyday business

3.2 Infrastructure

The infrastructure of a country is a critical element defining its competitiveness, as it allows products to be moved easily and quickly along the supply chain. Because the quality of the transportation network and the robustness of the electrical supply can have a significant impact on companies' establishment decisions, we here present the five components that are believed to be relevant:

- **Quality of overall infrastructure:** extent of development of transportation, telecommunication and energy infrastructure (gas, fuel, …)
- **Quality of roads:** extensiveness and efficiency of roads
- **Quality of railroad infrastructure:** extensiveness and efficiency of rail service
- **Quality of port infrastructure**: efficiency and accessibility of ports
- **Quality of electricity supply**: lack of interruption and lack of voltage fluctuation in the electricity supply

3.3 Health and primary education

Healthy workers who have access to a basic education can work to their full potential and thus improve the productivity of a country. The following components are believed to convey critical information when designing a logistics network:

- **Business impact of malaria**: impact of malaria (death, disability, medical expenses, absenteeism, etc...) on companies' operations
- **Business impact of tuberculosis:** impact of tuberculosis (death, disability, medical expenses, absenteeism, etc...) on companies' operations
- **Business impact of HIV/AIDS:** impact of HIV/AIDS (death, disability, medical expenses, absenteeism, etc...) on companies' operations
- **Quality of primary education**: quality of basic education offered in primary schools

3.4 Higher education and training

The quality of the higher education system and the training services of a country define its ability to provide skilled workers. Skilled workforce, which is able to improve companies' productivity, represents a competitive advantage in today's global supply chains. The following components are assumed to reflect the interests of companies when designing a logistics network:

- **Quality of the educational system:** extent to which the national educational system meets the needs of a competitive economy
- **Local availability of specialized research and training services:** extent to which high quality training services are available
- **Extent of staff training:** extent to which local companies invest in the training and development of their employees

3.5 Goods market efficiency

The goods market efficiency pillar describes the intensity of local market competition and its ability to foster healthy competition between companies based on their productivity and efficiency. The seven components presented here are believed to be significant to the design of logistics network as they reflect the difficulties/easiness for international companies to settle in foreign countries:

- **Intensity of local competition:** intensity and number of local competitors in most industries. This component recounts to which extent competition is fostered among local suppliers
- **Extent and effect of taxation**: extent to which the taxation systems limits incentives to work or to invest
- **Number of procedures required to start a business:** administrative easiness of starting and registering a business[1]
- **Prevalence of foreign ownership:** extent to which foreign ownership is widespread
- **Business impact of rules on FDI:** extent to which local policies encourage Foreign Direct Investments (FDIs)
- **Burden of customs procedures**: extent to which customs procedures, both for imports and exports, are efficient
- **Degree of customer orientation:** extent to which local companies and local suppliers are concerned with customer retention

3.6 Labor market efficiency

Flexibility of the labor market for wage determination and in terms of hiring and firing processes is more and more important to companies. In fact, firms are aiming to be able to rapidly adapt to change in demand and thus value countries where hiring/firing processes are efficient and unproblematic. For these reasons, the components of the labor market efficiency pillar presented here are crucial indicators when designing logistics networks:

- **Cooperation in labor-employer relations:** extent to which workers and employers collaborate
- **Flexibility of wage determination:** extent to which wages are individually determined by each company

[1] For this component, the GCI provides the number of administrative procedures (comprised between 1 and 20). In order to ensure the equality in importance for all components that form a pillar, those numbers have been rescaled to a 1 to 7 scale where a mark of 7 is given to countries requiring the minimum number of procedures.

- **Hiring and firing practices:** extent to which the hiring and firing process are complex
- **Pay and productivity:** extent to which the pay of workers is related to their productivity
- **Reliance on professional management:** extent to which managers are chosen by objective standards (merit, qualifications, skills, …)

3.7 Business sophistication

The business sophistication pillar assesses the business environment in a country. The business environment of a company is composed of a network of local suppliers that will support the day to day operations. The following four components are assumed to be relevant when designing a logistics network:

- **Local supplier quantity:** extent to which local suppliers are available
- **Local supplier quality:** extent to which local supplier provide goods and services of quality
- **Value chain breadth:** extent to which local companies are involved in the value chain, from the designing stage to the after sale process.
- **Production process sophistication:** extent to which local processes are using today’s prevailing technologies

Chapter 4 – Mathematical model

The following model is based on the mathematical model presented by Cordeau et al. (2006).

4.1 Weighted LNDP model

4.1.1 Model formulation

The presented model assumes the following:

- Demand is deterministic
- Customer demand has to be satisfied
- Products are fully manufactured in a single production plant (no transportation of subassemblies between plants)

<u>Sets:</u>

C	Set of Customers
F	Set of Finished Products
R	Set of Raw Materials
P	Set of Manufacturing Plants
W	Set of Distribution Centers
S	Set of Suppliers
I	Set of competitiveness pillars

Parameters:

d_{cf}	Demand of customer *c* for product *f*
a_{rf}	Amount of raw material *r* in product *f*
h_{fw}	Amount of capacity required by product *f* in facility *w*
G_p	Fixed cost of operating manufacturing facility *p*
G_{fp}	Fixed cost of operating facility *p* to manufacture product *f*
G_w	Fixed cost of operating warehousing facility *w*
G_{fp}^v, G_{fw}^v	Variable cost of handling product *f* at facilities *p* and *w*
G_{rs}	Cost of purchasing raw material *r* from supplier *s*
$GT_{fpw}^v, GT_{fpc}^v, GT_{fwc}^v$	Variable cost of transporting product *f* from facility *p* to facility *w*; from *p* to *c* and from *w* to *c*.
E_{pf}, E_w	Capacity of facility *p* for product *f* and overall capacity of warehouse *w*
E_{sr}	Capacity of supplier *s* to provide raw material *r*
CS_{ip}	Competitiveness Score for pillar *i* of plant *p*
α_i	Weight of competitiveness pillar *i* ($\alpha_i \leq 0$)

Variables:

X_{rsp}	Amount of raw material *r* shipped from supplier *s* to facility *p*
W_{fpw}	Amount of product *f* shipped from facility *p* to facility *w*
Y_{fpc}, Y_{fwc}	Amount of product *f* shipped from facility *p* /*w* to customer *c*
z_p, z_w	1 if facility *p* / *w is* opened, 0 otherwise
z_s	1 if supplier *s* is selected, 0 otherwise
u_{fp}	1 if product *f* is handled in facility *p*, 0 otherwise

Problem 1:

Minimize: $Z =$

$$\sum_{p} G_p z_p + \sum_{w} G_w\, z_w + \sum_{f,p} G_{fp} u_{fp}$$
$$+ \sum_{r,s} G_{rs} \sum_{p} X_{rsp} + \sum_{f,p} G^{v}_{fp} (\sum_{w} W_{fpw} + \sum_{c} Y_{fpc}) + \sum_{f,w} G^{v}_{fw} \sum_{c} Y_{fwc}$$
$$+ \sum_{f,p,w} GT^{v}_{fpw}\, W_{fpw} + \sum_{f,p,c} GT^{v}_{fpc} Y_{fpc} + \sum_{f,w,c} GT^{v}_{fwc}\, Y_{fwc}$$
$$+ \sum_{i} (\alpha_i \sum_{p} CS_{ip} \,(\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw})) \qquad (1)$$

Subject to:

$$d_{cf} - \left(\sum_{p} Y_{fpc} + \sum_{w} Y_{fwc} \right) = 0 \qquad \forall c, f \qquad (2)$$

$$\sum_{s} X_{rsp} - \left(\sum_{w,f} a_{rf} W_{fpw} + \sum_{c,f} a_{rf} Y_{fpc} \right) = 0 \qquad \forall r, p \qquad (3)$$

$$\sum_{p} W_{fpw} - \sum_{c} Y_{fwc} = 0 \qquad \forall w, f \qquad (4)$$

$$\sum_{p} X_{rsp} - z_s E_{sr} \leq 0 \qquad \forall s, r \qquad (5a)$$

$$\left(\sum_{w} W_{fpw} + \sum_{c} Y_{fpc} \right) - u_{fp} E_{pf} \leq 0 \qquad \forall p, f \qquad (5b)$$

$$u_{pf} - z_p \leq 0 \qquad \forall p, f \qquad (5c)$$

$$\sum_{c,f} Y_{fwc} h_{fw} - z_w E_w \leq 0 \qquad \forall w \qquad (5d)$$

$$X_{rsp}, W_{fpw}, Y_{fpc}, Y_{fwc} \geq 0 \tag{6}$$

$$z_p, z_w, z_s, u_{fp} \in \{0,1\} \tag{7}$$

4.1.2 Core model description

The set of finished products manufactured and distributed by a company is denoted by F. R is the set of raw materials. Every $r \epsilon R$ represents a raw material or a component used in the manufacturing of a specific finished product $f \epsilon F$. a_{rf} denotes the exact quantity of raw material r used for the assembly of one unit of f. S represents the set of suppliers considered by the company. E_{sr} and G_{rs} respectively denote the capacity of supplier s to supply raw material r and the cost to the company to purchase one unit of r from supplier s. The decision variable z_s is equal to 1 only if supplier s is selected to supply at least one raw material r. X_{rsp} denotes the amount of raw material r supplied by s and transported to manufacturing plant p.

The set of customers is denoted by C. Every $c \epsilon C$ represents a single customer or a group of customers that are geographically close and whose demand can easily be pooled. d_{cf} denotes the quantity of finished product $f \epsilon F$ ordered by every customer $c \epsilon C$.

To fulfill the network's demand, let P be the set of actual and potential manufacturing plants. For every manufacturing plant p, E_{pf} represents the available manufacturing capacity for product f at plant p. The decision variable u_{fp} is equal to 1 if product f is produced at plant p. If at least one product f is produced at p, the plant needs to be opened and the decision variable z_p is equal to 1. In the presented model, the operating costs of a specific manufacturing plant are composed of three different costs:

- G_p:fixed cost for opening the plant p

- G_{fp} **:** fixed cost of producing product f at p (this cost can correspond to the costs of acquiring a specific manufacturing technology for the manufacturing of product f)
- G_{fp}^{v}: variable cost incurred for the production of every unit of finished product f at manufacturing plant p.

Regarding the distribution component of the presented logistics network, let W be the set of actual and potential warehouses. The capacity of a warehouse $w \epsilon W$ is denoted by E_w. h_{fw} denotes the amount of capacity required for the storage of one unit of f in warehouse w. The decision variable z_w is equal to 1 if the warehouse w is used in the logistics network. For every warehouse w, the operating costs are composed of the fixed costs of opening the warehouse (G_w) and the variable costs (G_{fw}^{v}) incurred for the handling of each unit of finished product f transiting through warehouse w.

For every $f \epsilon F$, the transportation cost for one single unit of finished product f from a plant p to a warehouse w, from a plant p to a customer c and from a warehouse w to a customer c are denoted by GT_{fpw}^{v}, GT_{fpc}^{v} and GT_{fwc}^{v}.

The amount of finished product $f \epsilon F$ produced at a specific plant p is equal to the sum of the two following decision variables: $\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw}$. For each $p \epsilon P$, $\sum_{fw} W_{fpw}$ represents the amount of finished product f produced at p and transiting through all warehouses and for each $p \epsilon P$, $\sum_{fc} Y_{fpc}$ represents the amount of finished product f produced at p which is directly shipped to customer c.

Finally, let I be a set of the competitiveness pillars described in Chapter 3 (Institutions, Infrastructure, Health and Primary Education, Higher Education and Training, Goods Market Efficiency, Labor Market Efficiency and Business sophistication). α_i denotes the weight given by the company to each pillar $i \epsilon I$. The calculation of α_i is detailed in Section 4.2. For every plant $p \epsilon P$ and every pillar $i \epsilon I$,

CS_{ip} denotes the competitiveness score of plant p for pillar i. As the CS_{ip} score of a plant p for pillar i is equal to the average score of the plant scores for all components of pillar i, every CS_{ip} varies within a range comprised between 1 and 7. For example: the competitiveness score of a plant p, relative to the "Institutions" competitiveness pillar is equal to the average of the scores of the plant for the seven following components: Property rights, Irregular payments and bribe, Favouritism in decisions of governments officials, Burden of government regulation, Efficiency of legal framework in settling disputes, Business costs of terrorism and Business costs of crime and violence. Each one of these components' scores being graded on a scale from 1 to 7, the competitiveness score of plant *p* on "Institutions" will also vary within a range comprised between 1 and 7 as it represents the average score of the seven components. This also means that all manufacturing plants located in the same country will have the same CS_{ip} as the competitiveness scores for each pillar $i \epsilon I$ are computed by country in the Global Competitiveness Index.

According to the above notations the mathematical model describes the following:

The objective function (1) minimizes the sum of two main components. The first component represents all costs incurred within the network. These costs comprise fixed and variable costs for purchasing raw materials, for opening, manufacturing and handling products at facilities and for the transportation of raw materials and finished products across the network. The second component of the objective function represents the total weighted impact of each competitiveness pillar. The impact of a competitiveness pillar depends on three critical components:

- α_i : the weight of the pillar,
- CS_{ip} : the competitiveness score of the manufacturing plant for a specific pillar,
- $\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw}$: the amount of product shipped from each plant.

For every pillar $i \epsilon I$, the following outcome:$\sum_p CS_{ip} (\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw}))$ will be, from now on, referred to as the total Pillar Score on *i* *(PS_i).*

Constraints (2) guarantee that all customers' demands are satisfied. Equalities (3) ensure that the required amount of raw material is available at each facility, in order to deliver all products made at that plant. Constraints (4) ensure that all products entering a distribution center are also exiting it. Constraints (5a), (5b) and (5d) ensure the restriction of capacities for suppliers, manufacturing plants and distribution centers. Finally constraints (5c) ensure that a product is only handled at a facility if this facility is open.

4.2 Weight determination model

The model described above assumes that a weight (α_i) is associated to each competitiveness pillar *i.* To determine these weights, we here propose the use of an inverse optimization method.

Given an optimization problem P, forward optimization, which is commonly used in operations research, assumes that all parameters required to find the optimal solution are measurable. The usual measurable parameters used to find the optimal solution of P are: cost, lead times, distances, capacities, etc. The underlying assumption of forward optimization is thus that the observable and measurable parameters completely describe the problem P. Solving the forward optimization problem consequently leads to the optimal solution s_0.

Conversely, inverse optimization is based on two main assumptions:

- s_0, the optimal solution to the problem to the optimization problem P is known
- Problem P is both defined by measurable and non-measurable parameters.

Because s_0 is assumed to be the optimal solution to P, the purpose of inverse optimization is to find the "adjusted objective function" that gives s_0 as the optimal solution when comparing it to the set of all feasible solutions to problem P. The adjusted objective function in inverse optimization integrates both measurable and non-measurable parameters while inferring weights on the non-measurable parameters. These inferred weights lead to s_0 as an optimal solution (Ahuja and Orlin, 2001; Flisberg et al., 2012).

In our specific case, if we assume S to be the set of feasible solutions to a standard LNDP, then every solution in S is defined by the following measurable parameters: Total Costs of operation (TC_s) and total Pillar Score for each pillar i (PS_{is}). Using inverse optimization and assuming that $s_0 \epsilon$ S is the optimal solution to the LNDP will allow to determine the pillar's weights. These weights are parameters that are not directly measurable, as they represent the company's priorities regarding competitiveness attributes.

Determining the pillar's weights through inverse optimization can be done using two successive steps: generation of feasible solutions and determination of weights.

4.2.1 Step One: Generation of solutions for standard LNDP

In order to find the weights inferred on the competitiveness pillars included in the objective function of our inverse optimization problem, we have to compare the solution assumed to be optimal s_0, to a large set of feasible solutions for which all measurable parameters are known. Ideally, one should consider the full set of feasible solutions to determine the optimal weights. However, because this may lead to an intractable formulation, one may instead consider just a subset of solutions to approximate the weights.

To do so, we first need to generate a large and random set of solutions for a standard LNDP. The standard LNDP formulation used here only differs from the weighted LNDP formulation presented in Section 4.1 in the objective. In fact, the objective function of the standard LNDP does not integrate the last term: $\sum_i(\alpha_i \sum_p CS_{ip} (\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw}))$ used in the objective of Problem 1.

The measurable parameters of each one of the generated solutions (Total Cost and Total Score on pillar i) will then be recorded and used in the second step. By forcing, in the standard LNDP, some decisions such as: opening/closing of manufacturing plants, use of warehouses, use of specific suppliers, forcing the supply of a customer from a specific plant / warehouse, we generate a set of solutions for which the measurable parameters vary widely.

For every random solution generated, the following parameters are recorded:

- Total costs (TC_s):

$$\sum_{p} G_p z_p + \sum_{w} G_w z_w + \sum_{f,p} G_{fp} u_{fp} + \sum_{r,s} G_{rs} \sum_{p} X_{rsp} + \sum_{f,p} G_{fp}^{v} (\sum_{w} W_{fpw} + \sum_{c} Y_{fpc}) + \sum_{f,w} G_{fw}^{v} \sum_{c} Y_{fwc} + \sum_{f,p,w} GT_{fpw}^{v} W_{fpw} + \sum_{f,p,c} GT_{fpc}^{v} Y_{fpc} + \sum_{f,w,c} GT_{fwc}^{v} Y_{fwc}$$

- Total Pillar Score on every pillar *i* (PS_{is}) :

$$\sum_{p} CS_{ip} (\sum_{fc} Y_{fpc} + \sum_{fw} W_{fpw})$$

For every solution, the total pillar score on each pillar depends on the competitiveness score of the plant CS_{ip} and on the amount of finished products manufactured in each plant.

4.2.2 Step Two: Determination of each pillar's weight

The second step allows the determination of each pillar's weight by comparing all feasible solutions to the optimal solution s_0. The weights given by the following mathematical model ensure the optimality of s_0 when compared to all solutions in *S*:

Sets:

S	Set of randomly generated solutions
I	Set of pillars of competitiveness

Parameters:

TC_s	Total costs of solution *s*
PS_{is}	Total Pillar Score of pillar *i* in solution *s*
TC_{s_0}, PS_{is_0}	Total costs and total score of pillar *i* of optimal solution s_0

Variables:

α_i	Weight of competitiveness pillar *i*
β	Deviation measure

Problem 2:

$$\textbf{Minimize: } ZB = \beta \qquad (B1)$$

Subject to:

$$TC_{s_0} + \sum_i \alpha_i \, PS_{is_0} - \beta \le TC_s + \sum_i \alpha_i \, PS_{is} \qquad \forall s \epsilon S \qquad (B2)$$

$$\alpha_i \le 0 \qquad \forall i \qquad (B3)$$

The objective function (B1) minimizes the deviation between the summation of costs and weighted Total Pillar Scores of the chosen solution and every other solution in S. This deviation measure is required as the chosen solution s_0 is not ensured to be the optimal solution given the defined weights. If s_0 is the optimal solution for a given set of weights, then the deviation measure will be equal to 0.

The condition B2 is the central point of the inverse optimization method as it guarantees that given all weights α_i, the total mass of the optimal solution s_0 is less than the total mass of each solution in *S*.

Finally, constraint (B3) ensures that all pillars' weights are negative. The negativity condition on the pillars' weight is required to counterbalance the scaling system of the Global Competitiveness Index. In fact, the components of the competitiveness pillars are scaled in a way that grants:

- maximum scores (7) to highlight strong performances
- minimum scores (1) to highlight poor performances

Because of this scaling scheme, forcing the pillars' weight to be negative ensures their compatibility with the minimization objective of the core problem.

Chapter 5 – Case Study

5.1 BIC Corporation

BIC is a French company founded in 1945 by Marcel Bich. At its beginning, the company was mainly manufacturing pens at its only plant in Clichy (France). Throughout the years, BIC has diversified its operation and is now a MNE producing:

- **Stationary products (pens)**: Ball pens, correction tapes, highlighters, coloring pencils, glues, scissors...
- **Lighters:** classic, electronic, lighter cases, megalighter...
- **Shavers:** man shavers, woman shavers, using 1, 2, 3 or 4 blades...
- **Advertising and Promotional Products (APP):** branded mugs, bags, pens, book notes...

As a multinational enterprise, BIC's production and distribution operations are spread all over the globe. The following figure, extracted from "BIC Document de référence 2012", gives a detailed outlook of the location of BIC's 23 factories.

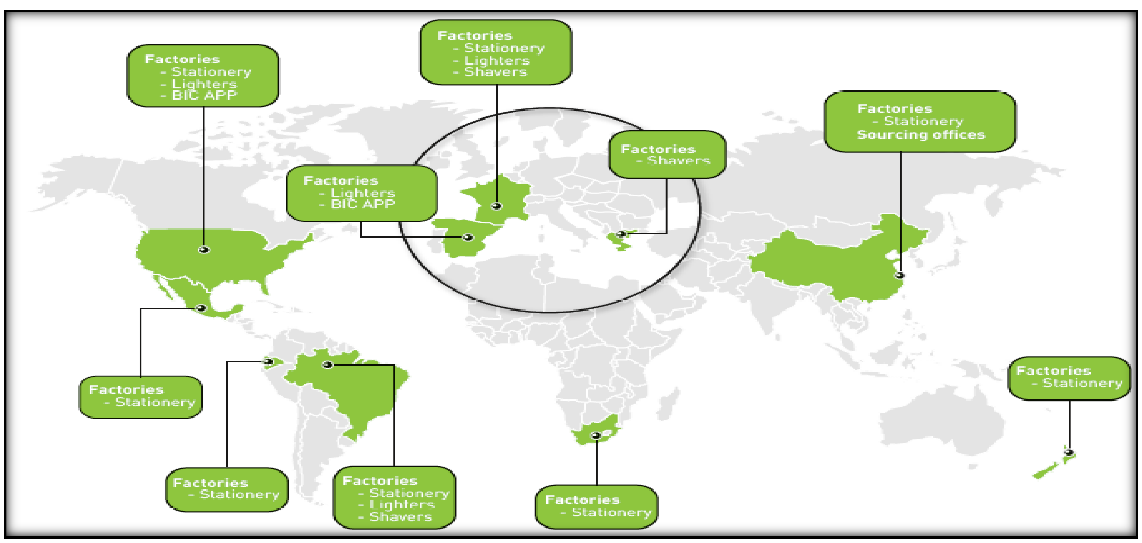

Figure 2: BIC's network

About 46 million BIC products are sold every day in more than 160 countries around the world. One in two lighters sold in the world is a BIC product. BIC stationary products are the number one sellers in Africa, Europe, India and Latin America. Finally, BIC's shavers are the second most sold one-piece shavers around the globe.

In 2012, BIC Corporation's net sales were the following:

- $637 Million in Europe
- $1076 Million in North America
- $784 Million in Developing countries

Finally, the company employs over 9,200 employees of which: 61% work in Production and R&D, 20% work in Marketing and Administration and 19% work in Sales and Customer Service (Groupe BIC, 2012a).

5.2 BIC Challenges

As mentioned in the previous description, BIC has four main divisions. Acknowledging the fact that BIC's APP division is a recent division - created in 2009 - whose mission and products have largely changed over the last years, this case study will only treat the global network of the following divisions: pens, lighters and shavers.

Planning for their manufacturing and distribution strategy for 2013, BIC leaders had the following facts in mind:

5.2.1 Lighters' norms and anti-dumping tax

a) Lighters are hazardous products that must be designed and manufactured in order to ensure a safe use by consumers. Two international standards are relevant for the manufacturing of lighters. First, the ISO9994 establishes the quality, reliability and safety specifications for lighters and all flame-producing devices. Second, the European Standard EN13869 establishes child resistance specifications to prevent young children from being able of generating a flame. Both of these norms prevail in the European Union (EU), Canada, Japan and South Korea. At least one of these two norms is applied in the following countries: US, Russia, Mexico, Argentina, Australia, South Africa, New Zealand and Indonesia (Groupe BIC, 2012a).

Since the 1990s, low-cost lighters designed and produced in some Asian countries do not respect any of the previous norms. Despite this fact, these Asian lighters represented 40% of lighters sold around the globe in 2012. These lighters are flooding the Asian market. These products are also putting at risk BIC's European market as they represent 70% of EU imported lighters. Although the Asian lighters do not conform to ISO9994 and EN13869, which were both adopted by the 27 countries of the EU, a failure in the application of the norms allows these products to be easily imported.

BIC has been pushing the European Commission for a consistent application of the measures that ensure the practical implementation of the norms but, as of December 2012, no reinforcing measures were adopted (Groupe BIC, 2012a).

b) Since 1991, an anti-dumping tax of 0.085$ is applied to every lighter imported from China. This tax, applied all across the EU, was created to restore the conditions of a fair competition between Chinese and European lighter manufacturers. In 2012, the EU Commission was studying the renewal of the anti-dumping duty (Lentschner and Mevel, 2012). The BIC Corporation has lobbied for their cause in Brussels, stressing the "unfair competition" of the lighters "made in China". The company has also threatened to suspend their investments in Europe. In fact, in an interview with a journalist from Le Figaro in November 2012, BIC's chairman of the board made the following statement:

> *"We have four lighters manufacturing facilities: in Redon (France) - where we produce 50% of our global production-, in Brazil, in USA and in Spain. I want to be clear. We have already decided on an investment plan of 10 million Euros for the next 3 years. As per today,*

> *a vast amount of those 10 million are for the Redon facility and will be maintained if the anti-dumping tax is renewed. Otherwise, we will re-examine our choices and it is as simple for us to expand our facilities in North or Latin America."*

On December 13th 2012, despite the lobbying and the threatening of BIC, the Directorate-General for Trade of the EU issued a negative recommendation concerning the renewal of the anti-dumping tax (AFP, 2012).

5.2.2 Growth in emerging markets

BIC has succeeded in being one of the biggest companies in the sectors it competes in. As a result, the company's overall net sales in 2012 have increased by 4% compared to the previous year. The sales for the European market are experiencing a stagnation phenomenon, while the North American market (US and Canada) and the market of developing countries have a growing net sales performance of 3.5% and 4.7% respectively (Société BIC, 2012) .

In Europe, due to the economic downturn, BIC has seen its sales plummet in North and Western European countries. On the contrary, in many countries of Eastern Europe, such as Russia, Ukraine and Turkey, the company has experienced a growth of about 5% in its sales. Lighters are a key contributor to Eastern Europe's sales increase.

The North American performance growth is mainly explained by the double digit growth in shavers' sales. An increase of 5% in the sales of pens and losses in sales volumes for the lighter division complete the North American picture.

For the developing countries, the situation is promising because of the following trends in sales (Société BIC, 2012):

- Latin America: 5% growth of sales volume for the pens and shavers divisions. Because of new non-smoking policies, lighter sales have dropped in many countries.

- Middle East and North Africa (MENA): 10% growth in sales of lighters and a stable performance for shavers and pens.
- Asia: Growth of sales of 8% in India and 12% in China for stationary products and important sales increases for lighters in Japan, Thailand, South Korea, Malaysia, China, Philippines, Vietnam, Hong Kong and Taiwan. Losses in sales volumes for shavers and a steady performance for lighters sales.

5.2.3 Supply Chain performance

In order to edit their “2012 Sustainable Development Report”, BIC assessed the carbon footprint of its products. One of the issues mentioned by the report was the high impact of distribution activities on the CO_2 emissions. The company has targeted a 4% reduction of its carbon emissions in 2013. To do so, changes in transportation modes, increases in some facilities’ capacity (near-shoring) and delivery route optimization initiatives are planned for 2013 (Groupe BIC, 2012b).

Challenge ahead

Acknowledging the unfavourable decisions of the EU commission, the growth of sales opportunities in emerging markets and the challenges in transportation, BIC’s Board of Directors has decided to look at these challenges as an opportunity to improve the company’s performance and aims at redesigning BIC’s global supply chain. As a matter of fact, it is the Board’s decision that the investments that were once planned to expand the company’s presence in Redon should be redirected toward building or enlarging BIC’s facilities around the world, in order to ensure the highest possible profit while respecting BIC’s vision and values and ensuring a better presence in the emerging markets (Lauer, 2012).

BIC’s new logistics network design will decide on:

- Expanding actual facilities or opening new ones
- Reviewing the distribution channels
- Modifying the flow of raw material and products

5.3 BIC's global network description

The Global network of BIC is composed of suppliers, manufacturing plants[2], warehouses and customers. An important part of the information presented below was found on BIC's official website (Groupe BIC, 2013).

5.3.1 Products

The products manufactured by BIC are every day consumable products. The production processes needed to manufacture shavers, pens and lighters are fairly simple activities, that do not require any complex technology. In the manufacturing facilities around the world the following machines can be found: molding machines, assembly lines, marking machines and packaging machines (Groupe BIC, 2012a). Because these machines are undemanding and widespread, no major investment in new technologies is needed when setting up a BIC facility.

BIC manufactures tens of types of shavers, pens and lighters. We here provide the description of a "typical" product of each division (Groupe BIC, 2005).

Product	Materials	Packaging
BIC Cristal pen	- 5.3gr: polystyrene - 0.4gr ink - 0.1gr steel	50 pens/box 923 box/pallet 26 pallets/TEU[3]
BIC classic shaver	- 6gr: polystyrene - 2.8gr: steel	150 shavers/box 84 box/pallet 26 pallets/TEU
Bic J6 lighter[4] (Maxi)	- 17gr: polystyrene - 5gr: steel - 4.6gr: isobutene	600 lighters/box 20 box/pallet 63 pallets/TEU

Table 2: Products' Bill of Materials

[2]BIC has two packaging centers These facilities are not taken into account in this case because no detailed information, describing the links between these facilities and BIC's manufacturing plants, was available.
[3] TEU refers to a Twenty foot Equivalent Unit (container)
[4] Weights were found using real measurements.

5.3.2 Manufacturing plants

The following table presents a detailed list of all production plants of the company around the world, their capacities and the number of employees in each plant. (Groupe BIC, 2012; Defrance, 2012; Export Leaders, 2012; Cordova, 2012; Moreno, 2012; ONE News, 2013; Europa Press, 2009; Merlin, 2012).

Product	Country	City	Capacity	Number of production employees
Lighters	France	Redon	650 million/year	350
	United States	Milford, CT	115 million/year	100
	Brazil	Manaus	210 million/year	150
	Spain	Tarragona	325 million/year	200
Shavers	Greece	Anixi	2350 million/year	1000
	Brazil	Manaus	325 million/year	200
	France	Longueil –Sainte-Marie	820 million/year	200
Pens	Brazil	Manaus	620 million/year	300
	Brazil	Rio de Janeiro	415 million/year	200
	Ecuador	Guayaquil 1	160 million/year	80
	France	Marne la Vallée	550 million/year	200
	France	Boulogne-sur-Mer	450 million/year	160
	France	Samer	300 million/year	80
	France	Vannes	450 million/year	160
	Mexico	Mexico City1	520 million/year	250
	South Africa	Johannesburg	520 million/year	250
	New Zealand	Auckland	15 million/year	15
	USA	Gaffney, SC	215 million/year	80
	Spain	Tarragona	845 million/year	300

Table 3: Specifications of actual manufacturing plants

For the purposes of the following work, we assume that the potential manufacturing plants would be located in geographical regions where the growth in consumption presented in Section 5.2.2 is significant for BIC. Therefore, the plants envisaged by BIC are located in the following cities:

- Lighters: Casablanca (Morocco), Tunis (Tunisia), Izmir (Turkey) and Warsaw (Poland)
- Shavers: Mexico City (Mexico), Guayaquil (Ecuador) and Bogota (Colombia)

- Pens: Bangalore (India), Shenzhen (China) and Jakarta (Indonesia)

In each of these cities, the potential manufacturing plants can be small, medium or large. The annual capacities of the small, medium and large manufacturing plants are respectively: 100, 300 and 600 million products. Appendix A displays the specifications of each new potential plant.

5.3.2.1 Costs

The fixed costs for each actual / potential manufacturing plant were approximated using the international warehouse rent rates issued in the Global Industrial Report of Colliers International (2013). Because we accepted that the technologies used in the manufacturing of BIC's products are standard technologies that do not lead to specific requirements in the plant's setup, we can assume that for BIC, the annual real estate possession costs incurred for the use of the manufacturing plant are equivalent to the annual costs incurred for the use of a warehouse. We computed the fixed annual costs of opening a plant as follows:

$$\begin{aligned}&Fixed\ cost\ of\ opening\ a\ plant\ (USD/YR) =\\ &\qquad Rent\ rate\ in\ plant's\ city\ \ (USD/SF/YR) \times plant's\ area\end{aligned}$$

The areas were all approximated using the actual square footage of Manaus manufacturing plant (Groupe BIC, 2012c). We computed the square footage of all plants as follows:

$$\begin{aligned}&Plant's\ area\ (SF) =\\ &\qquad Manaus'plant\ area\ (SF) \times \frac{Plant's\ capacity}{Manaus'plant\ capacity}\end{aligned}$$

The variable costs incurred at each production plant were computed based on the manufacturing wages indexed for the year 2012 by the private market intelligence firm Euromonitor. For Tunisia and Morocco, Euromonitor does not indicate any manufacturing wage. For these two countries, manufacturing wages where approximated using the wages applicable in the apparel industries in these countries (Werner International, 2012).

$$Variable\ cost\ at\ plant\ (USD/unit\ of\ product) = Hourly\ manufacturing\ wage\ \times production\ rate$$

For the variable costs, we assume that:

- All production employees work 40 hrs /week and 48 weeks/year, the annual working hours for a single employee is thus estimated at 1920 hrs/year.
- The annual production of each manufacturing plant is equal to 90% of actual plants' capacity.

Using the above assumptions, the production rate at each plant was computed as follows:

$$Production\ rate\ at\ plant\ (HR/unit\ of\ product) = \frac{1920\ \times Number\ of\ employees}{0.9\ \times Capacity\ of\ the\ plant}$$

For the new potential manufacturing plant in China, Poland, etc., the production rate was approximated using the production rate of the Manaus' manufacturing plants.

Appendix B displays fixed and variable costs at each actual and potential manufacturing plant.

5.3.3 Warehouses

BIC warehouses allow the distribution model to centralize shipments of different products when serving customers. BIC uses one warehouse in Spain and another one in the US.

According to the Warehouse Education and Research Council (2010), the average warehouse capacity used for a typical warehouse is equal to 85%. According to the same source, the average sales day of finished goods inventory in hand in a typical warehouse is equal to 32 days. Using this data along with the physical capacity at BIC's warehouses (Groupe BIC, 2012a) we can approximate the annual capacity of Barcelona's and Charlotte's warehouses.

$$Annual\ warehouse\ capacity = \frac{356}{32} \times 0.85 \times Physical\ capacity$$

Country	City	Physical Capacity	Annual Capacity	Employees
Spain	Barcelona	25 900 pallet places	245 000 pallets	62
USA	Charlotte, NC	37 900 pallet places	259 000 pallets	90

Table 4: Specifications of warehouses

Appendix C displays the fixed and variable costs for each warehouse. The same assumptions used to compute these costs for the manufacturing plants were used here.

5.3.4 Customers

The central distribution points will here be considered as the customers of BIC's network. In reality, these central points are connected to a total of 3.2 million retail points around the world. Because the distribution activities between the retail points and the central distribution points are not homogeneous (responsibility, quantities, lead times...) the retailing points will not be considered in this case study.

Because no advanced information is given about the distributed products, we here assume that each distribution center dispenses all BIC products. "BIC- Document de référence 2012" provides only the sold volumes per continent: Europe, Asia, North America, South America, Oceania and Africa. Acknowledging this fact, the demand of each country has here been assumed as being proportional to the demographic weight of the country in the continent. The global demand in 2012 was equivalent to: 5875 Million Pens, 2350 Million Shavers and 1300 Million Lighters.

Using the United Nations Demographic Yearbook (2012) and the list of central distribution points of BIC (Groupe BIC, 2012a), we computed the demand of a specific country for a single product as follows:

$$Demand\ of\ country\ (product/YR) =$$
$$Demand\ in\ continent \times \frac{country's\ population}{population\ of\ continent}$$

The population of a continent only takes into account the population of countries where a central distribution point exists. Appendix D displays the demand of each country for each product.

5.3.5 Suppliers

No information was available on the supply strategy of BIC. Acknowledging that raw materials used in the manufacturing of BIC products (mainly plastics and steel) can easily be found in every region of the world, we assumed that BIC would choose a local supply strategy. For every country where an actual/potential manufacturing plant is located, the price of raw materials needed was found using the UNComtrade database. The prices displayed by UNComtrade represent the exporting prices for every raw material in 2012. For this case study, the exporting price is therefore assumed to be representative of the local selling price. The capacity of local suppliers for all raw materials is assumed to be unlimited.

HS2012 Code	Product
390319	Polystyrene
271113	Isobutene
3215	Ink
721911	Stainless Steel

Table 5: Raw materials' code

Appendix E displays the price of each raw material in each country where it can be needed for manufacturing purposes.

5.3.6 Transportation

We first assume that BIC does not own a transportation fleet and that all products are transported either by truck or by ship. To evaluate the distance between each pair of: manufacturing plant/warehouse, warehouse/customer and manufacturing plant/ customer, we used:

- Google Maps: for ground roads
- Searates.com: for maritime routes

Using Google Maps, we also found for each non-coastal city used in BIC's network the major nearby industrial harbour from which merchandises can be sent or received. The list of these ports is displayed in Appendix F.

Because of the assumption that BIC uses local suppliers for raw materials, we here admit that all transportation costs for merchandises sent from suppliers to manufacturing plants are assumed to be insignificant. All other transportation costs were computed using the WorldFreightRates.com auction website. By testing different routes, we were able to uncover the average rates proposed to customers willing to send a shipment by truck or by sea. The tables below display the rates per kilometre for the shipment of a container (Twenty-foot Equivalent Unit (TEU)):

Continent	Europe	Asia	America (North and South)	Africa	Australia
Average rate ($/TEU- km)	2.16	2.24	2.00	3.34	1.87

Table 6: Ground transportation rates by continent

Distance	Average rate ($/TEU-KM)
Under 10 000 km	0.32
Over 10 000 km	0.15

Table 7: Maritime transportation rates

The following example illustrates the logic used when computing the variable costs for the delivery of one container of product from the manufacturing plant in Tarragona (Spain) to customers in Santiago (Chile):

Departure Point	Arrival Point	Distance (km)	Applicable rate ($/TEU- km)	Price ($/TEU)
Tarragona	Barcelona (Harbour)	100	2.16	216
Barcelona (Harbour)	San Antonio (Harbour)	14 000	0.15	2100
San Antonio (Harbour)	Santiago	100	2.00	200
Total				
Tarragona	Santiago			2516 $/TEU

Table 8: Example of transportation costs computation

5.3.7 Countries' competitiveness indicators

As presented in Chapter 3, we used "The Global Competitiveness Report 2011-2012" to compute the competitiveness score of each country on each pillar. The competitiveness scores of a plant are equal to the competitiveness scores of the country where it is located in. Each plant has seven competitiveness scores, one for each of the following pillars: Institutions, Infrastructure, Health and Primary Education, Higher Education and Training, Goods Market Efficiency, Labor Market Efficiency and Business Sophistication. The computation of each one of these scores is done as follow:

$$Competitiveness\ score\ of\ a\ plant\ for\ a\ pillar = \frac{Sum\ of\ Competitiveness\ Scores\ on\ each\ component\ of\ the\ pillar}{Number\ of\ components\ of\ the\ pillar}$$

Appendix G displays the competitiveness scores of all manufacturing plants, for each pillar.

Chapter 6 - Results and analysis

This chapter aims at analyzing the results obtained by the application of the weighted LNDP mathematical model proposed in Chapter 4 to BIC's case study.

GMPL is the modeling language that has been used together with the GLPK solver to model BIC's problem. GMPL is a subset of the AMPL language, allowing the modeling and solution of linear programming problems with integer variables.

A model's structure in GMPL is composed by two parts: the model description and the data description. The first part allows describing generically the mathematical model, its sets and its variables. The data description is then declared independently and GMPL calls the required data to solve the problem. This language was adequate to handle the medium-scale problem described here (17 suppliers, 24 plants, 2 warehouses and 48 customers).

In addition to the general conditions of the weighted LNDP described in Chapter 4 (deterministic demand, demand satisfaction and no transportation of subassemblies between plants), the following conditions have been applied to all solutions related to BIC's case, presented in Chapter 6:

- Transportation within a continent is done by truck (unless no road is available) and transportation across continents uses maritime transportation.
- Manufacturing plants purchase raw materials from local suppliers.

6.1 Preliminary analysis

Before analyzing the results of the weighted LNDP model, we describe two basic network configurations.

The two following networks are the result of standard LNDP resolution where all α_i are equal to zero:

- **BIC's actual network**: represents the network design that minimizes total costs while only choosing within BIC's actual plants presented in Table 3.
- **Minimal cost network**: represents the network design that minimizes total costs while choosing within BIC's actual and potential manufacturing plants presented in Table 3 and Appendix A.

BIC's current network uses the list of manufacturing plants described in Table 9.

Product Manufactured	Manufacturing plant
Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Manaus, Rio de Janeiro, Tarragona, Guayaquil 1, Mexico 1, Johannesburg, Auckland
Shavers	Longueuil, Manaus and Anixi
Lighters	Redon, Milford, Manaus and Tarragona

Table 9: Manufacturing plants of BIC's actual network

The minimal cost network opens the plants listed in Table 10.

Product Manufactured	Manufacturing plant	% of demand supplied from BIC's existing manufacturing plants
Pens	Gaffney, Manaus, Rio, Tarragona, Guayaquil 1, Mexico 1, Johannesburg, Bangalore 3, Shenzhen 3 and Jakarta 3	53%
Shavers	Longueil, Manaus, Guayaquil 4, Mexico 4 and Bogota 1	
Lighters	Manaus, Izmir 3 and Warsaw 3	

Table 10: Manufacturing plants of BIC's minimal cost network

Given the above configurations, Table 11 provides a comparison between the costs and total pillar's scores of the two configurations.

	Parameters	BIC's Actual Network (A)	Minimal Cost Network(B)	Performance of B compared to A
TC_s	Total costs ($)	356,981,000	278,399,600	-22%
PS_{is}	Total Score of Institution's pillar	37068.2	34392.7	-7%
	Total Score of Infrastructure's pillar	44022.2	36715.8	-17%
	Total Score of Health and Primary Education's pillar	52714.4	48262.1	-8%
	Total Score of Higher Education and Training's pillar	37091.1	35324.9	-5%
	Total Score of Good Market Efficiency's pillar	38675	37342.9	-3%
	Total Score of Labor Market Efficiency's pillar	33632.4	35555.9	+6%
	Total Score of Business Sophistication's pillar	43284.3	40399.7	-7%

Table 11: Comparison of networks A and B

We notice that the minimal cost network, which would be 22% less costly than the actual network would also be a network where all pillars' scores, except for Labor Market Efficiency, would be diminished.

According to the theory developed in this work, the minimal cost network is the optimal network configuration given by the weighted LNDP model when all pillar weights are null. If at least one of the pillar weights is different from zero, then the new optimal solution proposed by the weighted LNDP may deviate from the minimal cost network solution. The new proposed solution would be expected to be more costly than solution (B) but to perform better, at least, for the pillar whose weight is significant.

6.2 General weight variation analysis

In this section, we will force different weights on the pillars and examine the performance of the weighted LNDP model. In fact, before integrating weights corresponding to the inverse optimization method, we will here manually impose weights and analyze the changes in the proposed solutions for BIC's case study.

By changing one weight at a time, the objective is to validate that the weighted LNDP model behaves as expected.

Modified pillar	Weight value	Comparison with minimal cost network (B)		
		Score of modified pillar (%)	Cost performance (%)	Major network design changes
Institution	≤ -100 000	+11%	+25%	• Closing plants in Mexico, Ecuador, Colombia and Turkey • Opening plants in France, New Zealand, Greece and Tunisia
	-30 000	+10%	+17%	• Closing plants in Brazil and Turkey • Opening plants in France and Tunisia • Operating a small capacity plant in Poland
	-5 000	+0.6%	+0.1%	• Opening of one plant in France and closing a plant in USA
	-1 000	0%	0%	• No change
Infrastructure	≤ -100 000	+25%	+30%	• Closing plants in Brazil, Ecuador, Indonesia, Poland, Turkey and Colombia • Opening plants in France, New Zealand, Greece, USA, Spain and Tunisia
	-30 000	+23%	+23%	• Closing plants in Brazil, Ecuador, Colombia and Poland • Opening plants in France, Greece and Tunisia
Health and Primary Education	≤ -800 000	+13%	+30%	• Closing plants in India, Indonesia, Colombia and Turkey • Opening plants in France, Spain, New Zealand and Greece
	-200 000	+12%	+25%	• Closing plants in India, Indonesia and Colombia • Opening plants in France, Spain, New Zealand and Greece

Table 12: Manual variation on pillars' weight

According to the results presented in Table 12, forcing a weight on a competitiveness pillar changes the optimal solution proposed by the model.

To better acknowledge the mutation of the optimal solution given by the weighted LNDP, here is a detailed analysis of the observed changes when the weight $\alpha_{institution}$ is different from 0 while all other pillars' weight α_i are forced to be null:

- -1000 ≤ $\alpha_{institution}$≤0: the optimal solution proposed by the weighted LNDP is exactly equal to the minimal cost network (B)
- -5000 ≤ $\alpha_{institution}$≤-1000: the optimal solution proposed by the weighted LNDP closes a plant in the US and opens a new one in France. Acknowledging the fact that CS_{ip}, the Competitiveness Score on "Institution" for a plant in France, is equal to *4.9* and that it is equal to *4.4* for a US plant, the switch of manufacturing plants comes out as a consistent choice. By shifting the total amount of manufactured products from USA to France, the new solution improves the performance of the optimal solution on the institutions score PS_{is} (which depends both on CS_{ip} and the amount of products manufactured in each plant) by *0.6%*. The new optimal solution's cost is superior to the logistics costs of the minimum cost network by 0.1%.
- -30000 ≤ $\alpha_{institution}$≤-5000: the optimal solution proposed by the weighted LNDP closes 3 plants in Brazil (manufacturing pens and lighters), and one plant in each of the following countries: Turkey (manufacturing lighters), Ecuador (manufacturing pens), and Mexico (manufacturing pens). CS_{ip}, the competitiveness scores on "Institution" for these plants were equal to: *3.8* for Brazil's and Turkey's plants, *3.2* for Ecuador's plant and *3.4* for Mexico's plant. In France, four plants manufacturing pens and one manufacturing lighters have been opened. A plant manufacturing lighters has been opened in Tunisia. The competitiveness score on Institution in France and Tunisia are respectively equal to *4.9* and *4.7*. All these changes, along with the fact that this new solution uses a smaller plant in Poland, whose competitiveness score on Institution is equal to *4.3* (the plant used in the minimum cost network had an annual production capacity of 600 Million lighters, the plant used in this optimal solution has an annual production capacity of 100 Million lighters), increase the costs of the optimal solution by

17% in comparison with the cost incurred for the minimum cost network while improving its Institution's score by 10%.

- $\alpha_{institution}$≤-100000: the optimal network obtained once the weight on the Institution's pillar is smaller than -100000 keeps all the changes established when $\alpha_{institution}$ ϵ [-30000,-5000] and also replaces the manufacturing of shavers that was done in Colombia, Ecuador and Mexico, whose scores on the Institutions' pillar is respectively equal to *3.2, 3.2* and *3.4,* by the use of a new manufacturing plant in Greece. The competitiveness score on the Institution pillar of Greece is equal to *3.6*. This solution costs 25% more than the minimum cost network solution and provides the most efficient network in terms of Institution's score.

As we notice through the experiment regarding the Institution's pillar: decreasing the weight value (increase of absolute value) of a pillar increases the number of changes in the network. These changes improve the total score of the targeted pillar by closing manufacturing plants in countries with low competitiveness scores and opening new ones in countries with better competitiveness scores. Also, we notice that when decreasing the weight value of a pillar, the solution's cost increases. The increase in cost is due to the fact that the reinforcement of the constraint on the competitiveness pillar eliminates some plants for which manufacturing and distribution were the least costly.

The same pattern we've shown here for the Institution pillar is found for all other six pillars used in this model.

Finally, we need to acknowledge that changing a pillar's weight does not automatically change the solution. In the preliminary analysis, we made the assumption that: "*If at least one of* ***the pillar's weights is different from zero****, then the new optimal solution proposed by the weighted LNDP should deviate from the minimal cost network solution.*" But the weighted LNDP, when $\alpha_{institution}$ ϵ [-1000, 0], still proposes the minimal cost network as the optimal solution. We therefore have to review our initial assumption and conclude that the new optimal solution proposed by the weighted LNDP should deviate from the minimal cost network only if **the weight on at least one pillar is significant**.

6.3 Analysis of randomly generated solutions

In order to test the weighted LNDP model, we have to find the weights implicitly applied by BIC to choose the actual network. As stated in Section 4.2.1, to find the weights, we first have to generate a set of random solutions and record their measurable parameters.

To generate our set of feasible solutions for the standard LNDP, we used BIC's extended network which incorporates both BIC's actual manufacturing plants and BIC's potential manufacturing plants around the globe. By forcing, each time, a different situation on this extended network, we generated 165 different networks that are all able to satisfy all customers' demand. Situations forced on the extended network were randomly chosen and were either implying a single change (such as forcing the opening of a plant in India, forcing the closing of a plant in Poland...) or implying multiple changes (such as forcing the closing of all plants in Mexico, forcing the supply of European customers from European manufacturing plants...)

The following figure shows the variation in the total network costs of the ranked 165 randomly generated solutions.

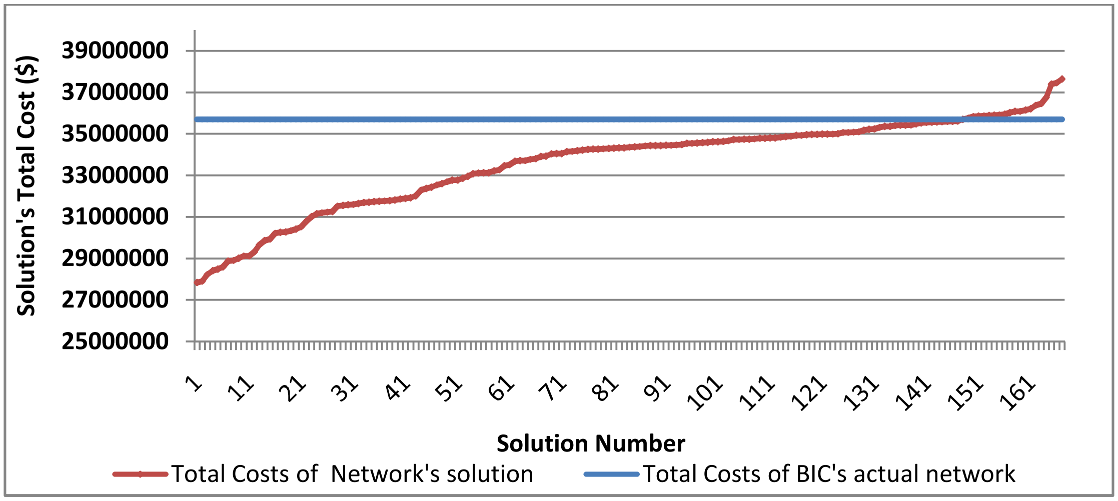

Figure 3: Total network costs variation of generated solutions

The parameters defining the total pillar score of each of the seven competitiveness pillars change within each solution. Here are the variation figures of two of these competitiveness pillars (Institution and Labor Market Efficiency).

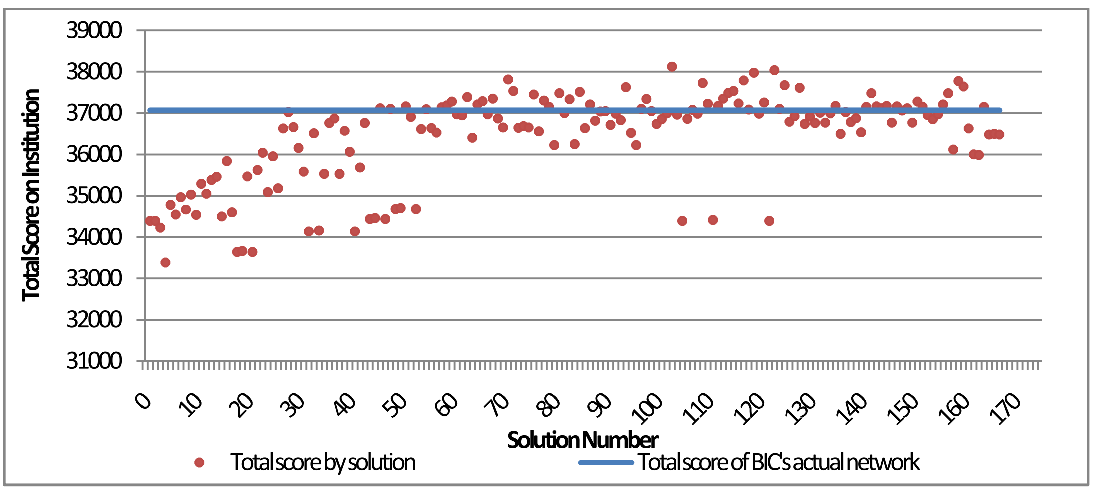

Figure 4: Variation of generated solutions' scores on the Institution's pillar

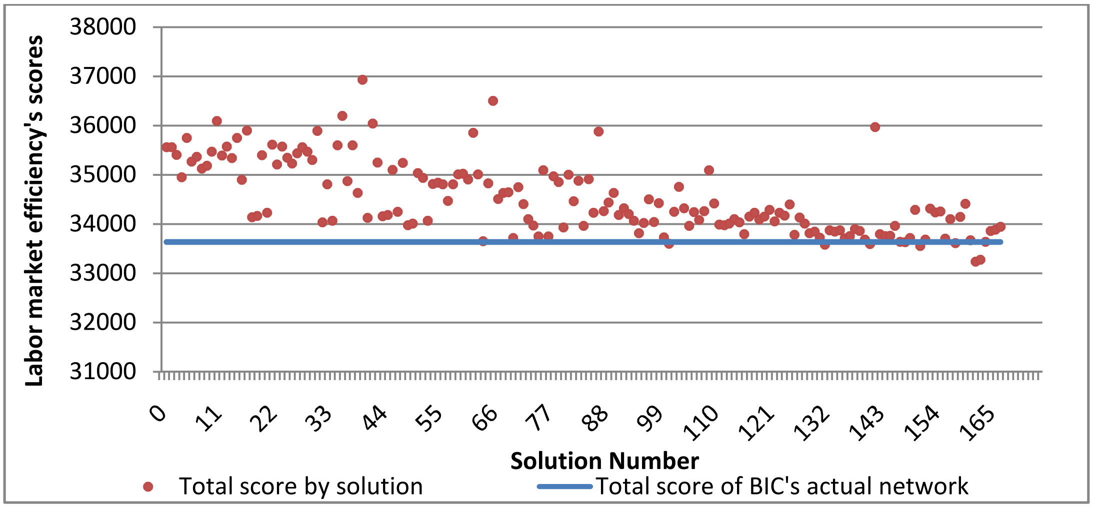

Figure 5: Variation of solutions' scores on the Labor Market Efficiency's pillar

It is easily noticeable that the forty less costly solutions are also solutions that are less efficient in terms of Institutions. This pattern repeats itself for the following pillars: Infrastructure, Health and Primary Education, Higher Education and Training, Goods Market Efficiency and Business Sophistication. The "Labor Market Efficiency" pillar is the only one producing a different pattern.

Despite the pattern for the forty first solutions and according to the above results, we can conclude that on the overall there is no clear correlation between a solution's costs and its total pillars scores. The absence of correlation validates the assumption that integrating the competitiveness variables to the problem formulation and altering their weights might change the resulting solution.

6.4 BIC case

6.4.1 Results and analysis

Applying the second step of the inverse optimization method, which allows the determination of each pillar's weight by comparing a set of feasible solutions to the optimal solution s_0, we here compare BIC's actual network's parameters to a set of respectively 10, 20, 70, 100, 120, 150 and finally 165 randomly generated solutions. The table below presents the weight given to each pillar by the inverse optimization problem depending on the number of solutions we compare s_0 to:

	Pillar's weight when comparing to:						
Number of solutions:	10	20	70	100	120	150	165
Set of Weights	C1	C2	C3	C4	C5	C6	C7
Institutions	0	0	0	0	0	0	0
Infrastructure	0	-10007	-17856	-10702	-14692	-19696	-19696
Health and Primary Education	0	-6282	-5646	-5156	-4113	-9453	-9453
Higher Education and Training	0	0	0	0	0	0	0
Goods Market Efficiency	-35445	0	0	0	0	0	0
Labor Market Efficiency	0	0	0	0	0	0	0
Business Sophistication	-16210	-12601	0	-1088	-7539	-9509	-9509

Table 13: Competitiveness weights for BIC's network

We see here that the first three sets of weights are highly different from set C4 to C7. In fact, the weight sets proposed when comparing s_0 to 10, 20 and 70 solutions exhibit a high inconsistency. In C1, weights are attributed to “Goods Market Efficiency” and “Business Sophistication” pillars. The C2 set gives no weight to “Goods Market Efficiency” but puts an important weight on “Business Sophistication”. Finally, when comparing s_0, to 70 feasible solutions, all weight on “Business Sophistication” vanishes and the significant pillars are: “Infrastructure” and “Health and Primary Education”. The high variability in weights seems to diminish when we increase the number of feasible solutions that are compared to s_0. When comparing s_0 to 100, 120, 150 and 165 feasible solutions, we notice that the weights are consistently assigned to the three same pillars: Infrastructure, Health and Primary Education and Business Sophistication. The predominance of the weight attributed to the Infrastructure's pillar is also consistent in all C4 to C7 sets.

As a final step, we integrate the weights found through the use of inverse optimization, to the weighted LNDP model presented in this work. For each set of weights presented above, we obtain a different network configuration. The table below presents these networks.

Used set of weights	Finished product	Manufacturing plants' location	% of demand supplied from BIC's existing manufacturing plants
C1	Pens	Marne, Boulogne, Samer and Vannes, Gaffney, Tarragona, Johannesburg, Bangalore 3, Shenzhen 3 and Jakarta 3	59%
	Shavers	Longueil, Manaus, Guayaquil 2, Mexico 4 and Bogota 3	
	Lighters	Redon, Izmir 3 and Warsaw 1	
C2	Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Manaus, Rio de Janeiro, Tarragona, Bangalore 3, Shenzhen 3 and Jakarta 1	72%
	Shavers	Longueil, Manaus, Anixi and Mexico 4	
	Lighters	Redon, Izmir 3 and Warsaw 1	
C3	Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Tarragona, Guayaquil 1, Mexico 1, Johannesburg, Bangalore 3 and Shenzhen 3	78%
	Shavers	Longueil, Anixi and Mexico 3	
	Lighters	Redon, Tarragona, Tunis 1 and Izmir 2	
C4	Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Manaus, Tarragona, Guayaquil 1, Bangalore 3, Shenzhen 3 and Jakarta 2	62%
	Shavers	Longueil, Manaus, Guayaquil 4, Mexico 4 and Bogota 1	
	Lighters	Redon, Izmir 3 and Warsaw 1	
C5	Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Manaus, Tarragona, Johannesburg, Bangalore 3 and Shenzhen 3	69%
	Shavers	Longueil, Manaus, Guayaquil 4, Mexico 4 and Bogota 1	
	Lighters	Redon, Tarragona, Tunis 1 and Izmir 2	
C6 and C7	Pens	Marne, Boulogne, Samer, Vannes, Gaffney, Manaus, Tarragona, Mexico 1, Bangalore 3 and Shenzhen 3	79%
	Shavers	Longueil, Anixi and Mexico 3	
	Lighters	Redon, Tarragona, Tunis 1 and Izmir 2	

Table 14: BIC's network configurations proposed for different weights

We noticed in the preliminary analysis of this chapter that the minimal cost network (B) only satisfies 53% of the demand using BIC’s existing plants. We can observe that the use of the weighted LNDP with any set of weights (C1, C2,...,C7) improves this percentage. The increase in supplied demand from existing BIC’s manufacturing plants, means that the successive optimal networks found using the weighted LNDP look more like BIC’s actual network and therefore better reflect the company’s preferences.

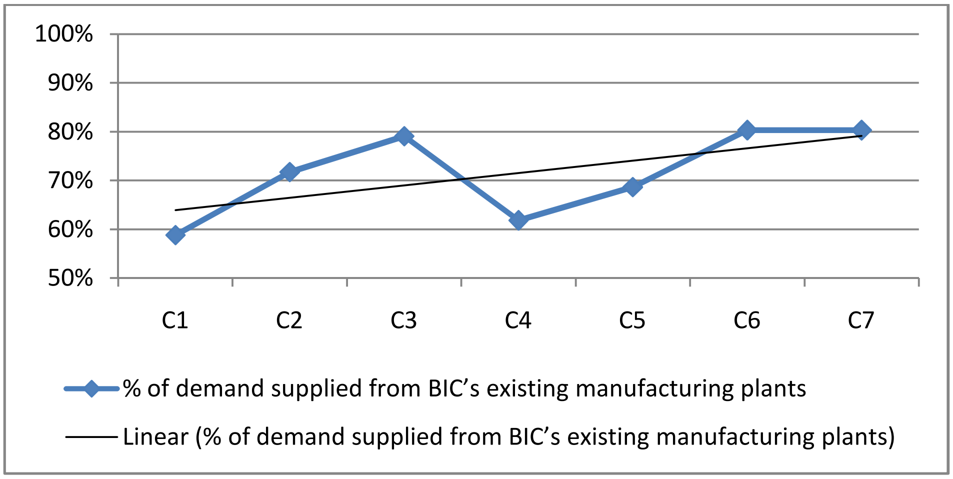

Figure 6: Fraction of demand supplied from BIC's existing plants in solutions C1 to C7

Figure 6 shows that increasing the number of solutions included in the set of comparison (C1 to C7), leads to an increase in the percentage of demand supplied from existing BIC’s plants, though this tendency is not linear.

The following figures compare BIC’s actual network performance and the performance of the optimal solutions found while integrating the set of weights C1, C2, C3, C4, C5, C6 and C7 in the weighted LNDP.

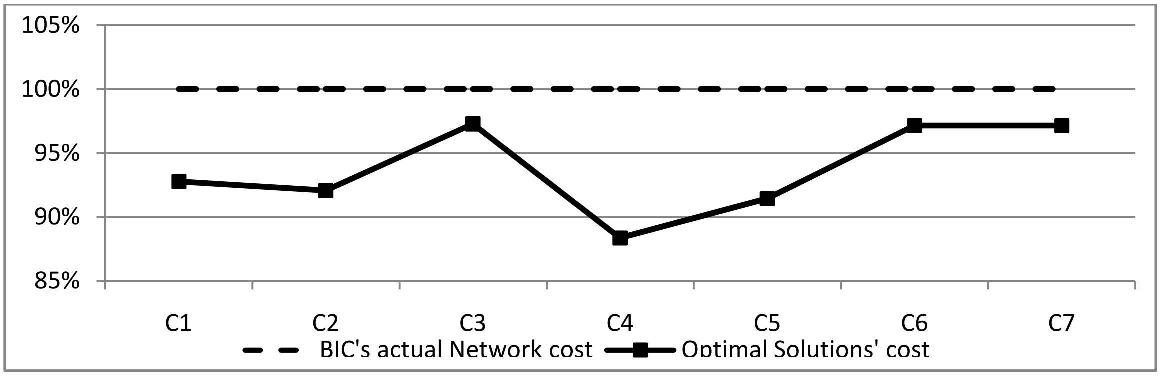

Figure 7: Optimal solutions' costs vs. BIC's actual network cost

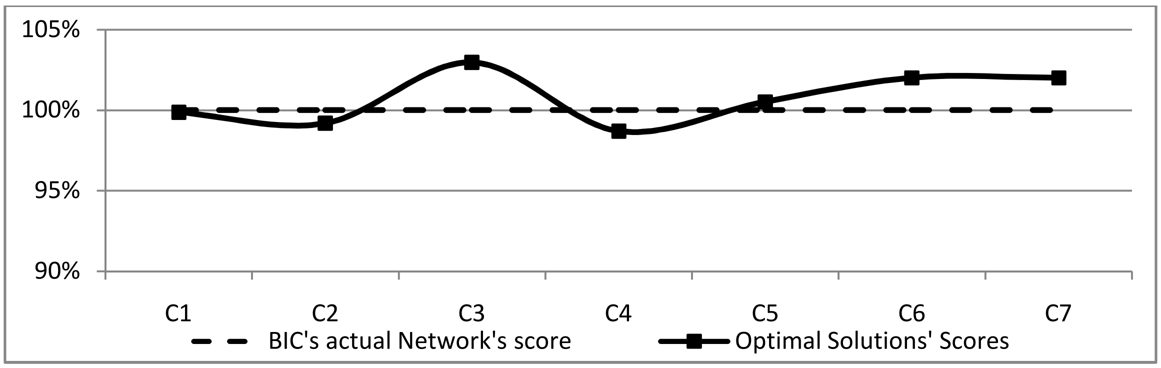

Figure 8: Optimal solutions' scores on Infrastructure. vs. BIC's actual network score

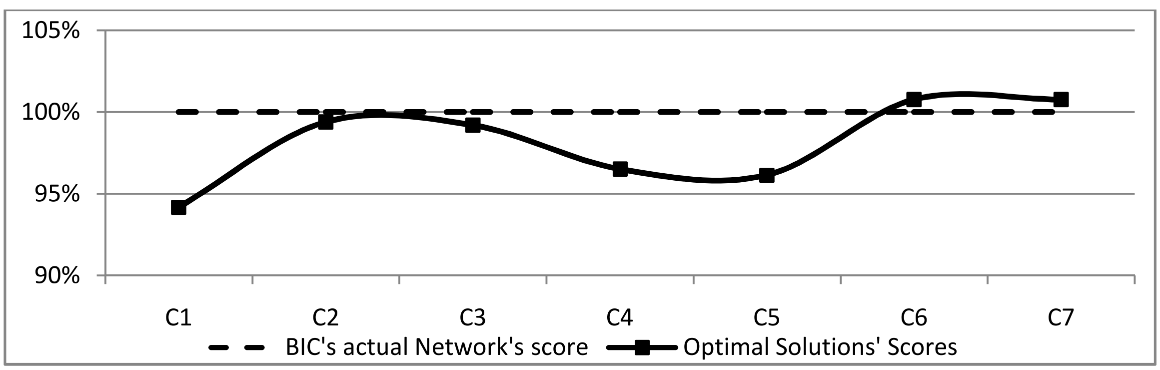

Figure 9: Optimal solutions' scores on Health & PE. vs. BIC's actual network score

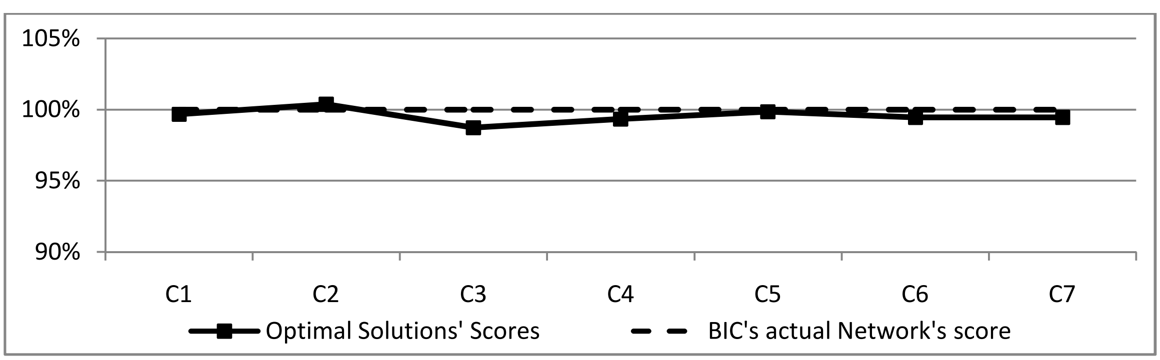

Figure 10: Optimal solutions' scores on Bus. Soph. vs. BIC's actual network score

Once again, we notice here that the changes in the pillars' scores are not linear but that there is a tendency for the significant pillars' scores to lean towards BIC's actual network performance.

Comparing the optimal network found when using the set C1 in the weighted LNDP to the optimal network found when using the set C7, we notice the following major changes:

- Plants in Guayaquil, Jakarta, Warsaw and Bogota have been closed. The competiveness scores of these plants for the Infrastructure's pillar are respectively equal to *3.5, 3.6, 3.5* and *3.4*. These 4 plants' score for Infrastructure are among the 5 worst in the pool of actual and potential plants proposed in the optimization problem. Plants closed in Guayaquil, Jakarta, Bogota and Johannesburg also scored poorly on the Business Sophistication pillar (all under *4.4*).
- Plants in Tarragona, Tunisia and Greece have been opened. The competitiveness scores of these plants are all over *4.1* for the Infrastructure pillar and superior to *6.2* for the Health and Primary Education pillar.

All the above changes allow the optimal solution to move towards a network that better reflects BIC's preferences. The optimal solution moves from a network that only supplies *57%* of the demand from existing BIC's plants to a solution that supplies *79%* of the demand from existing plants, while incurring an increase in cost of *4.7%.*

To find the proper weights that need to be integrated to the weighted LNDP, we relied on the inverse optimization. In our inverse optimization, we only compared s_0 (BIC's actual network) to 165 randomly generated solutions. We can infer that increasing the number of feasible solutions to compare to s_0, we will move toward weights that could lead to a more precise reconstruction of BIC's actual network. This prediction will be further discussed in Section 6.5.

6.4.2 Robustness analysis

To evaluate the robustness of the proposed methodology, we will alter the weights found when we compared s_0 to 165 feasible solutions and witness the effect on the proposed solution. We will therefore use the set of weights C7, where the pillars "Infrastructure", "Health and Primary Education" and "Business Sophistication" were the only pillars whose weight was different from 0.

The following table demonstrates the effect of varying one weight at a time on the proposed solution:

Modified parameters (Original weight value)	Weight variation (% of original weight)	Impact on proposed solution	Impact on solution's cost (% compared to solution using the set of weights C7)
Infrastructure (-19696)	> 25.9%	Proposed network design is modified (facilities and distribution)	0.6%
	[- 7.8%,25.9%]	No change in the proposed solution	0%
	[-12.2%,-7.8%]	• No change in the configuration of facilities • Change in the distribution's design	0.1%
	<-12.2%	Proposed network design is modified (facilities and distribution)	0.5%
Health and Primary education (-9453)	>12.2%	Proposed network design is modified (facilities and distribution)	0.5%
	[8%,12.2%]	• No change in the configuration of facilities • Change in the distribution's design	0.1%
	[-28.4%,8%]	No change in the proposed solution	0%
	[-28.6%,-28.4%]	• No change in the configuration of facilities • Change in the distribution's design	-0.6%
	<-28.6%	Proposed network design is modified (facilities and distribution)	0.1%
Business Sophistication (-9509)	> 66.8%	Proposed network design is modified (facilities and distribution)	0.5%
	[44.3%,66.8%]	• No change in the configuration of facilities • Change in the distribution's design	0.1%
	[44.3%, -63.8%]	No change in the proposed solution	0%
	<-63.8%	Proposed network design is modified (facilities and distribution)	-0.2%

Table 15: Robustness of the proposed solution

To better acknowledge the transformation of the optimal solutions given by the successive weighted LNDP resolutions, here is an analysis of the changes occurring when the weight $\alpha_{infrastructure}$ is modified while all other pillar's weight α_i are kept unchanged:

- $\alpha_{infrastructure}$= -24 820[5]: The optimal solution closes a pen's manufacturing plant in Manaus and instead opens two plants in Johannesburg and Auckland. By putting in place these changes, the network is closing a plant whose competitiveness score on the Infrastructure pillar is equal to *3.2* and replacing it by plants whose Infrastructure's scores are over *4.2*.
- -24 800 ≤ $\alpha_{infrastructure}$≤ - 18160[6]: the optimal solution proposed by the weighted LNDP is exactly equal to the solution proposed using the original set of weights C7.
- $\alpha_{infrastructure}$ = - 17400[7]: The optimal solution proposed for the following weight change uses the same network configuration as the network given by the use of C7 weights but, the use of capacity at some manufacturing plants is changed. In fact, the new network uses more capacity at the Manaus pen manufacturing plant and less at Bangalore's plant. In this case, where the absolute value of the new weight attributed to infrastructure (17400) is smaller than the absolute value given in C7 (19696), the constraint on Infrastructure is weakened. It's thus logical to notice the increased use of the Brazilian plant as the Infrastructure score of Manaus is equal to *3.2*, which is less than the score of *3.7* of the Indian plant.
- $\alpha_{infrastructure}$= -17 300[8]: By forcing this weight, we are once more weakening the impact of the Infrastructure pillar (in absolute terms 19696>17 300). The optimal solution proposed here closes a pen's manufacturing plant in Bangalore and instead opens a plant in Rio De

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[5] Weight variation as a % of original weight > 25.9%
[6] Weight variation as a % of original weight ϵ [- 7.8%,25.9%]
[7] Weight variation as a % of original weight ϵ [-12.2%,-7.8%]
[8] Weight variation as a % of original weight <-12.2%

Janeiro. By putting in place these changes, the network is closing a plant whose competitiveness score on the Infrastructure pillar is equal to *3.7* and replacing it by a plant whose Infrastructure's scores is equal to *3.2*. The total score on the Infrastructure pillar of this network is thus worse than the total Infrastructure score of the network found using the set of weights C7.

Finally and given the above results, modifying the weight of one of the significant pillars by increasing or decreasing its value will change the proposed solution only if the change in weight is considerable (around 30% of the original weight).

The impact on the solution's costs is only predictable when we decrease the weight of one pillar (increase its absolute value). In fact, the increase in the solution's cost is a logical result of the reinforcement of the constraint related to the pillar's weight. On the other hand, if we increase the weight on a specific pillar (decrease its absolute value) the solution's cost might go both ways. The weakening of one of the constraints does not necessarily lead to the decrease of the cost function. In fact, depending on the new relative influences of the other significant pillar's weight, the cost function might either decrease or increase.

According to the above conclusion, we can predict that the cost function of BIC's weighted LNDP will:

- Increase if all significant pillars' weights are decreased (absolute value increased)
- Decrease if all significant pillars' weights are increased (absolute value decreased)
- Unpredictably increase or decrease if the weights of significant pillars are changed independently

6.5 Limits of the proposed methodology

The methodology proposed in this work uses inverse optimization to find the weights that a company implicitly put on countries' competitiveness attributes when designing its logistics network. The ultimate objective is to provide the decision makers with guidance they can use to choose weights in future network design decisions.

Using BIC's case study, we have been able to demonstrate that the use of this methodology enables us to find weights that move us closer to the company's implicit weights. The weights that we found allowed us to recreate a network that uses almost 80% of BIC's actual capacity in order to supply worldwide demand. We did not, however, find the exact weights applied by BIC and which allowed them to build their actual network. If we had obtained those weights, the company's future decisions concerning the logistics network design would have been facilitated, as the optimal weights for competitiveness would have been identified parameters, ready to be used as an exact starting point in the weighted LNDP model and precisely reflecting BIC's preferences.

Considering the fact that when we increased the number of solutions that were compared to s_0, we obtained weights that allowed us to move closer to BIC's actual network, we previously envisaged that if we increased the number of feasible solutions we compare s_0 to (165 solutions used here), we would be able to exactly reproduce BIC's actual network. This deduction can be refuted based on the primary assumption of inverse optimization. In fact, the first assumption of inverse optimization is that s_0 is the optimal solution regarding the unknown parameters. This assumption is not fulfilled in the case study we propose here. BIC's actual total costs and total scores on every pillar are not optimal for all sets of weights we used (C1 to C7). Among the 165 proposed solutions and for every set of weight, there was each time at least one solution which provided a better objective function value, thus violating constraint (B2). The consequence of non-compliance with the optimality condition for s_0 is that even when increasing the number of solutions to which we compare s_0, the weights that we will find will improve the performance of the optimal solution for some parameters and deteriorate it for others.

This “non optimal” situation will likely present itself for any company’s network that one would like to analyze. Despite this fact, the proposed methodology can be useful to companies if:

- Decision makers can enumerate a set of countries they can envision to locate in,
- The inverse optimization is done by comparing the company’s actual network with a large number of feasible solutions,
- Decision makers use the weighted LNDP as a guidance tool and not as an optimization tool. In fact, this process allows moving toward a network that decreases the company’s total costs while reflecting its values and preferences but does not ensure the optimality condition toward a specific attribute.

The advantage of the proposed approach resides in the fact that it eliminates part of the subjectivity related to weight attribution. Inverse optimization allows a methodical computation of competitiveness pillar weights. These weights are the foundation for future decisions as they formally reflect the past choices of the company. Because the weights were found while relying on a pragmatic comparison involving an important set of viable solutions (not relying on the subjective evaluation of managers), these weights represent a key asset and a gain of time and energy, for companies when launching a new process of logistics network design / redesign.

6.5.1 Final recommendation for BIC case study

Acknowledging the limits of the proposed methodology, we would conclude the BIC case study with the following remarks:

- The network proposed using C7 weights, supplies 80% of the demand from actual BIC’s plants.

- The network proposed using C7 weights, opens plants in India and China. Because of the economic improvements in recent years, these countries are integrated into the network as they constitute attractive choices for costs and for competitiveness indicators.
- The network proposed using C7 weights reduces the total costs of the network in comparison with the actual network's costs.

The optimal solution found using the set of weights C7 seems to be realistic and viable. It is more likely to see BIC implement this network then the minimal cost network. This outcome obviously means that the weights attributed to the competitiveness pillars are more likely to resemble C7 than to be null.

If a real decision had to be taken for the redesign of BIC's logistics network, we would use the methodology proposed here and either accept the logistics network design found using the set of weights C7 or use this set as a baseline for a comparison exercise. Indeed, using the knowledge of BIC’s management, we would possibly weaken some of the significant weights of C7 and reinforce some others and evaluate the network configurations proposed, their costs and their competitiveness’ performances. In doing so, we would ensure that before making a decision, the managers can compare a set of network configurations which all represent robust solutions as they minimize costs while reflecting the companies’ competitiveness priorities.

The strength of this methodology doesn’t lie in the short term decisions, but in the guidance it can provide when integrating the economic evolution of countries, and presenting them as potential mid and long-term alternatives for future growth and expansion.

Chapter 7- Conclusion

The objective of this thesis was to evaluate if the robustness of a logistics network design could be improved by integrating some of the economic indicators describing countries' competitiveness into a mathematical optimization model. The evaluation of this theory has been applied to a hypothetical case study around the French company BIC.

First, using the Global Competitiveness Report and assuming that when designing their logistics network companies aimed at locating manufacturing plants and warehouses in a manner that minimizes their operating and distribution costs, we identified seven competitiveness pillars relevant to the Logistics Network Design Problem. The relevant pillars that we targeted are the following: Institutions, Infrastructure, Health and Primary Education, Higher Education and Training, Goods Market Efficiency, Labor Market Efficiency and Business Sophistication.

We then proposed a mathematical formulation integrating these competitiveness indicators in the optimization model of the LNDP. The main difference between a standard LNDP optimization model and the weighted LNDP optimization model we proposed lies in the objective function. The objective function of the weighted LNDP integrates a component representing the total weighted impact of each competitiveness pillar. For each competitiveness pillar, this weighted impact depends on the weight of the pillar, the competitiveness score of the manufacturing plants used in the network for a specific pillar and the amount of product shipped from each manufacturing plants used in the network. The main issue to overcome when integrating the competitiveness indicator is the attribution of a specific weight to each pillar. Assuming that every company, when designing its logistics network, has different requirements regarding the competitiveness performance of the countries it chooses to settle in, we proposed to use the inverse optimisation methodology to reveal the relative weights that have been attributed implicitly by a specific company to each competitiveness factor.

We applied this approach to BIC's case study. In order to find the weights on competitiveness factors applied by BIC, we first generated 165 random networks able to supply customers demand while using BIC's actual and potential manufacturing plants. These randomly generated networks were found while forcing some decisions into a standard LNDP optimization model (such as forcing the closing of all plants in Mexico, forcing the supply of European customers from European manufacturing plants...). For each of the 165 networks, the following attributes were recorded: total costs and total score on each competitiveness pillar. Then, using inverse optimization and assuming that BIC's actual network was an optimal solution, we found a set of weights corresponding to each competitiveness pillar. When we integrated this set of weights into the weighted optimization model presented in this work, we recreated a network that uses almost 80% of BIC's actual capacity in order to supply worldwide demand. This network can be considered a robust network as the manufacturing plants in low cost countries (used in the minimal cost solution) are replaced by manufacturing plants whose integration in the network increases total costs but also improves the competitiveness performance. Because the proposed approach improves the robustness of the proposed solution, the weights found in the case of BIC can be used as a baseline by managers for future logistics network design decisions.

Ultimately, this master thesis intended to take up the challenge proposed by Lee and Wilhelm (2010) to reconcile the fields of Operation Research and International Business in the specific area of logistics network design. We demonstrated that integrating competitiveness indicators is promising and that it leads to proposing more robust solutions to companies.

We also noticed that the use of the inverse optimization to find the weight of each competitiveness pillar does not provide a path to the absolute optimum. Therefore, the developed solutions need to be taken as improvements from the starting point, and human judgement is then needed to compare the proposed solutions and make a decision. Hence, the approach we propose does not totally eliminate the subjective evaluation of decision makers. Further research using Data

Envelopment Analysis as an approach to integrate countries competitiveness indicators into optimization models might both improve the robustness of the logistics network design and limit human subjective evaluation.

Appendices

Appendix A: Potential manufacturing plants locations and capacities

Product	Country	City	Capacity
Lighters	Morocco	Casablanca 1	100 million/year
		Casablanca 2	300 million/year
		Casablanca 3	600 million/year
	Tunisia	Tunis 1	100 million/year
		Tunis 2	300 million/year
		Tunis 3	600 million/year
	Turkey	Izmir 1	100 million/year
		Izmir 2	300 million/year
		Izmir 3	600 million/year
	Poland	Warsaw 1	100 million/year
		Warsaw 2	300 million/year
		Warsaw 3	600 million/year
Shavers	Mexico	Mexico City 2	100 million/year
		Mexico City 3	300 million/year
		Mexico City 4	600 million/year
	Ecuador	Guayaquil 2	100 million/year
		Guayaquil 3	300 million/year
		Guayaquil 4	600 million/year
	Colombia	Bogota 1	100 million/year
		Bogota 2	300 million/year
		Bogota 3	600 million/year
Pens	India	Bangalore 1	100 million/year
		Bangalore 2	300 million/year
		Bangalore 3	600 million/year
	China	Shenzhen 1	100 million/year
		Shenzhen 2	300 million/year
		Shenzhen 3	600 million/year
	Indonesia	Jakarta 1	100 million/year
		Jakarta 2	300 million/year
		Jakarta 3	600 million/year

Appendix B: Specifications, fixed costs and variable costs at each manufacturing plant

Plants	Products	Country	City	Area (SF)	Annual Rent rate ($/SF/year)	Annual Fixed Costs ($)	Number of employees	Hourly wages in manufacturing (US$)	Variable cost for the production of 1M units in $
Actual	Lighters	France	Redon	250000	11.76	2930000	350	24.8	25640
		United States	Milford	72000	9.07	646000	100	23.9	39910
		Brazil	Manaus	107000	10.55	1127000	150	3.6	4940
		Spain	Tarragone	143000	7.35	1047000	200	21	24820
	Shavers	Greece	Anixi	712000	6.32	4499000	1000	12.4	10140
		Brazil	Manaus	143000	10.55	1502000	200	3.6	4260
		France	Longueil sainte Marie	143000	11.76	1675000	200	24.8	11620
	Pens	Brazil	Manaus	214000	10.55	2253000	300	3.6	3350
		Brazil	Rio de Janeiro	143000	10.55	1502000	200	3.6	3340
		Ecuador	Guayaquil1	57000	7.25	413000	80	2.1	2020
		France	Marne la vallee	143000	11.76	1675000	200	24.8	17320
		France	Boulogne Mer	114000	11.76	1340000	160	24.8	16940
		France	Samer	57000	11.76	670000	80	24.8	12700
		France	Vanne	114000	11.76	1340000	160	24.8	16940
		Mexico	Mexico City1	371000	6.25	2314000	520	4.8	9220
		South Africa	Johannesburg	178000	6.97	1241000	250	7.1	6560
		New Zeland	Auckland	11000	3.95	43000	15	21.1	40520
		USA	Gaffney	57000	9.07	517000	80	23.9	17080

Plants	Products	Country	City	Area (SF)	Annual Rent rate ($/SF/year)	Annual Fixed Costs ($)	Number of employees	Hourly wages in manufacturing (US$)	Variable cost for the production of 1M units in $
		Spain	Tarragone	214000	7.35	1570000	300	21	14320
Potential	Lighters	Morocco	Casablanca 1	51000	6.97	355000	71	2.9	3980
		Morocco	Casablanca 2	153000	6.97	1064000	214	2.9	3980
		Morocco	Casablanca 3	306000	6.97	2127000	429	2.9	3980
		Tunisia	Tunis 1	51000	6.97	355000	71	2.7	3710
		Tunisia	Tunis 2	153000	6.97	1064000	214	2.7	3710
		Tunisia	Tunis 3	306000	6.97	2127000	429	2.7	3710
		Turkey	Izmir 1	51000	6.97	355000	71	4.1	5630
		Turkey	Izmir 2	153000	6.97	1064000	214	4.1	5630
		Turkey	Izmir 3	306000	6.97	2127000	429	4.1	5630
		Poland	Warsaw 1	51000	7.65	389000	71	6.2	8510
		Poland	Warsaw 2	153000	7.65	1167000	214	6.2	8510
		Poland	Warsaw 3	306000	7.65	2334000	429	6.2	8510
	Shavers	Colombia	Bogota 1	44000	9.7	425000	62	3.2	3790
		Colombia	Bogota 2	132000	9.7	1275000	185	3.2	3790
		Colombia	Bogota 3	263000	9.7	2550000	369	3.2	3790
		Mexico	Mexico City2	44000	6.25	274000	62	4.8	5680
		Mexico	Mexico City3	132000	6.25	822000	185	4.8	5680
		Mexico	Mexico City4	263000	6.25	1643000	369	4.8	5680
		Ecuador	Guayaquil2	44000	7.25	318000	62	2.1	2490
		Ecuador	Guayaquil3	132000	7.25	953000	185	2.1	2490

Plants	Products	Country	City	Area (SF)	Annual Rent rate ($/SF/year)	Annual Fixed Costs ($)	Number of employees	Hourly wages in manufacturing (US$)	Variable cost for the production of 1M units in $
		Ecuador	Guayaquil4	263000	7.25	1906000	369	2.1	2490
	Pens	India	Bangalore 1	35000	8.16	280000	48	0.7	650
		India	Bangalore 2	103000	8.16	840000	145	0.7	650
		India	Bangalore 3	206000	8.16	1680000	289	0.7	650
		China	Shenzhen 1	35000	3.36	116000	48	3.2	2970
		China	Shenzhen 2	103000	3.36	346000	145	3.2	2970
		China	Shenzhen 3	206000	3.36	692000	289	3.2	2970
		Indonesia	Jakarta 1	35000	9.48	326000	48	0.9	840
		Indonesia	Jakarta 2	103000	9.48	976000	145	0.9	840
		Indonesia	Jakarta 3	206000	9.48	1952000	289	0.9	840

Appendix C: Specifications, fixed costs and variable costs at each warehouse

Products	Country	City	Area (SF)	Annual Rent rate ($/SF/year)	Annual Fixed Costs ($)	Number of employees	Hourly wages in manufacturing (US$)	Number of pallets needed to handle 1 million product	Annual Capacity in of product f (in pallets)	Variable cost for the handling of 1M units in $
Pen	USA	Charlotte, NC	300000	3.34	1002000	90	23.9	4	259000	64
	Spain	Barcelona	205000	7.35	1507000	62	21	4	245000	41
Shavers	USA	Charlotte, NC	300000	3.34	1002000	90	23.9	79	259000	1,260
	Spain	Barcelona	205000	7.35	1507000	62	21	79	245000	806
Lighter	USA	Charlotte, NC	300000	3.34	1002000	90	23.9	26	259000	415
	Spain	Barcelona	205000	7.35	1507000	62	21	26	245000	265

Appendix D: Customers' demand

Geographical zones	Country	City	Demand for Pens (millions / year)	Demand for shavers (millions / year)	Demand for Lighters (millions / year)
			5875	2350	1300
Europe	France	Clichy	89	107	15
	Germany	Frankfurt	120	144	20
	Austria	Brunn am Gebirge	12	14	2
	Belgium	Bruxelles	15	18	2
	Spain	Tarragona	72	86	12
	Greece	Anixi	16	7	3
	Hungary	Budapest	15	6	2
	Ireland	Dublin	6	7	1
	Italy	Milan	83	100	14
	Netherlands	Breda	23	28	4
	Polska	Warsaw	56	23	9
	Portugal	Lisboa	15	18	2
	Romania	Bucharest	32	13	5
	United Kingdom	London	92	110	15
	Slovakia	Sered'	7	3	1
	Russia	Moscow	209	87	34
	Sweden	Goteborg	13	16	2
	Switzerland	Cadempino	10	12	2
	Turkey	Istanbul	104	43	17
	Ukraine	Kiev	70	29	11
North America	Canada	North York, Ontario	118	54	8
	USA	Charlotte, NC	940	510	74
Oceania	Australia	Melbourne	56	3	5
	New Zealand	Auckland	10	1	1
South America	Argentina	Buenos Aires	44	43	10
	Brazil	Manaus	208	203	46
	Chile	Santiago	17	17	4
	Colombia	Bogota	45	44	10
	Costa Rica	San José	4	4	1
	Ecuador	Guayaquil	15	15	3
	Guatemala	Guatemala	12	12	3

Geographical zones	Country	City	Demand for Pens (millions / year)	Demand for shavers (millions / year)	Demand for Lighters (millions / year)
	Mexico	Tlalneplantla	122	119	27
	Peru	Lima	29	29	6
	Uruguay	Montevideo	3	3	1
	Venezuela	Caracas	29	29	6
Asia	China	Shanghai	1293	181	426
	South Korea	Seoul	97	6	15
	India	Mumbai	411	163	384
	Japan	Osaka	881	17	41
	Malaysia	Selangor	56	4	9
	Singapore	Singapore	8	1	1
	Thailand	Bangkok	133	9	21
Africa	South Africa	Johannesburg	133	7	12
	UAE	Dubai	10	1	1
	Malawi	Limbe	33	2	3
	Mozambique	Maputo	51	3	5
	Tunisia	Bizerte	26	1	2
	Zambia	Lusaka	33	2	3

Appendix E: Price of raw materials

Raw Material	Supplier	Country	Price in $/kg
Polystyrene	Supplier 1	Brazil	1.88
	Supplier 2	China	2.08
	Supplier 3	Colombia	1.75
	Supplier 4	Ecuador	1.29
	Supplier 5	France	1.83
	Supplier 6	Greece	2.13
	Supplier 7	India	1.74
	Supplier 8	Indonesia	1.56
	Supplier 9	Mexico	1.68
	Supplier 10	Morocco	3.69
	Supplier 11	Tunisia	2.16
	Supplier 12	New_Zealand	7.32
	Supplier 13	Poland	1.83
	Supplier 14	South_Africa	1.31
	Supplier 15	Spain	1.88
	Supplier 16	Turkey	1.73
	Supplier 17	USA	1.81
Ink	Supplier 1	Brazil	4.11
	Supplier 2	China	5.76
	Supplier 4	Ecuador	6.27
	Supplier 5	France	16.38
	Supplier 7	India	3.52
	Supplier 8	Indonesia	12.97
	Supplier 9	Mexico	11.41
	Supplier 12	New Zealand	9.52
	Supplier 14	South Africa	13.31
	Supplier 15	Spain	9.82
	Supplier 16	Turkey	4.32
	Supplier 17	USA	7.96
Steel	Supplier 1	Brazil	2.34
	Supplier 2	China	2.42
	Supplier 3	Colombia	8.45
	Supplier 4	Ecuador	2.83
	Supplier 5	France	2.91
	Supplier 6	Greece	3.51
	Supplier 7	India	2.03
	Supplier 8	Indonesia	2.12

Raw Material	Supplier	Country	Price in $/kg
	Supplier 9	Mexico	2.29
	Supplier 10	Morocco	6.82
	Supplier 11	Tunisia	5.00
	Supplier 12	New_Zealand	4.69
	Supplier 13	Poland	3.24
	Supplier 14	South_Africa	2.61
	Supplier 15	Spain	3.18
	Supplier 16	Turkey	2.64
	Supplier 17	USA	3.18
Isobutene	Supplier 1	Brazil	1.17
	Supplier 5	France	0.94
	Supplier 10	Morocco	0.85
	Supplier 11	Tunisia	0.93
	Supplier 13	Poland	0.85
	Supplier 15	Spain	0.87
	Supplier 16	Turkey	0.87
	Supplier 17	USA	0.91

Appendix F: List of harbours used in BIC's distribution network

Departure / Arrival point in the network		Nearest Port
Country	City	
France	Redon	Le havre
France	Longueil sainte marie	Le havre
France	Marne la vallee	Le havre
France	Boulogne sur Mer	Le havre
France	Samer	Le havre
France	Vanne	Le havre
Spain	Tarragone	Barcelona
Greece	Anixi	Peraeus
poland	Warsaw	Gdansk
Turkey	Izmir	Izmir
India	Bangalore	Mangalore
China	Shenzhen	Shenzhen
Indonesia	Jakarta	Jakarta
USA	Milford	New York
USA	Gaffney	New York
Brazil	Manaus	Manaus
Brazil	Rio de Janeiro	Rio de Janeiro
Colombia	Bogota	Barranquilla
Ecuador	Guayaquil	Guayaquil
Mexico	Mexico City	Veracruz
South Africa	Johannesburg	Durban
Morrocco	Casablanca	Casablanca
Tunisia	Tunis	Tunis
New Zealand	Auckland	Auckland
Spain	Barcelona	Barcelona
USA	Charlotte, NC	Charleston, SC
France	Clichy	Le havre
Germany	Frankfurt	Hamburg
Austria	Brunn am Gebirge	Rotterdam
Belgium	Bruxelles	Antwerp
Spain	Tarragona	Barcelona
Greece	Anixi	Peraeus
Hungary	Budapest	Rotterdam
Ireland	Dublin	Dublin
Italy	Milan	Genoa
Netherlands	Breda	Rotterdam

Departure / Arrival point in the network		Nearest Port
Country	City	
Polska	Warsaw	Gdansk
Portugal	Lisboa	Lisboa
Romania	Bucharest	Peraeus
United Kingdom	London	London
Slovakia	Sered’	Rotterdam
Russia	Moscow	Saint Petersburg
Sweden	Goteborg	Gotenburg
Switzerland	Cadempino	Rotterdam
Turkey	Istanbul	Izmir
Ukraine	Kiev	Peraeus
Canada	North York, Ontario	New York
USA	Charlotte, NC	Charleston
Australia	Melbourne	Melbourne
Argentina	Buenos Aires	Buenos Aires
Brazil	Manaus	Manaus
Chile	Santiago	San antonio
Costa Rica	San José	Limon
Guatemala	Guatemala	Puerto quetzal
Peru	Lima	Lima (callao)
Uruguay	Montevideo	Montevideo
Venezuela	Caracas	puerto caballo
China	Shanghai	Shanghai
South Korea	Seoul	Seoul
India	Mumbai	Mumbai
Japan	Osaka	Osaka
Malaysia	Selangor	Kelang
Singapore	Singapore	Singapore
Thailand	Bangkok	Bangkok
UAE	Dubai	Dubai
Malawi	Limbe	Beira
Mozambique	Maputo	Maputo
Tunisia	Bizerte	Tunis
Zambia	Lusaka	Beira

Appendix G: Competitiveness scores on each pillar for all manufacturing plants

Manufacturing Plants	Institutions	Infrastructure	Health and Primary Education	Higher Education and Training	Good Market Efficiency	Labor Market Efficiency	Business Sophistication
Redon	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Longueil Sainte Marie	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Marne la Vallée	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Boulogne sur Mer	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Samer	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Vannes	4.9	6.4	6.3	4.9	4.9	4.0	5.6
Milford	4.4	5.5	5.8	5.1	4.8	5.5	5.4
Gaffney	4.4	5.5	5.8	5.1	4.8	5.5	5.4
Manaus	3.8	3.2	5.7	4.0	3.9	3.9	4.8
Rio de Janeiro	3.8	3.2	5.7	4.0	3.9	3.9	4.8
Tarragona	4.3	5.8	6.6	4.0	4.5	3.6	4.9
Anixi	3.6	4.1	6.6	3.4	3.8	3.3	4.1
Guayaquil1	3.2	3.5	4.9	3.4	3.3	3.7	3.8
Guayaquil2	3.2	3.5	4.9	3.4	3.3	3.7	3.8
Guayaquil3	3.2	3.5	4.9	3.4	3.3	3.7	3.8
Guayaquil4	3.2	3.5	4.9	3.4	3.3	3.7	3.8
Mexico City1	3.4	3.9	5.8	3.8	4.4	4.0	4.4
Mexico City2	3.4	3.9	5.8	3.8	4.4	4.0	4.4
Mexico City3	3.4	3.9	5.8	3.8	4.4	4.0	4.4
Mexico City4	3.4	3.9	5.8	3.8	4.4	4.0	4.4

Manufacturing Plants	Institutions	Infrastructure	Health and Primary Education	Higher Education and Training	Good Market Efficiency	Labor Market Efficiency	Business Sophistication
Johannesburg	4.1	4.2	3.8	3.8	4.7	3.6	4.4
Auckland	5.8	4.7	6.7	4.9	5.4	5.3	4.7
Casablanca1	4.2	4.1	5.2	3.9	4.4	3.9	4.1
Casablanca2	4.2	4.1	5.2	3.9	4.4	3.9	4.1
Casablanca3	4.2	4.1	5.2	3.9	4.4	3.9	4.1
Tunis1	4.7	4.7	6.2	4.5	4.6	4.1	4.5
Tunis2	4.7	4.7	6.2	4.5	4.6	4.1	4.5
Tunis3	4.7	4.7	6.2	4.5	4.6	4.1	4.5
Izmir1	3.8	4.3	6.2	3.7	4.5	4.2	4.5
Izmir2	3.8	4.3	6.2	3.7	4.5	4.2	4.5
Izmir3	3.8	4.3	6.2	3.7	4.5	4.2	4.5
Warsaw1	4.3	3.5	6.4	4.3	4.5	4.4	4.6
Warsaw2	4.3	3.5	6.4	4.3	4.5	4.4	4.6
Warsaw3	4.3	3.5	6.4	4.3	4.5	4.4	4.6
Bogota1	3.2	3.4	4.9	3.8	4.1	4.6	4.3
Bogota2	3.2	3.4	4.9	3.8	4.1	4.6	4.3
Bogota3	3.2	3.4	4.9	3.8	4.1	4.6	4.3
Bangalore1	3.8	3.7	4.6	4.2	4.3	4.6	4.6
Bangalore2	3.8	3.7	4.6	4.2	4.3	4.6	4.6
Bangalore3	3.8	3.7	4.6	4.2	4.3	4.6	4.6
Shenzhen1	4.4	4.6	5.3	4.2	4.4	4.7	4.5
Shenzhen2	4.4	4.6	5.3	4.2	4.4	4.7	4.5
Shenzhen3	4.4	4.6	5.3	4.2	4.4	4.7	4.5
Jakarta1	3.9	3.6	4.3	4.2	4.2	4.3	4.4
Jakarta2	3.9	3.6	4.3	4.2	4.2	4.3	4.4
Jakarta3	3.9	3.6	4.3	4.2	4.2	4.3	4.4

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