Allocation of Regional Logistics Hubs and Assessing Their Contribution to Saudi Arabia’s Logistics Performance Index Ranking

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Abstract: In 2016, Saudi Arabia published its vision for the year 2030, which is based on the Kingdom’s geographical, financial, social and religious potentials. Developing the logistics sector and improving the Kingdom’s ranking in the World Bank’s Logistics Performance Index (LPI) to the twenty-fifth rank was one of the most targeted success factors. Unfortunately, Saudi Arabia’s rank in this index has declined over the past years, until it reached the fifty-fifth rank as per the last published LPI report. This research proposes a set of logistics hubs (LHs) which are located at key multi-logistics areas within the regional trading zones of the country. A spatial model was implemented on a macro level to integrate multi-logistical, infrastructural and natural geographic information system (GIS) layers, and highlight their intersections as initial feasible areas. Subsequently, an optimization model based on integer linear programming (ILP) was used to maximize the number of allocated LHs and minimize the overall distances between allocated LHs and international trading nodes considering multiple factors. More than 80 selected subject matter experts (SMEs) from 9 different countries have participated in World Bank’s driven surveys that assess the contribution of the LHs’ allocation proposal on Saudi Arabia’s LPI ranking. An improvement of about 10% in the LPI overall score with a 20 rank promotion has been estimated as per the SMEs responses. These results demonstrate that investing in logistics infrastructure and ranking in LPI are perfectly, positively and highly related.

Keywords: integer linear programming (ILP); Logistics Performance Index (LPI); logistics hub location problem (LHLP); geographic information system (GIS)

1. Introduction

Being a global logistics hub (LH) is a strategic goal for most developed countries, since it has a major positive influence on the country’s economy. Attracting foreign direct investments and creating job opportunities are examples of the benefits that would be generated as consequence of realizing such a strategic goal.

Competing countries and world’s top corporates consider the World Bank’s Logistics Performance Indices as one of the most important factors that differentiate and attract new business opportunities.

Countries that are geographically located near to most of global markets and centralized between commercial trading traveling routes will have the highest opportunity to be transformed into global LHs, especially if they were economically strong and stable. Saudi Arabia is one of those countries, having a real opportunity to be a global LH due to its location that centralize the three old contents and the economy that is considered to be one of the highest among all countries. However, Saudi Arabia is not the only country that could benefit from this strategic location. Other Arabian Peninsula countries have similar access to all the advantages of this centralized location. In fact, neighboring gulf cooperation council (GCC) countries such as the United Arab Emirates, Qatar and Oman have unanimously improved their international LPI positions, throughout the recent years,
to even better ranks than the rank of Saudi Arabia, as extracted from the international LPI’s data [1]. Furthermore, Saudi Arabia has not been able to reach the desired 25th international LPI’s rank or at least maintain its best rank; unfortunately its international ranking has fallen backwards throughout the years.

Saudi Arabia has the potential constituents to be successfully transformed into a global LH. The country has an extensive internal land connection together with a perfect access to GCC’s free trade zones. The country’s transportation networks are widely spread and characteristically distinguished. Integrating all those transportation layers into a solid logistics network and scientifically specify some crossways nodes, which are structured to carry out some activities such as cross-docking, sorting, storing and clearance, will utilize each of those transportation modes, strengthen the country’s logistics infrastructure and reveal both the opportunities for improvement and flow bottlenecks.

The purpose of this research is to integrate and utilize those transportation layers and combine them together to produce a joint logistics network with its key nodes introduced as potential sites of LHs. Thus, this research aims to achieve the following two objectives:

A. To identify the best possible locations for establishing LHs in Saudi Arabia.
B. To propose a criterion that assesses the effect of allocating the proposed set of LHs on Saudi Arabia’s Global Ranking at the World Bank LPI.

The next section contains the relevant research contributions toward the logistics hubs allocation problems in addition to the assessment mechanisms which could be used to measure the contribution of LHs allocation to the international LPI. The materials and methods section illustrates the methodological approach which will be implemented to Saudi Arabia’s case study. The case study section presents the detailed steps of implementing the methodology using different programs. An evaluation of our results is discussed in the results section which covers the contribution of the proposed set of LHs. The discussion section analyses the results and explains the use of the resulted data from the previous section. Finally, the conclusions section sums up all of the previous sections.

2. Literature Review

Generally, LHs are defined as linking nodes, infrastructure facilities and crossroads points in logistics networks that primarily serve as transit stations for flows of goods [2]. Accordingly, there are many activities involved beside the storage activity, such as the processes of ordering, bundling, and unbundling [2].

In essence, LHs have a theoretical tripod: collaborative framework, asset sharing, and value-added services, which can be expanded and absorbed by the existing facility terminology despite their original nomenclature [3]. Even though greater economies of scale and scope are the main benefits of a hub, each one of them is unique according to the proposed typology [3]. The designer of a hub can consider the number of logistics service providers operating, transportation infrastructure, the nature of goods handled and the type of served markets [3].

LHs are varied in types and classes depending on their specific requirements. A simple differentiation using a spatial or functional analysis is usually completed to enable a classification of a LH [2]. As per the illustration by S. Huber et al. on hubs differentiation, “The following examples will provide the possible differentiation: A spatial differentiation can be made according to the spatial level (micro, meso, macro), for instance. Therefore, a transport logistics hub can be defined as hub (micro level) as well as a seaport (macro level). Regarding the functional differentiation, logistics hubs may consist of individual modules (e.g., single shipping facility) or several modules (intermodal terminal with rail freight center and freight forwarders)” [2] (p. 3).
2.1. World Bank’ Logistics Performance Indices

The World Bank has created an interactive benchmarking tool, which is called the Logistics Performance Index, to help countries determine the challenges and opportunities of their trade logistics and what the possible actions to improve their performance are [4]. The LPI is used to compare 160 countries, and by a worldwide survey-based assessment of ground operators (global freight forwarders and express carriers), providing feedback on the “friendliness” of their operating and trading activities at the countries where they locate [4]. They have combined in-depth knowledge to assess the countries in which they operate, informed qualitative assessments of other countries where they trade and report the experience of global logistics environment [4]. Operators’ feedback is supplemented with the performance of logistics chain quantitative data in each specific country [4].

The LPI assists countries build profiles of logistics friendliness and consists of both qualitative and quantitative measures, it is also used to measure performance of the logistics supply chain within a country and provides two different perspectives, the international LPI and the domestic LPI [4].

2.1.1. International Logistics Performance Index

A qualitative evaluation of a country over six dimensions by its trading partners—the logistics professionals working outside the country [1].

Based on the World Bank website, depending on recent theoretical and empirical research and on the practical experience of logistics professionals, the following six components of the International LPI were chosen:

- Customs, the efficiency of customs and border management clearance.
- Infrastructure, the quality of trade and transport infrastructure.
- Ease of arranging shipments, the ease of arranging competitively priced shipments.
- Quality of logistics services, the competence and quality of logistics services (trucking, forwarding, and customs brokerage).
- Tracking and tracing, the ability to track and trace consignments.
- Timeliness, the frequency with which shipments reach consignees within scheduled or expected delivery times.

2.1.2. Domestic Logistics Performance Index

Both qualitative and quantitative assessments of a country are provided by logistics professionals working inside it, which include detailed information on the logistics environment, core logistics processes, institutions, and performance time and cost data [5].

The domestic LPI focuses on the logistics environments details of 100 countries. For this measure, surveyed logistics professionals assess the logistics environments in their own countries. This domestic assessment contains more detailed information on countries’ logistics environments, core logistics processes and institutions, and time and distance data without including a country rank [5]. Four major factors of overall logistics performance are used to measure the country’s performance:

- Infrastructure.
- Services.
- Border procedures and time.
- Supply chain reliability.

2.1.3. LPI Questionnaires

World Bank uses a questionnaire approach to assess the logistics performance of different countries. LPI’s surveys evaluate countries’ logistics performances based on multiple sets of questions and with multiple considered factors. Those sets are either evaluating eight different countries other than the respondent’s-based country or the respondent themself.
Although the general concept and content of the questionnaires are similar, the number of questions varies slightly from year to year. Moreover, countries which will be assessed by a respondent are varied as per the respondent's-based country.

According to the World Bank’s “Connecting to Compete 2018” report, each respondent is asked to answer 35 questions in the LPI surveys [6]. Questions 1 to 9 gather the respondent’s nature of organization and duties, country and geographic region and other personal information. Questions 10 to 15 are focused on evaluating countries using the six measures of the international LPI which were discussed in Section 2.1.1 above. For each question that assesses the six core components of the international LPI, there are five multiple choices, and these rates are coded from 1 (worst) to 5 (best) based on the respondents’ judgment of evaluating the logistics maturity of a country [6]. Moreover, the World Bank considers many factors by considering economic and spatial differences between the targeted countries. Countries are divided economically into three groups: high-income, middle-income and low-income. Also, they are divided into two groups as per their geographic nature, which are the landlocked and coastal countries. For the coastal countries, the respondent is asked to evaluate eight countries, and those are randomly selected with variable limits from the list of most relevant overseas exporters, and most relevant importers and country groups. Whereas for the landlocked countries, the respondent is asked to evaluate eight countries randomly from the previously mentioned lists in addition to the list of relevant land-bridge countries. In both situations, the number of selected countries from each list is varied based on the income level for the respondent’s based-country. All lists are formed based on the residential country of the respondent except for the country groups list, which includes fixed separate country sub-lists from Africa, East and Central Asia, Latin America and Europe less Central Asia & Organization for Economic Co-operation and Development (OECD). Question 16 seems to be a general question that evaluates the environmental friendliness of the country’s logistics. Questions 17 to 35 measure the domestic LPI of the respondent’s based-country by evaluating the country using the four measures that mentioned in Section 2.1.2 above [6]. The first five questions are focused on measuring the performance of the country’s supply chain [6]. Question 23 evaluates the automation of processes and the efficiency of the platforms’ cybersecurity [6]. Questions 24 to 35 are mostly focused on the quantitative information of the country’s international supply chain [6].

2.1.4. Constructing LPIs and Countries’ Rankings

Aside from using different categories to assess the countries, the World Bank also uses different tools and techniques to remove outlier data points and fill out the non-completed questionnaires. One of the tools that used to be embedded in the survey engine is the Uniform Sampling Randomized (USR) approach, which is used to prioritize countries with lower trade volumes to appear in the list of selected countries for the respondent [6]. In a normal situation, the engine starts to select the countries with the largest trading volumes as discussed earlier in Section 2.1.3. However, after 200 questionnaires the engine will automatically shift to use the USR tool [6].

In case of missing values, the engine will use an injunction technique based on the countries’ average responses for each question, modified by the respondent’s average deviation from the country mean in the filled questions [6].

To calculate the international LPI for each country, the World Bank uses a tool called principal component analysis (PCA) [6]. This tool is used to normalize the scores of the international LPI’s six components by subtracting the sample mean from the average scores of a component for a particular country across all respondents and divided by the standard deviation [6]. On the other hand, the PCA also develops standard statistical tests, likewise the Kaiser criterion and the eigenvalue scree plot of the correlation matrix [6]. Those tests ultimately generate and assign different weights to the six components of international LPI. Later on, those weights are multiplied by the normalized scores for each component.
under each country. Summing up the multiplication results provides a single value that represents the international LPI score for a given country.

World Bank also added a final verification step that measures the sample error and considers the confidence intervals of international LPI’s scores before assigning ranks. The standard errors are estimated for a specific country using the all the respondents’ inputs [6]. 80% confidence intervals are approximately set to evaluate the scores of each country [6]. This approach can assist the World Bank on noticing the countries which significantly improved from year to year and ranking different with higher confidence. The more evaluations for some countries, the narrower the confidence intervals. Thus, small markets with a lower number of respondents’ evaluations receive a high level of uncertainty and a wide confidence interval, and vice versa. If the score of a country lays on the upper bound of the confidence interval, the upper bound will be the selected rank for that country and the opposite will be applied to a score that lays on the lower bound [6].

2.2. Logistics Infrastructure and LPI Relation

Improving the logistics infrastructure of a country is the most important factor that leads to improve the country’s international LPI rank. A.F. Haughwout claimed that both the productivity and the cost structure of businesses are significantly impacted by the logistics infrastructure [7]. B. Erkan included 113 countries in a relativity analysis test between the LPI and the infrastructure-weighted components of the global competitiveness index (GCI), and he concluded that a country must focus in developing railroad and port infrastructure to increase its international LPI rank [8]. Recently, Uluta¸s Alptekin and Karaköy Çagatay proved that the LPI overall score of a country is highly affected by the infrastructure of that country according to the results of their combined subjective step-wise weight assessment ratio analysis (SWARA) and objective criteria importance through intercriteria correlation (CRITIC) weighting methods [9]. Another verifiable research shows that foreign direct investment is attracted to areas with efficient logistics systems [10].

2.3. Logistics Hubs Location Problems

Location problems fall under one of three classes based on S.L. Gadegaard’s classifications: planar, network and discrete. A selection from a set of potential sites is discrete, a selection from the edges of a network is network while placing anywhere on the plane is planar [11]. Z. Turskis and E.K. Zavadskas introduced a new fuzzy additive ratio assessment method (ARAS-F) and validated his model through a case of selecting logistics center location in the European Union [12]. Y. Li et al. proposed axiomatic fuzzy set (AFS) clustering and technique for order preference by similarity to ideal solution (TOPSIS) combined methodology, and tested the methodology effectiveness through a logistics center location identification case [13]. In the same month, B. Erkayman et al. implemented a fuzzy decision-making approach to select the best location among three possible centers at the northeast region of Turkey [14]. B. Ka combined fuzzy—analytic hierarchy process (AHP) and elimination et choix traduisant la réalité (ELECTRE) to determine dry port sites along the new Eurasian continental bridge at the Chinese region [15].

In a specific case to one of the Chinese regions, a different approach was implemented to determine the logistics center location of Jilin Province using the center of gravity method (CGM) by X. Liu et al. [16]. In another featured case, Yahyaei applied their proposed method in an Iranian case study which aimed to select a proper LH among 260 cities [17].

Another 5 LHLP relevant papers were published within the year of 2014, A. Ruda proposed an uncommonly used approach in the literature, which depends on a strict rejection of risks methodology and an alternative selection strategy, where he considers Boolean, weighted linear combination (WLC) and ordered weighted average (OWA) models, respectively [18]. B. Wang proposed another technique using the fuzzy multicriteria decision making approach based on the credibility of decision makers, and implemented his model on a practical example rather than on a real-life problem [19]. B. Elevli combined fuzzy with the preference ranking organization method for enrichment evaluation
(PROMETHEE) to test the suitability of different areas. A case study in Samsun, Turkey was used to evaluate his methodology in ranking five proposed locations for the construction of a logistic center [20]. Kou-Huang Chen et al. included five factors: resource availability, location resistance, expansion possibility, investment cost and information abilities as their criteria in selecting the appropriate logistics center among many alternative locations [21]. A combination of three techniques including fuzzy, TOPSIS and multichoice goal programming (GP) were used to specify a single location for establishing the logistics center. J. ˙Zak and S. Weglirski presented a two-phase approach (macro and micro analyses) and applied ELECTRE to rank Poland’s regions according to the suitability of placing logistics centers [22].

In 2015, C. Rao et al. presented a new 2-tuple hybrid ordered weighted averaging (THOWA) operator combined with fuzzy and TOPSIS to evaluate a potential alternative of city logistics centers’ locations. However, after implementing the model to a practical case study, the authors found that it is not applicable for multi-attribute group decision making with hybrid criteria values [23].

Ramona Iulia Tarţavulea et al. proposed a model of selection methodology which depends on AHP and linear programing (LP). A case study based on Romania was introduced where they selected the ten best locations for establishing logistics centers among 100 possible locations [24].

A year later, Y. Zhang et al. applied their fuzzy TOPSIS approach to Yunnan province, China. A primary election and precision selection were used to choose the best possible location for establishing logistics center [25]. K. Komchornrit presented one of the most interesting cases in location selection academic papers. His CFA-MACBETH-PROMETHEE approach consists of confirmatory factor analysis (CFA), measuring attractiveness by a categorical based evaluation technique (MACBETH) and the previously discussed PROMETHEE, and depends on many realistic factors such as Airports, Highways, Seaports and industrial areas locations [26]. B. Chen and B. Wang proposed a logistics center location selection algorithm for 16 cities in southeastern China. The method considers six factors reflecting the logistics performance of the city: city location quotient, market prosperity degree, proportion of freight volume, urban centricity, per capita GDP, and population size. With the use of different algorithms, six cities were suggested and ranked according to their selection suitability [27].

In the following year, K. Witkowski et al. implied a combination of different techniques and different factors including the availability of markets, economic zones and the potential of the area in terms of social and economic factors, to select the optimal city for the location of a logistics center in Poland [28].

Four of the most recent papers discussed and used multiple techniques, especially LP, which will be used in the current research. Y. Ma et al. proposed multimodal hub locations of the China railway express in a way that minimizes the total cost with a restriction on total traveling time [29]. X. Shang used a bi-objective to minimize the overall costs while maximizing the delivery time. Multiple transportation modes were included in the Turkish case study which confirms the effectiveness of the developed methodology [30]. C.V. Plaza et al. studied locating logistics integration centers by implementing a multi-layer location-allocation model in the Brazilian soybean transportation [31]. S. Shahparvari et al. introduced one of the most relevant papers to the scope of the current research. The authors choose two Iranian regions as a case study where they implied multi-criteria decision tools and included multi-layers to select the best possible sites for establishing regional LHs [32].

Asian countries have the highest frequency of implemented cases, which indicates the current logistics development among those countries. Most of the relevant practical cases consider one, two or all of the solving models, and those include spatial modeling, optimization modeling and decision-making methodologies. Spatial modeling might be really effective as a first phase whenever the feasible space is widely spread, while optimization models can be used as a single method which might solve the whole problem and lead to an optimum or near optimum solution. Decision making methodologies could
be used in many scenarios and whenever there is a lack of data, set of alternatives need to be ranked or a very complex problem which is hard to be mathematically formulated.

In this paper, spatial modeling will be used due to the large area of Saudi Arabia as an initial phase to cut the feasible space and concentrate on those most suitable areas. Optimization modeling will be used as a second phase to improve the solution and prioritize the set of LHs. The World Bank’s methodology will be implemented in a customized approach due to the lack of literature relevant to this part of the research.

3. Materials and Methods

Formulating such problems require multiple steps and decisions to reach a convenient solution. In this case, Saudi Arabia was chosen to be the country which is targeted in allocation of LHs and measuring the effectiveness of the solution on the country’s international LPI. Hence, the methodological approach will be a combination of two parts. The practical part (allocation of LHs) will be dealing with quantitative data analysis, modeling and programming, while the theoretical part (contribution assessment) will be based on surveys and subject matter experts’ (SMEs) feedbacks.

Due to the widespread area of the country, double decision models will be implemented to increase the quality and ensure the full coverage of allocation. Spatial modeling (macro level) will be used first to identify the main clusters and initial locations of LHs. Secondly, an optimization modeling (micro level) will be implemented to select the most suitable locations.

The below diagram (Figure 1) illustrates the overview parts of the methodological approach and summarize the above listed information.

3.1. Part 1: Allocation of LHs

Starting with macro level spatial modeling is a must due to the huge area of the country. Spatial modeling is also required in analyzing the different modes of infrastructure layers. Spatial modeling is usually used by civil engineering and urban designing practitioners. Thus, only the basic commands and operations will be implemented and utilized in our case.
In this field, ArcGIS software is the most well-known software among the rest of Geographic Information System (GIS) programs. Most of the learning materials and available data are found to be relevant to ArcGIS. The software provides the user with many features to perform all types of spatial operations which are considered to be more than enough in identifying the initial clusters of feasible locations. To do so, different infrastructure and other relevant layers need to be imported to ArcGIS. Then, multiple operations will be used to find the initial clusters such as buffering, intersecting and erasing.

After identifying the initial feasible clusters, another tool will be used to optimize the solution and set the selection strategy. Spatial model output data like the initial clusters will be used along with the international trading data nodes as an input for the optimization model. A mathematical model will be structured before using an integer linear programming (ILP) solver. In this micro phase, the model will try to maximize the allocations while minimizing the distances between final selected locations and the closest trading nodes. Finally, LHs will be ordered and prioritized according to their weights, and a technique for measuring their weights will be clarified in the next section.

3.2. Part 2: Contribution Assessment

In this part of the case study, the selected LHs will be assessed against the LPI ranking of Saudi Arabia. Since there is no methodology discussed in the academic literature, focused group surveys will be implemented to measure the estimated change in LPI rank.

Subject matter experts in the supply chain field will be the only target participants in this survey. The survey will be derived from the original World Bank LPI surveys. Also, calculations and assigned weights for each question will be used to mirror the real criteria of the World Bank. Other countries rankings will be kept without any change as per the last published rankings to be able to estimate the contribution of allocating regional LHs on Saudi Arabia’s ranking only.

LinkedIn, the professional social website, will be used as the main hub to search for relevant SMEs and invite them for participation. Before all of that, targeted countries will be selected as per the World Bank usual criteria and survey questions will be structured with a short description of the allocation proposal. The next section shows the full implementation of the methodology which includes the identified targeted countries and the survey questions. Results will be then analyzed and the delta of change in Saudi Arabia’s LPI ranking will be measured and discussed.

4. Case Study

Allocating regional LHs by utilizing Saudi Arabia’s infrastructure requires an implementation of two main phases. A macro level analysis phase has been implemented to identify the initial clusters where each cluster contains multiple potential townships. Those townships are considered to be feasible locations of regional LHs. Whereas the second phase is more focused on selecting the best possible set of townships among the rest of townships using a micro level analysis. For the second part of the case study, a survey-based tool will be implemented to assess the contribution of allocating regional LHs on Saudi Arabia’s rank at the international LPI. The focused group of participants will be selected based on their years of experience in the field of supply chain and logistics.

4.1. P1: Macro Phase—Infrastructure-Based Spatial Clustering

ArcGIS software is a powerful tool that enables the researcher to select or draw areas very accurately by using the longitude and the latitude on a built-in geographic map. However, some features such as countries relevant point of interests, natural reserves, buildings or infrastructures are missing and need to be imported from external sources. Thus, the availability of data is an essential step, and those data points are usually found in the shape of coordinates and areas with different labeling. A set of defined data of some feature, such as highways, line or airports points is known as a layer. In this part of the
case study, multiple layers of Saudi Arabia will be combined and analyzed using ArcGIS software features.

4.1.1. Collecting Data Layers

13 layers of data about Saudi Arabia were imported from the NextGIS website [33], and a worldwide ports layer was downloaded from ArcGIS Hub website [34], due to unavailability of this layer among the NextGIS’s layers. The ports layer was later on edited to remove all data points of worldwide ports except those of Saudi Arabia, and to include the coordinates of Riyadh dry port as detailed in the Cogoport website [35]. (Table 1) below illustrates the general information of each layer.

Table 1. General Information of Spatial Layers.

<table>
<thead>
<tr>
<th>ID</th>
<th>Layer</th>
<th>Class</th>
<th>Description</th>
<th>Size of Data</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airport</td>
<td>Polygon</td>
<td>All type of airports locations</td>
<td>69</td>
</tr>
<tr>
<td>2</td>
<td>Boundary-land-lvl4</td>
<td>Polygon</td>
<td>Regions of Saudi Arabia</td>
<td>13</td>
</tr>
<tr>
<td>3</td>
<td>Boundary-land-lvl5</td>
<td>Polygon</td>
<td>Governorates of Saudi Arabia</td>
<td>147</td>
</tr>
<tr>
<td>4</td>
<td>Boundary-land-lvl6</td>
<td>Polygon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>5</td>
<td>Boundary-land-lvl7</td>
<td>Polygon</td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>6</td>
<td>Highway</td>
<td>Line</td>
<td></td>
<td>532,521</td>
</tr>
<tr>
<td>7</td>
<td>Land</td>
<td>Polygon</td>
<td>Land area of Saudi Arabia</td>
<td>889</td>
</tr>
<tr>
<td>8</td>
<td>Land-use</td>
<td>Polygon</td>
<td>Farm, military or residential reserved lands</td>
<td>45,840</td>
</tr>
<tr>
<td>9</td>
<td>Nature-reserve</td>
<td>Polygon</td>
<td>Natural reserved lands</td>
<td>23</td>
</tr>
<tr>
<td>10</td>
<td>Power</td>
<td>Line</td>
<td>High-voltage power lines or spots</td>
<td>2856</td>
</tr>
<tr>
<td>11</td>
<td>Railway</td>
<td>Line</td>
<td>Railways and stations</td>
<td>1535</td>
</tr>
<tr>
<td>12</td>
<td>Township</td>
<td>Point</td>
<td>Villages, towns and likewise</td>
<td>10,949</td>
</tr>
<tr>
<td>13</td>
<td>Vegetation</td>
<td>Polygon</td>
<td>Vegetation reserved areas</td>
<td>945</td>
</tr>
<tr>
<td>14</td>
<td>Updated-ports</td>
<td>Points</td>
<td>Saudi Arabia’s sea and dry ports</td>
<td>17</td>
</tr>
</tbody>
</table>

The spatial representation of those layers will be shown in below (Figure 2). Due to the macro level view and the large spread area of Saudi Arabia, ArcGIS software was unable to provide clear visual representation for some of the above layers, which include layers 2A, 2C, 2M and 2N. In later stages, different operations will be implemented using more than one layer to generate valuable pieces of information. For example, merging layer 2N, which represents the distribution of Saudi Arabia’s dry and sea ports, with layer 2G, which represents the country’s land area, will illustrate the visual relation between the port and its spatial location at the land of Saudi Arabia. In other words, those layers represent raw data, and they require further analysis and operations to be useful and valuable according to the researchers’ objectives. Following ArcGIS operations will emphasize the 14 selected layers highlighting the initial feasible area for locating regional LHSs.

4.1.2. Dissolving Data Attributes

Dissolving the data attributes is an important step that frees the memory and enables the software to perform the operations in a fast and easy way. One of the trials, using a series of just three sequential operations, resulted in more than 70 million rows of data after 2 days of running the software. Consequently, the software was unable to perform any further operation or even view and analyze the current huge data points. To avoid this issue, all layers to be used in later intersecting operations have been dissolved. Dissolving those layers is not an issue in this case since both the area and the shape of data will be kept registered.
4.1.3. Buffering Infrastructure Layers

Considering the distance variation between the different nodes of infrastructure layers and the reserved areas for vegetations, residential and nature, adding buffers would be a logical step that needs to be added to increase the feasible space. In this operation, assumed buffers have been assigned to different layers based on their spread of data and each layer’s degree of importance. S. Shahparvari et al. assigned multiple buffers and suggested that those were the ideal distances where a LH should be allocated [32]. As per their suggestion, the ideal conditions of locating a hub should be within 50 km from an airport, within 2 km from a highway, within 10 km from a train station and within 1 km from a port [32]. In Saudi Arabia’s case, and due to the different considered spread areas and the data availability, and to make sure that all potential locations are covered and considered in the initial feasible space, buffers will be assigned with distances equal or larger than the assigned buffers of the previous study. This will maximize the feasible space and initially include larger suitable locations for the macro-phase spatial modeling. On the micro-phase analysis which will be implemented later, optimization modeling will be enabled to search for the most suitable locations within the largest possible feasible space. The following (Table 2) shows the estimated assigned buffers in kilometers per infrastructural layer.

Table 2. Estimated Buffers for Infrastructural Layers.

<table>
<thead>
<tr>
<th>Layer ID</th>
<th>Layer</th>
<th>Assigned Buffer (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Airports</td>
<td>50</td>
</tr>
<tr>
<td>6</td>
<td>Highways</td>
<td>5</td>
</tr>
<tr>
<td>10</td>
<td>Power Lines</td>
<td>30</td>
</tr>
<tr>
<td>11</td>
<td>Railways</td>
<td>100</td>
</tr>
<tr>
<td>14</td>
<td>Ports</td>
<td>50</td>
</tr>
</tbody>
</table>

Combining all those buffered infrastructure layers and intersecting them in the coming operations would lead to different feasible clusters. Those feasible clusters are the most suitable areas for allocating LHs as per the hypothesis of this research.

The result of adding all buffered areas together in a single view screen is shown in the below (Figure 3).
4.1.4. Intersecting Layers

In this operation, the 5 infrastructure buffered layers will be intersected together to highlight the key intersected clusters of Saudi Arabia’s infrastructure. Ultimately, there will be two types of clusters: the Power-Highway-Air-Railway-Port (PHARP) clusters, and the Power-Highway-Air-Railway (PHAR) clusters. Both of them are highly feasible, but the priority of allocation will be given to PHARP clusters as they consider more intersected layers. PHARP clusters are usually near to the coast lines of Saudi Arabia except for Riyadh city due to the dry port which is located there. PHAR clusters are important clusters as they cover internal areas which are not considered by PHARP clusters, and they are usually located within inland regions. PHARP and PHAR clusters are both illustrated on a topographic ArcGIS’s built-in base map in the (Figure 4) below.

Due to the dissolving of data attributes, intersecting PHAR and PHARP clusters with the townships layer is a must to highlight and identify the coordinates of the townships within each cluster. In addition, regions layer, the union of governorates A, B and C layers and the land layer have been all intersected with the prior intersections to remove the out-of-boundaries buffers and link the townships to their relevant governates and regions as shown in the following (Figure 5).

4.1.5. Erasing Operation

Erasing unavailable areas is the final step that will be implemented using the spatial model of ArcGIS. Layer 28, 29 and 43, which represent nature reserves, used lands and vegetations, respectively, will be kept free by removing their intersections from the initial set of townships and the initial PHARP and PHAR clusters. Last but not least, adding latitude and longitude coordinates has been implemented to label each township with its exact location to be accurately used in the next phase. Out of 10,949 townships, 368 have been highlighted to be the most feasible townships within the PHARP clusters, while 1304 were identified as the second-best feasible townships and those are located within the PHAR clusters.

4.2. P1: Micro Phase—Trading-Based Optimization Programming

Optimizing and improving the results of the spatial modeling is required to enhance the size of feasible townships. Currently, the majority of the feasible townships seem to be adjacent and very close to each other. Thus, selecting one township and neglecting the close adjacent townships will not negatively affect the current solution, rather than enhancing it.

In this phase, the current set of feasible townships will be selected according to their distances to the determined nodes of exporting and importing as per Saudi Arabia published data. The following sequential operations will be performed to minimize the feasible space without affecting the quality of the initial solution.

4.2.1. Preparing Input Data

Output results from the previous phase in addition to the international trading (import and export) data of Saudi Arabia which are published by the General Authority of Statistics [36], will both be used as inputs to the new model.

In order to utilize the trading data, an average export and import of the three most recent quarters has been considered in calculating the trading weight for each node. Moreover, the latitude and longitude coordinates for each trading node has been manually added to be used in the coming operation. (Table 3) below shows the weight (total trade) in million Saudi Riyals (SAR) and location coordinates per trading node.

Locations of the existing LHs are another type of data that need to be prepared and used as an input for this phase. Currently, there is only one existing LH that is located south of Jeddah city at a township called Khomra. Establishing LH at Khomra township was announced by the Saudi Minister of Transport, Dr. Nabil Al-Amoudi during the 3rd Saudi Logistics Conference which was held in Riyadh city between 13–15 October 2019 [37].
Fortunately, Khomra township was one of the feasible townships that were highlighted within PHARP clusters.

Figure 4. Initial Representations of Clusters: (A) PHAR and (B) PHARP.
boundaries buffers and link the townships to their relevant governates and regions as shown in the following (Figure 5).

**Figure 5.** Initial Feasible Townships.

### 4.1.5. Erasing Operation

Erasing unavailable areas is the final step that will be implemented using the spatial model of ArcGIS. Layer 28, 29 and 43, which represent nature reserves, used lands and vegetations, respectively, will be kept free by removing their intersections from the initial set of townships and the initial PHARP and PHAR clusters. Last but not least, adding latitude and longitude coordinates has been implemented to label each township with its exact location to be accurately used in the next phase. Out of 10,949 townships, 368 have been highlighted to be the most feasible townships within the PHARP clusters, while 1304 were identified as the second-best feasible townships and those are located within the PHAR clusters.

### 4.2. P1: Micro Phase

— Trading-Based Optimization Programming

Optimizing and improving the results of the spatial modeling is required to enhance the size of feasible townships. Currently, the majority of the feasible townships seem to be adjacent and very close to each other. Thus, selecting one township and neglecting the close adjacent townships will not negatively affect the current solution, rather than enhancing it.

In this phase, the current set of feasible townships will be selected according to their distances to the determined nodes of exporting and importing as per Saudi Arabia published data. The following sequential operations will be performed to minimize the feasible space without affecting the quality of the initial solution.

<table>
<thead>
<tr>
<th>ID</th>
<th>Node</th>
<th>ID</th>
<th>Node</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Jeddah Islamic Sea Port</td>
<td>3</td>
<td>King Khalid International Airport</td>
</tr>
<tr>
<td>2</td>
<td>King Abdulaziz Port</td>
<td>4</td>
<td>Bat’ha</td>
</tr>
<tr>
<td>3</td>
<td>King Khalid International Airport</td>
<td>5</td>
<td>Jubail Industrial Port</td>
</tr>
<tr>
<td>4</td>
<td>Jubail Port</td>
<td>6</td>
<td>Jeddah Islamic Sea Port</td>
</tr>
<tr>
<td>5</td>
<td>King Fahad Airport</td>
<td>7</td>
<td>King Abdulaziz International Airport</td>
</tr>
<tr>
<td>6</td>
<td>King Abdulaziz International Airport</td>
<td>8</td>
<td>Riyadh (Dry Port)</td>
</tr>
<tr>
<td>7</td>
<td>King Fahad Bridge</td>
<td>9</td>
<td>Ras Tannorah Port</td>
</tr>
<tr>
<td>8</td>
<td>King Fahad Bridge</td>
<td>10</td>
<td>King Abdullah Seaport</td>
</tr>
<tr>
<td>9</td>
<td>King Fahad Bridge</td>
<td>11</td>
<td>Haditha</td>
</tr>
<tr>
<td>10</td>
<td>King Fahad Bridge</td>
<td>12</td>
<td>King Abdullah Seaport</td>
</tr>
<tr>
<td>11</td>
<td>King Fahad Bridge</td>
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<td>Haditha</td>
</tr>
<tr>
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<td>King Fahad Port</td>
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<td>Yanbu Port</td>
</tr>
<tr>
<td>17</td>
<td>King Fahad Bridge</td>
<td>19</td>
<td>Wadea Airport (Najran)</td>
</tr>
</tbody>
</table>

**Table 3.** International Trading Data of Saudi Arabia.
4.2.2. Converting Longitudes and Latitudes to XY Coordinates

Current longitudes and latitudes coordinates are very complex to be used in our mathematical calculation. Thus, software called Lat Long Coord Converter has been used to specify the XY coordinates for our database. The software is very helpful, one of its kind, and is available for the public on a community platform for software developers called GitHub [38].

To be able to convert the geographic coordinates to XY coordinates, the centre of meridian or the zone of Saudi Arabia should be firstly identified. The centre of Saudi Arabia is located at zone 38 according to the Universal Transvers Mercator (UTM) which is found at Jaworski Mapping and GIS website [39]. Therefore, Saudi Arabia is located at zone 38 according to the Universal Transvers Mercator (UTM) which is found at Jaworski Mapping and GIS website [40].

4.2.3. Formulating Mathematical Model

Problem formulation in a mathematical model is key step that needs to be accomplished before the computerized model. Parameters, decision variables and constraints notation are listed below.

- **Parameters:**
  - Set of Townships, \( i, j \in I \) & \( j \)
  - Set of Trading Nodes, \( k \in K \)
  - \( D_{ij}, \) Distance between township \( i \) and township \( j \) in km
  - \( S_{ik}, \) Distance between township \( i \) and trading node \( k \) in km
  - \( F_{ik}, \) Considered weighted distance between township \( i \) and trading node \( k \) in km
  - \( X_i, \) X coordinate of township \( i \)
\[ Y_i, \ Y \text{ coordinate of township } i \]
\[ M_k, \ X \text{ coordinate of trading node } k \]
\[ N_k, \ Y \text{ coordinate of trading node } k \]
\[ W_k, \ \text{Weight of trading node } k \text{ in Billion SAR} \]

**Decision Variables:**

\[ T_{ij} \begin{cases} 1, & \text{if township } i \text{ is selected for allocating LH} \\ 0, & \text{Otherwise} \end{cases} \]

Then, the list of Equations will be as follow:

\[
\text{Max } Z = \sum_i \sum_k T_{ik} F_{ik} W_k \tag{1}
\]

Subject to,

\[
D_{ij} = \sqrt{\left(X_i - X_j\right)^2 + \left(Y_i - Y_j\right)^2} / 1000 \quad \forall \ i \in I, \ j \in J, \ i \neq j \tag{2}
\]

\[
S_{ik} = \sqrt{\left(X_i - M_k\right)^2 + \left(Y_i - N_k\right)^2} / 1000 \quad \forall \ i \in I, \ k \in K \tag{3}
\]

\[
T_i + T_j \leq \begin{cases} 1, & \text{if } D_{ij} \leq 50 \\ 2, & \text{Otherwise} \end{cases} \quad \forall \ i \in I, \ j \in J, \ i \neq j \tag{4}
\]

\[
F_{ik} = \begin{cases} 50 - S_{ik}, & \text{if } S_{ik} \leq 50 \\ 0, & \text{Otherwise} \end{cases} \quad \forall \ i \in I, \ k \in K \tag{5}
\]

\[
T_i \in \{0, 1\} \quad \forall \ i \in I \tag{6}
\]

The first Equation (1) represents the objective function that maximize the allocation of LH which maximizes the benefit of considered distances between the selected townships and the trading nodes considering the different assigned weights. Equation (2) calculates the distances between any two townships in km using their XY coordinates. Equation (3) also calculates the distances using a similar method, but between trading nodes and townships instead. Equation (4) limits the allocation of LHs to be only one or fewer in a radius of 50 km squared area. Equation (5) neglects the preference of allocating townships that is located in more than 50 km far from a trading node and limits the selected townships to be at least close to a single trading node with 50 km or less distance. Also, this equation is very important since it calculates the distance in a flipped way, and enables the higher number to be the preferred choice to fit into the maximization objective function. Equation (6) defines the decision variable as a binary variable.

### 4.2.4. Implementing the Computerized Model

Lingo optimization software was used to structure the computerized code and solve the current problem. The solver uses a Branch and Bound technique to solve the following ILP model lingo code (Algorithm A1) in the Appendix A.

The experiment was performed on a Lenovo ThinkPad laptop with an Intel® Core™ i7-8565U CPU@ 1.80 GHz–1.99 GHz processor. Though, the generator memory of Lingo was not able to solve the problem on the default setting. Therefore, the generator memory was extended to 2,099,999,999 MB to be able to solve the problem. Also, due to the large number of data points and constraints (1672 townships and more than 4 million constraints), the experiment had to be divided into two trials. Luckily, PHARP relevant townships were planned to have the highest priority of allocation earlier as discussed in the macro level phase, (0) Section 4.1 of the current chapter. So, the first trial of the experience will be focused only on allocating LHs at the townships relevant to the PHARP clusters, while the second trial will include the selected locations from the first trial as an input data to decide the allocation of LHs at the townships of the PHAR clusters. This will only prioritize
the allocation criteria only and will not prioritize the allocation ordering which will be discussed in the next section.

The first trial was able to select 14 more LHs beside Khomra LH and the solver was able to find the global optimal solution. However, to perform the first trial, a few adjustments to the original lingo code were executed along with the related definitions at data source. The first trial adjusted lines are shown below (Algorithm A2) in the Appendix A.

For the second trial, 28 more LHs were selected, and the solver was also able to reach the global optimal solution. The locations and the solution for first trial was all used as an input data for the current trial. Updating the defined cells at the data source and adjusting the lingo code were required before running the solver for the last time. Adjusted Lingo code for the second trial is shown in the following (Algorithm A3) in the Appendix A.

4.2.5. Prioritizing and Ordering the Selected Logistics Hubs

A total of 42 locations were selected beside the existing Khomra LH as discussed in the above section. In this section, the variable that register the closeness of the selected locations and neglect the outlying distances (more than 50 km) to the list of trading nodes will be multiplied as a matrix with the matrix of trading nodes’ weights to calculate the allocation priority for each selected location. The following Equation (7) explains the suggested approach to order the selected location, the existing Khomra LH will be also included in the calculations.

\[
\text{LH}_i \text{ assigned weight} = \begin{bmatrix} F_{ik} & \cdots & F_{iK} \\ \vdots & \ddots & \vdots \\ F_{IK} & \cdots & W_K \end{bmatrix} \begin{bmatrix} W_k \\ \vdots \\ W_K \end{bmatrix} \quad \forall \quad i \in I, \ k \in K
\]  

Applying the above equation will result in assigning different weights to each LH considering their nearness to how many trading nodes and how critical they are in the matter of international trading. Below (Table 4) orders LHs as per the resulted scores and shows the other type of information, such as their relevant governorate, region and coordination.

4.3. P2: Assessing the Contribution of LHs on LPI

The World Bank uses a survey-based methodology to assess countries logistics performances domestically and globally among the different selected countries. As discussed earlier in Section 2.1.4, international LPI is focused on assessing and ranking countries, while the domestic LPI is more focused on evaluating the logistics environment within a selected country and does not compare a country to another. Hence, only international LPI relevant questions will be considered in this research.

Moreover, the customized methodology will only consider Saudi Arabia estimated enhancement without considering or estimating the development of other countries. Thus, 2018’s ranks for all other countries will be used as is except for Saudi Arabia in order to estimate the contribution of the proposed solution correctly. Considering such a scenario will minimize statistical analysis which is currently considered by the World Bank while measuring LPIs.

A short description of the proposed solution will be added to the survey in addition to the six core questions that assess the international LPI dimensions. Another two required questions that register the supply chain relevant years of expertise and the relevant residential country for each respondent will be added to test and analyse the results.

4.3.1. Structuring Survey Sections

The World Bank survey questions will be considered with minor adjustments to fit our case. The well-known SurveyMonkey website will be used to host the assessment survey. Two pages with ten questions and a short description of the proposal will be added to minimize the effort and encourage the SMEs for participation.
Table 4. Allocation Prioritization of Selected Locations.

<table>
<thead>
<tr>
<th>Order ID</th>
<th>Township ID</th>
<th>Township</th>
<th>Governorate</th>
<th>Region</th>
<th>Latitude</th>
<th>Longitude</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>102</td>
<td>Khumrah</td>
<td>Jiddah</td>
<td>Makkah</td>
<td>21.37278</td>
<td>39.22611</td>
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<td>2</td>
<td>241</td>
<td>Mina’ al Khubar</td>
<td>Khobar</td>
<td>Eastern</td>
<td>26.27916</td>
<td>50.22222</td>
<td>1186.345781</td>
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<td>3</td>
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<td>Ras Tanmurah</td>
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<tr>
<td>4</td>
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<td>Riyadh</td>
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<td>Al Jubayl</td>
<td>Eastern Region</td>
<td>26.8525</td>
<td>49.56416</td>
<td>571.2055279</td>
</tr>
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<td>Al Jumum</td>
<td>Makkah</td>
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<td>Ad Dilam</td>
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<td>Makkah</td>
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<td>25.58333</td>
<td>49.25</td>
<td>0.001523793</td>
</tr>
<tr>
<td>36</td>
<td>1453</td>
<td>Mistah</td>
<td>Hail</td>
<td>Hayel</td>
<td>27.40944</td>
<td>41.45444</td>
<td>4.09298 \times 10^{-3}</td>
</tr>
<tr>
<td>37</td>
<td>1482</td>
<td>Gar al Sandok</td>
<td>Hail</td>
<td>Hayel</td>
<td>27.55838</td>
<td>41.93519</td>
<td>3.4593 \times 10^{-3}</td>
</tr>
<tr>
<td>38</td>
<td>1417</td>
<td>Al ‘Ishsh</td>
<td>Hail</td>
<td>Hayel</td>
<td>27.08317</td>
<td>41.81079</td>
<td>1.37106 \times 10^{-5}</td>
</tr>
<tr>
<td>39</td>
<td>1574</td>
<td>Khabb Layjah</td>
<td>Dawamat Al Jandal</td>
<td>Al Jawf</td>
<td>29.657</td>
<td>39.88389</td>
<td>3.0139 \times 10^{-6}</td>
</tr>
<tr>
<td>40</td>
<td>1578</td>
<td>Nawazi an Nuwaythah</td>
<td>Sakaka</td>
<td>Al Jawf</td>
<td>29.71667</td>
<td>40.41666</td>
<td>2.29122 \times 10^{-6}</td>
</tr>
<tr>
<td>41</td>
<td>1646</td>
<td>Shaib Umm al Maqabir</td>
<td>Sakaka</td>
<td>Al Jawf</td>
<td>30.125</td>
<td>40.10833</td>
<td>1.56447 \times 10^{-6}</td>
</tr>
<tr>
<td>42</td>
<td>1535</td>
<td>Tuus al Laban</td>
<td>Hail</td>
<td>Hayel</td>
<td>27.86666</td>
<td>41.53333</td>
<td>3.42324 \times 10^{-8}</td>
</tr>
<tr>
<td>43</td>
<td>372</td>
<td>Marah</td>
<td>Samtah</td>
<td>Jazan</td>
<td>16.66667</td>
<td>43</td>
<td>0</td>
</tr>
</tbody>
</table>

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4.3.2. Summary and Purpose

A short description of the allocation proposal and the used methodology will be added to the top of the first page to inform the participant about the purpose of this survey. The exact description used will be written as the following paragraph “A set of regional logistics hubs (LHs) suitable locations have been proposed within the Kingdom of Saudi Arabia. A geographic information system was used to integrate all transportation modes (Sea, Air, Road and Rail) together with different considered infrastructural and natural geographic layers (e.g., Nature Reserves, Urban Areas, Power Lines and Vegetations), and highlight the buffered key areas as initial potential locations for locating LHs. Out of those potentials, locations that are the nearest to the international trading (exports and imports) nodes have been selected as LHs’ most suitable locations using an optimization programming model considering multiple factors. If implemented, what will be the estimated contribution of such a solution on Saudi Arabia’s ranking at the international LPI?”.

4.3.3. Respondent’s General Information

The first page will also include four general questions that evaluate and gather general information about the respondent. The first question will evaluate each respondent according to his/her relevant years of experience within the field of supply chain and logistics. The second question will evaluate the frequently-used freight mode of each respondent. The third question will evaluate the trading direction which is usually practiced by the respondent. The fourth and final general question will gather the country of work for each respondent.

4.3.4. LPI Assessment Questions

The second page contains the core questions of the survey. Those questions are very similar to the actual questions that are used by the World Bank. The efficiency of the clearance process, quality of trade and transport related infrastructure, ease of arranging competitively priced shipment, overall level of competence and quality of logistics services, ability to track and trace your consignments and scheduled or expected delivery time fulfilments need to be all evaluated, considering the implementation of allocation proposal.

4.3.5. Identifying Targeted Country Groups

Saudi Arabia is classified as a high-income country as per the World Bank most recent classifications [41]. Since Saudi Arabia is also a costal country, World Bank selects the country groups of respondents as per the following methodology which was discussed earlier in Section 2.1.4. The selected country groups to evaluate the logistics performance of Saudi Arabia will include two countries randomly from the list of five most important importers, and the five most important exporters, a random country from Africa, a random country from East Asia and Central Asia, a random country from Latin America, a random country from Europe less Central Asia and OECD and two more random countries from the combined country groups [36]. As per the General Authority for Statistics, the five most important importers to Saudi Arabia are China, United Arab Emirates, United States of America, Germany and India. The five most important exporters are China, India, Japan, South Korea and United States of America. To complete the list, Egypt will be selected to represent African countries as it comes first as it is considered to be the most important trading party from Africa, with the seventh rank at the exporters list and eighth rank at the importers list. Also, Brazil will be selected to represent the countries of Latin America as it lays at the 18th rank of most important exporters and 13th rank at the list of most important importers. The list of targeted countries for the assessment will contain respondents working at logistics firms from the following countries (Table 5).
Table 5. Targeted Country Groups for Survey Respondents.

<table>
<thead>
<tr>
<th>ID</th>
<th>Selected Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>China</td>
</tr>
<tr>
<td>2</td>
<td>United Arab Emirates</td>
</tr>
<tr>
<td>3</td>
<td>United States of America</td>
</tr>
<tr>
<td>4</td>
<td>Germany</td>
</tr>
<tr>
<td>5</td>
<td>India</td>
</tr>
<tr>
<td>6</td>
<td>Japan</td>
</tr>
<tr>
<td>7</td>
<td>South Korea</td>
</tr>
<tr>
<td>8</td>
<td>Egypt</td>
</tr>
<tr>
<td>9</td>
<td>Brazil</td>
</tr>
</tbody>
</table>

4.3.6. Selecting and Inviting Respondents

LinkedIn is a social media application that is usually used for creating, sharing and searching for professional experiences and businesses relevant contents. This hub will be used to search for potential respondents and invite them for survey participation.

“Logistics” as a keyword is used to search for people’s profiles each time with a set filter on one of the nine targeted countries. From each country, a minimum of 10 SMEs will be invited to share their opinion regarding the contribution of the allocation proposal on Saudi Arabia ranking at international LPI.

5. Results

83 SMEs from the targeted countries have participated in the published survey with direct invitation. However, only 65 of them have completed the whole survey questions due to irrelevancy or lack of judgment as per the non-completed surveys’ responses. Moreover, 2 respondents have selected their country of origins instead of their current country of work. Fortunately, SurveyMonkey hosting website enables an IP address tracking tool and we were able to identify their country of work by utilizing this tracking tool.

For the first question which evaluates respondents’ relevant years of experience in supply chain and logistics, about 40% of the respondents have at least 15 years of experience and were highly familiar with the topic of this survey. Approximately half of the respondents were used to multimodal fright mode as per the results of the second question, while none of them were familiar with the railways mode in general. The same thing goes with primer direction of trade and transport that respondents used to deal with. About half of them were used to different trade directions, which include exporting, importing, domestic and international transits. The geographic divisions of the respondents’ countries of work are as per the following diagram, considering that all of Sudan’s respondents are actually based in the United Arab Emirates (Figure 6).

In contrast with the above four general questions, the following assessment core questions were answered by 65 respondents as mentioned earlier. The first question of the LPI assessment part and the fifth question of the survey used to rate efficiency of the clearance process (i.e., speed, simplicity, and predictability of formalities) by border control agencies, including customs in Saudi Arabia in case of establishing and operating the proposed logistics hubs. SMEs responses were as the following (Table 6). The participants responded on a 5-point Likert scale, where average means the median value of a particular process or activity [42].

The following question evaluates the quality of trade and transport related infrastructures in Saudi Arabia also considering the To-Be situation after implementing the proposed solution. Below (Table 7) represents the SMEs’ responses for the second LPI assessment question.
Table 6. Responses for Rating the Efficiency of Clearance Process by Border Control Agencies.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>1.54%</td>
</tr>
<tr>
<td>Low</td>
<td>9.23%</td>
</tr>
<tr>
<td>Average</td>
<td>63.08%</td>
</tr>
<tr>
<td>High</td>
<td>16.92%</td>
</tr>
<tr>
<td>Very high</td>
<td>9.23%</td>
</tr>
</tbody>
</table>

Table 7. Responses for Evaluating the Quality of Trade and Transport Infrastructures.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>0.00%</td>
</tr>
<tr>
<td>Low</td>
<td>4.62%</td>
</tr>
<tr>
<td>Average</td>
<td>47.69%</td>
</tr>
<tr>
<td>High</td>
<td>36.92%</td>
</tr>
<tr>
<td>Very high</td>
<td>10.77%</td>
</tr>
</tbody>
</table>

Regarding the third LPI question that assesses the ease of arranging competitively priced shipment to Saudi Arabia, respondents had rated the To-Be easiness as per the following (Table 8).

Table 8. Responses for Measuring the Easiness of Arranging Competitive Priced Shipments.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very difficult</td>
<td>3.08%</td>
</tr>
<tr>
<td>Difficult</td>
<td>13.85%</td>
</tr>
<tr>
<td>Average</td>
<td>60.00%</td>
</tr>
<tr>
<td>Easy</td>
<td>23.08%</td>
</tr>
<tr>
<td>Very easy</td>
<td>0.00%</td>
</tr>
</tbody>
</table>

The fourth LPI relevant question evaluates the future overall level of competence and quality of logistics services in Saudi Arabia. SMEs responses were distributed as shown in (Table 9).
Table 9. Responses for Assessing the Competence and Quality of Logistics Services.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>1.54%</td>
</tr>
<tr>
<td>Low</td>
<td>10.77%</td>
</tr>
<tr>
<td>Average</td>
<td>44.62%</td>
</tr>
<tr>
<td>High</td>
<td>40.00%</td>
</tr>
<tr>
<td>Very high</td>
<td>3.08%</td>
</tr>
</tbody>
</table>

The fifth LPI question evaluates the ability to track and trace consignments when shipped to Saudi Arabia in case of establishing the proposed LHS. Responses were very similar to the previous question as shown in the below (Table 10).

Table 10. Responses for Evaluating the Ability and Trace Consignments.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>3.08%</td>
</tr>
<tr>
<td>Low</td>
<td>9.23%</td>
</tr>
<tr>
<td>Average</td>
<td>43.08%</td>
</tr>
<tr>
<td>High</td>
<td>41.54%</td>
</tr>
<tr>
<td>Very high</td>
<td>3.08%</td>
</tr>
</tbody>
</table>

The final question of the survey assesses the improvement of possibility and the accuracy of delivering shipments to the consignee within the scheduled or expected delivery time. The following (Table 11) presents the opinions of the respondents regarding the accuracy of estimating delivery timings.

Table 11. Responses for Measuring the Accuracy of Delivering Shipments to Consignees within the Scheduled Delivery Time.

<table>
<thead>
<tr>
<th>Answer Choices</th>
<th>Responses</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hardly ever</td>
<td>3.08%</td>
</tr>
<tr>
<td>Rarely</td>
<td>4.62%</td>
</tr>
<tr>
<td>Sometimes</td>
<td>53.85%</td>
</tr>
<tr>
<td>Often</td>
<td>23.08%</td>
</tr>
<tr>
<td>Nearly always</td>
<td>15.38%</td>
</tr>
</tbody>
</table>

6. Discussion

Based on the last calculated LPI in 2018, Saudi Arabia came at rank 55 with a weighted LPI score of 3.01. The weighted scores for each of the six LPI measures were scored as per the following (Table 12) [6].

Table 12. Saudi Arabia’s 2018 LPI Ranking and Scores.

<table>
<thead>
<tr>
<th>LPI Rank</th>
<th>LPI Score</th>
<th>Customs</th>
<th>Infrastructure</th>
<th>International Shipments</th>
<th>Logistics Competence</th>
<th>Tracking &amp; Tracing</th>
<th>Timeliness</th>
</tr>
</thead>
<tbody>
<tr>
<td>55</td>
<td>3.01</td>
<td>2.66</td>
<td>3.11</td>
<td>2.99</td>
<td>2.86</td>
<td>3.17</td>
<td>3.3</td>
</tr>
</tbody>
</table>

As per the results of the accomplished surveys, participated SMEs have evaluated the contribution of the allocation proposal on the six measures to be as per the following (Table 13) which represents the mean scores across all respondents per each LPI measure.
Table 13. Saudi Arabia’s LPI Scores as per Surveys’ Respondents.

<table>
<thead>
<tr>
<th>LPI Score</th>
<th>Customs</th>
<th>Infrastructure</th>
<th>International Shipments</th>
<th>Logistics Competence</th>
<th>Tracking &amp; Tracing</th>
<th>Timeliness</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.31</td>
<td>3.23</td>
<td>3.54</td>
<td>3.03</td>
<td>3.32</td>
<td>3.32</td>
<td>3.43</td>
</tr>
</tbody>
</table>

This means that estimated improvements are about 21% in Customs performance, 14% in Infrastructure, 1% in International Shipments, 16% in Logistics Competence, 5% in Tracking and Tracing and 4% in Timeliness with a weighted improvement of about 10% to the country LPI Score.

Analyzing responses as per SMEs relevant years of experience, we can see that the estimated LPI score as per respondents with 5 years of experience or less is about 3.27, and respondents with 6 to 10 years of experience is close 3.26. Whereas, SMEs with 11 to 15 years of experience estimate that the improved score to reach 3.45 and 3.30 by respondents with more than 15 years of experience. This indicates that even the SMEs with a lot of experience in supply chain and logistics predict that allocating regional LHs will eventually improve the international LPI ranking and scores of the country.

To construct the estimated change in ranking, the World Bank’s Equations and formulas will be implemented, which were discussed earlier in Section 2.1.4. The upper and lower bounds of the LPI score need to be calculated using the following Equation (8).

\[
\text{LPI} = t_{(0.1, N-1)} S \sqrt{\frac{1}{N}} 
\]

where, \( t \) is student’s \( t \)-distribution, \( N \) is number of respondents, \( S \) is the estimated standard error.

\( N \) is 65 excluding the respondents who did not complete the LPI assessment part of surveys and \( S \) equals 0.5648. Therefore, \( t \) (0.1, 64) is approximately 1.296 as per the \( T \) distribution table found online or in the Montgomery & Runger book [43]. Hence, the upper bound is equal 3.40 while the lower bound is equal to 3.22. Based on these results in comparison to the last published rankings by the World Bank, those results may fit Saudi Arabia anywhere between those international LPI ranks (35–38) with a very high possibility to be at the 35th rank considering the similarity to Chile’s scores which is ranked 34 and scores of the calculated lower bound in comparison with the lower bounds of 35th to 38th ranked countries [6]. Thus, integrating different logistics modes and allocating regional LHs will indeed contribute in improving the country’s international LPI ranking with a very markable positive effect.

7. Conclusions

In conclusion, Saudi Arabia targeted the 25th rank at the international LPI rankings of 2030 as per the Saudi Vision, which was published back in 2016. Since then, the country’s ranking decreased until it reached the 55th rank in the 2018 World Bank reports. This problem was investigated both from academic and practical perspectives, and infrastructural measures were selected as the most effective measures which drive the overall ranking of countries. Utilizing and integrating Saudi Arabia’s different logistics modes and proposing a set of locations to establish linking LHs and testing the contribution of this proposal was the key objective of this research.

The World Bank’s logistics performance measures have been studied and analysed to develop solid, realistic situations and propose assorted driven approaches. A thesis statement that examines the contribution of allocating regional LHs to Saudi Arabia’s international LPI ranking has been tested by implementing a two-part approach.

The first part introduced a double-phase case study, where both spatial modelling and optimization modelling have been used to allocate 43 regional LHs. Different layers were used as input data for the macro spatial GIS software and those include all transportation modes (Sea, Air, Road and Rail) with multiple infrastructural and natural geographic layers (e.g., Nature Reserves, Urban Areas, Power Lines and Vegetations). For the micro
phase optimization modelling, suitable areas which represent the output data from the
spatial modelling were used together with the international trading (exports and imports)
node. Most suitable townships to allocate LHs have been identified considering the nearest
townships to trading nodes with the highest weighted trading volumes.

The second part considers the point of views of the supply chain and logistics’ SMEs
from 9 different countries which represent different continents, and appeared on the top
exporters and importers lists for Saudi Arabia. LinkedIn, the social professional platform,
has been used as a main hub to search for suitable SMEs and invite them for participation.
Survey results were later on analyzed, tested and compared to the World Bank’s standard
formulas and methodologies to estimate the contribution of the allocation proposal using
realistic measures. Finally, an improvement of about 20 international LPI ranks has been
estimated as a resulted contribution for allocating regional LHs within Saudi Arabia.

Hence, based on the results of the practical case study, international LPI ranking of a
country will be positively affected by locating regional LHs at the key intersection points
of the country’s logistics infrastructure.

Since the World Bank and different academic studies prove that LPI ranking is highly
affected by logistics infrastructure, authors may test and explore different scenarios for
improving the infrastructure other than the allocation of LHs. Different solutions might be
later on tested and benchmarked against each other according to multiple factors.

For future potential opportunities, multiple ideas could be tested for relevant research,
and there is also room for improvements which might be considered for similar scope and
similar cases.

Mainly, there are two potential improvement paths that might be explored as comple-
mentary stages for this thesis:

1. More layers might be added to the GIS software, such as the layer of topography,
which will add another suitability test for allocation. The author may consider the
nature of the soil and the suitable level of height that enable the logistics movement
from-to the allocated LH easy and accessible. In case of data availability on a micro
level, the author may even be able to jump into designing the supply chain model for
each of the proposed LHs to suit their selected location from different natural, social
and geographic aspects.

2. The World Bank may introduce a new methodology for measuring LPIs for different
countries as per non-official news. Also, there is no literature relevant to suggest-
ning new methodologies for calculating and categorizing countries based on their
logistics performance. This might be a very huge improvement to the logistics field
in general if authors investigate and study for more efficient ways for estimating
logistics performances.

A more modern and trending scope may also be explored by integrating new technolo-
gies with supply chain systems or logistics infrastructure and assessing their effect on the
logistics performance of a country. Nowadays, technologies such as artificial intelligence,
the internet of things, machine learning and blockchain are becoming involved with differ-
ent phases of the supply chain process. Blockchain technology as an example might be used
to generate reliable decentralized smart transportation ecosystems which digitize documen-
tation cycles and different transactions [44]. This may positively and directly affect three
LPI measures that include the efficiency of customs and border management clearance,
the ability to track and trace consignments and the frequency with which shipments reach
consignees within scheduled or expected delivery times. Blockchain technology is really
effective when it comes to traceability and transparency and could enable authorities or de-
cision makers to highlight bottlenecks and opportunities for improvements and seek more
attractive and sustainable supply chain and logistics environments [45]. The technology is
essential, especially for developing countries which aim to develop their logistics maturity
level and desire a sustainable supply chain [46,47].
Author Contributions: Conceptualization, M.A. (Malk Almalki); Data curation, M.A. (Malk Almalki); Formal analysis, M.A. (Malk Almalki); Funding acquisition, M.A. (Malk Almalki); Investigation, M.A. (Malk Almalki); Methodology, M.A. (Malk Almalki); Project administration, M.A. (Malk Almalki); Resources, M.A. (Malk Almalki); Software, M.A. (Malk Almalki); Supervision, M.A. (Mohammed Alkahtani); Validation, M.A. (Malk Almalki); Visualization, M.A. (Malk Almalki); Writing—original draft, M.A. (Malk Almalki); Writing—review & editing, M.A. (Malk Almalki). All authors have read and agreed to the published version of the manuscript.

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Informed Consent Statement: Not applicable.

Data Availability Statement: Available in online data sources with fees.

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Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Algorithm A1. Lingo Original Code

sets:
Township/1..1672/;
Trading_Node/1..39/;
TDistance(Township,Township):D;
NDistance(Township,Trading_Node):S,F;
TCoordinate(Township):X,Y,T;
NCoordinate(Trading_Node):M,N,W;
endsets

data:
X = @ole();
Y = @ole();
M = @ole();
N = @ole();
W = @ole();
@ole() = T;
@ole() = F;
enddata

!Objective Function;
max = @sum(NDistance(i,k):T(i)*F(i,k)*W(k));

!Constraints;
@for(NDistance(i,k):S(i,k) = @sqrt(@sqr(X(i) - M(k)) + @sqr(Y(i) - N(k)))/1000);
@for(TDistance(i,j)|i#ne#j:D(i,j) = @sqrt(@sqr(X(i) - X(j)) + @sqr(Y(i) - Y(j)))/1000);
@for(TDistance(i,j)|i#ne#j:T(i) + T(j) <= @if(D(i,j)#le#50,1,2)));
@for(NDistance(i,k):F(i,k) = @if(S(i,k)#le#50,50 - S(i,k),0));

!Selecting Khomra township to be existing LH;
T(102) = 1;
@for(TCoordinate:@bin(T));

Algorithm A2. Adjusted Lingo Code for the First Trial

!Adjusting the set of townships to only include the PHARP's townships;
Township/1..368/;
References

20. Elelvi, B. Logistics freight center locations decision by using Fuzzy-PROMETHEE. Transport 2014, 29, 412–418. [CrossRef]


31. Plaza, C.V.; Guimarães, V.d.A.; Ribeiro, G.; Bahiene, L. Economic and environmental location of logistics integration centers: The Brazilian soybean transportation case. *TOP* 2020, 28, 749–771. [CrossRef]


42. She, C.; Pena-Mora, F. Blockchain for cities—A systematic literature review. *IEEE Access* 2018, 6, 76787–76819.


44. Kshetri, N. Blockchain and sustainable supply chain management in developing countries. *Int. J. Inf. Manag.* 2021, 60, 102376. [CrossRef]