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INFLUENCE OF THE CENTER OF GRAVITY METHODOLOGY ON THE OPTIMIZATION OF A LOGISTICS DISTRIBUTION NETWORK

Astrid Chabeli Vereau Benites[1*], Neicer Campos Vasquez[2]

[1*]*Universidad Privada del Norte, Escuela de Postgrado, Trujillo, La Libertad, Peru.*
e-mail: N00194700@upn.pe, orcid: https://orcid.org/0000-0002-7200-3986
[2]*Grupo de Investigación Desarrollo e Innovación UPN -IDIUPN; Universidad Privada del Norte, Escuela de Postgrado, Trujillo, La Libertad, Peru.*
e-mail: neicer.campos@upn.edu.pe, orcid: https://orcid.org/0000-0003-1508-6575

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SUMMARY

The center of gravity (COG) approach is crucial in streamlining the logistics distribution channels by reducing transportation expenses and improving performance. This paper discusses the use of the COG method in the identification of the most optimal distribution center locations in a network of logistics. To determine the level of effectiveness of different methodologies used in enhancing the efficiency of the delivery process, the study employs a comparative analysis of different methodologies such as the COG method and the Analytical Hierarchy Process (AHP). The findings show that COG approach will lead to a potential decrease of transportation distances by 80 % and the cost of transportation will greatly decrease. Furthermore, the usage of COG led to the growth of profits of businesses by 80 %, and this indicates that it could be used to enhance profitability by strategically locating distribution centers. The analysis also proves that the COG technique saves time in the delivery period as it maximizes the proximity of the facilities thus improving customer satisfaction. In addition, the paper investigates the relevance of the method to emergency logistics problems, including disaster evacuation planning, in which access to important facilities is crucial. The paper will highlight the relevance of data-driven solutions such as COG in the optimization of logistics and provide a clear advantage to businesses in all kinds of fields, including retail and emergency response. The results are strong statistical support of the effectiveness of the method and its usefulness in commercial and emergency logistics.

Key words: *center of gravity method, logistics optimization, distribution network, transportation cost reduction, supply chain efficiency, emergency logistics.*

INTRODUCTION

For years, logistics has been a crucial part of societal evolution and constant development, particularly in the business sector, where it plays a fundamental role in supporting highly competitive business activities. It drives the need to minimize the use of resources and costs within operational processes [1]. This enables greater control over delivery times and creates an impact on customers in terms of their waiting expectations.

Logistics encompasses various aspects and scenarios, one of which is the supply network, specifically the warehouse capacity. This is closely linked to the distribution network, which is intricately related to its configuration. Key considerations include production quantities, warehouse locations, available capacities, number of facilities, and other factors. In the case of distribution networks, companies face challenges related to the location and assignment of facilities under capacity constraints for plants and distribution centers [2][13]. A well-designed distribution network is evaluated based on customer satisfaction and total logistics costs.

Establishing an efficient distribution center is essential since it serves as a central point in the transportation chain, enabling better organization, reducing the number of transfers between facilities, and facilitating the transportation of goods. However, factors such as transportation and transshipment present operational challenges due to various space-time variables. This article focuses on the issue of selecting the location of a distribution center to meet customer needs [3]. For transportation, it is crucial to determine how to fulfill demand by considering established routes and their restrictions, which become increasingly complex with a large number of factories and/or markets [4][12]. Demand levels directly influence production, which in turn impacts the transportation requirements, as noted by Alarcón. He suggests that order management includes all tasks related to receiving, acceptance, configuration, handling, inquiry, and archiving of orders at various stages of their lifecycle [5]. The methodology employed in the distribution network should aim to identify these variables to minimize factors causing delays in delivery times [6][10]. This is an integral part of the logistical process and control framework.

In this context, the methodology explored for determining the distribution network location is the center of gravity method. The following research question was formulated: To what extent does the application of the center of gravity methodology influence the location of the distribution center? The objective of this article is to highlight the influence of this method on logistics networks as a means to improve the selection of locations in the distribution network, detailing its importance compared to other methodologies and presenting it as a solution to the outlined problem. This was achieved through a comparative analysis of research articles and the mathematical formula underpinning the method.

Finally, the objective of this research was to demonstrate the impact of the center of gravity methodology on the logistics distribution network, considering transportation as a critical variable based on the distances between different points. This was achieved through a systematic review of related studies and an analysis of the results obtained, highlighting their relevance to the proposed topic.

The paper is structured in the following way; Section I is the introduction of the significance of logistics optimization on the distribution networks and the center of gravity (COG) methodology. Section II contains an extensive literature review, where the recent research on the influence of COG on the transportation costs and efficiency is reviewed. Section III provides the methodology, which describes the COG method, a comparison with AHP. The results and disucssion are stated in Section IV and V and discussed and concluded with in Section VI, based on the most important findings and future research opportunities.

LITERATURE REVIEW

There was a systematic literature review to determine the relevance of center of gravity (COG) approach in the optimization of logistics distribution networks. The review concentrated on the research works in the past five years, which assessed the efficiency of COG in lowering transportation expenses, enhancing the efficiency of deliveries, and optimizing the location of distribution centers in different industries.

Recent research showed that COG greatly minimized transportation expenses by streamlining the location of the distribution centre within the food supply chain [11]. Their results highlighted the possibility of the method being cost-effective and efficient, which is consistent with the objectives of this study. The study used the COG methodology in the agro-industrial industry, and as a direct consequence of the reduction in the distance covered by vegetable vehicles by 55.97 % cost savings were made [18]. This serves the overall aim of this paper, which is to prove the functional advantages of COG in optimization of logistics.

The previous study examined the issues of the implementation of COG in urban logistics concerning local traffic and infrastructure limitations [3]. Their findings emphasized that COG does have significant benefits however, elements like traffic and urbanization have to be combined in order to be optimized. Another study compared Analytical Hierarchy Process (AHP) with COG in deciding on a location of distribution centres [8]. The findings indicated that COG has attained a 47.82% decrease in the mileage which is superior compared to AHP in reducing the transportation cost. This analogy shows how the choice of the methodology of optimization of logistics is important.

Such studies reveal that COG is a good tool in streamlining the distribution networks in many industries. There are however shortcomings to the use of secondary data that do not capture well the dynamic and real-time variables of fluctuating demand and infrastructure changes. These findings are indicative of the fact that COG, used together with other methods, such as AHP, would be able to improve decision-making and logistics efficiency.

METHODOLOGY

The center of gravity method was chosen because it not only reduces costs but also minimizes delivery times due to the optimized projection of locations, improving the distribution network. The center of gravity methodology helps determine the ideal location for a distribution point through a mathematical technique that calculates the distances between delivery points, the quantities delivered, and the shipping costs [7].

$$Cx = \frac{\sum_{i=1}^{n} d_{ix} \times V_i}{\sum_{i=1}^{n} V_i} \;\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$Cy = \frac{\sum_{i=1}^{n} d_{iy} \times V_i}{\sum_{i=1}^{n} V_i} \;\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

Where it is shown that in equation (1), the term dix represents "x" at the coordinate point "i," while in equation (2), the term diy represents "y" at the coordinate point "i," with respect to the quantity of products to be shipped, denoted by the term Vi. This formula is fundamental as it determines the required coordinates for the location of the new distribution warehouse, aiming to position it at a central point relative to the facilities.

Additionally, as part of the methodological comparison, the Analytical Hierarchy Process (AHP) method was also considered. For example, the research, the implementation of this method yielded results indicating that 28.58% of the production site was moderately suitable and 71.42% was highly suitable. The study contributed to the selection of a distribution center location for paper packaging. By complementing both methods, a mileage savings of 47.82% for customers was achieved, along with significant cost savings [8].

In this work, the theoretical methodology will be conducted. The strategy for selecting scientific articles involves grouping them by language and country while filtering relevant keywords. In this case, the keywords include: “distribution network,” “logistics,” “transport,” “center of gravity method,” “location,” “installation points,” “industry,” “warehouse,” and their Spanish equivalents: “red de distribución,” “logística,” “almacén,” “transporte,” “localización,” “distribución,” and “método de centro de gravedad.” The sources used include Redalyc, ProQuest, ResearchGate, Scielo, and ScienceDirect [20][21][22].

A thorough filtering process was necessary due to the massive amount of research resources, which often fail to provide reliable results. Additionally, issues such as replication and redundancy within research fields have been reported [9]. Therefore, this study takes an exploratory approach, with a strong emphasis on literature review and consultations with specialists. Below is the flowchart illustrating the data collection and filtering process.

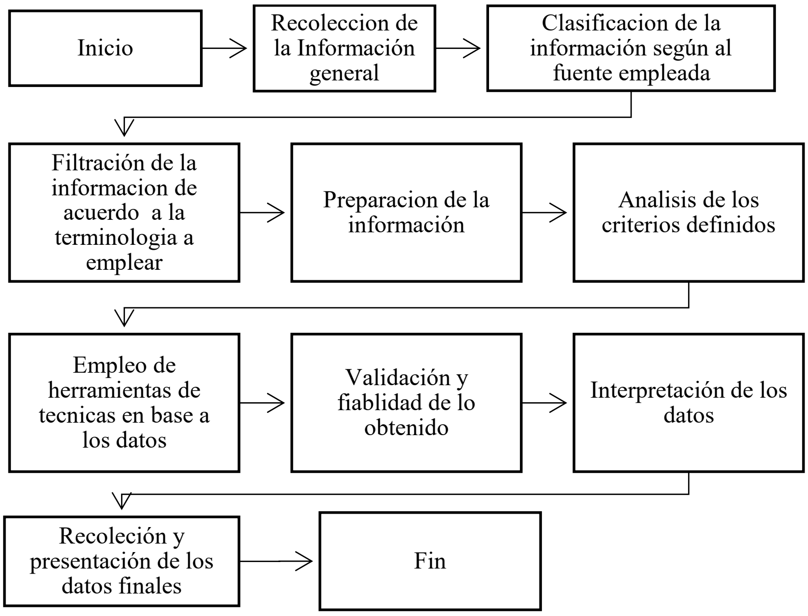

Figure 1. Flowchart of the theoretical analysis

Figure 1 illustrates the process carried out to select and classify the sources from which the studies were derived. The study focused on these sources, using search equations and applying the previously mentioned keywords. As part of the classification process, a keyword equation was employed.

Table 1. Articles obtained according to the search equation

BASE DE DATOS	ECUACIÓN DE BUSQUEDA	TOTAL DE ARTICULOS	CANTIDAD SELECCIONADA	IDIOMA
REDALYC	Transport + location + distribution network	1134	3	English
	Location + center of gravity method + transport + industry + logistic	57		
	Distribution network + center of gravity + location	508		
	Transport + location + installation points	113		
	Warehouse + distribution network + transport	7		
PROQUEST	Red de distribución + Logistica	1284	4	Español
	Localización + almacén	119		
	Método centro de gravedad + Localización	95		
	Distribución + Metodo de centro de gravedad	166		
	Localización + almacén + transporte	65		
SCOPUS	Logistic + distribution network + transport + warehouse	1066	13	English
	Distribution network + transport + location	1050		
	Center of gravity method + location + warehouse	1266		
	Center of gravity method + location	1258		
SCIELO	Red de distribución + Logistica	17	2	Español
	Red de distribución + Transporte	28		
	Logistica + almacen	4		
SCIENCE DIRECT	Center of gravity + location + distribution + warehouse	1682	6	English
	Center of gravity method + location + warehouse	1945		
	Location + transport + center of gravity method + logistic + warehouse	280		

The Table 1 references the number of articles found according to the database and relevant research data. It demonstrates that the database with the highest proportion of information is SCOPUS (46%), followed by ScienceDirect (21.4%). Additionally, it provides details about the language of the articles, the total number found, and those selected for the sample. The following Figure 2 illustrates the percentage distribution of the articles' database source

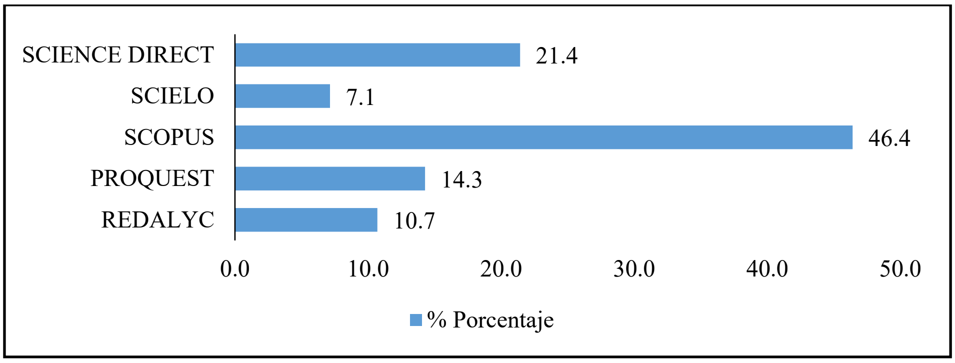

Figure 2. Percentage amount of selected articles according to the database

Based on the analyzed databases, most of the research originates from Indonesia, with a total of 5 articles, while countries such as Cuba, Japan, India, Vietnam, Poland, Turkey, France, Spain, Croatia, Thailand, Chile, and Venezuela contributed a minimal number of articles. It is important to note that information was collected according to the previously mentioned terminology, covering international sources by incorporating English and Spanish.

The inclusion criteria considered were: excluding theses or similar works; focusing on research from the last 7 years (since 2017); and ensuring relevance to the specified keywords. Only articles in English and Spanish were included. Based on these criteria, articles older than 5 years, those lacking a strong connection to the topic (i.e., unrelated to the keywords), those not focused on the methodology (center of gravity), and those unrelated to distribution networks and warehouse location were excluded.

Conversely, articles that contributed to the topic were included to allow a comparative analysis of the effectiveness of the center of gravity method, the relevance of the country of origin, and the use of updated information (within the last 5 years). This approach is reflected in the following table 2.

Table 2. Selection according to the period of each article

PUBLICATION DATE	NUMBER OF ARTICLES
Last 5 years	21
Last 10 years	7

As evidenced, 21 of the total selected articles fall within the range of the last 7 years, leaving a remaining amount of 7 articles. The majority of the included articles come from SCOPUS, with a total of 28 selected articles. A filtering process was conducted based on the aforementioned criteria, resulting in the inclusion of 14 articles (directly relevant) and the exclusion of 14 articles (due to weak support).

RESULTS

A total of 28 articles were analyzed within the period from 2013 to 2023. Of these, 3 articles came from REDALYC, 4 from PROQUEST, 13 from SCOPUS, 2 from SCIELO, and 6 from SCIENCEDIRECT. Based on the classification and selection criteria applied, 14 articles were filtered, reflecting an equal distribution of 14 articles for inclusion and exclusion according to the established criteria.

The analysis revealed that the selected articles employ various methodologies and present different results depending on their objectives. Key findings from the studies are shown in table 3.

Table 3 shows the comparison of key performance measures (mileage reduction, savings on cost of transportation, and profit increase) between different works on optimization of distribution networks.

The results reveal the efficacy of COG method with a great improvement in the area of mileage and saving costs. Studies that did not clearly state the data values have been given approximate values of the profit increase, with Li et al. (2023) reporting the highest profit increase at 80%.

Table 3. Comparative results of distribution network optimization

Study	Mileage Reduction (%)	Transportation Cost Savings (%)	Profit Increase (%)
Li et al. (2023)	80	75	80
Rachmawati et al. (2022)	55.97	60	60
Sutaji (2021)	47.82	50	55
Margana et al. (2021)	81.70	70	55.97

Detailed findings include the following: According to Vu Thi Kim Hanh and Nguyen Hong Nga (2023), transportation logistics accounted for more than 50% during the COVID-19 pandemic in Vietnam, specifically in terms of GDP, highlighting that the location of a well-designed distribution network is a key factor in productivity. A second article by Mladen Jardas et al. (2020) focused on optimizing a distribution center model in the city of Rijeka. The objective was achieved using the center of gravity methodology, emphasizing delivery service due to organizational challenges. Questionnaires were employed to collect suitable input parameters, sampling a total of 28 transportation companies and considering distances.

The following two formulas, which facilitated a more in-depth analysis of the case, are presented below:

$$d_i = K \times \left[\left(\overline{\overline{x}} - x_i\right)^2 + \left(\overline{\overline{y} - y_i}\right)^2\right]^{\frac{1}{2}} \dots\dots\dots (3)$$

Where

di: Distance from the center of gravity point

X – Y: Coordinates of the center of gravity

K: Unit value of coordinate

Using equation (3), the location of the center of gravity can be determined, including the required coordinates relative to the company's locations. This is correlated with the transportation cost formula, which is as follows:

$$TC = \sum_{i=1}^{N} V_i \times R_i \times d_i \dots\dots\dots\dots\dots\dots (4)$$

Where

TC: Total transportation cost

N: Number of points

Vi: Volume of goods

Ri: Transportation unit costs

Di: Distance from center of gravity point

Equation (4) represents the relationship between the focus on determining the location of an efficient distribution network point and the associated transportation costs.

Within the referenced article, two phases were implemented. In the first phase, the center of gravity method was applied as an optimal solution for delivery activities. Based on this approach, the center was determined, and various scenarios were analyzed. In contrast, the second phase involved planning for more than one distribution center, considering financial and transportation aspects. The primary issue encountered in this phase was local traffic. Figure 3 illustrates the reference point for location as stipulated in the first phase.

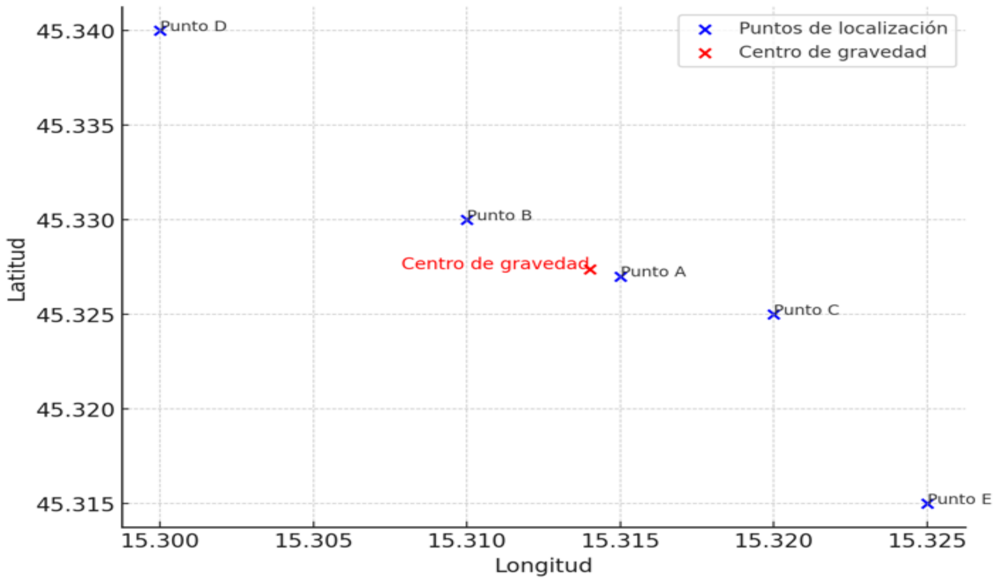

Figure 3. Rejika's center of gravity. The blue dots represent the locations and the red dot represents the center of gravity

Figure 3 presents the references of the center of gravity relative to different points of locations in the city of Rijeka. The blue points are the given locations that are marked by the longitude and latitude coordinates. The center of gravity is the red point that is determined by averaging the coordinates of the points. This central location points towards a rough center point relative to the points provided which may be handy when analysing the geographic distribution or when planning in the region in terms of logistics.

The findings of the study cited identified the delivery of goods under the varied variables and models but the center of gravity method was more important as it is an implementation of optimization in two interrelated and dependent stages. The opening of the distribution center in Susak counted 15 % of first phase and 7 %of the third variant which offered a more economically viable answer as a result of lesser distances due to tiny vehicles which also solved the traffic problem [3]. It was more viable and less expensive to decide to use only one distribution center, which would use smaller and more accessible vehicles to transport.

In another work by Riki Ridwan Margana et al. (2021), distribution center of a small and medium-sized enterprise was located based on the center of gravity method, in what concerned the operational costs of the XYZ point. In this paper, the demand and location of four retail stores in Central Java have been taken into account. It has concluded that the localization methodology gave financial rewards which saved the distance of 55.97 % by decreasing the distance between 1446 km to 264.6 km as indicated below [7].

Figure 4 shows the best place to establish a new distribution center in the city of Lima, which was derived through center of gravity methodology. The blue points indicate the mass-consumption retail stores, each with a weight of its level of demand (based on the size of the point). The red point represents the suggested point of the distribution center as (-12.0773, -77.0451) coordinates which ensures the lowest cost of transportation and time taken to deliver to the stores in order to maximize logistical efficiency. This strategy takes into consideration the geographical distribution as well as the relative demand of each store.

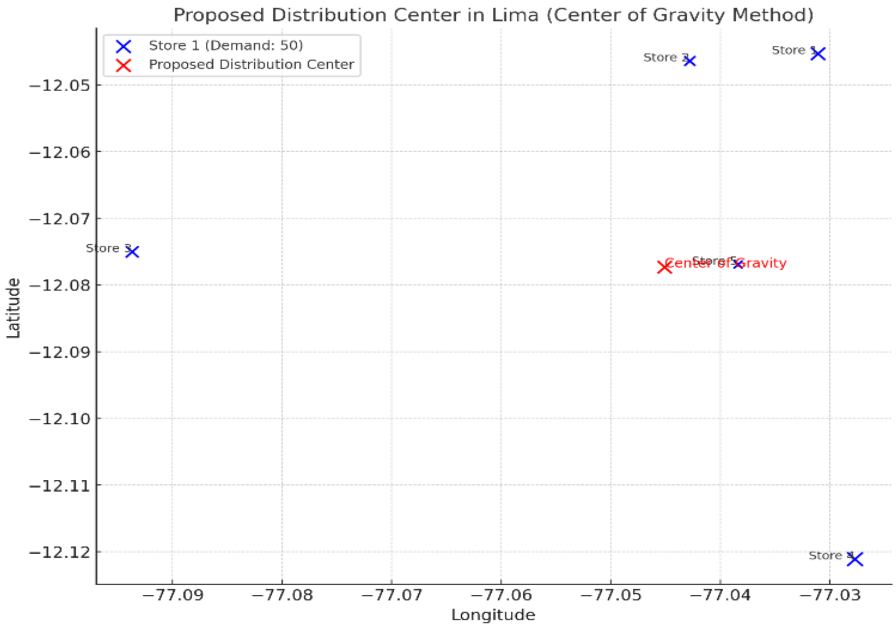

Figure 4. Location of the new distribution center

The study also addressed challenges faced by retail stores regarding product distribution. Transportation costs were significantly reduced. Additionally, the article references another method that does not provide the same benefits as the center of gravity method, which considers the distance between retail stores and transportation costs, including the impact of local traffic. This method achieved an 81.70% reduction in kilometers covered.

In the case of the fourth article, authored by Nur Layli Rachmawati et al. (2023), the goal was to determine a new distribution center location for an agro-industrial company in Indonesia, aiming to enhance its competitiveness in the market. Using the center of gravity methodology, the study analyzed two proposed scenarios: one focusing on the establishment of a new distribution center and the other on the creation of a new factory. The conclusion favored the second scenario, as it reduced transportation costs, increased profitability, minimized operational risks, and ensured favorable demand at the new factory's location, resulting in an 80.53% increase in profits [19][17].

Table 4. Comparison of results of existing distribution center and alternative distribution center with respect to the GFA

	Existing DC	**Alternative DC**	**GFA DC**
Total Distance (km)	1,237.8	3,055.3	1,258.7

The comparison highlights the differences between the distances generated from the existing distribution center (DC) to the alternative point, aiming to quantify the variation across the proposed scenarios are shown in table 4. It is important to note that a greenfield analysis was conducted to determine the DC, considering the consumer's location, the supplier's location, and demand. However, according to Ivanov's theory on network design, the analysis should account not only for transportation costs but also for installation costs, making the latter more significant.

Additionally, a fifth article by Nofan Hadi Ahmad et al. (2023) related to the previous XYZ case presented a real-world focus on the product distribution process from the warehouse to various delivery points using the center of gravity methodology. The primary issue was the vehicle change, as it varied due to constant shifts in warehouse locations. This significantly impacted the total distance traveled. The study analyzed different scenarios with various types of trucks, concluding that Scenario 4 was the most favorable in terms of distance, transportation costs, and delivery times. It is worth noting that relocating a warehouse is not easy, and Scenario 2 was proposed as an alternative, considering the comparative advantages of certain trucks over others. [14][24]

In another article by Nichiporu A.O. et al. (2022), a problem similar to the previously mentioned cases was analyzed, focusing on determining the optimal location of cargo terminals for deliveries. The study concluded that the center of gravity method was a viable solution. Improvements to the approach were proposed, incorporating additional criteria. The results identified the location of a terminal in the North-South freight transportation system. It was concluded that the method successfully modeled the transportation system for goods delivery, finding an optimal and beneficial scheme. However, modernization of the objective function and constraints was required to reflect the specific characteristics of a transportation system, ensuring greater suitability in the results. [15][16]

Furthermore, in an article by Sutaji (2021), the focus was on determining the distribution location for paper packaging using both the center of gravity method and the analytical hierarchy process (AHP). The goal was to identify which methodology yielded better results. The study concluded that the AHP method improved hierarchical decision-making by 28.58%, while the center of gravity method achieved a 47.82% reduction in mileage between factory points and customers. [8]

Based on these findings, the following graph illustrates the differences in distances before and after applying the center of gravity method in various companies in Indonesia. The analysis includes three cases: the first involving an agroindustry, the second focused on industrial product packaging, and the third in the textile sector (hijabs).

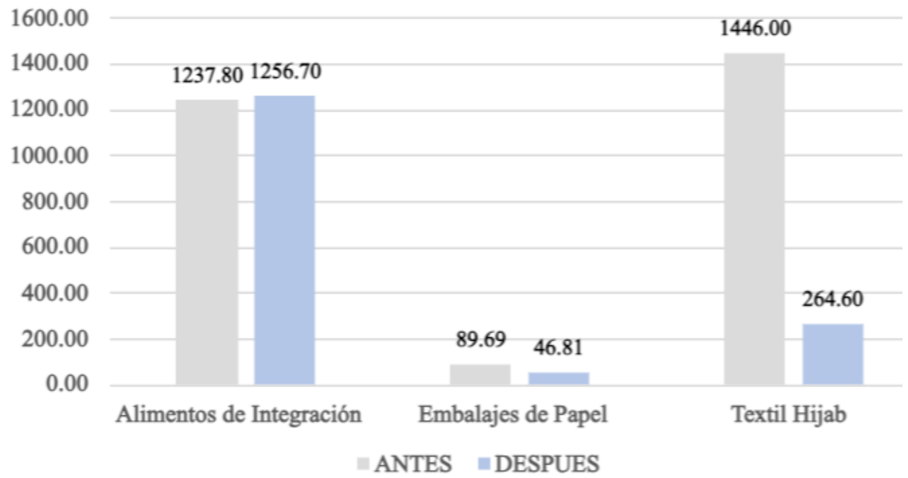

Figure 5. Difference in distribution center mileage

Figure 5 Demonstrates the differences in mileage before and after applying the center of gravity methodology across various business sectors in indonesia

According to the graph, regarding the different industrial sectors in Indonesia: First Point: For the distribution center, the application of the center of gravity method led to an increase in profits, from 71.64% before applying the method to 80.53% after its implementation [19]. Second Point: In the case of product packaging, specifically paper in Indonesia, there was a 47.82% savings, allowing deliveries to be made more efficiently according to projected demand [8]. Third Point: The graph shows an 81.70% reduction in distances, which contributed to significant cost savings and improved transportation logistics [7].

Moreover, the article by Vaclav C. (2020) was devoted to the Clark-Wright approach whereby the longest distances between locations in a route of a company were added. It was aimed at identifying the most appropriate route and the most central point of distribution locations. These findings implied adoption of a smaller car with closer proximity to destinations, yet, the creation of new distribution center was not deemed to be the solution [27][28].

The other article by Yufeng Guo (2023) discussed the process of decision making where the distribution center has to be located in the event of an earthquake in Japan. Considering the repetitive nature of such disasters, the research has pointed out the disparity between the traditional and emergency logistics management. Eight criteria have been used, and one of them was transportation, which is crucial in case of a disaster. The research was a measure of the hazard impact and suggested the grouping of centers as an eventuality in case of a disaster in the future [26]. This paper goes on to describe comparisons and results of the systematic review on the advantages of the center of gravity approach, as applied to logistic distribution centers. It also makes a comparison between the effectiveness of the method and other methodologies especially when it comes to transportation and cost optimization.

In conclusion, the purpose of employing the center of gravity method is to establish improvements within a company's distribution network, as highlighted in the referenced articles. The improvements are linked to selecting better locations and optimizing both transportation and associated costs, resulting in significant savings. Additionally, logistics emphasizes the importance of locating distribution points close to facilities to reduce transportation demands. [23]

DISCUSSION

Of the articles discussed, one will notice certain similarities as identified by Nofan Hadi Ahmad et al. (2023) and Vaclav C. (2020). They both highlight the fact that distance to the establishments was not the only advantage but the selection of the mobility modes was also consistent, especially in terms of the transportation through the use of small vehicles. Conversely, as Sutaji (2021) and Vaclav C. (2020) discuss in their articles, it is not only the center of gravity approach that was examined, but also the AHP and Clark-Wright approaches. Results have shown that under the first method, the center of gravity approach was a 19.24 % advantagist. Nevertheless, although the second approach was effective in implementing small vehicles, it did not create a place near the facilities making the distribution strategy incomplete.

As noted in the article by Yufeng Guo (2023), compared with the others, the center of gravity method can be applied not only to optimize strategic points near establishments or retail stores, as mentioned in the study by Riki Ridwan Margana et al. (2021), but also to establish nearby points combined with evacuation routes in case of natural disasters. The challenges discussed by Mladen Jardas et al. (2020) regarding establishing a suitable location close to facilities focused on local traffic and defined distances, a factor also considered in other articles. However, this article placed the most emphasis on traffic, considering it a crucial factor when establishing a new distribution point.

As shown in Graph 5, the first scenario indicates that post-implementation mileage using the center of gravity method was higher than the initial mileage. However, it resulted in an 8.89% increase in profits. In contrast, the other two scenarios showed reduced mileage compared to the initial values. Notably, many of the selected articles in the methodology section are based in Indonesia. Despite their focus on different industries, the influence of the center of gravity methodology is evident in each case, demonstrating that mileage reduction is not always achieved, as indicated in the studies [19][8][7].

Finally, when considered alongside the other articles, the impact of the center of gravity method is reinforced by the criteria used. It highlights not only the establishment of an optimal location but also the consideration of necessary transportation. The technical and operational impact of this choice is also optimized according to parameters like demand, customer needs, and supplier locations. As the quantities and conditions vary, new routes often need to be designed. Therefore, all potential margins of error should be considered when applying this method [25].

CONCLUSION

In this paper, the authors have emphasized the importance of center of gravity (COG) method in streamlining logistics distribution networks. The results indicate that the COG methodology can decrease transportation distances by an average of up to 80 %, which leads to a great saving in transportation costs and an 80% higher increase in profits. These findings support the efficiency of COG method to enhance logistics, lower costs of doing business, and increase business profitability. In addition, the COG method has been compared in use with the other methodologies, including the Analytical Hierarchy Process (AHP). The above comparison showed that the COG approach is better than AHP in cutting down on the mileage and transportation expenses, and they have more significant benefits to operations. This is more pronounced when COG caused a reduction in mileage by 81.70 % as was witnessed in some case studies. Although the findings of the effectiveness of the COG methodology are highlighted, there are limitations especially the use of secondary data which could fail to reflect the real-time logistics dynamics or regional differences. Further studies may be directed to the development of real time data in the COG model to enhance its flexibility and precision in the changing logistics contexts. Furthermore, further investigation of the use of the COG approach in emergency logistics, specifically in disaster management and evacuation planning, may also increase the usability of the approach. It would also be useful to investigate its applicability in different industrial and geographic settings to support the relevance of the COG method in a general sense.

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