Acta logistica - International Scientific Journal about Logistics
Volume: 12 2025 Issue: 3 Pages: 443-454 ISSN 1339-5629



*https://doi.org/10.22306/al.v12i3.598* *Received: 23 July 2024; Revised: 28 Aug. 2025; Accepted: 22 Sep. 2025*

# Optimization of the current logistics network with a focus on a specific company in the state of Nuevo Leon, Mexico

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***Keywords:*** logistics network, consolidation, warehouse location problem (WLP), optimization, forecast.
***Abstract:*** One of the key strategic decisions to make as an enterprise is the optimization of the current logistics network. The main parameters to be considered are the location and amount of storage facilities, as well as cost, the availability and proper function of existing infrastructure and targeted market expansion milestones. The scope of this paper deals with a construction Company in the state of Nuevo León, Mexico. Nearshoring has been one of the main driving factors of increased population growth in the region. Urban expansion is becoming increasingly complex and decentralized, complicating the flow of materials in material distribution networks. Each allotment is presently developed with a warehouse, which in turn requires an investment in infrastructure, overhead, security and management. This paper aims to establish an optimized supply network through consolidated storage facilities without compromising the reliability of the existing routes. The chosen modelling method is optimization through mixed-integer programming. The main object of study in this paper is the comparison between the existing cost structure and the projected costs that would result from consolidating storage facilities and transportation. The results of the analysis are presented, having executed a successful application of the model, and display a 20.9% decrease in cost associated to operating the logistics in a ten-year forecast for a construction Company.

## 1 Introduction

Enterprises today have multiple challenges to overcome in the field of logistics. Many aspects of this problem have been successfully understood; transportation, flow materials, inventory and warehouse analysis, through the implementation of digital techniques for collecting and interpreting data that streamline the decision-making process. Logistics poses an interesting challenge in the field of construction, with specific issues that must be resolved. Housing development is a steady state process with increasing complexity and a decentralized nature, which is one of the reasons why consolidating warehouse locations and means of transportation is not usually considered. Having a warehouse that's dedicated to each individual work site allows for the timely delivery of construction materials.

Positioning is important for enterprises in Nuevo León as it perceives approximately 72% of the nearshoring that occurs in Mexico. The automotive and electronics industries concentrate 43% of their presence in Northeastern Mexico. These conditions will create an increasing need for housing in strategic zones, intensifying the rate of urban development in the area.

Recent events like the COVID-19 Pandemic and the onset of Nearshoring have triggered a series of strategic logistic countermeasures in Nuevo León. This paper aims to ascertain the viability of a consolidation scheme for warehouse locations through a new design of the existing distributions network in such a way that costs, reliance on inventory and warehouse locations is reduces and operating flexibility is increased.

Picking a location and storage capacity for a warehouse is an exercise that requires looking at many different factors, location, average traffic/transit times, shipping loads, availability of transportation and overhead are good examples. A poor choice in warehouse location and/or capacity can very well be the cause for additional expenses and delays in the operating schedule.

The problem at hand deals with choosing a correct logistic structure that allows for an uninterrupted transition in the operating schedule while reducing storage overhead. This process is navigated through the use of cutting-edge techniques that aim to create insight for decision makers in the effort of continued expansion. Some of the key aspects of this analysis involve forecasting capacities that aim to determine the optimum location for development, with additional analysis dedicated towards acquisition processes.

The desire for a predictive model with increased accuracy is natural and to be expected. Making correct forecasts regarding promising locations and increasing logistic viability are at the forefront of the main objectives in this endeavour. Consolidation of the existing warehouse structure should agree with an overall reduction in operating expenses, increased security measures and custom-made protocols for prefabricated materials. These considerations have an important consequence in storage facility design; warehouse performance must be increased through a streamlined floor plan that allows for on-schedule operation and correct planning for inventory capacity, personnel and delivery vehicles.

This paper reviews a real-world case for the WLP (Warehouse Location Problem). The Optimization model is based on Khairuddin's 2017 paper and showcases a construction Company primarily occupied with residential development in the metropolitan area of Nuevo León, Mexico. The work that follows is structured as indicated; A literature review of the sources cited is conducted, the optimization model is explained in detail, a solution and the subsequent analysis is presented before coming to some general concluding remarks.

## 2 Literature review

The problem of finding the correct storage capacity and location for warehouses so that costs are optimized without compromising service-rates and fulfilment of orders headed towards different destinations plays a crucial role in determining the profitability of a logistics system. (Weber, 1909) Alfred Weber pioneered the solution to the WLP through a model that allows the user to locate a point in a two-dimensional coordinate system that minimizes the sum of costs towards delivery destinations [1].

Aided by Weber's contributions, Hakimi (1960) formulated extensions of the simpler problems and developed the p-median algorithm, allowing a user to locate the ideal location for a warehouse as a function of distinct delivery points, usually cities or customers, through an objective function that minimizes commute times, distances and cost of transportation [2].

The Simple Plant Location Problem was defined in tasks, Straka (2019), Galli and Letchford (2021) and is based on a system that takes customer location, provider location and miscellaneous points of interest as inputs. The model aims to minimize the transportation costs between nodes along the logistics network, as well as the cost related to construction. Another feature in the model is that it allows for the opening of an additional location, in the event that such a solution achieves a minimization of the parameters described earlier in this paragraph. This model is based on linear programming and has benchmarked progress in many models that are currently in use today [3,4].

The Capacitated Warehouse Location Problem (UWLP) was developed by Khumawala in 1972 and uses combinatorial algorithms, which makes it a robust tool in the WLP and also popular in unrelated fields such as genetic algorithms [5].

Wang (2013) proposed the Two Stace Capacitated Warehouse Location Problem, which further classifies storage facilities as either primary or secondary. Like other methods here described, its primary task is that of minimizing distribution and delivery costs [6].

Hansen (1994) builds on the work of Perl and Daskin (1985) and introduces the restrictions of variable and fixed costs, as well as transportation cost, in the optimization algorithm [7].

Hidaka and Okano (1997) solved the UWLP for cases where the model is allowed to exhibit divergent behaviour in a specific parameter (storage capacity in this particular case) [8].

In 2001, Kratika proposed a solution to the SPLP through the methodology of genetic algorithms. His model allows the user to solve for systems where up to 1000 customer locations/delivery points are used. By 2004 (Laurent Michel) had developed a solution to the UWLP that incorporated a tabu-search algorithm in the optimization protocol. Efforts to increase the solving capacity of these methods continued with Bhatti (2007) and others, with an implementation of the method that allows for decision makers to input large numbers as parameters through integer-binary programming and a heuristic algorithm [9-12].

El Karim (2020) developed methods for incorporating GIS' (Geographical Information Systems) into the data collection capacities of the algorithm. They further increased the accuracy with which decision-makers can obtain insights into logistics and operation and represented increased progress in the objective of optimizing operating and distribution costs [13].

Given the complex, multi-faceted nature of the quantitative and qualitative analysis of warehouse location, Choquet's Integral has been chosen as a mathematical tool fit for the task of an accurate model that incorporates uncertainty and error. Demirel (2010) uses this method and determines that the main criteria are costs, characteristics of the workforce, infrastructure and the state of the market. Some secondary criteria also mentioned are fiscal incentives, tax structures, access to workforce personnel and the quality and availability of transport [14].

Khairuddin (2017) proposed a simulated annealing process that solves the WLP through a mixed-integer programming solution. The main contribution of this analysis is introducing a restriction that accurately models storage capacity for each warehouse [15].

Adasme (2018) further classified the existence of restrictions to the problem based on topological figures such as the ring, tree and star. Novel methods in mixed-integer programming and the P-Median problem are also discussed [16].

A comparative method that uses K-Median algorithms and mixed-integer linear programming optimization was published by Meng You (2019) further advancing the capacity of WLP models to incorporate large datasets as inputs. MILP was shown to be more accurate than K-Median based algorithms through a series of partial dynamic optimizations [17].

Doungpan (2020) used the MILP approach to shed light on the Location Setcovering Problem (LSCP), providing solutions that detail storage facility arrays as a function of growing demand in a complex environment [18].

Yachba, Belayachi and Bouamrane (2022) uses an artificial beehive (ABC) method to optimize the locations for distribution centres that supply customers with a given product. The method is named after observed behaviour of bees as a communal structure [19].

Haoxiang, Yangcheng and Zhenyi (2024) proposed a linear programming model based on the simulated annealing algorithm to address cargo volume allocation following the closure of logistics sites. Additionally, a logistics network optimization model was developed using the particle swarm optimization algorithm to dynamically adjust the structure of the logistics network [20].

Rahman et al. (2025) employed a hybrid approach to optimize the location of logistics centres, sequentially applying different techniques. The process began with a clustering method using K-Means based on spatial locations, followed by the application of the P-Median method to determine the final placement of the centres of interest. This latter method also incorporates factors such as the number of deliveries and population density as weighting criteria [21].

# 3 Methodology

This analysis is broken up into three phases: Acquiring and processing raw datasets detailing the recent trends in urban development and population growth from INEGI, so that a forecast can be made as to which areas can show the most promise for future development. Secondly, the processed data is used to conduct a MILP analysis and determine locations and capacities for storage facilities. Lastly our solution and proposed logistics network is compared to the existing network, with commentary and general conclusions.

## *3.1 Forecast method*

Estimating a rate for the expansion of housing can be obtained through the analysis of multiple factors that are readily available from INEGI datasets. Information related to industrial development and population per locality is procured and a forecast is then obtained through regression models, which can then be compared to historical datasets to check for accuracy.

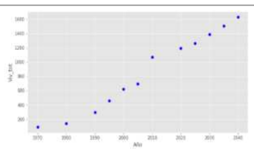
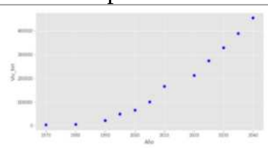
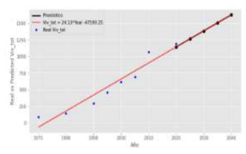
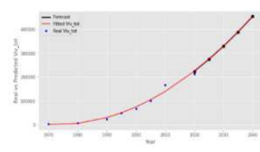
| Locality | Linear Regression | Polynomial Regression |
|---|---|---|
| | Abasolo | Apodaca |
| Scatter Plot |  |  |
| Forecast for number of housing units every five years |  |  |
| Model Accuracy | R2 = 0.9739829908390727<br>MAPE = 24.50100234190121<br>RMSE = 84.1743496863782 | R2 = 0.9962462795737199<br>MAPE = 14.11309226558786<br>RMSE = 9246.449698696257 |

*Figure 1 Forecast for increasing trend in housing for the localities of Abasolo and Apodaca through linear and polynomial regression, years 2020, 2025, 2030, 2035 and 2040*

Figure 1 displays results for the forecasting method. The accuracy for the regression model is also displayed for two localities, allowing for a rigorous treatment of data.

The model allows decision makers to understand how the rate of increase for housing units has behaved for different localities according to its main driving factors like Nearshoring. Figure 2 displays scatter plots for the increment in housing units in the last 50 years for each locality.

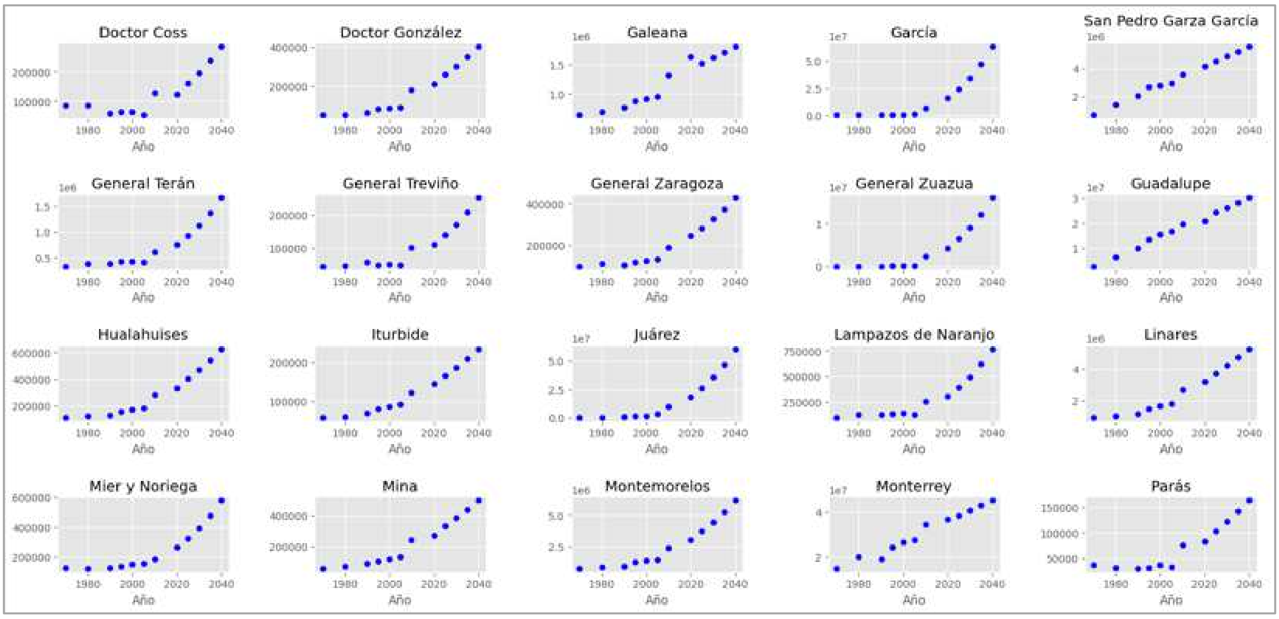



*Figure 2 Scatter plots for growth in housing units per locality in the State of Nuevo Leon, 1970-2040*

### *3.2 Location model*

Once the viability of future locations is ascertained, raw data can be input into a model to display how the logistic structure in the distributions network will be affected by parameters such as geographical location, amount of housing units, the typology and models for each project.

***Glossary and notation:***

*k: denotes the **kth** customer; k = {1,2,3,...,K}*
*i: denotes the **ith** warehouse and/or potential location for a warehouse;* $i \in A$
$A = E \cup N; (j,i) \in (E \times A)$ *where:*

- *E = set of existing warehouses in each locality*
- *N = set of locations for future developments under the consolidation scheme*

***Model Parameters:***

$S_{ik}$ *: Unitary cost for storage in the **ith** warehouse and transportation between the ith warehouse and the **kth** client*
$r_{ji}$ *: Cost of relocating unitary storage capacity **j** to consolidated storage facility **i*** $(j \neq i)$
$c_j$ *: Storage capacity of **jth** existing warehouse*
$d_k$ *: Demand associated to **kth** customer*
$f_i^c$ *: Cost per storage capacity unit of the **ith** warehouse*
$f_i^m$*: Fixed overhead cost related to the **ith** warehouse, excludes costs related to storage capacity*
$f_i^s$ *: Cost reduction associated to the shutdown of the **ith** warehouse*

***Main Variables (Decision Variables):***

$X_{ik}$ *: Volume of shipped materiel from the **ith** warehouse to the **kth** customer*

$$Z_{ji} = \begin{cases} 1, & \text{If the } jth \text{ storage capacity } (j \in E) \text{ is relocated to the ith site } (i \in A,\ i \neq j) \text{, or if the } jth \text{ existing warehouse } (i \in E)\ i = j) \text{ remains operational} \\ 0, & \text{Otherwise} \end{cases}$$

**Target Function:**

$$Min \sum_{i \in A} \sum_{k \in C(i)} S_{ik} X_{ik} + \sum_{i \in A} r_{ji} Z_{ji} + \sum_{i \in A} f_i^c + \sum_{j \in A} C_j Z_{ji} + \sum_{i \in E} f_i^m Z_{ii} + \sum_{i \in N} f_i^m W_i - \sum_{j \in E} \left[ f_j^s \left( 1 - \sum_{i \in A} Z_{jk} \right) + f_i^m \sum_{\{i \in E, i \neq j\}} Z_{ji} \right] \quad (1)$$

**Constrains:**

$$\sum_{k \in C(i)} X_{ik} \leq \sum_{j \in E} C_j X_{ji} \qquad \forall\, i \in A \quad (2)$$

$$\sum_{i \in D(k)} \boldsymbol{X_{ik}} = d_k \qquad \forall\, k \in K \qquad (3)$$

$$\sum_{j \in E} Z_{ji} \leq |E|\, Z_{ii} \qquad \forall\, i \in E \qquad (4)$$

$$\sum_{j \in E} Z_{ji} \leq |E|\, W_i \qquad \forall\, i \in N \qquad (5)$$

$$\sum_{i \in A} Z_{ji} \leq 1 \qquad \forall\, j \in E \qquad (6)$$

$$X_{ik} \geq 0 \qquad \forall\, i \in A, k \in K \qquad (7)$$

$$Z_{ji,} W_i \in \{0,1\} \qquad \forall\, j \in E, i \in A \qquad (8)$$

The target function (1) minimizes the combined costs of transportation, relocation and storage, maximizing the amount of savings associated to the closing or consolidation of existing warehouses. Restriction (2) ensures that shipping capacity won't exceed the maximum storage capacity of the warehouse or consolidated storage location servicing a particular order. Restriction (3) satisfies demand according to progress at specific job sites. Restriction (4) states that upon the consolidation of two or more warehouses, at least one must remain operational so that the combined storage capacity can be considered. Restriction (5) states that the current storage capacity of a particular location can't be transported elsewhere without the prior construction of a new warehouse. Restriction (6) considers several scenarios for an existing warehouse j, these include: warehouse j remains open, warehouse j will be consolidated into another existing warehouse, warehouse j's storage capacity will be relocated to a new site or warehouse j is closed. Restriction (7) is a condition of non-negativity for the variables of interest and Restriction (8) forces them to take values of 1's and 0's.

## 4 Scope of analysis

The scope of this paper focuses on the improvement of the existing structure for a logistics network belonging to an Enterprise in the residential construction business through the implementation of consolidated storage facilities that can service materiel according to progress and availability of a predetermined expansion scheme. This particular case study happens in the metropolitan area of Monterrey, located in the state of Nuevo Leon, Mexico (Figure 3).

The state is made up of 51 localities and covers a superficial area of 64,156.2 square kilometres (about 3.3% of the surface area for Mexico). Population density is 90.2 inhabitants per square kilometre, there are 1,655,256 inhabited dwelling units (4.7% of the gross national total). Each dwelling unit has an average occupation of 3.5 occupants and 99% of them are equipped with basic sanitation facilities and access to power (INEGI, 2020).

According to INEGI datasets, as of 2020, Nuevo Leon is ranked 7th in a national consensus of gross population. From 2000 to 2020, population has increased by 50.8% with a 13.1% rate between 2015 and 2020. Nuevo Leon's current population is 5,784,442, with an annual growth of 133,000 inhabitants expected. Considering these circumstances, the growth can be identified as exponential and it's subsequent impact has been a driving factor for increasing demand for residential housing units, public services, roadways and transportation (INEGI, 2020).

### *4.1 Data acquisition*

#### 4.1.1 Identifying territories

The forecast model allows decision makers to identify and make predictions in regard to the urban blot in the state of Nuevo Leon. It's important to note that between 85.5 and 86.2% of the increase in housing units for the state will occur within Monterrey and the greater Metropolitan Area over the course of the next twenty years. Localities like Garcia and Juárez, however, will host a considerable majority of the newly developed housing units, outmatching other localities like Monterrey, Apodaca, Guadalupe and Escobedo. Figure 4 displays the forecast for the number of housing units in the localities of Monterrey's Metropolitan Area.

The accuracy in the results offered by this forecasting model is acceptable. The model can only take inputs produced from the INEGI datasets, which have been further shown to contribute to the trending growth in housing in the state. Additional factors, such as commercial infrastructure, healthcare services, transportation, education, recreation and general zoning restrictions could have an impact on the growth rate related to urban development but are not included in the forecasting model due to a lack of available datasets.

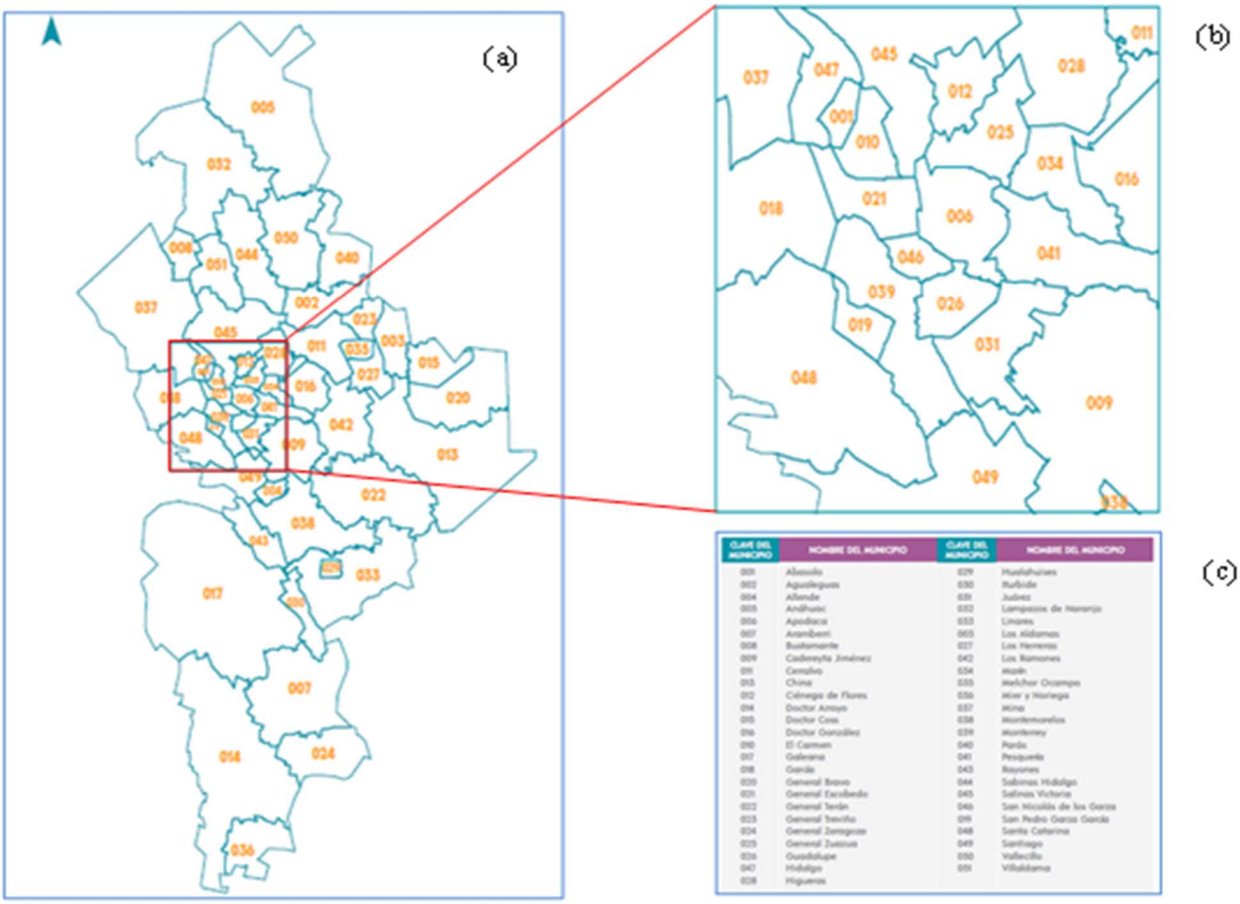



*Figure 3 Area of interest: a) Map of Nuevo Leon localities by administrative jurisdictions, b) Monterrey and greater Metropolitan Area, c) key and nomenclature for all 51 localities*

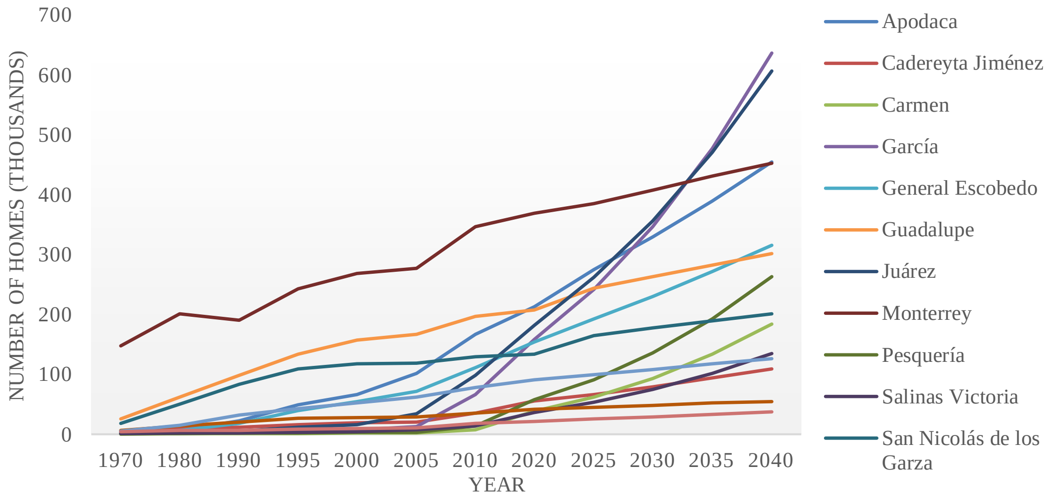



*Figure 4 Scatterplot forecast of the increase in housing units in Monterrey's Metropolitan Area*

Acta logistica - International Scientific Journal about Logistics
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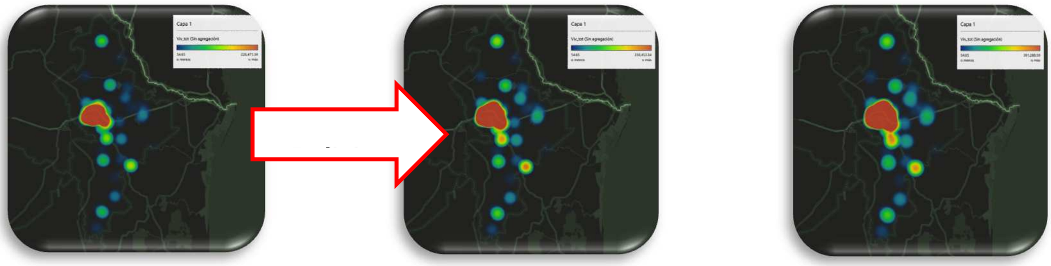

Current Housing: 2020 Estimate 2030 Estimate 2040

*Figure 5 Forecast of the increase in housing developments through linear and polynomial regression, years 2030, 2040, State of Nuevo Leon, Mexico*

Using the previously discussed findings and considering our variables of interest/parameters, a complete forecast for the years 2025, 2030, 2035 and 2040 was produced. Figure 5 displays the expansion and increasing demand for land reserves.

### 4.1.2 Construction masterplan

Forecasting and territorial acquisition immediately has a scaling effect on the master development plan. To begin, a housing unit typology is chosen for construction in each area of interest. Two main types of housing units are considered in this study, low and medium interest housing units. Unrelated to interest rates associated to mortgage loans or other financial instruments, Low and medium interest housing units are associated to housing that's made available for sections of the population with low and medium income, respectively. An average low interest housing unit spans between 42 to 76 square meters in floor area, while a medium interest housing unit is usually 150 to 220 square meters.

There are over 80 different architectural design models in the Company archives. Each locality is equipped with approximately six different designs in the construction masterplan. A materiel inventory and construction scheduled is procured for each different design. Each of the available designs requires at least 260 unique inventory pieces during the construction process. Construction times are variable and depend on lot size, chosen model and typology. Low interest housing units take between 54 and 72 days to build with medium interest rate housing units taking between 120 and 180 days to complete.

*Table 1 Planning schedule for construction per locality (2021-2030) for social interest housing units in Monterrey's Metropolitan Area*

| | | | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Municipality** | **Cluster** | **Division** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| Juárez-Cadereyta | Affordable housing | Palmanova C y D | | | 243 | 355 | 372 | | | | | |
| Juárez-Cadereyta | Affordable housing | Villa Palmanova (Ochoa) | 92 | 270 | 78 | 361 | 481 | 686 | 750 | 750 | 750 | 750 |
| Juárez-Cadereyta | Affordable housing | Villa Palmanova l3 | | | 114 | 79 | | | | | | |
| Juárez-Cadereyta | Affordable housing | Porto Alegre Norte | | | 241 | 299 | | | | | | |
| Juárez-Cadereyta | Affordable housing | Porto Alegre Sur | | | | 79 | 599 | | | | | |
| Juárez-Cadereyta | Affordable housing | Valle de Oporto 2 Sector | | | | | 120 | 160 | | | | |
| Juárez-Cadereyta | Affordable housing | Cydsa | | | | | 300 | 600 | 650 | 650 | 700 | 750 |
| García | Affordable housing | Portales de Lincoln Sur | 485 | 558 | 546 | 162 | | | | | | |
| García | Affordable housing | Portales de Lincoln Norte | | | | 478 | 689 | 700 | 800 | 690 | | |
| Apodaca | Affordable housing | Rincon de las Fuentes | | | 259 | 314 | 318 | 131 | | | | |
| Pesquería | Affordable housing | Haciendas Sector Frances | 274 | 613 | 655 | 649 | 262 | | | | | |
| Pesquería | Affordable housing | Las Haciendas 2 | | | | | 299 | 700 | 300 | | | |
| Zona norte | Affordable housing | Pilares Sector Aurora | | 56 | 924 | 296 | 400 | | | | | |
| Zona norte | Affordable housing | Pilares Sector Aurora 2 | | | | 402 | 465 | 661 | | | | |
| Escobedo | Affordable housing | SMP Solana | | 444 | | | 490 | 528 | | | | |
| Escobedo | Affordable housing | SMP San Manuel 3 | | | | | 222 | 250 | | | | |
| Escobedo | Affordable housing | Ladera de San Gabriel | | | | | | 200 | 300 | 450 | 500 | 454 |
| Escobedo | Affordable housing | San Emilio | | | | | 342 | 400 | 500 | 600 | 700 | |
| Juárez-Cadereyta | Affordable housing | Valle Real 2 | | | | | | 200 | 300 | | | |

Tables 1 and 2 display the estimated planning as far as 2030. As time passes, new localities are considered and incorporated into the forecast depending on the sales performance of each available lot. The plan is iterated in tri-annual periods and is modified according to each cycle's performance.

*Table 2 Planning schedule for construction per locality (2021-2030) for medium interest housing units in Monterrey's Metropolitan Area*

| | | | Year | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Municipality** | **Cluster** | **Division** | **2021** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| Guadalupe | Mid-range housing | Fontana | 77 | 105 | 140 | 151 | | | | | | |
| Apodaca | Mid-range housing | Puerta jardin | | 54 | 134 | 85 | 169 | 300 | 300 | 300 | 300 | 350 |
| Apodaca | Mid-range housing | Arbado marquesa | | | | 80 | 80 | | | | | |
| Apodaca | Mid-range housing | Arbados vi | | | | | 60 | 120 | 140 | 100 | | |
| Apodaca | Mid-range housing | Albero (romero) | | | | 80 | 80 | 120 | | | | |
| Monterrey | Mid-range housing | PH Linces 2 | 46 | 86 | 89 | 18 | | | | | | |
| Monterrey | Mid-range housing | PH Linces 3 | | | | 70 | | | | | | |
| García | Mid-range housing | Alcazar | | | | 75 | 75 | 60 | 70 | 70 | 80 | |
| García | Mid-range housing | Alcazar 2 | | | | | 75 | 100 | 100 | 110 | 82 | |
| García | Mid-range housing | Arborea (Montenova 2) | | 155 | 155 | 39 | | | | | | |
| García | Mid-range housing | Altrysa 2 | | | 78 | 154 | 170 | 17 | | | | |
| García | Mid-range housing | Azara | | | | 94 | | | | | | |
| García | Mid-range housing | Adara | | 117 | 40 | 161 | 117 | 170 | | | | |
| García | Mid-range housing | Parque Zafiro | | 100 | 196 | 47 | | | | | | |
| García | Mid-range housing | Padre Mier | | | | | 38 | 38 | 38 | 38 | | |
| Santiago | Mid-range housing | Santiago (Linos) | | 43 | 44 | 58 | 79 | 70 | 62 | | | |

This study considers a construction plan that spans the years 2023-2030. Forecasted demand is considered from 2024 onward. Opening times were calculated for new job sites and the corresponding servicing needs in the materiel stage from a consolidated storage facility. Existing job sites or job sites that are currently equipped with storage facilities are considered for selection in servicing multiple job sites across the network in future operation.

*Table 3 Amount of forecasted social interest housing units per locality, active job sites or planning phase/concluding phase for site completion*

| **Municipality** | **Cluster** | **Division** | **Active work or planned** | **Demand 2024-2030** | **Time remaining until closure (years)** |
|---|---|---|---|---|---|
| Juárez-Cadereyta | Affordable housing | Palmanova C y D | Active | 727 | 2 |
| Juárez-Cadereyta | Affordable housing | Villa Palmanova (Ochoa) | Active | 4528 | 7 |
| Juárez-Cadereyta | Affordable housing | Villa Palmanova l3 | Active | 79 | 1 |
| Juárez-Cadereyta | Affordable housing | Porto Alegre Norte | Active | 299 | 1 |
| Juárez-Cadereyta | Affordable housing | Porto Alegre Sur | Active | 678 | 2 |
| Juárez-Cadereyta | Affordable housing | Valle de Oporto 2 Sector | Planned | 280 | 2 |
| Juárez-Cadereyta | Affordable housing | Cydsa | Planned | 3650 | 6 |
| García | Affordable housing | Portales de Lincoln Sur | Active | 162 | 1 |
| García | Affordable housing | Portales de Lincoln Norte | Active | 3357 | 5 |
| Apodaca | Affordable housing | Rincon de las Fuentes | Active | 763 | 3 |
| Pesquería | Affordable housing | Haciendas Sector Frances | Active | 911 | 2 |
| Pesquería | Affordable housing | Las Haciendas 2 | Planned | 1299 | 3 |
| Zona norte | Affordable housing | Pilares Sector Aurora | Active | 696 | 2 |
| Zona norte | Affordable housing | Pilares Sector Aurora 2 | Active | 1528 | 3 |
| Escobedo | Affordable housing | SMP Solana | Planned | 1018 | 2 |
| Escobedo | Affordable housing | SMP San Manuel 3 | Planned | 472 | 2 |
| Escobedo | Affordable housing | Ladera de San Gabriel | Planned | 1904 | 5 |
| Escobedo | Affordable housing | San Emilio | Planned | 2542 | 5 |
| Juárez-Cadereyta | Affordable housing | Valle Real 2 | Planned | 500 | 2 |

Tables 3 and 4 display locality, housing unit model/typology, residential development nomenclature, job site status, amount of lots to be developed and time remaining for job completion.

*Table 4 Amount of forecasted medium interest housing units per locality, active job sites or planning phase/concluding phase for site completion*

| **Municipality** | **Cluster** | **Division** | **Active work or planned** | **Demand 2024-2030** | **Time remaining until closure (years)** |
|---|---|---|---|---|---|
| Guadalupe | Mid-range housing | Fontana | Active | 151 | 1 |
| Apodaca | Mid-range housing | Puerta jardin | Active | 1804 | 6 |
| Apodaca | Mid-range housing | Arbado marquesa | Active | 160 | 2 |
| Apodaca | Mid-range housing | Arbados vi | Planned | 420 | 4 |
| Apodaca | Mid-range housing | Albero (romero) | Active | 280 | 3 |
| Monterrey | Mid-range housing | PH Linces 2 | Active | 18 | 1 |
| Monterrey | Mid-range housing | PH Linces 3 | Active | 70 | 1 |
| García | Mid-range housing | Alcazar | Active | 430 | 6 |
| García | Mid-range housing | Alcazar 2 | Planned | 467 | 5 |
| García | Mid-range housing | Arborea (Montenova 2) | Active | 39 | 1 |
| García | Mid-range housing | Altrysa 2 | Active | 341 | 3 |
| García | Mid-range housing | Azara | Active | 94 | 1 |
| García | Mid-range housing | Adara | Active | 448 | 3 |
| García | Mid-range housing | Parque Zafiro | Active | 47 | 1 |
| García | Mid-range housing | Padre Mier | Planned | 152 | 4 |
| Santiago | Mid-range housing | Santiago (Linos) | Active | 269 | 4 |

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### 4.1.3 Material demand

Materiel quantities per day and week, displayed in Figure 6, are calculated for each locality using the construction masterplan and the job site staging classification.

Performance associated to the distribution networks is essential for adherence to operating schedules and resource exploitation. This paper partly intents to demonstrate that decentralizing storage facilities from the Metropolitan Area and the main construction hubs in Nuevo Leon would not compromise service rates and performance of the distribution networks. No transportation logistics are included in this study beyond a general recommendation in equipment and routing for materiel delivery. The model provides basic information through the parametrization of factors that provide insight into delivery times and transportation costs.

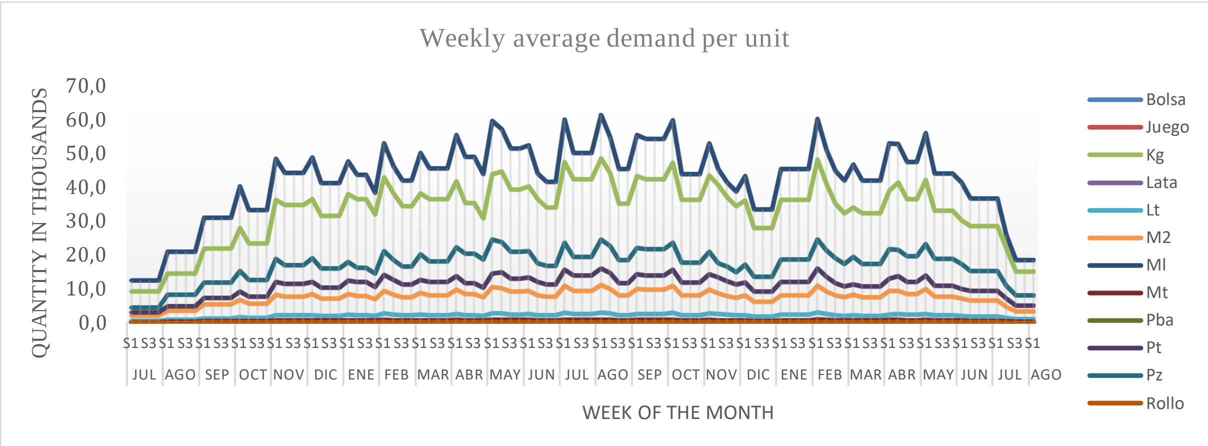


*Figure 6 Average demand analysis for a period of two years*

### 4.1.4 Distribution network data

Costs related to infrastructural development were procured from recent and historical datasets, management, security, utilities, inventory, losses and transportation costs were also obtained. Using the construction masterplan and assuming that new storage facilities are continually implemented and maintained for each locality, the cost analysis forecast calculates $146,575,03MXN as gross operating overhead. A breakdown of this figure is provided in Table 5.

*Table 5 Opening and maintenance costs for warehouses in the construction masterplan (2030)*

| | Year | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Concepts** | **2022** | **2023** | **2024** | **2025** | **2026** | **2027** | **2028** | **2029** | **2030** |
| Warehouses | 12 | 16 | 24 | 24 | 21 | 13 | 10 | 7 | 4 |
| Infrastructure | $969,618 | $820,050 | $844,350 | $854,541 | $875,651 | $982,046 | $931,606 | $813,578 | $901,815 |
| Wages | $5,114,571 | $6,819,429 | $10,229,143 | $10,229,143 | $8,950,500 | $5,540,786 | $4,262,143 | $2,983,500 | $1,704,857 |
| Security | $6,387,660 | $8,516,880 | $12,775,320 | $12,775,320 | $11,178,405 | $6,919,965 | $5,323,050 | $3,726,135 | $2,129,220 |
| Uniforms | $182,081 | $242,775 | $364,162 | $364,162 | $318,642 | $197,254 | $151,734 | $106,214 | $60,694 |
| Services | $846,092 | $1,128,123 | $1,692,184 | $1,692,184 | $1,480,661 | $916,600 | $705,077 | $493,554 | $282,031 |
| Material loss | $461,700 | $1,044,600 | $285,800 | | | | | | |
| Transportation | $390,960 | $521,280 | $781,920 | $781,920 | $684,180 | $423,540 | $325,800 | $228,060 | $130,320 |
| **Total** | **$13,961,722** | **$18,571,856** | **$26,190,959** | **$25,915,350** | **$22,803,859** | **$14,556,651** | **$11,373,610** | **$8,122,981** | **$5,078,616** |

### 4.1.5 Costs

Distances between existing and planned points of interest was calculated so as to be fed into our optimization model.

*Table 6 Distance measured in kilometres between points of interest in the 30-year forecast*

| Division | Code | Frente_1 | Frente_2 | Frente_3 | Frente_4 | Frente_5 | Frente_6 | Frente_7 | Frente_8 | Frente_9 | Frente_10 | … |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Fontana | Frente_1 | 0.00 | 14.32 | 11.25 | 11.16 | 11.64 | 25.00 | 25.07 | 29.57 | 31.60 | 27.55 | … |
| Puerta Jardin | Frente_2 | 14.32 | 0.00 | 9.97 | 10.55 | 10.13 | 30.43 | 30.52 | 34.21 | 36.31 | 31.60 | … |
| Arbado Marquesa | Frente_3 | 11.25 | 9.97 | 0.00 | 0.60 | 0.41 | 20.48 | 20.57 | 24.37 | 26.48 | 21.81 | … |
| Arbados VI | Frente_4 | 11.16 | 10.55 | 0.60 | 0.00 | 0.68 | 19.92 | 20.01 | 23.84 | 25.95 | 21.29 | … |
| Albero (Romero) | Frente_5 | 11.64 | 10.13 | 0.41 | 0.68 | 0.00 | 20.30 | 20.39 | 24.15 | 26.26 | 21.58 | … |
| PH Linces 2 | Frente_6 | 25.00 | 30.43 | 20.48 | 19.92 | 20.30 | 0.00 | 0.09 | 4.63 | 6.61 | 3.50 | … |
| Ph Linces 3 | Frente_7 | 25.07 | 30.52 | 20.57 | 20.01 | 20.39 | 0.09 | 0.00 | 4.56 | 6.53 | 3.48 | … |
| Alcazar | Frente_8 | 29.57 | 34.21 | 24.37 | 23.84 | 24.15 | 4.63 | 4.56 | 0.00 | 2.12 | 2.73 | … |
| Alcazar 2 | Frente_9 | 31.60 | 36.31 | 26.48 | 25.95 | 26.26 | 6.61 | 6.53 | 2.12 | 0.00 | 4.74 | … |
| Arborea (2) | Frente_10 | 27.55 | 31.60 | 21.81 | 21.29 | 21.58 | 3.50 | 3.48 | 2.73 | 4.74 | 0.00 | … |
| … | … | … | … | … | … | … | … | … | … | … | … | 0.00 |

Delivery times were estimated for different times of the day in order to determine average commute times. Using this method, delivery schedules can be organized with delivery times between origin and destination nodes calculated also.

Delivery times for suppliers are included in the model absent calculation. A supposition that 100% of providers will complete their schedules deliveries is made and confirmed to agree with the circumstances of this particular case. Through the consolidation scheme, and with fewer storage facilities, providers can count on maintaining the shipping volume required by the company while reducing the overall amount of transportation requirements associated to the operation.

## 5 Results and discussion

Table 7 displays the aggregate results obtained when implementing the proposed model to the problem of redesigning a logistics network using the construction masterplan as a main reference. Each scenario allows the user to determine warehouse location and the corresponding serviced localities. The model was developed using the LINGO software (version 20.0.23). Run-time for each iteration of the solution averaged 48 seconds and utilized 366Kb in the memory disk.

If the trend of equipping each locality with an individual storage facility continues up to 2030, the company would have to undergo $146,575,603MXN in costs. The most cost-effective scenario produced by the model involves keeping 4 storage facilities active until 2030, with the following distributions: Puerta Jardín 17%, Villa Palmanova 36%, Portales Lincoln Norte 21% and Ladera San Gabriel 26%.

Equilibrium solutions are achieved through the minimization of costs related to infrastructure, security, personnel and utilities. Improvements in inventory control have resulted in the reduction of lost and wasted materiel. Costs such as the acquisition of load bearing vehicles are also intended for optimization within this framework.

*Table 7 Model output comparing overall costs for each scenario*

| Scenario | Number of Warehouses | Locality | Assigned Sectors | Total Cost |
|---|---|---|---|---|
| 1 | 35 | Warehouse by project | 1 | **$146,575,603** |
| 2 | 2 | CYDSA y San Manuel3 | 16 y 19 | **$128,472,274** |
| 3 | 3 | Albero, Villa Palmanova y Laderas San Gabriel | 12, 9 y 14 | **$119,058,469** |
| 4 | 4 | Puerta Jardín, Villa Palmanova, Portales Lincoln Norte Y Ladera San Gabriel | 6, 9, 6 y 14 | **$115,808,734** |
| 5 | 5 | Puerta Jardín, Villa Palmanova, Portales Lincoln Norte, Pilares Sector Aurora2 y Ladera San Gabriel | 5, 7, 5, 4 y 14 | **$126,312,893** |

Figure 7 displays the different modelled scenarios and their respective total cost. The most cost-effective scenario involves continuing operations for only 4 storage facilities; Puerta Jardín, Villa Palmanova, Portales Lincoln Norte are existing facilities and Ladera de San Gabriel will be developed ahead of the construction schedule allotted for the modelled period.

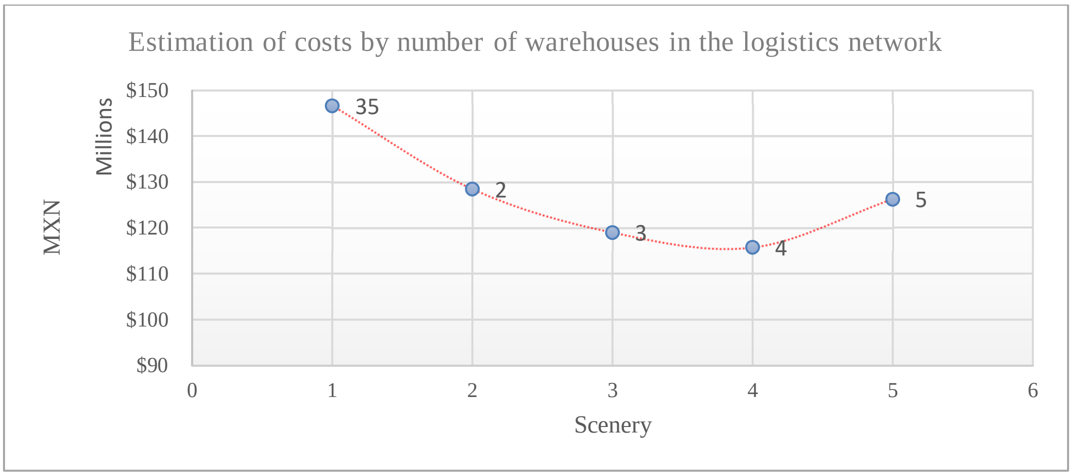


*Figure 7 Forecast for overall cost structure of different scenarios depending on amount of storage facilities available for materiel delivery*

Figure 8 displays a proposed solution based on the consolidation scheme detailed in this paper. The model reported a 20.9% increase in savings in the optimized scenario.


*Figure 8 Locations for storage facilities as selected for opening and sourcing for work-site materiel requirements*

The results display an interesting bias towards creating assignments that are locality-specific, with an interesting advantage in exploiting the proximity of certain sectors and the corresponding load consolidation/reduced transportation cost without compromising delivery times.

## 6 Conclusions

One of the primary challenges the company is currently facing is the high operational costs associated with maintaining its existing storage facility structure across different localities. While these costs are considerable, the efficiency of servicing and delivery times remains a critical factor that cannot be compromised. This study has demonstrated that urban development in the state of Nuevo León is increasingly decentralized and complex. Using both linear and polynomial regression models, supported by datasets obtained from INEGI, the company has been able to gain valuable insights into real estate acquisition strategies, particularly identifying locations with strong development potential.

A key finding of this research is that many of the most promising developments tend to be clustered in specific areas. This clustering presents an opportunity for optimizing the company's logistics network, specifically regarding the distribution of construction materials and personnel to various job sites. Recognizing this, the proposed master plan incorporates a revamped logistics network, which has been developed using a Mixed-Integer Linear Programming (MILP) algorithm. The primary advantage of this optimized network is its ability to significantly reduce overall gross operating costs while maintaining if not improving servicing and delivery times.

This paper presents an application of two location models aimed at addressing the facility location and opening problem within the context of a construction industry company. The proposed methodology is designed to streamline the decision-making process by minimizing costs while ensuring that the necessary number of destination nodes continues to be served effectively. By consolidating storage facilities, the company can enhance operational efficiency, reduce redundancy, and improve resource allocation.

It is important to note that certain assumptions were made in the development of this study. Specifically, the forecasting related to real estate acquisition was based on available data trends, and some constraints—such as zoning regulations in different localities—were not explicitly considered. Additionally, variations in demand for materials at job sites due to external factors, including weather conditions and scheduling fluctuations, were not incorporated into the model. While these assumptions simplify the analysis, they also highlight areas for future research and refinement to further enhance the robustness and applicability of the proposed approach.

Overall, this study provides a structured framework for companies in the construction sector to make data-driven decisions regarding storage facility locations. By leveraging predictive modelling and optimization techniques, firms can achieve greater cost efficiency while ensuring seamless logistics operations that support ongoing and future development projects.

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**Review process**
Single-blind peer review process.