Enhancing Last-Mile Logistics Efficiency: A Geospatial Perspective from Casablanca's Urban Landscape

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Abstract

In our study, conducted within the Moroccan context, we adopt a thorough methodology to strategically determine optimal parcel locker locations. This involves integrating clustering techniques based on attractors, population density, and surface area, utilizing the Huff model. By combining these factors, we aim to improve the precision and contextual relevance of our location selection process. Our approach provides a comprehensive and effective strategy for identifying the most suitable locations within the Moroccan last-mile delivery landscape.

1 Introduction

With the rise of e-commerce and the increasing demand for delivery services, the need for efficient parcel delivery solutions has become more prominent. Delivery solutions relying on home delivery face the challenge of delivery failures[Kawa, 2020], highlighting the need for a more efficient solution. Opting for collection and delivery points proves to be a more effective strategy for optimizing last-mile delivery, categorized into two primary forms: pick-up points and automated locker boxes, commonly referred to as parcel lockers or smart lockers. Pick-up points are predominantly found within retail stores and commercial establishments, offering a convenient option for customers to collect their parcels. The parcel lockers serve as temporary storage units for parcels, permitting customers to retrieve their items within a designated timeframe by utilizing their unique order code reference. [Lagorio and Pinto, 2020]. The intricate nature of last-mile logistics demands a high degree of efficiency. Achieving optimal functionality in parcel lockers necessitates the careful consideration of various factors. Extensive literature highlights several challenges, among which the configuration of parcel lockers holds significance. This involves decisions regarding the size of the lockers and the composition of the locker mix, encompassing mobile and static parcel lockers. [Montreuil and Faugere, 2017] assert that providers must deliberate on the number of modules per station and the specific type of modules employed. Within the context of the sharing economy, the collaborative approach, which seeks to distribute costs, tasks, and benefits, emerges as a promising concept and has garnered increasing attention in recent scientific literature. Notable studies in this domain include those by [Zhou et al., 2018] and [Fernandez-Anez et al., 2018]. Furthermore, in the pursuit of enhancing parcel locker efficiency, the challenge of optimal location selection emerges as a crucial aspect within the broader framework of last-mile logistics, affecting the willingness of customers to use the stations. We introduce the notion of attractors defined as the locations that are easily accessible and most likely to be visited regularly by potential future users. [Iwan et al., 2016] This may include for example supermarkets, train stations, and service stations.

In our study, we employed clustering to group attractors based on a proximity criterion, resulting in the identification of several dense zones. Subsequently, for each cluster and attractor, we calculated the number of attractors within a close proximity buffer zone (less than R = 1km). The third-ranking was determined using the Huff model, incorporating a ratio between the attractor's size and the distance to centroids of population densities as an attractiveness function. Our comprehensive approach involves considering the Huff model, attractor size, accessibility, and population density as factors in evaluating optimal parcel locker locations.

2 Methodology and results

Our area of study is The city of Casablanca and its outskirts Bouskoura, Dar Bouazza and Mediouna. We collected attractors data from Overpass turbo which is an openstreemap API. the dataset contains longitude, latitude, name, and type for each of them. We then extracted the road network of Casablanca with OSMnx, a python library. it is a graph of 75431 nodes and 198918 edges. size and footprint area of attractors were retrieved by the measurement tool of Google Earth.We generated observed data for parameter tuning assuming a sample of inhabitants prefer the nearest facity. we were also able to collect data on population density within our study area from wordPop. This one is a dataset containing three columns: the longitude and latitude coordinates of points regularly distributed throughout the study area with a distance of 0,5 km, and the third one containing the number of individuals per km^2. Figure 1 shows population density overlaid by a total of 225 attractors.

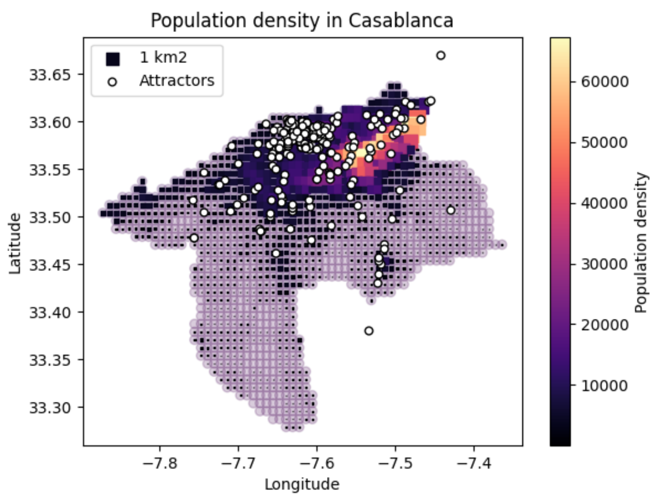


Figure 1: Study area and population density with attractors locations.

This comprehensive approach ensures a well-rounded dataset for our study, facilitating a thorough analysis of optimal parcel locker locations in the dynamic urban landscape of Casablanca.

The dataset containing the inventory of attractors forms the fundamental basis of our approach. The inherent complexity in determining and locating demand has prompted our reliance on these infrastructures qualified by DHL, Laposte, and InPoste in a study conducted by [Lagorio, 2020] as strategic locations conducive to the installation of parcel lockers . Indeed, these facilities attract a significant demographic concentration and substantial traffic flow. We combined them with population density to model and locate demand for parcel retrieval and shipping operations.

We first of all subjected this data to a customized KMeans algorithm. it is an unsupervised machine learning methodology designed to partition a dataset into distinct, non-overlapping groups. The K-means algorithm makes use of a distance metric (generally Euclidean) and aims to identify centroids for clusters where the intra-cluster variability is minimized, consequently reducing the inertia or the sum-of-squares criterion, as expressed in equation 1.

$$I = \sum_{j=1}^{k} \sum_{i=1}^{n} ||x_i^{(j)} - c(j)||^2 \tag{1}$$

In order to consider the geospatial nature of the data and the real traffic conditions in the city's road network, we employed, in this study, the length of the shortest path between two points in the road network as distance metric in our Kmeans algorithm, thereby forming distinct zones shown in figure 3.

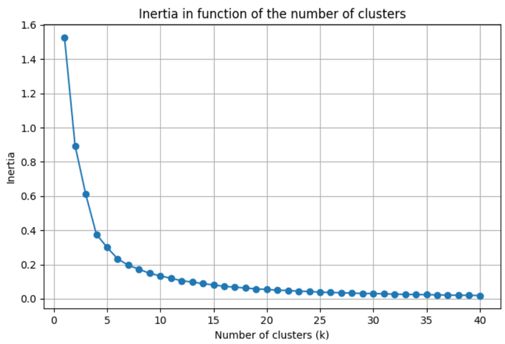


Figure 2: Elbow method

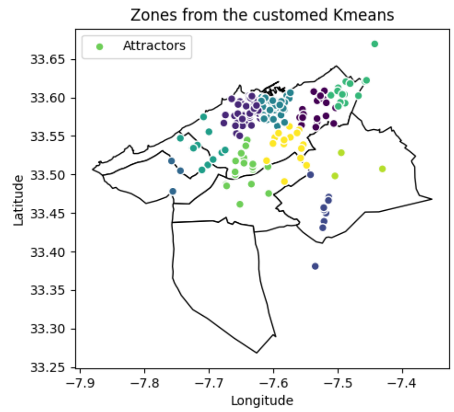


Figure 3: Clusters of attractors after Kmeans algorithm

Once the clusters have been formed, We determined, for each cluster, a ranking of the optimal locations for parcel lockers. This ranking is based on the Huff gravity model (Huff, 1963), The Huff Model states that the probability P_{ij} for an inhabitant in location i to prefere a parcel locker situated next to an attractor j is given by the formula 2 :

$$P_{ij} = \frac{U_{ij}}{\sum_{k=1}^{N} U_{ik}} \tag{2}$$

where U_{ij} is the relative utility of the attractor, a ratio between an attractiveness function and the distance separting inhabitants from attractors :

$$U_{ij} = \frac{A_j^{\alpha}}{D_{ij}^{\beta}} \tag{3}$$

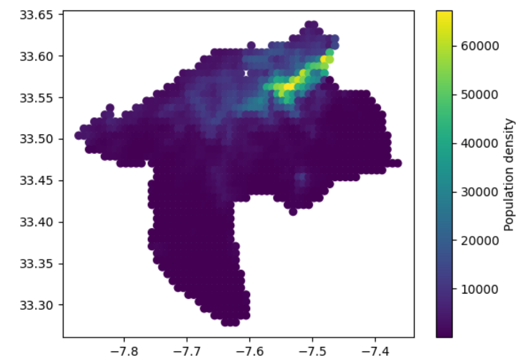
The parameter β expresses the customer´s willingness to overcome a certain distance and α is used to adjust the sensitivity of the model to Attractiveness. In this paper, we integrated multiple factors to determine the attractiveness function as explain in [Suhara, 2019]. the first one is the size S_j as in many others studies ([Suárez-Vega, 2015], [Wang, 2016], [Yue, 2012], [Ratti, 2006]). Considering that attractors are focal points of significant traffic [Lagorio, 2020], we considered as a measure of accessibility the number of opportunities (here attractors) from which access to j is obtained by traveling less than 1 kilometer [D. O'Sullivan and Shearer, 2000] and used it as second factor for our attractiveness function : Acc_j. And the last one is the total population density PD_j in a one mile buffer zone aound j. with this factor, The attractiveness of attractor j increases with the number of population residing nearby. Consiring all that, the attractiveness function we used in this paper is shown in equation 3. For each type of attractor, we calculated the α and β parameters of the Huff model (see Table 1) using the Particle Swarm Optimization (PSO) heuristic optimization method :

$$A_j = S_j * Acc_j * PD_j \tag{4}$$

$$U_{ij} = \frac{S_j * Acc_j * PD_j}{D_{ij}} \tag{5}$$

Attractor s type	α	β
Transport stations	0.041	1.215
Fuel stations	-0.038	0.771
Super Markets	-0.103	0.939

Table 1: Results of the Huff model parameters obtained through the PSO heuristic optimization method



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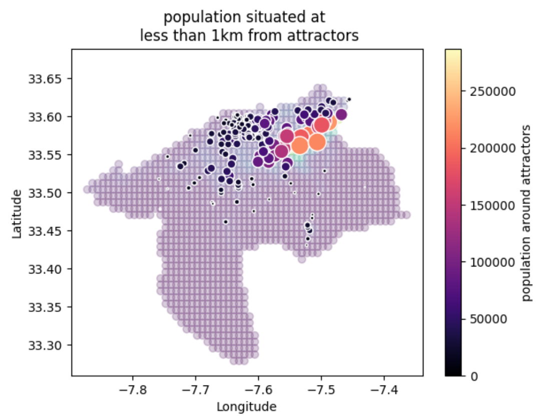
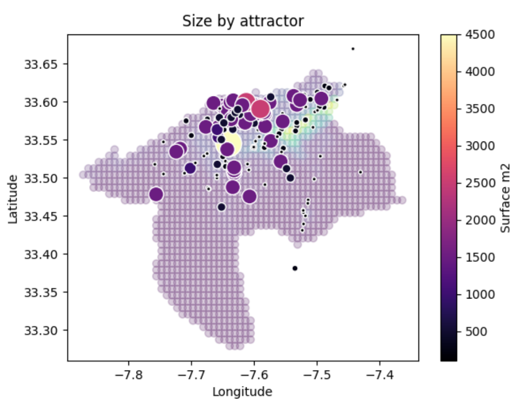


Figure 5:



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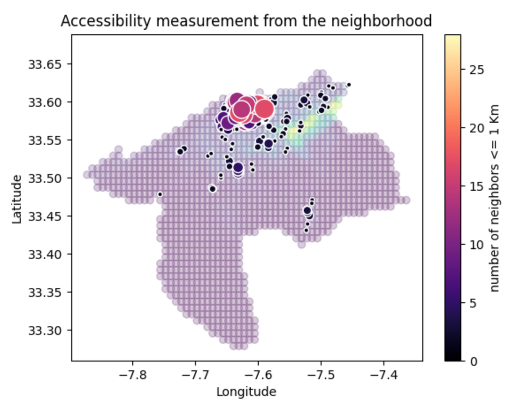

Figure 7:

Figure 8: Integrated data visualisation

With these parameters, we applied the Huff model to each type of attractor to determine the optimal locations for parcel lockers within each cluster. Results for supermarkets and gas stations are depicted in Figure 9.

3 DISCUSSION AND CONCLUSION

The methodology we employed to determine optimal parcel locker locations in the Casablanca region integrated various geospatial data, including attractors, road networks, and population density. Using

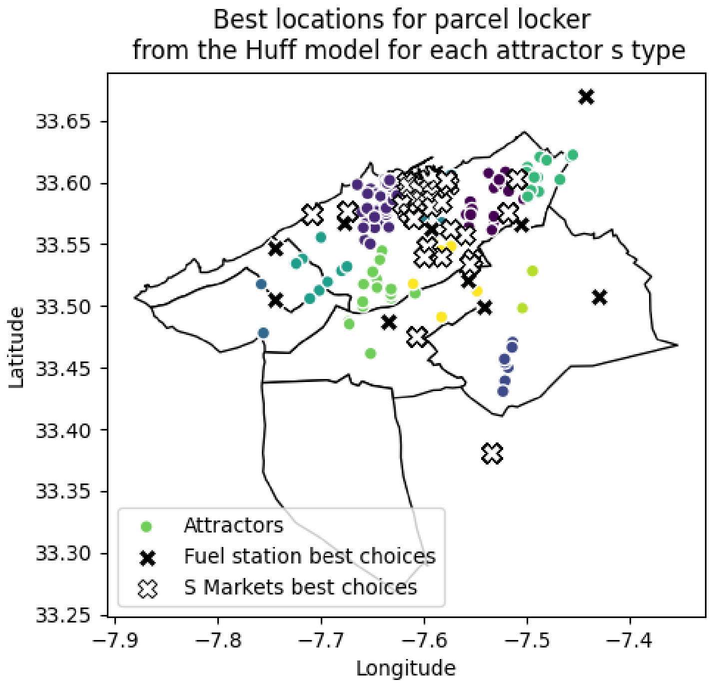

Figure 9: Optimal locations determined by the Huff model for each cluster and by type of attractor

an approach based on the Huff model and PSO heuristic optimization method, we identified the most suitable locations for installing these lockers, considering the characteristics of each cluster and attractor type.

The results, depicted in Figure 9, provide valuable insights for logistics planning and deploying parcel locker networks in urban areas. We observe that the results generated by our Huff model prioritize population density for supermarkets and accessibility for gas stations. This aligns with intuitive expectations. In a future study, we may decide to choose through the aid of a well-elaborated multicriteria decision support system. By integrating geospatial data with optimization methods, our study offers strategic perspectives for enhancing last-mile delivery efficiency and meeting the growing demand for e-commerce services.

In conclusion, our approach combines advanced data analysis techniques with optimization methods to pinpoint the best locations for parcel lockers in a dynamic urban environment. These findings can inform strategic decisions for logistics companies and urban planners, contributing to the development of sustainable and efficient urban logistics solutions.

References

[D. O'Sullivan and Shearer, 2000] D. O'Sullivan, A. M. and Shearer, J. (2000). Using desktop gis for the investigation of accessibility by public transport: an isochrone approach," international journal of geographical information science.

[Fernandez-Anez et al., 2018] Fernandez-Anez, V., Fernández-Güell, J. M., and Giffinger, R. (2018). Smart city implementation and discourses: An integrated conceptual model. the case of vienna. *Cities*, 78.

[Iwan et al., 2016] Iwan, S., Kijewska, K., and Lemke, J. (2016). Analysis of parcel lockers' efficiency as the last mile delivery solution - the results of the research in poland. volume 12.

[Kawa, 2020] Kawa, A. (2020). *Out-of-Home Delivery as a Solution of the Last Mile Problem in E-commerce.*

[Lagorio, 2020] Lagorio, A. (2020). Validating gravity-based market share models using large-scale transactional data. *8th International Conference on Information Systems, Logistics and Supply Chain.*

[Lagorio and Pinto, 2020] Lagorio, A. and Pinto, R. (2020). The parcel locker location issues: An overview of factors affecting their location.

[Montreuil and Faugere, 2017] Montreuil, B. and Faugere, L. (2017). Hyperconnected pickup delivery locker networks. *4th International Physical Internet Conference.*

[Ratti, 2006] Ratti, C. F. (2006). Mobile landscapes: Using location data from cell phones for urban analysis.

[Suhara, 2019] Suhara, Y. (2019). The parcel locker location issues: an overview of factors affecting their location.

[Suárez-Vega, 2015] Suárez-Vega (2015). Locating a supermarket using a locally calibrated huff model.

[Wang, 2016] Wang, Y. J. (2016). Evaluating trade areas using social media data with a calibrated huff model.

[Yue, 2012] Yue, Y. (2012). . exploratory calibration of a spatial interaction model using taxi gps trajectories.

[Zhou et al., 2018] Zhou, L., Baldacci, R., Vigo, D., and Wang, X. (2018). A multi-depot two-echelon vehicle routing problem with delivery options arising in the last mile distribution. *European Journal of Operational Research*, 265.