BJ O&PM Brazilian Journal of Operations & Production Management

ISSN 2237-8960 (Online)

ABEPRO ASSOCIAÇÃO BRASILEIRA DE ENGENHARIA DE PRODUÇÃO

RESEARCH PAPER

Optimal humanitarian warehouses location considering vulnerability previous condition*[1]

Wendy Chipana-Surquislla[1], Christian Cornejo-Sanchez[1], Jorge Vargas-Florez[1]

[1]Pontifical Catholic University of Peru, Lima, Peru.

How to cite: Chipana-Surquislla, W., Cornejo-Sanchez, C. and Vargas-Florez, J. (2022), "Optimal humanitarian warehouses location considering vulnerability previous condition", *Brazilian Journal of Operations & Production Management*, Vol. 19, No. 2, e20221434. https://doi.org/10.14488/BJOPM.2022.003

ABSTRACT

Goal: This study tackles on location problem, analyzing the urban shape base on vulnerability previous conditions in affected areas.

Design / Methodology / Approach: A numerical analysis is performed using an integer programming model to find optimal preposition warehouses location.

Results: The minimum cost is reached when the needs of all the people affected by the natural disaster are met. Excess construction of warehouses implies additional maintenance and administration expenses, while lack of construction of warehouses implies expenses originated by unsatisfied demand.

Limitations of the investigation: Among the main limitations found in this study were the lack of updated data and few studies related to natural disaster prevention in the case study.

Practical implications: Organizations should implement the recommendations given by the new model. This is because the model minimizes the cost, since the damage caused by a natural disaster is much more expensive than preventing it.

Originality / Value: The novelty in this study is the creation of a punishment factor based on the level of vulnerability of the routes used in transportation. This is to simulate the impact the deterioration of routes has on the response time of sending aid supplies.

Keywords: Humanitarian Logistics; Earthquakes; Disaster; Vulnerability; Location Problem.

INTRODUCTION

Research in humanitarian logistics is relatively new since the first publication was in 1996 and it has proliferated especially in recent years, especially a growth has been seen between the years 2010-2015 (Besolin et al., 2018). The studies mentioned in Fosso Wamba (2020) affirm that a country that has a greater development in humanitarian logistics can better face a natural disaster, since it understands its social and environmental reality. However, despite of the fact that many natural disasters have occurred in South America, it is worrying that contributions in this field are scarce since less than 2% of the investigations consulted by Flórez were carried out by Latin American institutions (Flórez, 2018).

One example of this occurred on August 15th, 2007, where the last earthquake occurred in Peru with epicenter in the city of Pisco. The magnitude of the disaster registered by the

* This article is from the Production and Operations Management Society (POMS) and was invited to be published in the June/2022 Special Issue of the Brazilian Journal of Operations & Production Management, due to its relevance and contribution to the field.

Financial support: None.
Conflict of interest: The authors have no conflict of interest to declare.
Corresponding author: wendy.chipana@pucp.edu.pe
Received: 3 Mar 2022.
Approved: 3 Mar 2022.
Editor: Fiorella Patricia Cardenas Toro, Maria Isabel Quispe, and Adriana Leiras.

Geophysical Institute of Peru (IGP) was 7.0 Richter (ML), and according to INDECI, there were 596 deaths and 1,296 people injured. As a result of this earthquake, 368 kilometers of roads and 213 linear meters of bridges were affected in Ica and Pisco (Bambarén and Alatrista, 2009). The supply of electricity and telephony were also interrupted from the first moments, in addition to the water and sewerage services suffered serious damage (Instituto Nacional de Defensa Civil, 2009). These damage to the infrastructure significantly slowed down the response to the disaster.

It is because of disasters like the situation described above that it is considered a critical point to assess the vulnerability of the possible affected area and estimate the damage that the access roads may suffer and quantify the extra time it takes to reach the affected places to distribute food supplies humanitarian aid in the most efficient way possible. This is the reason for which a mathematical model will be proposed that designs a network of warehouses taking into consideration the previous vulnerability of the place.

The paper is organized as follows: section two presents a review of the literature on the importance of vulnerability measurement in disasters, section three presents previous works on the use of vulnerability measurement for the design of scenarios, section four presents an application case, and the paper concludes with the results, conclusions, and references.

WAREHOUSE LOCATION FOR HUMANITARIAN RESPONSE

As previously mentioned, in recent years there has been an increase in publications in the field of humanitarian logistics. In particular, in the last decade articles have been published that review applications of mathematical models to emergency logistics.

Caunhye et al. (2012) focused his literature review on optimization models applied to emergency logistics and classified them into three categories: facility location, relief distribution and casualty transportation, they broken down the humanitarian logistics operations in two parts: pre-disaster operations and post-disaster operations. Following that author, in this research we focus on facility location and relief distribution deterministic models with single-objective; both problems are relevant because they influence the efficiency of post-disaster operations.

Regarding facility location models are very important to save lives and reduce suffering for those affected by disaster, Boonmee et al. (2017). Those optimization models are usually based on mixed integer linear programming and have been applied in evacuation, vehicle movements, stock pre-positioning and warehouse location and son on (Boonmee et al., 2017).

One facility location approach is the p-median problem whose objective is to minimize the weighted distance between humanitarian aid warehouses and demand centers. Jia et al. (2007) evaluated p-median for warehouse location for large-scale emergencies; Marcelin et al. (2016) employed a p-median model linked to a geographic information system (GIS) framework to site humanitarian aid distribution facilities and to face the hurricanes' impacts. Xi et al. (2013) modified p-median problem model and developed Variable Neighborhood VNS-based algoritm to solve the model.

In humanitarian logistics, p-center models minimize the maximum (minimax) distance between warehouses and demand centers, subject to a maximum number p of facilities. Huang et al. (2010), Ye et al. (2015) and also Jia et al. (2007) evaluated p-center model in humanitarian logistics contexts; in particular Jia et al. (2007) for medical supplies; in addition Ye et al. (2015) similar to Xi et al. (2013) also developed VNS algorithm. On the other hand, according to Boonmee et al. (2017) "the objective of the covering problem is to cover the demand points within distance or time limits", in this regard, Maharjan and Hanaoka (2017), Kusumastuti et al. (2013) and also Jia et al. (2007) determine the optimal number and locations of warehouses with maximum covering model, by contrast to them, Alizadeh and Nishi (2020) utilized set covering and maximal covering location and they conclude that hybrid model providing better coverage compared to others covering models.

In the last two decades some single-objective deterministic optimization models for relief distribution has been published, however, one existing strand of research on the topic focuses in multi-objectives models.

Some recent single-objective models published are (Sheu et al.,2005) designed fuzzy clustering and vehicle routing linear programming to determine distributed quantity of each damaged area under the objective of minimal traveling time. McCall (2004)´model minimize the distance traveled by pre-positioning of assistance pack-up kids and shortages during disasters. On the other hand, as Özdamar et al. (2006) points out, the planning of response operations in emergency situations involves the delivery of medicines, medical equipments and personnel, food, rescue teams, and others, to demand centers that require humanitarian aid as soon as possible to attend to the victims. For that purpose, relief distributions optimization models have been developed. Afshar and Haghani (2012) and Ozdamar et al. (2006) designed a mathematical model whose constraints details vehicle routing, the pick-up or delivery schedules as well as the search for the optimal locations and takes into account the capacity limitations of the facilities and transport vehicles. Nevertheless, Özdamar et al.'s (2006) objective function model (McCall, 2004) minimize amount of unsatisfied demand and is decomposed into two problems, a linear model for conventional commodities and integer integer for vehicle flows, instead Afshar and Haghani (2012) minimizes the total amount of weighted unsatisfied demand.

VULNERABILITY MANAGEMENT TP PREVENT RISK

According to Brooks (2003), Adger (1999) and Burton et al. (2002), vulnerability is associated with different terms such as sensitivity, resilience, hazard, risk, adaptation and so on. According to Kumalasari et al. (2019), vulnerability is associated with the capacity of people to protect themselves from the negative effects of a disaster without the help of others. Cardona (2003) says that vulnerability is an internal risk factor that mathematically is expressed as the feasibility of an exposed subject or system to be affected by the phenomenon that characterizes the hazard. Vargas (2002) points out that it is a function of the degree of exposure, pre-established protection, immediate reaction, basic recovery, and reconstruction. Prieto (2016) mentions that vulnerability emphasizes the probability of being negatively affected by a geographic or meteorological phenomenon and presents a multifaceted character. Sugiarti et al. (2019) points out that vulnerability has a dynamic spatiotemporal characteristic, since it is influenced by the number of populations, houses, and environmental conditions in areas with high hazards.

According to Yodmani (2001) disaster risk or vulnerability reduction is the basis of community-based approaches to disaster management. The main content of disaster management activities revolves around reducing vulnerable conditions and the root causes of vulnerability. The main vulnerability reduction strategy is through increasing a community's capacities, resources, and coping strategies. Vargas (2002) points out that vulnerability reduction is the most effective way to prevent natural and socio-natural disasters. Thus, risk prevention is achieved through vulnerability reduction when action is taken in one or more of the five areas that comprise it: (1) reducing the time and intensity of exposure, (2) moving away from the threatened area, (3) taking protective actions, (4) improving the capacity for immediate reaction through early warning mechanisms, community organization and training, and (5) creating the capacity to comprehensively address the basic recovery of the affected ecosystem. Cardona (2003) states vulnerability reduction is indissolubly linked to the intervention of the prevailing basic development needs, which is why it can be affirmed that there is a relationship between the conditions of eco-economic marginality and vulnerability seen from the perspective of disasters.

Scenario design and vulnerability assessment

Designing selection criteria in a stepwise manner helps explore how different criteria influence the choice of scenarios. The results show that the combination of criteria based on vulnerability and diversity can provide a systematic approach and clear method for the selection of scenarios; (Carlsen et al., 2016). "A methodology has been developed to design a set of valid scenarios able to assess disaster needs in regions subject to recurrent disasters. the proposition has been formulated based on two functions widely studied by the existing literature; (1) future occurrences of disasters can be taken as globally equivalent to past ones and (2) future disaster impacts will depend on two main factors: vulnerability and resilience"; (Vargas-Florez et al., 2021).

There are four key points that must be fully answered in the vulnerability assessment: the goals of the assessment, how it is framed, who participates and how it will be used in the assessment of vulnerability, and the technical methods that will be used; (Huai, 2016). As an example, a methodology to measure vulnerability applied to assess the Yaqui Valley agricultural system presents the expected value of the sensitivity of selected variables of concern to identified stressors divided by the state of the variables relative to the threshold of four essential aspects: adaptive capacity, damage, exposure and sensitivity; as a method to quantifying vulnerability; (Luers et al., 2003).

CASE

Peru is one of the countries located in The Ring of Fire, a highly seismic place where 80% of earthquakes occur, according to Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (2014). The case study for which the proposal was implemented is the city of Pisco, for which a network of warehouses will be designed to be in its eight districts in the event of a major earthquake.

Estimating vulnerability of the case

After an earthquake has occurred, it is usual for the access roads or roads to the populated centers to suffer deterioration such as broken tracks, the falling of light posts, among others. This is one of the main reasons for which the response time of humanitarian aid supplies will be affected in proportion to the severity of deterioration of these routes. To implement this influence on the access routes, a punishment factor will be assigned based on the level of vulnerability of these routes.

To assign the punishment factor, the vulnerability indicators present in each district will be identified: resilience (F1), exposure (F2) and fragility (F3). The process used to obtain the assignment is illustrated in Figure 1:

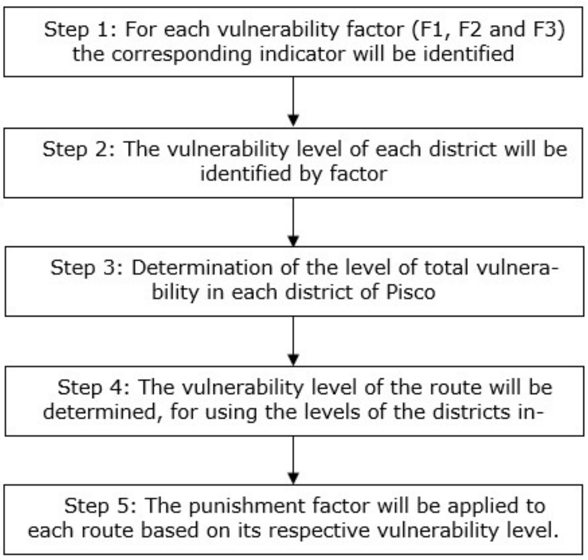

Fig. 1. Flowchart: Steps to determine the vulnerability level of the routes. *Source:* The authors

The risk factor on the routes will be classified into four levels, which were defined according to the estimated damages that the main routes could suffer during a disaster. In the case of study, values of 1.1, 1.5, 2, 2.5 were assigned for each of these levels as factors in order to simulate the possible delays due to the damages on the different routes.

After identifying the level of vulnerability of each route for the study case, we proceeded to multiply the punishment factor assigned to each distance between the districts, resulting in the punished distances.

Methodology

In the present work, a mixed integer programming model (PLEM) was designed that complements the work presented by Serpa (2014) and for which were taken considerations proposed by Vargas et al. (2015), whose objective is the total minimization of costs, which are: installation cost, warehouse management cost, transportation cost and cost of unattended victims.

To estimate the number of victims and those affected, the "Manual para la evaluación de riesgos por sismos", prepared by Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (2017), will be taken into account. From this manual, the most relevant characteristic was the type of construction material to determine the level of vulnerability, which was obtained from the information collected by "Instituto Nacional de Estadística e Informática" -a peruvian public institution- in the 2017 National Census. The estimated number of victims is shown in the Table 1 below.

Table 1. Number of people affected.

District	Affected (High L.)	Affected (Very high L.)	Population of victims
Pisco Distrito	13,169	1,470	14,639
Huancano	75	529	604
Humay	502	1,006	1,508
Independencia	1,603	3,335	4,938
Paracas	2,546	61	2,607
San Andrés	2,363	217	2,580
San Clemente	3,141	2,533	5,674
Túpac Amaru Inca	4,185	361	4,546

To estimate the warehouse parameters C_i used in the simulation, two criteria were used: amount of vulnerable population(criteria 1) and population density(criteria 2).

Mixed integer linear programming model

To determine the amount and location of warehouses in the city of Pisco, a mathematical model of mixed integer linear programming will be formulated that will have as sources the models proposed by Serpa (2014) and Vargas et al. (2015) that allows to minimize the total cost. The variables involved in the model are indicated below:

Variables:

Rj: Unmet demand in district j

Yi: 1 if the warehouse is located in district j, 0 otherwise

wij: 1 if the route ij is used, 0 otherwise

Xij: Number of kits delivered from district i to j

Parameters:

cud: Unit cost of the unmet demand

fi: Installation cost of the warehouse in district i

t: Fuel cost

Dj: Demand to be satisfied on the district j

nw: Maximum number of warehouse

Ci: Capacity of the warehouse in the district i

Dij: Distance of the districts i and j

vi: Unit cost of managing groceries in warehouse i

The objective function focuses on minimizing the cost incurred during the entire process. This involves the costs of installation and management of warehouses, the cost of transporting the kits, and the cost of unmet demands.

$$\min \quad CT = C.\sum_{i=1}^{8}\sum_{j=1}^{8}\left(w_{ij}\cdot d_{ij}\right).Z_{ij} + \sum_{j=1}^{8}\left(f_j + C_i{*}V_i\right).\,Y_j + cud\sum_{i=1}^{8}R_j$$

The following constraints were used in our approximation:

Equation 1 ensures that the number of beneficiaries in district j plus the unmet demand is equal to the total demand in district j.

$$\sum_{i=1}^{8}X_{ij} + Rj = Dj, \qquad \forall j \tag{1}$$

Equation 2 Limits stores to a quantity less than or equal to nw.

$$\sum_{i=1}^{8}Y_i \le nw, \tag{2}$$

Equation 3 Ensures that the number of people that received kits by the district i does not exceed the capacity of said warehouse if it is built.

$$\sum_{i=1}^{8}X_{ij} - CiY_i \le 0, \quad \forall i \tag{3}$$

Equation 4 ensures that if no shipments are sent from district i to district j, there is no need to make the trip from i to j.

$$.\ w_{ij} - X_{ij} \le 0 \quad \forall i, \forall j\ . \tag{4}$$

Equation 5 indicates that the travel from district i to j is necessary in case kits are shipped from district i to j.

$$X_{ij} \le Mw_{ij}, \quad M \gg 0, \tag{5}$$

Equation 6 implies that there is no need to build a warehouse in district i if it does not deliver kit.

$$\sum_{j=1}^{6}X_{ij} \ge Y_i, \quad \forall i \tag{6}$$

Equation 7 delimits the variable of number of kits delivered to be integer, and warehouse construction decision variables in i and path traversal from i to j as Boolean variables.

$$X_{ij}\ integer,\ \ Y_i \in \{0,1\},\ \ w_{ij} \in \{0,1\} \tag{7}$$

The model is solved for different capacities of the model.

RESULTS

The LINGO modeling language version 18 was used. We had 6 different scenarios depending on the number of warehouses which are shown in Tables 2 and 3.

Table 2. Scenario results based on criteria 1

Scenario (Number of warehouses built)	Unmet demand of victims	Total Cost (S/.)
1	12,237	36,060,060.00
2	509	15,781,490.00
3	0	14,937,670.00
4	0	15,515,330.00
5	0	18,232,400.00
6	0	22,747,220.00

Table 3. Scenario results based on criteria 2

Scenario (Number of warehouses built)	Unmet demand of victims	Total Cost (S/.)
1	7,265	27,461,010.00
2	228	15,295,200.00
3	0	14,929,920.00
4	0	15,434,210.00
5	0	18,693,960.00
6	0	22,781,140.00

The results of these scenarios are shown graphically in Figure 2. An evident trend can be observed: the scenarios that present the lowest cost are those that present the highest percentage of installed warehouses. This can be justified because it minimizes the unmet demand of the districts along with the distance traveled for the delivery of food. Also, due to the presence of warehouse installation and maintenance costs, the minimum cost will not be reached with the installation of warehouses in all permitted districts.

Fig. 2. Figure cost vs number of warehouses. *Source:* The authors

CONCLUSION.

Initially, it is possible to think that to satisfy all the unmet demand, all possible warehouses should be built. However, when the behavior of the total cost of Figure 2 is analyzed through the variation of the number of warehouses, it was found that the optimum occurs when just 3 warehouses are built, since a growth of the total cost is observed when increasing the number of warehouses. This is due to the fact that when 3 of the warehouses are built, the total unmet demand is covered and this cost is zero, and for the following cases (when the quantity of warehouses is 4, 5 and 6) this cost remains zero, however the cost of administration and installation of warehouses increases for each warehouse built. These findings suggest that the optimal number of warehouses to minimize total cost is obtained when the estimated demand is reached for the first time.

What is new in this research is the consideration of the level of vulnerability in the affected locality since it measures the level of damage to the infrastructure and access roads of that place. This generates an increase in the travel duration for the delivery of humanitarian aid supplies. One way to include this vulnerability is with the incorporation of a punishment factor to the potential routes of food transfer for the inclusion of structural damage in the model.

REFERENCES

Adger, W.N. (1999), "Social vulnerability to climate change and extremes in coastal Vietnam", *World Development*, Vol. 27, No. 2, pp. 249-69.

Afshar, A. and Haghani, A. (2012), "Modeling integrated supply chain logistics in real-time large-scale disaster relief operations", *Socio-Economic Planning Sciences*, Vol. 46, No. 4, pp. 327-38.

Alizadeh, R. and Nishi, T. (2020), "Hybrid set covering and dynamic modular covering location problem: application to an emergency humanitarian logistics problem", *Applied Sciences*, Vol. 10, No. 20, pp. 1-23.

Bambarén, C. and Alatrista, M. (2009), "Estimación del impacto socioeconómico del terremoto en Pisco en el sector salud peruano", *Revista Médica Herediana*, Vol. 20, No. 2, pp. 177-84.

Besolin, P., Gonçalves, V., Andrade, A. et al. (2018), "A bibliometric analysis regarding humanitarian operations and critical situations", *Revista GEINTEC - Gestão, Inovação e Tecnologias*, Vol. 8, No. 3, pp. 4508-21.

Boonmee, C., Arimura, M. and Asada, T. (2017), "Facility location optimization model for emergency humanitarian logistics", *International Journal of Disaster Risk Reduction*, Vol. 24, pp. 485-98.

Brooks, N. (2003), *Vulnerability, Risk and Adaptation: a Conceptual Framework*, Tyndall Center, United Kingdom.

Burton, I., Huq, S., Lim, B. et al. (2002), "From impacts assessment to adaptation priorities: the shaping of adaptation policy", *Climate Policy*, Vol. 2, No. 2-3, pp. 145-59.

Cardona, O.D. (2003), *La Necesidad de Repensar de Manera Holística los Conceptos de Vulnerabilidad y Riesgo "Una Crítica y una Revisión Necesaria para la Gestión*", Centro de Estudios sobre Desastres y Riesgo, Panamá.

Carlsen, H., Lempert, R., Wikman-Svahn, P. et al. (2016), "Choosing small sets of policy-relevant scenarios by combining vulnerability and diversity approaches", *Environmental Modelling & Software*, Vol. 84, pp. 155-64.

Caunhye, A., Nie, X. and Pokharel, S. (2012), "Optimization models in emergency logistics: a literature review", *Socio-Economic Planning Sciences*, Vol. 46, No. 1, pp. 4-13.

Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (2014), *Manual para la Evaluación de Riesgos Originados por Fenómenos Naturales*, 2ª ed., CENEPRED, Lima.

Centro Nacional de Estimación, Prevención y Reducción del Riesgo de Desastres (2017), *Manual para la Evaluación de Riesgos por Sismos*, CENEPRED, Lima.

Flórez, N. (2018), "Desarrollo de la logística humanitaria: una revisión de la literatura", *Science of Human Action*, Vol. 3, No. 2, pp. 317-339.

Fosso Wamba, S. (2020), "Humanitarian supply chain: a bibliometric analysis and future research directions", *Annals of Operations Research*. In press.

Huai, J. (2016), "Integration and typologies of vulnerability to climate change: a case study from Australian wheat sheep zones", *Scientific Reports*, Vol. 6, No. 1, pp. 6.

Huang, R., Kim, S. and Menezes, S. (2010), "Facility location for large-scale emergencies", *Annals of Operations Research*, Vol. 181, No. 1, pp. 271-86.

Jia, H., Ordóñez, F. and Dessouky, M. (2007), "A modeling framework for facility location of medical services for large-scale emergencies", *IIE Transactions*, Vol. 399, No. 1, pp. 41-55.

Kumalasari, R.H., Koestoer, R. and Hasibuan, H. (2019), “Disaster risk mitigation of landslide for sustainability of geothermal production in Bandung Regency, West Java Province, Indonesia", *IOP Conference Series: Earth and Environmental Science*, Vol. 256, 012020.

Kusumastuti, R.D., Wibowo, S. and Insanita, R. (2013), “Modeling facility locations for relief logistics in Indonesia", in Zeimpekis, V., Ichoua, S. and Minis, I. (Eds.), *Humanitarian and Relief Logistics*, Springer, New York, pp. 183-205.

Luers, A., Lobell, D., Sklar, L. et al. (2003), "A method for quantifying vulnerability, applied to the agricultural system of the Yaqui Valley”, Mexico", *Global Environmental Change*, Vol. 13, No. 4, pp. 255-67.

Maharjan, R. and Hanaoka, S. (2017), "Warehouse location determination for humanitarian relief distribution in Nepal", *Transportation Research Procedia*, Vol. 25, pp. 25.

Marcelin, J.M., Horner, M., Ozguven, E. et al. (2016), "How does accessibility to post-disaster relief compare between the aging and the general population? A spatial network optimization analysis of hurricane relief facility locations", *International Journal of Disaster Risk Reduction*, Vol. 15, pp. 61-72.

McCall, V. (2004), *Designing and Prepositioning Humanitarian Assistance Packup Kits (HA PUKS) to Support Pacific Fleet Emergency Relief Operations*, Master’s Thesis, Naval Posgraduate School, USA.

Instituto Nacional de Defensa Civil (2009), *Lecciones Aprendidas del Sur-Sismo de Pisco 15 de Agosto 2007*, INDECI, Lima.

Özdamar, L., Ekinci, E. and Küçükyazici, B. (2006), "Emergency logistics planning in natural disasters", *Annals of Operations Research*, Vol. 129, No. 1-4, pp. 217-45.

Prieto, M.B. (2016), “Vulnerabilidad sociodemográfica en el aglomerado urbano de Bahía Blanca-Argentina”, available at: http://www.abep.org.br/~abeporgb/publicacoes/index.php/anai s/article/viewFile/1817/1776 (accessed 3 March 2022).

Serpa V. (2014), *Optimización y Localización de Almacenes de Abastecimiento para la Atención de un Terremoto de Gran Magnitud en Lima Metropolitana y Callao*, Tesis de Grado, Pontificia Universidad Católica del Perú, San Miguel, available at: http://hdl.handle.net/20.500.12404/5352 (accessed 3 March 2022).

Sheu, J.-B., Chen, Y.-H. and Lan, L. (2005), "A novel model for quick response to disaster relief distribution", *Proceedings of the Eastern Asia Society for Transportation Studies*, Vol. 5, pp. 2454-62.

Sugiarti, A., Meilianda, E. and Fatimah, E. (2019), “An overview of the down-scaling values of physical and social vulnerability parameters for tsunami disaster at the city level: a case study of Banda Aceh”, *IOP Conference Series: Earth and Environmental Science*, Vol. 273, 012030.

Vargas, J. (2002), *Políticas Públicas para la Reducción de la Vulnerabilidad Frente a los Desastres Naturales y Socio-Naturales*, Serie Medio Ambiente y Desarrollo, No. 50, CEPAL, Bogotá.

Vargas, J., Lauras, M., Okongwu, U., Dupont, L. (2015), “A decision support system for robust humanitarian facility location”, *Engineering Applications of Artificial Intelligence*, Vol. 47, pp. 23-33.

Vargas-Florez, J., Lauras, M. and Comes, T. (2021), “Designing Valid humanitarian logistics scenario sets: application to recurrent peruvian floods and earthquakes", in Taghipour, A. (Ed.), *Demand Forecasting and Order Planning in Supply Chains and Humanitarian Logistics*, IGI Global, Hershey, pp. 66-88.

Xi, M., Ye, F., Yao, Z. et al. (2013), "A modified p-median model for the emergency facilities location problem and its variable neighbourhood search-based algorithm", *Journal of Applied Mathematics*, Vol. 2013, pp. 1-10.

Ye, F., Zhao, Q., Xi, M. et al. (2015), "Chinese national emergency warehouse location research based on VNS algorithm", *Electronic Notes in Discrete Mathematics*, Vol. 17, pp. 61-8.

Yodmani, S. (2001), "Disaster risk management and vulnerability reduction: protecting the poor", in *The Asia and Pacific Forum on Poverty*, Asian Development Bank, Philippines.

Author contributions: Introduction - JVF; Literature review - JVF, CCS, WCS; Case - WCS; Methodology - WCS, JVF; Model - WCS, CCS; Results - WCS, JVF; Conclusion – WCS