Stock Prepositioning for disasters in Mexico: A case

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Abstract

Different governments are recurring to stock prepositioning to improve immediate disaster response because it can reduce procurement delays and distribution lead-time. However, it can be an expensive policy. Mexico has used this policy for several years with poor results. The purpose of this research is to integrate GIS and optimisation for the analysis of the location of warehousing facilities and prepositioning of stock at a national level.

The system was tested using data obtained from Mexican disaster authorities and compared to the current policy, showing better coverage in terms of quality and a reduction of shipment time for several areas.

Keywords: Stock prepositioning, humanitarian logistics, disaster management

Introduction

From 1992 to 2012 around 4.4 billion were affected by disasters with almost 2 trillion USD in damages and 1.3 million people killed globally (UNISDR, 2012). A disaster is a physical event that affects a society by disrupting its normal dynamics along with turning its priorities and goals (Van Wassenhove, 2006). Reacting for these situations involves significant logistical deployment to supply the required items.

Disaster management is complex because of the conditions experienced during emergencies. To tackle that complexity, several researchers have developed solutions for disaster management in the literature (Kunz and Reiner, 2012). However, most research has been developed based on developed countries, even though over 70% of disasters between 1970 and 2009 have occurred in developing countries (Julca, 2012).

The impact of disaster events can vary widely between developed and developing countries (Julca, 2012). The lack of resources, poor urban planning, and high vulnerability are reasons behind the steep impact of disasters on these countries. Those challenges combined with high frequency stress the importance of increasing the research focused on the conditions of developing countries (Kovács and Spens, 2011).

During 2011, Mexico had around 3.7 million victims caused by disasters, the tenth highest number globally (Guha-Sapir et al., 2012). From 1950 to 2015, the country suffered 241 reported large-scale disasters, being the most affected country by disasters in the Americas after the United States (CRED, 2016), with an average occurrence of nearly 4 large-scale disasters per year.

To improve immediate response after disasters, the Mexican government has adopted a prepositioning policy. That approach has been used in different countries because of its potential to expedite availability of resources for immediate response. Prepositioning is the storage of relief goods for post-disaster distribution on locations close to the potential disaster (Ukkusuri and Yushimito, 2008). This strategy improves disaster response by totally or partially disposing of procurement delays (Bozkurt and Duran, 2012) and reducing the distribution lead-time (Ukkusuri and Yushimito, 2008). Nonetheless, the uncertainty of the occurrence and magnitude of the event can complicate the adequate allocation of resources (Oloruntoba and Gray, 2006), resulting in very high costs.

Despite the cost incurred, different governments have adopted this policy without exploiting it fully. This is the case of Mexico, where this policy has been used for several years with poor results, often experiencing relief shortages (Santos-Reyes et al., 2010).

There is an opportunity to provide an analytical method to identify the optimal location and number of items stored in the facilities available. The purpose of this research is to provide an analysis of the current stock prepositioning policy in the country, identify the opportunities for improvement, and design a model to perform the location and allocation of resources based on the current disaster management policy in Mexico.

The paper is organised as follows: the next section provides a review of the main contributions in the literature for stock prepositioning. Next, the system is introduced and the analysis of the Mexican case and the current prepositioning policy is presented. Afterwards, the results of the application of the optimisation model are discussed and a comparison with the current policy is drawn. Finally, conclusions about this research are stated.

Literature Review

The storage in advanced of inventory in strategic locations to enhance relief distribution after a disaster is called stock prepositioning (Ukkusuri and Yushimito, 2008). This strategy was borrowed from military operations to increase the efficiency of the supply chain (Richardson et al., 2010) as it reduces lead time (Bozkurt and Duran, 2012, Ukkusuri and Yushimito, 2008).

The location of supply facilities and stock prepositioning is a very natural synergy, focusing on two of the main activities for disaster preparedness. Campbell and Jones (2011) incorporated risk of facility disruption for one supply point using equations aiming to determine the optimal stock quantity and the total expected cost associated with deliveries. Galindo and Batta (2013) accounted for possible destruction of supply points during the disaster event by increasing a percentage of the supplies prepositioned (i.e. safety stock) with amplifying factors. The model minimises the total expected cost including deliveries and cost of units destroyed.

Considering coverage of stock prepositioning at international level and incorporating scenarios in the formulation, Balcik and Beamon (2008) presented a model based on the MCLP looking to maximise the demand attended by distribution centres including the probability of occurrence of the disaster and the level of coverage. Jomon Aliyas and Hariharan (2012) developed a framework to position relief from the Strategic National Stockpile to deliver medicines to hospitals in cases of disaster. The first step uses FEMA HAZUS-MH to simulate scenarios, and simultaneously potential locations of stockpiles are determined. Then, demand is grouped in clusters, and next the model is used to determine locations and capacities of stockpiles by minimising the social cost. Finally, the mini-max regret decision making rule is used to determine the policy. Duran et al. (2011) studied the location of global distribution centres and stockpiles for CARE International considering multiple disasters. The authors designed an inventory-location model seeking to minimise the average response time, constraining the solution to the inventory amount to keep in the network. Building upon that, Bozkurt and Duran (2012) used the same model to expand the warehouse network of CARE International and to determine the level of stock prepositioned, suggesting a fourth warehouse in Kenya.

Even though distance is used as a measure to reduce lead time, the articles presented are static and struggle to ensure coverage within different time frames (for instance, the first four or twelve hours after then disaster, in which the propositioned relief is essential for immediate response), except for Balcik and Beamon (2008). However, their model cannot ensure distance coverage to *all* potential areas. Additionally, none of the articles allow shared use of resources. During large-scale disasters, national governments are supported by other national and international organisations. Despite the benefits of sharing resources stated in the literature, none of the articles mentioned incorporated the participation of different organisations or the use of shared facilities to improve operations. Finally, none of the articles mentioned are focused on developing countries. The application of these solutions to such countries is important to explore the suitability of the approach to be incorporated in disaster management policy.

This article contributes to the current body of knowledge proposing a model to develop a plan for facility location and stock prepositioning with quality levels to ensure relief deployment at relevant time intervals incorporating facilities and resources from multiple organisations (or suppliers) applied to real information from Mexico.

System design

This research uses a combination of Geographical Information Systems (GIS) and optimisation to develop a facility location and stock prepositioning plan at country level.

Geographical analysis

To include the spatial distribution of the facilities and the areas to serve, a vector GIS can be used. The purpose is to perform network analysis based on the facilities provided by authorities for the transportation of relief.

The analysis includes the use of information about facilities and the road network to determine distances and coverage levels. The inclusion of facilities and demand areas can be achieved by creating a point layer in vector GIS. Each point can be located either using coordinates or the road network of the region/country. Having the layer of facilities and the road network, the GIS can provide Euclidian distances (i.e. direct distances) or distances based on the available roads.

Optimisation model

Optimisation was used to design a model to determine the optimal location and allocation of resources ensuring every demand region in the country is covered depending on the probability of occurrence of an event. The objective is to maximise the number of items that can reach all demand areas at different levels of coverage. Resources and facilities from different organisations can be included to improve collaboration, improve coverage, and reduce duplication of efforts.

Let QC_{iojq} be the level of coverage of facility *i* from organisation *o* to area *j* at quality level q, R_j the probability of disaster occurrence at region j, L_{jq} the required quality of coverage q per area j, V_n the volume of product n, H_{io} the capacity of facility i from organisation *o*, F the number of facilities to open, A_{no} the number of products type *n* from organisation o available, QP_n the minimum level of satisfaction od product type *n* for every region. The structure of the model is:

$$Max\ coverage = \sum_{i}\sum_{j}\sum_{o}\sum_{q}\sum_{n} P_{ion} * QC_{iojq} * R_j * L_{jq} \quad (1)$$

s.t

$$\sum_{n} P_{ion} * V_n \leq H_{io} * x_{io} \qquad \forall\, i, o \quad (2)$$

$$\sum_{i}\sum_{o} x_{io} = F \quad (3)$$

$$\sum_{i}\sum_{o} P_{ion} = \sum_{o} A_{no} \qquad \forall\, n \quad (4)$$

$$\sum_{i}\sum_{o} P_{ion} * QC_{iojq} \geq \sum_{i}\sum_{o} P_{ion} * QP_n * L_{jq} \qquad \forall\, j, q, n \quad (5)$$

$$X_i \in \{0,1\}$$

$$P_{ion} \in Z \geq 0$$

Where x_{io} is the decision to open the distribution centre *i* from organisation *o* or not, and P_{ion} the number of items type *n* to store at facility *i* from organisation *o*. The objective function maximises the number of items reaching demand areas. Expression (2) forces the model to abide by the capacity of the facilities whereas constraint (3) determines the number of facilities to open. Equation (4) ensures the supply capacity of the organisations involved is not exceeded and expression (5) ensures every region can be supplied a minimum of resources at the coverage level determined by the probability of occurrence. Finally, the declaration of binary and integer variables is presented.

Case study

The analysis is centred in Mexico, a country prone to disaster occurrence because of its geographical location between the Atlantic and Pacific Oceans. The country has been significantly affected by disasters historically. Just from 2000 to 2016, around 113 registered disasters have occurred in the country (EM-DAT, 2017).

The States of Oaxaca, Veracruz, Guerrero, Chiapas and Tabasco have been the most disaster affected regions. Looking at disasters with a high number of people affected in either of these States, this analysis uses information from the flood of Tabasco in 2007, the flood of Veracruz in 2010 and the flood in Acapulco in 2013. The details of the three situations are shown on Table 1. The number of people sheltered was obtained from freedom of information request sent to organisations in charge of sheltering across health, civil protection and the military.

Table 1. Characteristics of the three events

Year	*Location*	*Description*
2007	Villahermosa, Tabasco	Flood depth: 4 meters Start and end date: 29th October 2007 – 23rd May 2008 Number of people sheltered: 99,000
2010	Veracruz, Veracruz	Flood depth: 1.5 meters Start and end date: 19th September 2010 –19th October 2010 People sheltered: 5,140
2013	Acapulco, Guerrero	Flood depth: 1.5 m Start and end date: 16th September 2013 – 26th November 2013 Number of people sheltered:13,062

Current prepositioning policy

Following the impact of the 1985 earthquake in Mexico, in 1986 the Civil Protection National System (SINAPROC) was created to provide support in cases of disaster. Decision-making in disaster situations in Mexico is centralised, portraying the role of SINAPROC as a coordinator of national and international participants.

Disaster management in the country is performed through four main branches: executive coordination, technical coordination, technical support and co-responsibility. Co-responsibility refers to the organisations charged with the responsibilities to provide supplementary support along with human and material resources to the emergency activities on top of their normal duties (SEGOB, 2006). As part of this branch, DICONSA is the organisation charged with the management of supply facilities and the procurement of disaster relief products under disaster circumstances.

Data from DICONSA was obtained about current and past stock prepositioning plans in the country. Using that information combined with data about three of the most damaging disasters experienced in the country, this section elaborates on the performance of the current policy.

Information from DICONSA revealed the use of ten distribution centres for stock prepositioning in Mexico. The facilities used by authorities can be seen in Figure 1, with the layer of the road network to identify their relative location in the country. The facilities are distributed across the country, with more concentration towards the centre.

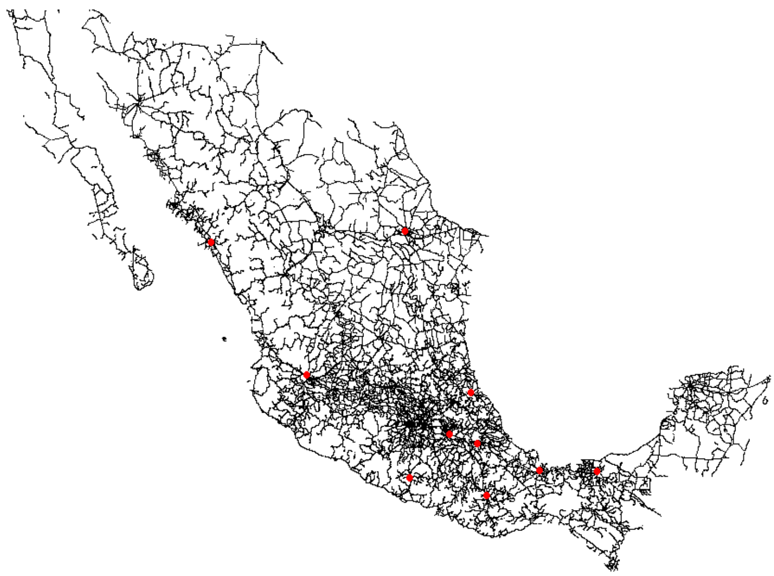

Fig.1 Current distribution centres

Considering the current plan, Table 2 shows the minimum time required to reach the capital city of each State. This approach is used to allow resources to be sent to a distribution node to organise, separate and deploy required resources from DICONSA's regional centre to each affected zone. The time was obtained considering an average speed of 40 miles/hour, which complies with the highway speed limits in Mexico.

Table 2. Minimum time to reach each area using the current policy

ID	*State*	*Time (h)*	*ID*	*State*	*Time (h)*	*ID*	*State*	*Time (h)*
Z1	B. C. Sur	43.88	Z12	Nayarit	3.06	Z23	Morelos	2.40
Z2	B. C.	21.19	Z13	Jalisco	0.38	Z24	Michoacán	4.95
Z3	Sonora	10.61	Z14	Guanajuato	4.29	Z25	Colima	3.25
Z4	Chihuahua	12.73	Z15	Aguascalientes	3.57	Z26	Guerrero	0.05
Z5	Coahuila	1.77	Z16	Querétaro	5.15	Z27	Oaxaca	0.13
Z6	N. León	0.12	Z17	Hidalgo	2.42	Z28	Chiapas	4.09
Z7	Tamaulipas	4.76	Z18	Veracruz	2.35	Z29	Tabasco	0.08
Z8	San Luis	5.47	Z19	Puebla	0.07	Z30	Campeche	7.12
Z9	Zacatecas	5.04	Z20	Tlaxcala	0.53	Z31	Yucatán	10.01
Z10	Durango	7.80	Z21	Edo. de Méx.	2.98	Z32	Quintana Roo	13.12
Z11	Sinaloa	0.14	Z22	D.F.	2.06			

Within the first twelve hours after the emergency declaration, twenty-eight of the capital cities can be reached. Responsiveness seems to be good for most of the States. However, it takes nearly a day and nearly two days to reach the capital cities of Baja California Sur and Baja California by road, respectively. This shows that equity and fairness are not contemplated in the current system. Moreover, considering priorities because of disaster occurrence, it takes nearly two days to reach Baja California Sur, which is the State with the twelfth highest number of registered disasters in the country.

These numbers provide an overview of the performance of the system. However, information from the three cases shown on Table 2 was used to obtain more insights. Table 3 shows the amount of relief that could reach the demand area within the first day of the disaster. Considering each food package can provide relief for four people according to Mexican regulations, the last row shows time required to serve demand.

Table 3. Relief arrival per period

Time	*Veracruz*	*Guerrero*	*Tabasco*
4 Hours	8334 (33336)	5000 (20000)	4166 (16664)
8 Hours	17500 (70000)	14167 (56668)	5833 (23332)
12 Hours	20000 (80000)	20000 (80000)	15000 (60000)
16 Hours	25000 (100000)	22500 (90000)	20000 (80000)
20 Hours	25000 (100000)	25000 (100000)	20000 (80000)
24 Hours	27500 (110000)	27500 (110000)	25000 (100000)
Time to meet demand	2.9 hours	Less than one hour	22.7 hours

As can be seen, there are significant differences in terms of the time required, mostly because of the difference in magnitude. Nevertheless, it can be seen how Tabasco is less covered than Veracruz and Guerrero in general terms, even though Tabasco has suffered floods every year of great magnitude, even more than the other two cases.

Application of the model

The previous analysis showed the performance of the current policy under different angles. One of the shortcomings of models in the literature and the current policy is the disregard of organisations different than the government. Therefore current systems allow significant discrepancies among regions which are not justified by disaster occurrence records, as shown by the previous section.

This analysis proposes the opportunity to improve coverage considering fairness for all the states in the country. Therefore, this section introduces the use of the optimisation model designed to the case of Mexico to discuss potential improvements.

To account for the number of organisations, one model including facilities from the Mexican Government and Red Cross are used, whereas another includes the use of government facilities only to show the adaptability of the model. Figure 2 shows the facilities chosen for each one of the instances.

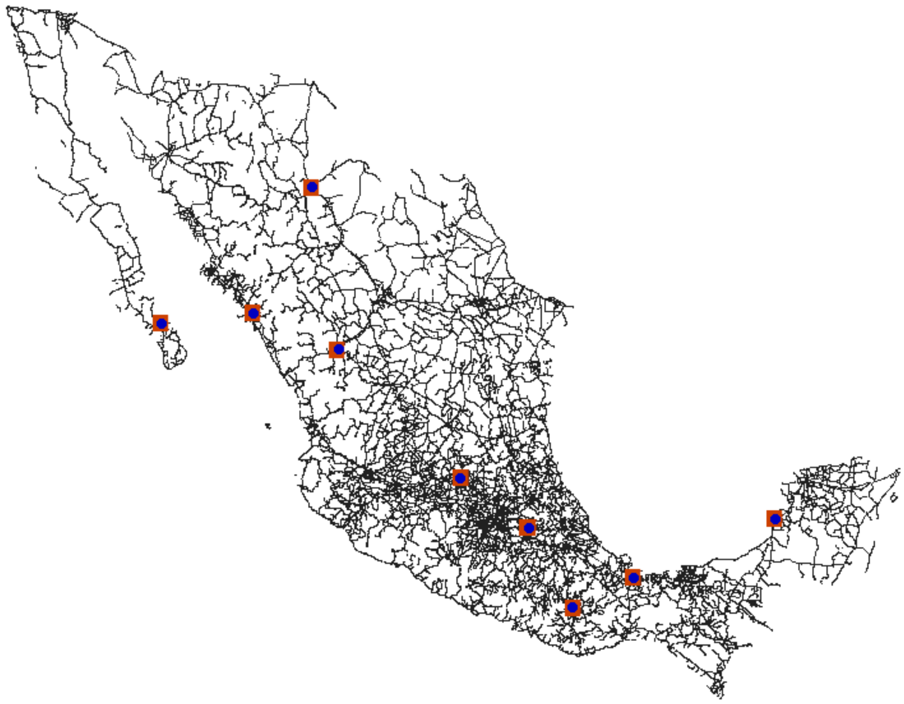

Fig.2 Proposed distribution centres from the government (blue) and shared facilities (orange)

Applying the model to both instances, the maximum and average distances to reach the different States are reduced, as shown by Table 4. The comparison shows better performance in terms of the coverage of potential demand areas.

Table 4. Comparison of distance coverage among policies.

Distance (miles)	*Government only*	*Shared facilities*	*Current policy*
Maximum	19.43525	19.42	43.88
Minimum	0.0195	0.02	0.05
Average	4.144016	4.131563	5.799063

Similarly, Table 5 shows improvement in the coverage per time from both instances obtained using the model compared to the current policy. The current policy is unable to provide total coverage within 12 hours after the emergency declaration, whereas the optimisation model was able to reach a hundred percent of coverage within that time.

Table 5. Comparison of time coverage among policies.

Time to reach the area	*Percentage of coverage*		
	Government only	*Shared facilities*	*Current policy*
4 hours	59.375	59.375	53.125
8 hours	81.25	81.25	81.25
12 hours	96.875	96.875	87.5
18 hours	96.875	96.875	93.75
24 hours	100	100	96.875

Finally, Table 6 shows the comparison among the three policies in the cases of disasters in Tabasco, Veracruz and Guerrero. All instances have a similar performance in terms of Veracruz. The current policy could have reacted to the situation in Guerrero more than 4 hours before the proposed system. Nevertheless, it would have taken more than twice the time to provide support for Tabasco in comparison to the policy obtained from the model. This is relevant because that emergency represented the most disastrous case and the most challenging one as well. Overall, the model provides a more balanced response across the three cases and reasonable response times in general and for the selected instances.

Table 6. Comparison of time coverage among policies.

Time	*Current policy*			*Shared facilities*			*Government only*		
	Ver.	*Gue.*	*Tab.*	*Ver.*	*Gue.*	*Tab.*	*Ver.*	*Gue.*	*Tab.*
4 h	8334	5000	4166	19250	0	1375	19250	0	1375
8 h	17500	14167	5833	22687	21312	2750	22687	21312	2750
12 h	20000	20000	15000	22687	22687	23375	22687	22687	23375
16 h	25000	22500	20000	24062	22687	24062	24062	22687	24062
20 h	25000	25000	20000	24750	23375	24062	24750	23375	24062
24 h	27500	27500	25000	25438	25438	24062	25438	25438	24062
Time to reach demand	2.9 hours	Less than 1 hour	22.7 hours	2.8 hours	5.3 hours	10.3 hours	2.8 hours	5.3 hours	10.3 hours

Analysis of results

The analysis of the stock prepositioning policy in the country shows significant differences among potential demand areas. Despite the number of facilities and their geographical dispersion, there are regions not properly covered within 24 hours after the disaster. The purpose of stock prepositioning is to reduce lead time and provide immediate support after the disaster, but the current policy shows room for improvement in terms of responsiveness. The proposed model was used considering instances with shared facilities and governmental facilities only. In both cases, the level of coverage at different time periods and the average distance to each one of the demand areas were improved in comparison to the current policy.

To show the level of coverage in real emergencies, information from three case studies was used. The results show how the proposed model is able to provide a more consistent response across cases and across periods. Although the three cases occurred in highly covered areas under the current policy, the instances prepared provided more prompt response for two out of the three cases, including the disaster with highest magnitude. The reason the current policy was able to deliver more food after 24 hours was the extended coverage obtained from forcing the model to ensure each potential demand area is covered within different time periods depending on the disaster probability occurrence.

The closeness of the results between the instances with shared and governmental facilities is because Red Cross and the government have several facilities in the same cities. Despite the result, the practical implications have to be mentioned. Allowing the use of shared facilities can prevent duplication of efforts resulting from each organisation establishing a prepositioning policy independently. The model allows pooling resources from different actors, which is an effective approach for disaster operations (Balcik et al., 2010). Future research will focus on testing the model with several organisations to show potential improvements from this approach, such as the use of multiple suppliers.

The use of stock prepositioning as a policy itself has to be argued as well. Despite of the great advantages provided by stock prepositioning, this policy can result on very high costs and the uncertainty of events can affect perishable items. As a result, there are articles exploring alternative solutions. Oloruntoba and Gray (2006) argued that the use of effective demand-led inventory management using postponement can allow quick responsiveness while maintaining lowers cost in comparison to prepositioning. Later on, Saputra et al. (2015) explored the trade-off between transport modes and end-of-shelf-life policies for medicine prepositioning in cases of disaster. Using the operations of Médecins Sans Frontières in Zimbabwe, the authors concluded that if the mean time between disasters is smaller than the actual remaining shelf-life of stocked items, then most likely the resources will be used before expiry. Kunz et al. (2014) also argued the feasibility of stock prepositioning by analysing the differences between that strategy and investing in disaster management capabilities. These capabilities include training staff, pre-negotiating customs agreements, or harmonizing import procedures with local customs. The paper used system dynamics to represent the process including time delays as a relevant factor and considering nonlinear functions. Using data from the 2011 Horn of Africa crisis, the article showed the importance of applying a preparedness strategy, the high-level of service and high-cost relationship inherent of prepositioning, and the potential of investing in disaster management capabilities with good levels of service and lower costs than stock prepositioning. To outweigh the cost of a stock prepositioning policy and manage expiration dated, the Mexican policy uses DICONSA. The company in charge with stock prepositioning is also the company managing social programs. Considering the nature of the products used for stock prepositioning, inventory can be depleted constantly and linked to social programs to allow the renovation of the stock frequently, thereby preventing expiration. However, that ought to be supplemented by the investment in disaster management capabilities, as mentioned by Kunz et al. (2014), to improve the flow of resources within the country and from outside of the country.

Conclusions

This research provided an analysis of the current stock prepositioning policy for disasters in Mexico. A significant investment has been undertaken to improve immediate response after disasters, but the analysis performed shows areas of opportunity for future improvement. The current policy was analysed in terms of the general response capability of the system and using data from three recent disasters to assess its performance

The model with different coverage quality levels proposed can provide a more consistent coverage for every potential demand area, improve the allocation of resources and reduce response time to sensible periods. Additionally, the model proposed showed a very good performance in terms of percentage of coverage per period and responsiveness for the three cases analysed.

Finally, the inclusion of shared facilities is a possibility to improve disaster response in the country. The shared management of facilities an inventories can improve lead time at the same time as the investment is reduced and overlaps among organisations are minimised.

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