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Invited Review

Prepositioning of assets and supplies in disaster operations management: Review and research gap identification

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ABSTRACT

Prepositioning of assets and supplies prior to a disaster strike accelerates the response activities as it reduces the supply chain burden associated with humanitarian relief items. Unlike prior survey papers on pre-disaster and post-disaster humanitarian logistics, our paper has a specific focus on prepositioning of assets and supplies in the domain of natural disasters. The first aim of our paper is to review the main Operations Research and Management Science (OR/MS) journal papers published between 2000 and 2018 on this topic. We have statistically analyzed these papers based on contributions in different journals, number of papers per year, and type of disaster. We have also categorized the papers based on their decision variables into three categories: Allocation papers (“A”), Location papers (“L”), and Location-Allocation papers (“LA”). After that, we have assessed our current literature based on some of the methodological issues in Humanitarian Operations that gathered by Kovacs and Moshtari (2018). The second aim of our paper is research gap identification. Our key findings in this domain are that there is a lack of papers that: consider demand-side costs in their proposed model objectives; deal with uncertainty in funding, budget, asset and supply quantities, and infrastructure; considering prepositioning as a risk mitigation strategy; take reliability into account for reducing the risk of loss; consider prepositioning of medical staff and emergency crew; discuss the best time to start prepositioning of supplies and assets in confronting a foreseen disaster; use social media to better prepare for upcoming disasters.

1. Introduction

The year 2017 was catastrophic as far as natural disasters are concerned. In August 2017, more than 1000 people were killed in Sierra Leone floods and landslides. In the same month, Hurricane Harvey made landfall in Southwestern Texas and caused $ 125 billion in damage and resulted in a death toll of 107. After Hurricane Harvey, Hurricane Irma struck Florida and caused $ 65 billion in damage and resulted in a death toll of 134. Weeks after Hurricane Irma, Hurricane Maria struck Puerto Rico. Maria was the third costliest hurricane in history, after Katrina and Harvey. The lack of aid after Hurricane Maria caused a humanitarian crisis that was the worst after Hurricane Katrina. Significant earthquakes also made 2017 a devastating year. Two major earthquakes struck Mexico in September 2017. The first one killed 98 people, and the second 370 people. In November 2017, an earthquake with magnitude 7.3 occurred in Sarpol-e Zahab county in Kermanshah, Iran, and it killed more than 500 people (see Jeffery, 2017; Wikipedia, 2018). The October wildfire in North California killed at least 11 people and destroyed more than 1500 buildings. In December, Southern California was faced by the largest wildfire in the history of this State, which burned more than 280,000 acres (Jeffery, 2017). These examples of disasters were a subset of disasters that happened just in the year 2017. There are numerous examples of disasters that resulted in extensive property damage and deaths prior to 2017. The mentioned natural disasters in 2017 were highlighted with the intent of demonstrating the destructive strength of natural disasters and the lack of preparedness from a logistical perspective. Prepositioning of items such as water, food, and medicine, transportation supplies such as gasoline, power supplies such as generators, and rescue supplies such as boats and vehicles is one way to combat the impacts of such disasters, and is the focus of this review paper.

It is important to point out that it is difficult to plan for prepositioning of non-climate induced disasters (e.g. earthquakes), as the location, intensity and timing of non-climate disasters are not predictable. However, relief supply for climate change induced disasters (e.g., hurricanes) can benefit significantly from prepositioning, due to their predictability. It is also important to make clear that we are not making an assertion that prepositioning is the most valuable approach in the preparedness for natural disasters.

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However, we believe that it is an approach which has been used by humans for centuries when they have been confronted with uncertain situations (for instance, pirates used to hide and store food on remote islands where they could go if stranded). We note that some papers question prepositioning as a viable strategy due to the risk of losing prepositioned supplies and assets from the disaster event itself. We believe that this concern can be addressed by positioning supplies and assets close enough, but not too close, to the disaster event.

1.1. Overview of prepositioning in Humanitarian Operations (HO)

Prepositioning is a complex activity and in order to understand its elements we present various features of prepositioning that provide the reader of the scope of this activity in relation to HO. The elements that we elaborate on are: (i) general definition of prepositioning, which specifies its timing and the common supply and asset items; (ii) national versus international response, which specifies what the differences are when international organizations get involved in HO; (iii) intricacies of prepositioning, which specify how various relief organizations coordinate in HO; and (iv) role of kits in prepositioning, which specify how items are bundled together in HO so as to be useful to the end users.

1.1.1. General definition of prepositioning in HO

Prepositioning of assets and supplies is agreed upon by researchers to be an activity that occurs in the preparedness phase. It can either be done over a short time horizon just prior to the disaster (tactical) or over a long time horizon significantly before the specific disaster details are known (strategic). We note that the terms “assets” and “supplies” have a broad meaning. Assets can include items like shelter locations, vehicles, and expert teams. An example of this type of prepositioning is the deployment and prepositioning of search and rescue personnel and medical staff prior to the arrival of the hurricane, c.f. FEMA (2017), Katz (2018), and Alvarez (2018). Supplies can include items like food, water, blanket, and medicines which are often prepositioned in kits (see Section 1.1.4 for more details).

In this paper, we sometimes use the term “stock” to reflect both assets and supplies, to simplify presentation.

1.1.2. National/regional versus international response

The chief role of prepositioning is to enhance preparedness. The concept of preparedness can be applied at different levels. The nation/region needs to be prepared for the forthcoming event. Organizations and other countries need to be prepared to offer assistance during and after the event. These organizations can include private companies as well as international relief agencies such as the Red Cross. National and regional governments usually take into account beneficiary preferences, climate and standards, whereas international organizations must follow global standards and are not able to take into account local preferences. Location and allocation are key decisions in both nation/region and international response to a disaster that justifies the need for prepositioning relief items (see Adıvar & Mert, 2010; Kovács & Spens, 2009).

1.1.3. Intricacies of prepositioning

A group of organizations often jointly preposition with the possibility of cross-utilization. An example of this is UNHRD depots, which often lead to “blanket stock” which are prepositioned, and these are later allocated to specific organizations and disasters (see Adida, DeLaurentis, & Lawley, 2011; Jahre et al., 2016). It is up to specific organizations to decide who will end up delivering what items from this blanket stock. Thus the question of location/allocation of disaster relief items can be addressed at the “blanket stock” level for UNHRD depots, as well as at the local/regional level of a specific disaster.

1.1.4. Use of kits in prepositioning

Kits are often used in prepositioning so as to ensure usability of the items. For example, if one were to provide cooking utensils then one would also need to provide tools and cutlery, stoves, and fuel for stoves. As another example, water, sanitation and hygiene items come in packages that include buckets and cleaning equipment. Thus standardization and modularization of items is necessary in kitting decisions (Balcik, Beamon, Krejci, Muramatsu, & Ramirez, 2010; Chandes & Paché, 2010; Vaillancourt et al., 2015). Perishability of items also needs to be addressed in inventory models.

1.2. Previous research and motivation

There are several survey papers in the area of HO and disaster management. Altay and Green III (2006) surveys Operations Research and Management Science (OR/MS) literature and discusses issues in disaster operations management. Jia, Ordóñez, and Dessouky (2007) reviews the literature related to facility location problems for regular emergencies in three traditional categories: covering model, p-median model, and p-center model. Further, the authors propose a facility location model for medical services in a large-scale emergency. Başar, Çatay, and Ünlüyurt (2012) systematically classifies emergency service station location problems from an operations research perspective. Caunhye, Nie, and Pokharel (2012) proposes a comprehensive review of optimization models in emergency logistics in OR/MS journals until 2011. The focus of this paper is on optimization models in pre-disaster and short-term post-disaster plannings. Galindo and Batta (2013b) continues the work of Altay and Green III (2006) and reviews the OR/MS papers in disaster operations management in the timeframe 2005–2010. Their work reveals to what extent the gaps found by Altay and Green III (2006) are covered until 2010. Holguín-Veras, Pérez, Jaller, Van Wassenhove, and Aros-Vera (2013) discusses the literature on post-disaster humanitarian logistics by categorizing models based on their objective function into three categories: primarily logistic costs, only a proxy measure of human suffering, and both logistic costs and a proxy measure of human suffering. The authors finally suggest the use of social costs in the objective function of post-disaster humanitarian logistics models as the preferred objective function. Rennemo, Rø, Hvattum, and Tirado (2014) surveys literature related to disaster response planning. The authors provide some information about the models used in the literature like problem type, uncertainty treatment, and objective function. Özdamar and Ertem (2015) surveys mathematical models in humanitarian logistics that have focused on disaster response and recovery phases. Gutjahr and Nolz (2016) surveys multicriteria optimization models in natural disaster and humanitarian crisis management. Gupta, Starr, Farahani, and Matinrad (2016) assesses the macro level of disaster management research from 1957 to 2014. Jabbour et al. (2017) surveys literature on humanitarian logistics and supply chain management. In this paper, articles are classified based on their economic context, focus, method, type of disaster, phase of disaster relief, type of humanitarian organization, region of authorship and region of disaster. None of these review papers, however, is focused on stock prepositioning in HO and disaster management. Caunhye et al. (2012) discusses facility location models combined with relief distribution and stock prepositioning in a special section, but it only includes a specific type of papers related to stock prepositioning.

Prepositioning of assets and supplies is known as one of the main pre-disaster operations (Caunhye et al., 2012). Given that we could not find any survey paper with the focus on this important operation, we decided to systematically examine the published articles between the years 2000 and 2018 (in the main journals of operations research and management science) that worked on this operation in the domain of natural disasters. Natarajarathinam, Capar, and Narayanan (2009) categorizes the literature in supply chain crisis management in categories conceptual, analytical, empirical, and applied research. In the present work, we limit our literature to analytical papers.

1.3. Research contributions and findings

1.3.1. Contributions

- *Comprehensive source of related past work*: even though many review papers exist in the disaster logistics space, there is no review specific to prepositioning of assets and supplies in HO.
- *Classification of literature stream based on various characteristics*: first a statistical view of the papers in this area, second an explicit categorization of relevant papers from an operations research perspective, and third an overview of critical concerns in HO (gathered by Kovacs & Moshtari (2018)) that are addressed or neglected by our literature. The statistical classifications we provide include journal contributions, number of relevant papers per year, and the type of disasters investigated by the literature. From an operations research perspective, we group papers based on decision variables used to three categories: location papers ("L"), allocation papers ("A"), and location-allocation ("LA") papers. Further, we provide detailed information about the literature in each of these categories, e.g. model objectives, decision variables, constraints, type of model, uncertain parameters, planning horizon, solution methodology, and case study. After that, we assess our current literature based on some of the methodological issues in HO gathered by Kovacs and Moshtari (2018), to see how many and which papers considered these critical items in their research. These critical issues in HO are categorized in the following six categories: problem definition and research design, understanding contextual factors, acknowledging the uncertainties in HO, choosing the appropriate data and research methods, incorporating uncertainty in the modeling, and use of enabling technologies for model development and implementation. By performing these classifications we were able to identify several research gaps.
- *Research gap identification*: we identify research gaps in the prepositioning domain of HO. While we intend to work on some of these research gaps in our continued work in this area, we also hope that other researchers in HO will work on the other identified gaps, so that collectively we can help complete the toolkit for prepositioning in the HO context.

1.3.2. Findings

Our findings by applying mentioned classifications on the current literature reveal several gaps and future research directions, which are as follows: lack of tailored models for specific type of disasters, lack of papers that consider demand side costs in their proposed model objectives, a need for more research on considering prepositioning as a risk mitigation strategy, a need for more research on combining the prepositioning problem in preparedness phase with the expected cost of the last mile problem in response phase, a need for papers that take reliability into account for reducing the risk of loss, lack of papers that consider prepositioning of medical staff and emergency crew, a need for more realistic models, lack of papers that discuss the best time to start prepositioning of supplies and assets in confronting a foreseen disaster, and a need for more research on using social media to better prepare for upcoming disasters.

1.4. Organization of paper

The rest of this paper is organized as follows: Section 2 illustrates key fundamental concepts that this paper relies on and specifies the search methodology used to acquire relevant papers. Section 3 presents statistical classifications that we have assessed, e.g. journal contributions, number of relevant papers per year, and the type of disasters investigated. Section 4 categorizes and analyzes papers based on model decision variables. Section 5 assesses our current literature based on some of the methodological concerns in HO that are gathered by Kovacs and Moshtari (2018). Section 6 identifies and provides an in-depth discussion of the gaps found, with the hope of providing fruitful future research directions for the OR/MS humanitarian logistics research community. Finally, Section 7 provides a summary of the paper.

2. Search boundaries and methodology

In this research we applied the systematic literature review steps to provide a comprehensive review of literature in POD area. Section 2.1 provides a brief description of a systematic literature review and implementation of it in the current paper. In order to find papers related to prepositioning of assets and supplies in the domain of natural disasters, we first have to specify what we mean by the term "disaster". This is the focus of Section 2.2. After providing our definition for this term, we used a systematic search methodology to acquire related papers. Details of this search methodology are explained in Section 2.3.

2.1. A systematic review

A systematic review should follow a list of specific steps to assure that relevant studies regarding the topic are acquired without any bias. These steps are summarized as follow: (1) identification for the need for a review, (2) identifying a sample of potentially relevant works, (3) selecting the relevant literature, (4) summarizing the evidences, (5) reporting the results and findings (Durach, Kembro, & Wieland, 2017; Khan, Kunz, Kleijnen, & Antes, 2003; Tranfield, Denyer, & Smart, 2003). The mentioned steps are all followed in the current study. Section 1.2 presents the first step. Sections 2.2 and 2.3 present the second and third steps. Sections 3, 4, 5, and 6 present the fourth and fifth steps.

2.2. Definition of the term disaster

There are several definitions for the term disaster in the literature. The International Federation of Red Cross and Red Crescent Societies (IFRC) defines the term disaster as "a sudden, calamitous event that seriously disrupts the functioning of a community or society and causes human, material, and economic or environmental losses that exceed the community's or society's ability to cope using its own resources" (IFRC). In Van Wassenhove (2006), the term disaster is defined to be a disruption that physically affects the entire system and may change its goals and priorities. Another specification of the term disaster is found in Altay and Green III (2006), who compare routine and catastrophic events; they assume that catastrophic events do not include routine and daily emergencies and cannot be handled by a governmental agency through a standard procedure, implying that more resources need to be involved than usual to save lives and provide safety. Another definition for the term disaster that covers all the previous definitions and seems to consider all aspects of it, is as follows: "a disaster is a shocking event that seriously disrupts the functioning of a community or society, by causing human, material, economic or environmental damage that cannot be handled by local agencies through standard procedures" (Galindo & Batta, 2013b). We have chosen to rely on this definition for the term disaster.

Another important thing to discuss is the type of disaster. IFRC defines two general types of disasters, namely natural disasters and man-made disasters. We note that IFRC includes health disasters in its natural disaster category. In this paper, we focus on natural disasters while excluding health disasters (like disease epidemics and insect/animal plagues), since in our opinion the origins of these kinds of disasters are sometimes natural and sometimes man-made. For simplicity of presentation, in the rest of our paper when we use the term "disaster" we mean natural disasters while excluding health disasters.

2.3. Search methodology

After understanding the key concepts (the terms "disaster" (see Section 2.2) and "prepositioning"(see Section 1.1)), we focused on the task of finding published journal papers that are related to "prepositioning of assets and supplies in the domain of natural disasters logistics" (POD). To do this, a systematic approach was used, as now described. The search engine that is used the most was Google Scholar. We supplemented the use of Google Scholar with the following databases, ISI's Web of Science, INFORMS search engine, and Wiley Online Library. Keywords "disaster", "evacuation", "rescue", "hurricane", "cyclone", "flood", "Wildfire", "storm", "drought", "extreme temperature", "emergency", and "humanitarian" were searched in the *title* of journal papers published in English, to collect all the papers that had at least one of these keywords in their title. The set of keywords that we have chosen were carefully selected after several discussions between the coauthors with the goal of having a comprehensive coverage of the journal papers related to the POD area. Book chapters, conferences proceedings, theses and working papers were excluded from this study. The period of our search was limited to the year 2000 and thereafter. To be more precise, if a journal paper related to our topic has been published (in the specific type of journals illustrated in the next paragraph) before the end of the January 2018, we included it in our study. However, we do not claim that all papers in the POD area are presented in this work.

To acquire main journals in OR/MS field for this study, we used the InCites Journal Citations Report website (InCites, 2016), where journals are ranked based on their impact factors. We limited the category of journals to Operations Research and Management Science, and the Journal Citations Reports year to the year 2016. We also considered both available editions "SCIE" and "SSCI". Through this method, we ended up with 83 journals. The reason for considering journals with impact factors is an impact factor for a journal shows the relative importance of that journal within its field. Moreover, it is not feasible to consider all of the OR/MS journals since we have a very large number of them in this field. Hence, in this paper we decided to consider the main OR/MS journals.

After searching for our keywords through the mentioned journals, we acquired 2301 papers as the initial result. We were certain that many of these papers did not fit in our scope. Hence, we defined two levels of filtering to extract the most related papers to the POD topic:

- First Level: check the title of the papers and eliminate the papers with titles completely different from our research domain. Otherwise, check the abstract to remove irrelevant papers. (For example in this stage, we have eliminated papers with titles or abstracts related to man-made disasters or papers with titles and abstracts that clearly and totally talk about post-disaster phases (response and recovery phases).)
- Second Level: for papers that passed the first filter, check problem description, formulation (especially check the decision variables to see if the decision variables are related to prepositioning problems), and the conclusion to eliminate unrelated papers.

By applying the first level filter, we ended up with 223 papers. Then by applying the second level filter, we had a total of 74 papers left in our survey effort.

The papers analyzed above were gathered from searching on the main OR/MS journals contained in InCites (2016). This does not mean that papers in POD do not exist in other journals. Indeed, we found some seminal papers in POD area in the some other journals: International Journal of Physical Distribution and Logistics Management, Journal of Humanitarian Logistics and Supply Chain Management, International Journal of Disaster Risk Reduction, and Disasters. For the sake of completeness, we have included them in Section 4, but they are not part of the analysis in Sections 3 and 5.

These papers are as follows: Hale and Moberg (2005), Şahin, Alp Ertem, and Emür (2014), Hong, Jeong, and Feng (2015a), Cavdur, Kose-Kucuk, and Sebatli (2016), Mohamadi and Yaghoubi (2017), and Horner, Ozguven, Marcelin, and Kocatepe (2018).

3. Statistics and characteristics of the articles

We now provide statistics and characteristics for the 74 papers that we studied in detail. This includes contributions in different journals, and trends in number of papers by year and type of disaster. A summary of our findings is also provided.

3.1. Contributions in different journals

Fig. 1 shows that from 83 OR/MS journals proposed by the website (InCites, 2016), only 25 journals remained in our survey based on the two-level filtering we discussed in Section 2.2. It means that only around one-third of these journals had a contribution in the POD area from 2000 till January 2018. This fact uncovers one of our motivations of writing this paper, which is to encourage the rest of the OR/MS journals to seek papers that address the POD area, which we believe is one of the most important and challenging tasks in the pre-disaster phase. As one can see in Fig. 1, the first place based on the number of published papers, belongs to the"International Journal of Production Economics" with 10 papers. The second, third, fourth, and fifth place are occupied by "Annals of OR" with 9 papers, "Transportation Research Part E" with 7 papers, "EJOR" with 5 papers, and "Socio-Economic Planning Science", "JORS" and "Computer and OR", each with 4 papers, respectively. Moreover, one can see that from the year 2000 to January 2018, the first place journal has published only one paper per every 2 years approximately, which shows the lack of work and research in this area despite a large number of disasters that could have benefited from judicious prepositioning of assets and supplies. For example, in Hurricane Harvey, which impacted Houston, Texas, USA, in 2017, if assets such as evacuation boats and supplies like medical supplies had been prepositioned prior to the extensive flooding that occurred the outcomes from this event would likely have been significantly improved.

3.2. Trend in number of papers by year and type of disaster

Fig. 2 provides information about the number of papers during the years 2000–2017 and the type of natural disasters considered by these papers. Note that when we were writing this paper, the year 2018 is not finished yet. Hence, we eliminated this year from Fig. 2. The disaster type "general" which is shown by the color light blue in Fig. 2, refers to those papers which did not mention any specific type of natural disaster. To be more precise, they claimed applicability of their proposed methods to all type of natural disasters.

Based on Fig. 2, between the years 2005 and 2008, we only see one or two papers in each year, which is a low number. Then, between the years 2010 and 2014, the number of papers is between

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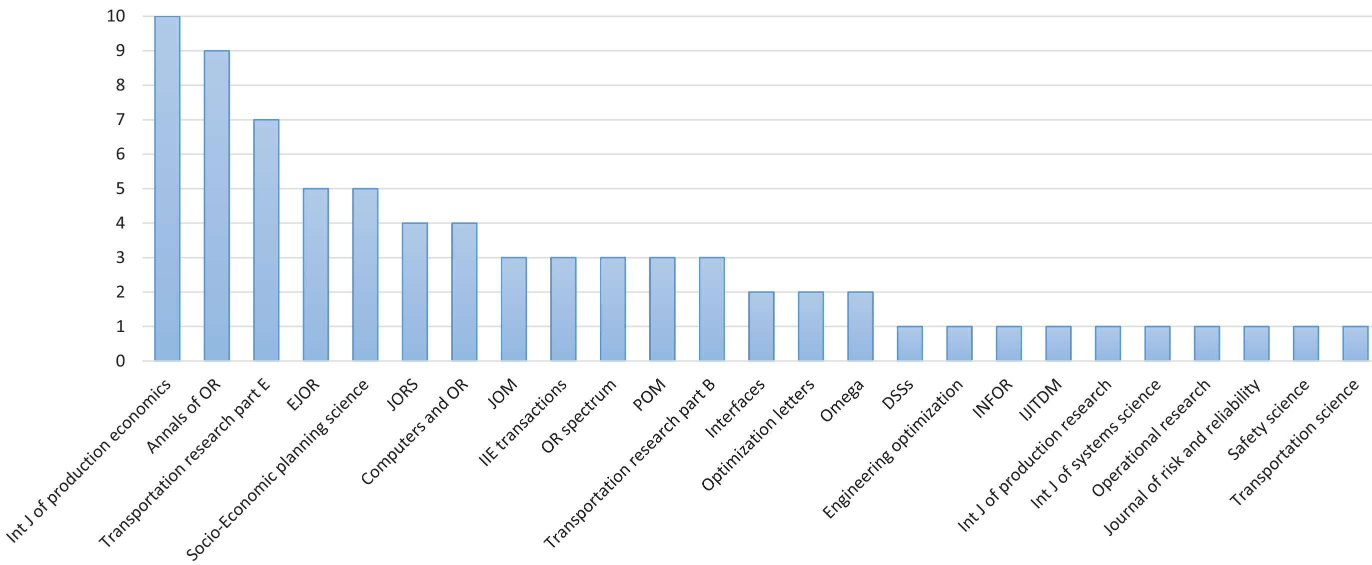

Fig. 1. Number of published articles in OR/MS journals in the period 2000–2018. (Complete name of journals with abbreviation name in figure 1: European Journal of Operational Research (EJOR), Journal of the Operational Research Society (JORS), Journal of Operations Management (JOM), Production and Operations Management (POM), Decision Support Systems (DSSs), Information Systems and Operational Research (INFOR), and International Journal of Information Technology and Decision Making (IJITDM).)

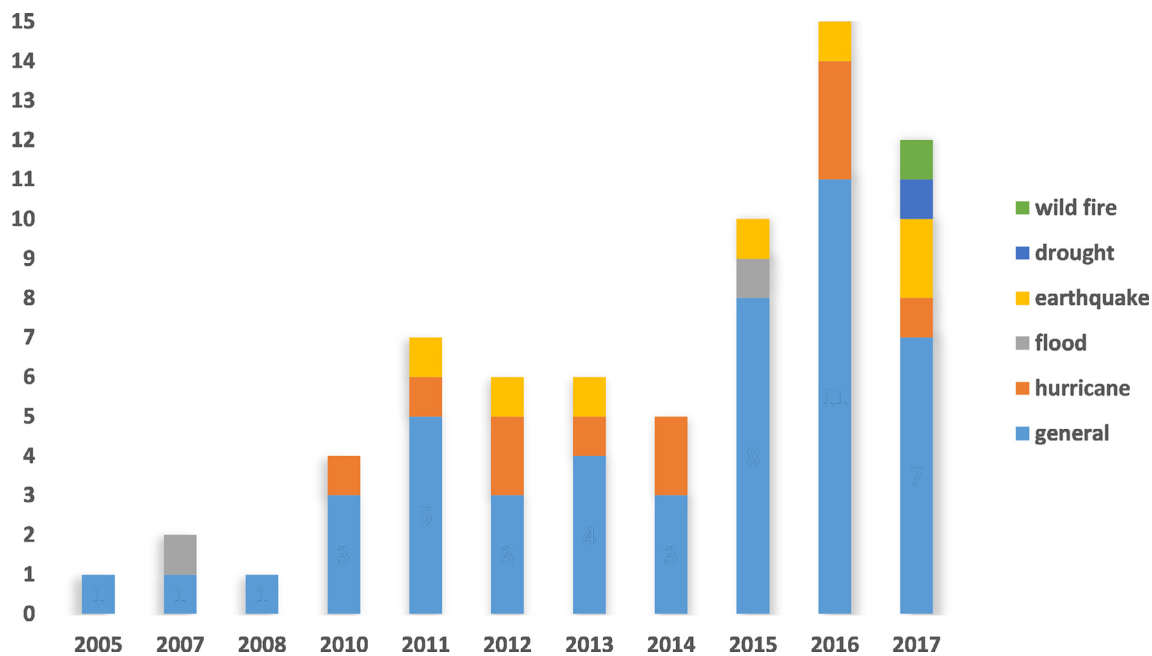

Fig. 2. Trend of published papers in OR/MS journals over time and type of disasters considered. (For interpretation of the references to color in this figure, the reader is referred to the web version of this article.)

four and seven each year. Finally, between the years 2015 and 2017, the number of papers is between ten and fifteen. Hence, on average we see a significant upward trend in the number of papers in the POD area. Moreover, there is a tangible rise in this number from the year 2015 and after, in comparison with their previous years, which shows an increase in researchers' attention to the POD area in recent years. In addition, in the year 2017, we see that two papers considered wildfire and drought natural disasters, a category that was not considered by earlier papers. We explain the potential reasons behind an increase in research activity in the POD area further in Section 3.2.2.

3.2.1. Statistics on disaster types considered

The last point about Fig. 2 is the fact that, each year, more than half of the papers are papers that considered the "general" type of natural disasters. Actually, by some basic calculations, one can see that, around 70% of the papers considered general natural disasters, and a small portion of 30% is devoted collectively to specific disaster types, like hurricanes, earthquakes, floods, droughts, and wildfires. Gupta et al. (2016) have a similar finding for papers in the Humanitarian Operations (HO) area, they found that a high number of HO papers claim that their work can be applied to any kind of natural disaster. An example to illustrate the differences in requirements between disaster types is found between earthquakes (where physical injuries are one of the usual concerns and consequently medical supplies, and medical teams are in priority) and droughts (where food and water shortages are the usual concerns) (IFRC, 2000).

This gap has also been widely discussed by Kovacs and Moshtari (2018) in which they emphasize the significant role that reviewers of papers and books have in the process of accepting work while maintaining high academic standards. One of these

Table 1
List of disasters and related papers.

Hurricane	Taskin and Lodree Jr (2010), Taskin and Lodree (2011), Lodree Jr, Ballard, and Song (2012), Li, Nozick, Xu, and Davidson (2012), Galindo and Batta (2013a), Kelle et al. (2014), Chakravarty (2014), Paul and MacDonald (2016), Morrice et al. (2016), Pacheco and Batta (2016), Dalal and Üster (2017)
Earthquake	Ahmadi et al. (2015); Döyen et al. (2012); Edrissi et al. (2013); Görmez et al. (2011), Baskaya et al. (2017); Ebrahimi and Modam (2016); Khalilpourazari and Khamseh (2017)
Flood	Chang, Tseng, and Chen (2007); Garrido, Lamas, and Pino (2015); Rodríguez-Espíndola et al. (2018)
Drought	Burkart, Nolz, and Gutjahr (2017)
Wildfire	Yang et al. (2017)

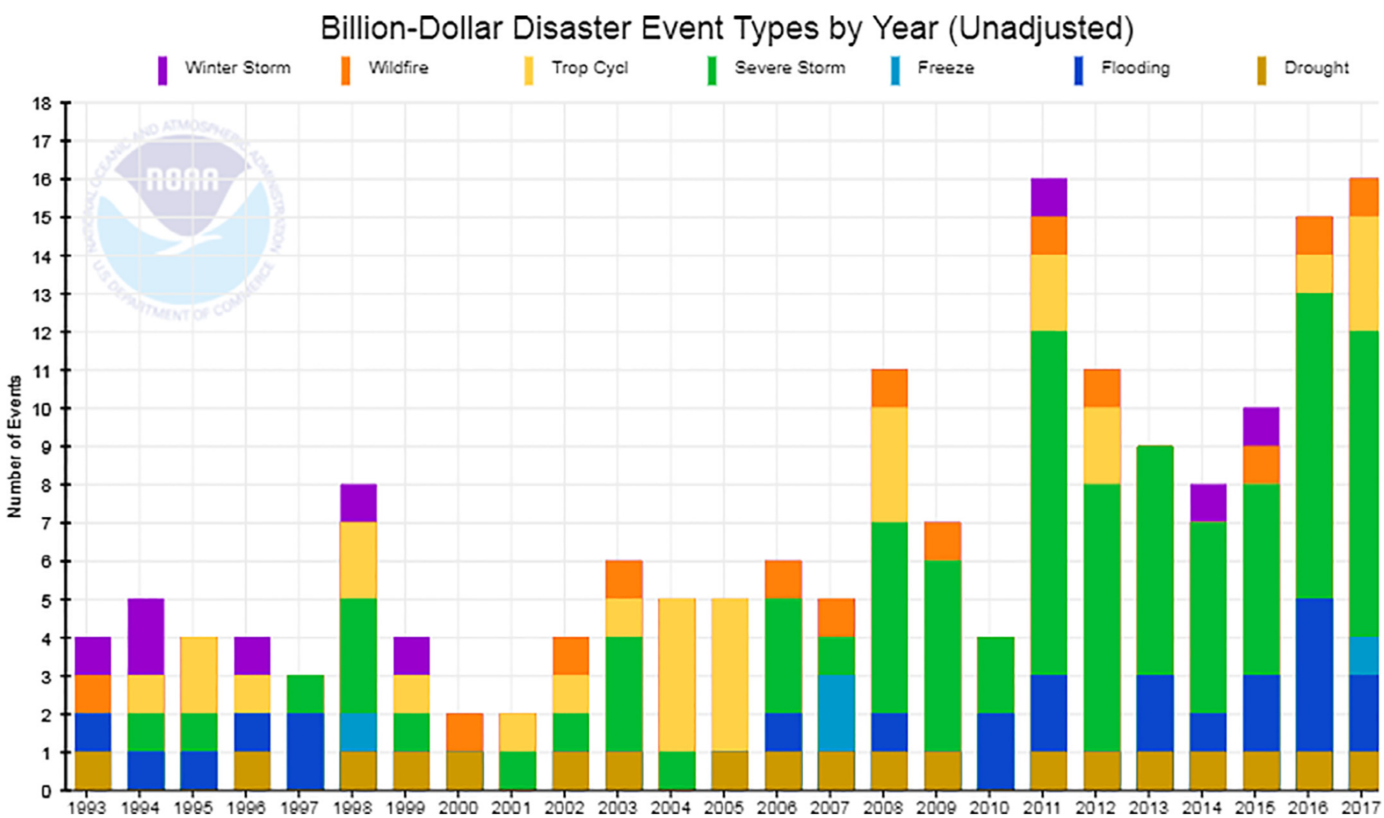

Fig. 3. Number of climate change related natural disasters over the years (NOAA, 2018).

standards in HO is to have studies that instead of claiming applicability of their findings to all type of disasters, propose models and methods for each type of disaster based on its specific characteristics. In Table 1, we provide the list of our reviewed papers that consider a specific type of disaster.

3.2.2. Climate change and climate disasters

It is predicted that the Earth is going to experience a gradual increase in the global average temperature because of rising in the greenhouse gas concentration. This event which is called "global warming" or "climate change" would cause fewer cold days and more hot days in all the areas with a high probability. As a consequence, some areas like mid and high northern latitudes are likely to face an increase in the frequency and intensity of precipitation events like floods and hurricanes, and some regions like part of Africa and Asia are going to observe a rising in the frequency and intensity of natural disasters like droughts and fires (Van Aalst, 2006). Kron (2012) claims that the number of climate disasters (natural disasters that are caused by climate change, are called climate disasters, like floods, hurricanes, droughts, and wildfires) has increased on all continents since 1980, most notably for North America. This claim can be strengthened by Fig. 3 (NOAA, 2018). Fig. 3 shows the number of billion-dollar climate disasters (overall damages/costs reached or exceeded $1 billion) over the years in the United States. Overall, despite some fluctuations, an increasing trend in the number of climate disasters over the years is evident in this figure.

Non-climate induced disasters are difficult to plan relief supply for from a prepositioning perspective, as they are not predictable. However, relief supply for climate change induced disasters can benefit significantly from prepositioning, due to their predictability. Over the last decades, the number of losses due to climate disasters has significantly increased (see Huggel, Stone, Auffhammer, & Hansen, 2013; Mechler & Bouwer, 2015; Pielke Jr et al., 2005). This increase in the number of climate disasters and the number of losses due to them we believe has stirred researchers to work on POD for climate disasters like wildfires and drought (see Fig. 2). The key point is that scientists predict that we are going to see an upward trend in the number of climate disasters in the decades ahead, and this emphasizes the urgent need for communities and local and national governments to prepare for future natural disasters (UNISDR, 2012). A key component of such preparation is judicious prepositioning of assets and supplies. Hence, we definitely need more researchers to work and publish applicable papers in the POD area.

3.3. Summary of article statistics and characteristics

A summary of our findings is as follows:

Table 2
Group "L" papers: Model objective.

Author	Model objective
Dekle, Lavieri, Martin, Emir-Farinas, and Francis (2005)	min total number of DRCs.
Hale and Moberg (2005)	min total number of secure sites (facilities).
Jia et al. (2007)	max demands coverage.
Li et al. (2012)	min average travel time.
Lu (2013)	min max demand-weighted travel time between relief stations and URDCs.
An, Cui, Li, and Ouyang (2013)	min travel cost, vehicle and evacuation cost, penalty cost and facility set-up cost.
Sheu and Pan (2014)	min travel distance for evacuees to arrive to shelters, min operational cost, min psychological cost for affected people.
Verma and Gaukler (2015)	min transportation cost.
Salman and Yücel (2015)	max demand covered with in specified distance.
Akgün, Gümüşbuğa, and Tansel (2015)	min max the risk that a demand point is not covered.
Ghezavati, Soltanzadeh, and Hafezalkotob (2015)	min transportation cost, fixed cost of establishing facilities, and fixed cost of using different roads.
An et al. (2015)	min en-route travel cost, facility setup cost and in-facility queuing cost.
Ahmadi et al. (2015)	min expected cost of violation from Standard Relief Time for vehicles and expected total distribution cost and other cost.
Hong et al. (2015a)	min goal deviations of target total logistic cost, target expected number of disrupted relief items, and target demand coverage.
Charles, Lauras, Van Wassenhove, and Dupont (2016)	min transportation cost and cost of maintaining and running the warehouses.
Mohamadi, Yaghoubi, and Pishvaee (2016)	min expected value of total demand weighted travel distance, max expected value of the total demand coverage, min expected value of total probability of evacuees' failure to arrive at shelters.
Stauffer et al. (2016)	min standard and expedited vehicle transportation cost, and structural cost of hub like maintaining and staffing.
Cavdur et al. (2016)	min total number of facilities, total distance travelled, and unmet demand.
Elluru et al. (2017)	min fixed setup cost, transportation cost, and risk cost. min re-routing cost, and penalty cost like non-delivery, time delay, lost in waiting time.
Burkart et al. (2017)	min travel cost and opening cost of DCs. min unserved demand.
Mohamadi and Yaghoubi (2017)	min total demand weighted transportation time between facilities, and total network costs.
Chapman and Mitchell (2018)	min operational cost, average walking cost for the population and δ-CVaR (Conditional Value at Risk) walking cost across the population (for minimizing disutility).
Horner et al. (2018)	min transportation cost between demand locations and facilities.

- One third of the journals examined have published at least one paper in the POD area.
- The three journals with the most number of POD papers are "International Journal of Production Economics", "Annals of OR", and "Transportation Research Part E".
- There has been a sharp increase in the number of papers in the POD area in recent years.
- 70% of the papers develop models for general disaster types.

4. Categorizing papers into location, allocation and location-allocation

In prepositioning there are typically two considerations, location of depots where supplies and assets are placed, and allocation of supplies and assets to established depots. Some papers discuss only one of these aspects and others discuss both aspects. For this reason, categorization of papers based on location, allocation and location-allocation is meaningful. Formally, these classifications are as follows:

(1) Location papers ("L"): papers in this group seek the best locations to preposition facilities. These papers do not attempt to find the inventory level of supplies and assets to be stored or deployed at these facilities.

(2) Allocation papers ("A"): papers in this category seek the best inventory level of supplies and assets (food, water, blankets, medical devices, medicines, medical staff and etc.) to be stored or deployed at the facilities. Note that, in this category, the locations of facilities are known.

(3) Location-allocation papers ("LA"): papers in this category look for both the best location of facilities and inventory level of stocks.

Note that by the word "allocation" in categories "A" and "LA", we only mean allocation of supplies and assets like food, water, medical staff, blankets, and vehicles to facilities, not demands or evacuees. Hence, papers that only look for the location of facilities and assigning demand points or evacuees to them, are not considered in the "LA" category. They belong to the "L" category. The reason is that these papers do not include our intended concept of the term "allocation".

We now separately analyze (in different sub-sections) papers in the "L", "A", and "LA" categories, based on decision variables and optimization goals. Tables are provided for this analysis. There exists papers in each of these categories that simply cannot be classified based of decision variables and optimization goals. These exceptions include papers that aim to provide managerial insights and papers that use a decision-theoretic framework. These papers with exceptions are not included in the tables and their contributions are reviewed after the analysis of the papers in the tables.

Key information related to the optimization models proposed in our reviewed papers are summarized in Tables 2–7 and S1–S3 in the "Supplementary materials". The information in Tables 2–7 includes the following attributes: objective function, decision variables, and constraints. The information in the Tables S1–S3 includes the following attributes: type of models, planning horizon, solution methodologies, and case studies.

Note that for conciseness of the paper, we delegate the largest tables which are Tables S1–S3 in the "Supplementary materials".

Two attributes we believe need further explanation. The first is the "type of model". The optimization model can be deterministic, stochastic, or robust based on the data parameters. If the type of model is stochastic or robust, it means there are some uncer-

Table 3
Group “L” papers: Decision variables and constraints.

Author	Decision variables	Constraints
Dekle et al. (2005)	facility location	residents distance of nearest DRCs
Hale and Moberg (2005)	location of secure storage areas	min and max total distance between facilities and demand points, coverage
Jia et al. (2007)	facility location, assigning demand points to facilities, demand points coverage	number of facilities
Li et al. (2012)	facility location	facility capacity, budget
Lu (2013)	facility location, assigning demand points to facilities	number of facilities
An et al. (2013)	facility location (evacuee pick up facility), assigning demand points (evacuees) to facilities	
Sheu and Pan (2014)	facility location (emergency shelters, medical centers, distribution centers)	facility capacity, evacuees flow capacity
Verma and Gaukler (2015)	facility location, assigning demand points to facilities	number of facilities, facility capacity, all demand satisfaction
Salman and Yücel (2015)	facility location, assigning demand points to facilities	number of facilities, coverage distance limit
Akgün et al. (2015)	facility location	number of facilities
Ghezavati et al. (2015)	facility location, amount of flow from demand points to first and second level facilities on specific roads, amount of flow between first and second facilities on specific roads, roads usage, unsatisfied demands	number of facilities, facility capacity (max and min), flow from the first level facilities to the second level, road capacity
An et al. (2015)	facility location, assigning demand points to facilities (victim to facility), facility priority decisions of each demand group, link flow	demand assignment and coverage
Ahmadi et al. (2015)	facility location(distribution center, local depot), vehicle routing, last mile distribution of relief goods	facility capacity, vehicle capacity, time limit, multiple use of vehicles
Hong et al. (2015a)	facility location, assigning demand points to facilities	facility capacity, number of facilities
Charles et al. (2016)	facility location, number of facility	number of facilities, time limit
Mohamadi et al. (2016)	facility location (shelter, RDC, and backup RDC), assigning demands to shelters, affected area coverage by telecommunication towers, RDCs, and shelters, assigning shelters to RDCs or backup RDCs	number of facilities (shelter, RDC), facility capacity (shelter, RDC), demand coverage, telecommunication coverage, shelter demand
Stauffer et al. (2016)	facility location (hub), assigning vehicles to facilities, number of vehicles paid by general or earmarked fund	earmarked budget
Cavdur et al. (2016)	temporary disaster response facilities allocation, assigning demands to neighborhoods, relief distribution	facility capacity, number of facilities, safety level of neighborhood for allocating facilities, demand satisfaction
Elluru et al. (2017)	facility location, vehicle routing, vehicle arrival time at customer and waiting time there	facility capacity, facility capacity expansion, vehicle capacity, route capacity, demand coverage
Burkart et al. (2017)	facility location, unsatisfied demands, vehicle load, share of demands	facility capacity, vehicle capacity
Mohamadi and Yaghoubi (2017)	facility location, assigning demands to facilities, flow volume between facilities	facility capacity, coverage of min condition of AA, time limit, demand satisfaction
Chapman and Mitchell (2018)	facility location, assigning demands to facilities, δ-Var and δ-CVaR for the optimal solution, the absolute difference between walking cost and δ-VaR,η	facility capacity
Horner et al. (2018)	facility location, assigning demands to facilities	facility capacity, number of facilities

Table 4
Group “A” papers: Model objective.

Author	Model objective
Taskin and Lodree Jr (2010)	min inventory ordering cost, excess inventory holding cost, and inventory shortage cost.
Lodree Jr et al. (2012)	min prepositioning cost, min expected cost of redistributing inventory, inventory shortage, and excess.
Davis, Samanlioglu, Qu, and Root (2013)	min expected prepositioning cost, expected supply distribution cost, expected supply redistribution cost, expected supply shortage cost, and expected prepositioned supply loss cost.
Kelle et al. (2014)	min prepositioning cost, min expected transportation cost of evacuees and commodities and the shortage or surplus cost, min max regret associated with selected subset of scenarios.
Zhan, Liu, and Ye (2014)	min total time (vehicles travel time from supply points to demand points plus the time delay coming from disaster scenario updates), min total unmet demand, min total expansion costs for vehicles and relief supplies and total travel cost for vehicles to distribute supplies.
Garrido et al. (2015)	min the cost of transporting supplies to demand zones, the cost of moving vehicles between depots, shipping origins, and destinations, the cost of carrying pre-positioned supplies.
Alem et al. (2016)	min pre-positioning stock cost, hiring vehicle cost, expected cost of inventory and unmet demand.
Morrice et al. (2016)	first stage (after observing 5 day forecast): min transportation cost, expected loss sales in the first stage, expected cost of managing inventory in the second stage. second stage (after observing both 5 and 3 days forecast): min inventory shipment, shortage, and excess cost.
Dufour, Laporte, Paquette, and Rancourt (2018)	min the logistic costs associated with all stocks.

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Table 5
Group "A" papers: Decision variables and constraints.

Author	Decision variables	Constraints
Taskin and Lodree Jr (2010)	order quantity	generic constraints
Lodree Jr et al. (2012)	inventory level, transshipment of inventories among retailers	generic constraints
Davis et al. (2013)	inventory level, the unutilized capacity of supply nodes, amount of supplies shipping among supply nodes, relief distribution	facility capacity, time limit
Kelle et al. (2014)	inventory level, distribution of supplies among supply nodes, relief distribution, transportation of evacuees, surplus and shortage amount of supplies	facility capacity
Zhan et al. (2014)	number of vehicles and relief supplies added to suppliers, number of vehicles assigned to routes from supply nodes to demand nodes, relief distribution.	relief supplier expansion capacity, vehicle capacity
Garrido et al. (2015)	inventory level, supply distribution, the flow of empty relocated vehicles	facility capacity, vehicle capacity
Alem et al. (2016)	inventory level, the number of vehicles to be used for supplies distribution, shortage amount of supplies	facility capacity, amount of supplies that can be procured, budget
Morrice et al. (2016)	inventory level, time of prepositioning	facility capacity
Dufour et al. (2018)	the number of containers of each kind of product, the number of supplies shipped from suppliers to the regional distribution center and users	facility capacity, demand satisfaction

Table 6
Group "LA" papers: Model objective.

Author	Model objective
Chang et al. (2007)	min facility setup cost, average costs for rescue equipment, expected future transportation cost, supply shortage cost, supply surplus penalty, and demand shortage penalty cost.
Mete and Zabinsky (2010)	min cost of operating facilities, expected transportation duration, and unfulfilled demand penalties.
Rawls and Turnquist (2010)	min expected cost related to facility location and size, commodity acquisition and stocking decision, shipment of supplies to demand points, unmet demand penalties, and holding cost for unused materials.
Salmerón and Apte (2010)	min expected casualties and unmet demand for transfer population.
Duran, Gutierrez, and Keskinocak (2011)	min average response time.
Rawls and Turnquist (2011)	min expected cost related to facility location and size, commodity acquisition and stocking decision, shipment of supplies to demand points, unmet demand penalties and holding cost for unused materials.
Döyen et al. (2012)	min total costs associated with establishing facilities (regional rescue centers(RRC) and local rescue centers(LRC)), inventory holding at RRC, relief item transportation, and penalty for shortage.
Paul and Hariharan (2012)	1-for pre warning disasters: min fatality cost, cost of maintaining stockpile at facilities 2-for unpredicted disasters: min fatality cost, cost of maintaining stockpile at facilities, min max regret decision making rule for choosing across the scenarios.
Noyan (2012)	min total cost with considering the CVaR(conditional-value-at-risk) as the risk measure.
Rawls and Turnquist (2012)	min expected cost related to facility location and size, commodity acquisition, and stocking decision, shipment of supplies to demand points, unmet demand penalties, and holding cost for unused materials.
Bozorgi-Amiri, Jabalameli, and Al-e Hashem (2013)	min expected total costs, cost variability, expected penalty for infeasible solution due to uncertainty, max customer satisfaction.
Galindo and Batta (2013a)	min expected cost of prepositioning, relief distribution, and cost of lost supply units at destroyed facilities.
Şahin et al. (2014)	min total travel distance between supply and demand points.
Hong, Lejeune, and Noyan (2015b)	min cost of prepositioning, expected cost of demand shortage and surplus, and transportation cost.
Tofighi et al. (2016)	min cost of prepositioning, and expected cost of distribution time, unused inventories, supply shortage, and unmet demand.
Moreno et al. (2016)	min total expected cost of opening and operating of facilities and vehicle assignment, and cost of transportation, inventory, meeting demands, and unmet demands.
Bastian, Griffin, Spero, and Fulton (2016)	min expected goal deviations for target response time, target budget, and target demand met.
Caunhye et al. (2016)	min total preparedness cost, worst case total supply transportation cost, and penalty for unfulfilled demands.
Rezaei-Malek et al. (2016)	min total preparedness cost, expected transportation cost, and penalty cost for unused relief supplies, max utility level of delivered relief supplies at the demand points, min the expected max difference of utility levels among demand points.
Paul and MacDonald (2016)	min cost of locating facilities, supply cost, and fatality cost.
Khalilpourazari and Khamseh (2017)	min total supply chain cost, min transportation time
Mahootchi and Golmohammadi (2017)	min cost of establishing facility, holding depot, transportation, and unsatisfied demand.
Bai et al. (2017)	min the Value-at-Risk (VaR) of total cost which consists of fixed cost, acquisition cost, inventory cost, and transshipment cost.
Chowdhury, Emelogu, Marufuzzaman, Nurre, and Bian (2017)	min expected overall cost which includes facility cost, total transportation cost, and average inventory holding cost.
Manopiniwes and Irohara (2017)	min cost of prepositioning, expected cost of relief distribution, and transporting evacuees.
Dalal and Üster (2017)	min fix cost and max evacuee travel distance and combination of average and worst case flow cost over scenarios.
Rodríguez-Espíndola et al. (2018)	min cost associated with facility locations, personnel, procurement, and transportation, min max unfulfilled products and services.
Klibi, Ichoua, and Martel (2018)	min cost of transportation, procurement, and penalty associated to satisfying demands with higher covering level.
Ni et al. (2018)	min prepositioning cost, and worst case distribution cost.

Table 7
Group "LA" papers: Decision variables and constraints.

Author	Decision variables	Constraints
Chang et al. (2007)	facility location, resource allocations, relief distribution, and structure of the rescue organizations	facility capacity
Mete and Zabinsky (2010)	facility location, inventory level, supply distribution	facility capacity for each kind of supply, vehicle capacity
Rawls and Turnquist (2010)	facility location and size, inventory level, supply distribution	facility capacity, link capacity
Salmerón and Apte (2010)	facility location and capacity expansion, relief distribution, engagement and use of transportation means	facility capacity,facility capacity expansion, route capacity, budget, operating time
Duran et al. (2011)	facility location, number of facilities, inventory level, and inventory type in each facility	max number of facilities, total available inventory
Rawls and Turnquist (2011)	facility location and size, inventory level, supply distribution	facility capacity, link capacity, service quality constraints
Döyen et al. (2012)	facility locations (for both RRC and LRC), inventory level in each RRC, LRC demand point assignment, flow amount, shortage amount	LRC capacity, max transportation time between LRC and RRC
Paul and Hariharan (2012)	facility location, resource allocation	facility capacity, available budget
Noyan (2012)	facility location, inventory level, supply distribution	facility capacity, link capacity
Rawls and Turnquist (2012)	facility location and size, inventory level, supply distribution, binary decision variable related to reliable set of scenarios	facility capacity, arc capacity, demand satisfaction for scenarios in reliable set
Bozorgi-Amiri et al. (2013)	facility location and size, inventory level, supply distribution	facility capacity, supplier capacity
Galindo and Batta (2013a)	facility location, inventory level, supply distribution	facility capacity, budget constraint for facility opening cost
Şahin et al. (2014)	facility location, inventory level, assigning demand points to supply points	container weight and volume capacity, tent number, demand coverage, average destruction power
Hong et al. (2015b)	facility location and size, inventory level, supply distribution	arc capacity, demand satisfaction with a high probability, certain level of fairness
Tofighi et al. (2016)	facility location, inventory level, supply distribution	facility capacity
Moreno et al. (2016)	facility location, inventory level for each type of supply, supply transportation and distribution, assigning demand points to facilities, assigning vehicles to facilities	facility storage capacity and per product capacity, vehicle capacity, available number of vehicles of each type
Bastian et al. (2016)	facility location, inventory level, supply distribution, assigning facilities to depots (suppliers)	depot capacity, facility capacity, number of trips based on the budget
Caunhye et al. (2016)	facility location, inventory level, supply distribution, vehicle routing	facility capacity, vehicle capacity, supplies availability, service level for demand satisfaction
Rezaei-Malek et al. (2016)	facility location, inventory level, supply distribution, vehicle routing, utility level at each demand point	facility capacity, routes availability shortage level for each demand point
Paul and MacDonald (2016)	facility location and capacity, inventory level, assigning demand points to facilities	budget
Khalilpourazari and Khamseh (2017)	temporary and permanent facility location (blood collection centers), inventory level, blood distribution from collection centers to blood center, assigning each type of vehicle to collection facilities	facility capacity, number of available vehicles, coverage radius for collection facilities
Mahootchi and Golmohammadi (2017)	facility location, inventory level, supply distribution	facility capacity, link capacity, demand satisfaction
Bai et al. (2017)	facility location and size, inventory level, supply distribution	facility capacity, arc capacity, service quality
Chowdhury et al. (2017)	facility location, inventory level	area coverage, distance between facilities and demand points
Manopiniwes and Irohara (2017)	facility location, inventory level, supply distribution, vehicle routing, evacuation planning	facility capacity, vehicle capacity, number of available vehicles, demand satisfaction, response time
Dalal and Üster (2017)	facility location (shelter and distribution center(DC)), relief distribution from DCs to shelters, assigning evacuees to shelters	facility capacity
Rodríguez-Espíndola et al. (2018)	facility location (shelter and distribution center), organization activating or not, inventory level from organizations, relief distribution from DCs to shelters with transportation mode, personnel allocation from organizations to DCs and shelters, healthcare team allocation from organizations to shelters, vehicles allocation from organizations to DCs, assigning evacuees to shelters	facility capacity, supplies and vehicles availability
Klibi et al. (2018)	facility location and capacity, inventory level, relief distribution	facility capacity, budget, vendor supply quantity, demand satisfaction
Ni et al. (2018)	facility location, inventory level, supply distribution	facility capacity, supplies availability

tain parameters among the model parameters. If there are no uncertain parameters, the type of model is deterministic. The uncertain parameters for stochastic and robust models, are provided in Tables S1–S3 for the papers of the categories "L", "A", and "LA", respectively.

The second attribute that needs explanation is "planning horizon". Information related to the planning horizon attribute is provided in Tables S1–S3. There are two types of planning horizons in the context of disaster preparedness. They are "strategic" and "tactical". Long-term planning before a disaster strike, or planning for an unpredictable disaster that may or may not happen in the future, are called "strategic" planning. Planning a short time before a predictable disaster strike, is called "tactical". For instance, building stock prepositioning facilities for the potential future earthquakes, is "strategic" planning because the exact day and time of earthquakes are not predictable. Another example of "strategic" planning is the preparedness relief activities in confronting hurricanes, before the start of a hurricane season. In this situation, the planning is counted as strategic because it includes preparedness activities for a potential hurricane that may or may not happen. The National Hurricane Center (NHC) starts providing predicts of a hurricane's intensity and path 5 days before its landfall (NHC). Preparedness activities performed by Federal, State and local authorities and by national humanitarian organizations during the days prior to the predicted hurricane disaster are examples of "tactical" planning. These efforts are usually aimed at improving post-disaster relief activities.

We have taken several steps to present our result in a concise and easily understandable manner. These steps are now described.

In Tables 3, 5, and 7, only constraints that have insights for making decisions about disaster logistics are provided (for instance non-negativity constraints and flow conservation constraints that are generic constraints in the location/allocation and vehicle routing models, are not provided).

The word "facility" which is used in Tables 2–7 and S1–S3, is a generic word which we use as a representative of all types of facilities, like shelters, warehouses, relief distribution centers (RDC), distribution centers (DC), rescue centers (RC), disaster response facilities, and emergency service facilities.

We have now set the stage for separately analyzing each of the "L", "A" and "LA" categories.

4.1. Analysis of group"L" papers

Group "L" papers that are considered in Tables 2, 3, and S1 consist of problems such as the facility location problem, the vehicle routing problem, the relief distribution problem and the commodity flow problem.

In Table 2, the objective functions of models in the papers examined are provided. Most of these papers have traditional objectives. These objectives can be categorized into three groups, facility-related, travel-related, and demand-related. Facility related objectives focus on setup cost, staffing cost, running cost, and maintaining the cost of facilities. Travel related objectives include evacuee travel time or travel distance to reach shelter facilities, relief distribution transportation cost, and the cost of transferring evacuees to a safe place. Demand related objectives focus on demand coverage and unsatisfied demands.

While the majority of papers use traditional objectives, there are some papers which use new and creative terms in their objectives:

Elluru, Gupta, Kaur, and Singh (2017) proposes a proactive and a reactive version of the location-routing problem with time windows. In the proactive model, risk factors associated with each facility selection is considered. These risk factors are introduced as preventive rates for disaster caused disruptions.

Sheu and Pan (2014) proposes a three-stage multi-objective location-routing model. In each stage, the objective functions consist of traditional objectives coupled with non-traditional objectives like minimizing the psychological cost, which is a demand-side cost.

Chapman and Mitchell (2018) proposes a capacitated facility location model with an objective function that includes a form of deprivation cost which is also a demand-side cost. Including this term in the objective function comes from the goal of providing a fair level of service to each member of the affected population, with the idea that fair division minimizes disparities in these costs.

Table 3 displays decision variables and constraints of the group "L" proposed models. Facility location and assigning demand points and vehicles to facilities are the most frequent decision variables in this category. Facility capacity, vehicle capacity, and the number of facilities are the most common constraints in this category. The budget constraint is frequently introduced by limiting the number of facilities to a predefined number. Time limit constraints, which are infrequent in Table 3, define time horizons for demand deliveries.

Table S1 shows model details of the group "L" papers. As one can see, most of the papers propose deterministic models with a strategic planning horizon. Uncertainty in demands, uncertainty in roads, and uncertainty in the availability of facilities are the uncertain parameters considered in the stochastic and robust models of this category.

4.1.1. Group "L" papers that are not included in the tables

We now discuss group "L" papers that are not introduced in Tables 2, 3, and S1. The reason that these papers are excluded is that they use a *decision making* framework, as opposed to a traditional optimization approach. We therefore summarize them separately.

Roh, Pettit, Harris, and Beresford (2015) considers the problem of pre-positioning of warehouses for humanitarian relief organizations in both macro and micro perspectives with the aim of providing readers managerial insights. The authors use the Analytic Hierarchy Process (AHP) and fuzzy-TOPSIS method to find the relative importance of each of the criteria and to rank the locations. Moreover, by using a robust multi-criteria decision-making framework, they suggest possible locations of humanitarian relief organizations.

Saksrisathaporn, Bouras, Reeveerakul, and Charles (2016) proposes a decision model which evolves over time to choose the most appropriate supplier, the adopted warehouse, and the transportation means for the French Red Cross organization. In order to achieve a proper decision, the authors use an integration of AHP and TOPSIS methods.

Ebrahimi and Modam (2016) intends to select the best zones to add a new emergency service to optimize service response time in Tehran, Iran. An algorithm, including a combination of fuzzy AHP and fuzzy TOPSIS, is established to solve the problem and rank the zones.

4.2. Analysis of group "A" papers

This subsection and the next subsection, analyze group "A" papers. The first part of group "A" papers are presented in Tables 4, 5 and S2. Papers that are not included in these tables are presented in Section 4.2.1.

Table 4 presents the objective functions proposed by optimization models in the mentioned papers. As one sees, minimizing the cost associated with prepositioning of supplies, the expected supply distribution cost, the expected cost of shortage and surplus of supplies, and the expected unmet demand cost are the common objective functions that appear in almost all of the papers in this group. However, Kelle, Schneider, and Yi (2014) proposes a new and creative objective which is different with the mentioned popular objectives. This objective is minimizing the maximum regret associated with a selected subset of scenarios. The authors define regret for each scenario as the difference between the objective function values given by the overall compromise solution and the optimal solution for that scenario. Moreover, for avoiding the dominance of worst case scenarios with very low probabilities which may cause some loss, the authors disregard the lowest chance scenarios and consider only higher chance scenarios with a total probability of being chosen close to one.

Table 5 shows the models' decision variables and constraints for the papers cited in Table 4. Inventory level and supply distribution are the most frequent decision variables in these papers. Also, facility capacity and vehicle capacity are the most popular constraints among them. Morrice, Cronin, Tanrisever, and Butler (2016) considers the best time to make a large initial allocation versus making a series of sequential allocations, as a decision variable, in addition to inventory level, in response to a hurricane threat. Most papers do not consider a limit on the number of supplies that can be procured. In contrast, Alem, Clark, and Moreno (2016) constrains the amount of supplies that can be acquired and used through disaster relief.

Based on Table S2, the majority of the papers use stochastic models which consider uncertain parameters like demand, supply, disaster characteristics, and route and budget availability.

4.2.1. Group "A" papers that are not included in the tables

We now discuss group "A" papers that are not introduced in Tables 4, 5, and S2. These papers are excluded since they do not use a traditional optimization approach (i.e., one that uses a single model). We organize these papers based on the approach used–game theory, decision making, stochastic process, managerial insights, and utilization of more than one optimization model.

Game theory

Lodree Jr and Taskin (2008) introduces four variations of the newsvendor model that are used to assist decision-makers in determining appropriate inventory levels in anticipation of a potential disaster-relief operation. These models account for demand uncertainty as well as the uncertainty surrounding the occurrence of an extreme event. The authors define the insurance premium associated with proactive disaster-relief planning as the difference between the optimal inventory level determined by the proposed newsvendor models and the classic newsvendor solution. The insurance policy framework represents a practical approach for decision-makers to quantify the benefits and risks associated with stocking decisions related to preparing for disaster relief efforts or supply chain disruptions.

Adida et al. (2011) models joint inventory stockpiling of medical supplies for groups of hospitals prior to a disaster, as a non-cooperative strategic game. Demand is assumed to be uncertain in this paper, and some managerial insights and public health policy implications for disaster planning are provided by the authors.

Decision making

Taskin and Lodree (2011) addresses an inventory management problem in preparation for potential humanitarian relief efforts in response to an observed hurricane. To address the problem from the manufacturer's perspective, a sequential Bayesian decision model that incorporates one of the National Hurricane Center's prediction models is proposed. In the proposed work, each retailer demand is a random variable which is affected by the trajectory of the observed hurricane.

Chakravarty (2014) explores a 2-stage proactive/reactive approach where the prepositioned inventory is determined before disaster strike, while the response time and the relief amounts are decided after disaster strike to maximize the acquired social value from saving lives.

Stochastic process

Yadavalli, Sundar, and Udayabaskaran (2015) considers a disaster inventory system which stores two perishable substitutable products. In this paper, a continuous review analysis of the disaster inventory is made by formulating the problem as a two-dimensional stochastic process. The authors also adopt an adjustable joint reordering policy for replenishment.

Managerial insights

Kunz, Reiner, and Gold (2014) evaluates the effects of investing in disaster management capabilities through system dynamic modeling. The authors suggest that investing in DMC is a valuable alternative to pre-positioning, which incurs a high cost. Finally, the authors find that the best performance would be achieved by allocating part of the available funding to disaster management capabilities and part of the funds to a pre-positioning strategy.

Acimovic and Goentzel (2016) proposes new humanitarian logistics metrics based on stochastic optimization models, to describe the system capacity across many agents to respond to disasters. The authors use the empirical data on inventory stored by various organizations in United Nations facilities and in their own warehouses to offer practical insights about the current humanitarian response capabilities. Finally, they come to the conclusion that by repositioning inventory already deployed, the system could respond to disasters in the same expected time with a range of 7.4–20.0% lower cost for the items in their sample.

More than one optimization model

The last paper that we want to introduce in group "A" papers is Yang, Guo, and Yang (2017) which proposes a two-layer emergency logistics system for wildfire suppression with single depot and multiple demand sites. In the first layer, a fire propagation model is built. And in the second layer, based on the forecasted fire behavior, the emergency level of fire sites are calculated. Finally, the corresponding resource allocation and vehicle routing problem is addressed for two different cases. First for an optimization model for rapid fire propagation, and second for slow fire propagation.

4.3. Analysis of group "LA" papers

Group "LA" has the largest number of papers in comparison with groups "A" and "L". These papers consist of problems such as facility location, relief allocation, the relief distribution, vehicle routing, and commodity flow.

Based on Table 6, the most frequent cost terms in the model objectives used in the group "LA", are facility setup cost, prepositioning related cost, inventory holding cost, expected transportation cost, expected unmet demand penalties, and expected supply surplus penalties. However, there are some papers that propose different objective functions:

Salmerón and Apte (2010) considers the expected casualty cost in addition to unmet demand cost in its model objective function.

Noyan (2012) uses Conditional-Value-at-Risk (CVaR) to represent the risk component in the objective function.

Bai, Gao, and Liu (2017) minimizes the Value-at-Risk (VaR) of the total cost in the objective function.

Rezaei-Malek, Tavakkoli-Moghaddam, Cheikhrouhou, and Taheri-Moghaddam (2016) defines a new utility level of delivered relief commodities at demand points and maximizes this utility in the objective function. This utility level has been developed to measure the benefit level of each demand point in a disaster area. The author also minimizes the maximum difference of utility levels among demand points in the objective function.

Table 7 shows decision variables and constraints used in group "LA" papers. Facility location, inventory level, supply distribution, and assigning vehicles and evacuees to facilities are the mostly used decision variables in this category. Vehicle routing is another decision variable which is considered by Caunhye, Zhang, Li, and Nie (2016); Rezaei-Malek et al. (2016), and Manopiniwes and Irohara (2017). The constraints that are used frequently in this category are facility capacity, vehicle capacity, route capacity, budget, supplies availability, and levels of demand satisfaction. Döyen, Aras, and Barbarosoğlu (2012) defines a constraint that limits the maximum transportation time allowed between regional rescue centers (RRCs) and local rescue centers (LRCs). Manopiniwes and Irohara (2017) proposes a constraint for expected response time, specifically that in the expected response time for selected routes must be less than a predefined upper bound.

Table S3 presents more details of category "LA" models. The majority of papers in this group propose stochastic models by considering uncertainty in parameters like demand locations and quantity, supplies quantity and availability, route availability after a disaster strike, and disaster characteristics (e.g., the exact time and location of strike, and the intensity level of disaster, which is a measure for the expected amount of damages). It is worth mentioning that most of the papers in this group propose a strategic planning horizon for future disasters. The solution methodologies for solving the proposed models and case studies are provided in Table S3.

4.3.1. Group "LA" papers that are not listed in the tables

We now discuss group "LA" papers that are not introduced in Tables 6, 7, and S3. These papers are excluded since they do not use a traditional optimization approach (i.e., one that uses a single model). We organize these papers based on the approach used-decision theory and stochastic programming, decision making, managerial insights, and utilization of more than one optimization model.

Decision theory and stochastic programming

Pacheco and Batta (2016) proposes a dynamic model for relief prepositioning in preparation for a predicted hurricane. Their model uses the forecast advisories from the National Hurricane Center to find the best time for starting the prepositioning and the correct amount and location for prepositioning and reprepositioning of supplies.

Decision making

Sahebjamnia, Torabi, and Mansouri (2017) propose a hybrid decision support system to configure a three-level humanitarian relief chain. The main performance measures are coverage, total cost, and response time. Then, based on these three measures, the best facility location, supply allocation, and distribution plan are determined for each scenario.

Managerial insights

Edrissi, Poorzahedy, Nassiri, and Nourinejad (2013) focuses on minimizing the number of casualties after an earthquake. The authors define three subproblems, which are the renovation of destroyed and low-quality buildings, the strengthening of the transportation infrastructures, and location/allocation of resources. Then, the authors suggest that collapsing these three subproblems into one problem can lead to a better common objective. In other words, the goal of this paper is not to build a better relief inventory model or a more advanced network rehabilitation model, but to present the efficiency of working together for saving humans life.

More than one optimization model

Görmez, Köksalan, and Salman (2011) studies the problem of locating disaster response and supply facilities in the City of Istanbul to serve as distribution points and also storage for assets and supplies for an expected future earthquake. The authors investigate the trade-off between two objective functions: (i) minimizing the average weighted distance between casualty points and nearest facilities; (ii) opening a small number of facilities considering distance limit and backup requirements. Several optimization models with different criteria are presented in this paper. Then based on the results, they suggest that a small number of facilities would be sufficient.

Baskaya, Ertem, and Duran (2017) introduce three mathematical models to find the location and number of supply facilities, the number of supplies to be prepositioned in each facility, and the quantity of lateral transshipment between these facilities. These include a direct transshipment model, a lateral transshipment model, and a maritime lateral transshipment model. Through a comparison of these three models, the authors claim that the second and third model give a better result than the first model, and considering lateral transshipment option accelerates supply delivery to beneficiaries.

5. Key methodological concerns in HO

To identify methodological concerns in HO we need to use a systematic approach. Rather than develop a new approach, we lean on the methods that are highlighted in a recent paper by Kovacs and Moshtari (2018). Specifically, Kovacs and Moshtari (2018) highlight a set of essential methodological items that must be considered when conducting research in HO. The authors explain these critical items in the following six categories: problem definition and research design, understanding contextual factors, acknowledging the uncertainties in HO, choosing the appropriate data and research methods, incorporating uncertainty in the modeling, and use of enabling technologies for model development and implementation. Furthermore, the authors define some subcategories for each of these categories and gather all of them in a table. All these categories and some of their subcategories are included in Table 8 which is inspired from the mentioned table in Kovacs and Moshtari (2018).

In what follows, we assess our current literature based on some of the methodological issues gathered by Kovacs and Moshtari (2018), to see how many and which papers considered these critical items in their research. Hence, in Table 8, we cite our surveyed papers that address these issues.

In the followings, we explain the type of papers cited in each subcategory in Table 8:

- Collecting field and real data

In this category, we introduce the papers that instead of hypothetical data, use field and real data in their case studies.

- Different characteristics of each disaster

In this category, we cite the papers that instead of claiming the applicability of their findings to all natural disasters, develop their model only for one particular natural disaster.

- Beneficiary needs

In this category, we introduce the papers that deal with demand uncertainty in their model.

- Supplied commodities

In this category, we cite the papers that consider the uncertainties exist in the supply quantities and assets.

- Funding uncertainty

In this category, we introduce the papers that deal with funding and budget uncertainty in their model.

- Limited or damaged infrastructure

In this category, we cite the papers that consider the vulnerability of roads, transportation, and facilities in their model.

- Objective functions

Table 8
Key items addressed in the review papers.

Items	References
1. Problem definition and research design	
- Collecting field and real data	Dekle et al. (2005); Duran et al. (2011); Noyan (2012); Rawls and Turnquist (2010); Taskin and Lodree Jr (2010), Li et al. (2012); Lodree Jr et al. (2012); Paul and Hariharan (2012), An et al. (2013); Bozorgi-Amiri et al. (2013); Galindo and Batta (2013a); Lu (2013), Kelle et al. (2014); Salman and Yücel (2015); Sheu and Pan (2014); Verma and Gaukler (2015); Zhan et al. (2014), Ahmadi et al. (2015); Akgün et al. (2015); Hong et al. (2015b); Moreno et al. (2016); Tofighi et al. (2016), Bastian et al. (2016), Alem et al. (2016); Bai et al. (2017); Burkart et al. (2017); Khalilpourazari and Khamseh (2017); Mohamadi et al. (2016); Morrice et al. (2016); Rezaei-Malek et al. (2016); Stauffer et al. (2016), Chowdhury et al. (2017); Dalal and Üster (2017); Mahootchi and Golmohammadi (2017), Dufour et al. (2018); Manopiniwes and Irohara (2017), Chapman and Mitchell (2018); Rodríguez-Espíndola et al. (2018), Klibi et al. (2018), Ni et al. (2018).
2. Understanding contextual factors	
- Different characteristics of each disaster	Chang et al. (2007); Taskin and Lodree (2011); Taskin and Lodree Jr (2010), Döyen et al. (2012); Görmez et al. (2011); Li et al. (2012); Lodree Jr et al. (2012), Chakravarty (2014); Edrissi et al. (2013); Galindo and Batta (2013a); Kelle et al. (2014), Ahmadi et al. (2015); Garrido et al. (2015); Morrice et al. (2016); Paul and MacDonald (2016), Baskaya et al. (2017); Burkart et al. (2017); Dalal and Üster (2017); Ebrahimi and Modam (2016); Khalilpourazari and Khamseh (2017); Pacheco and Batta (2016); Yang et al. (2017), Rodríguez-Espíndola et al. (2018).
3. Acknowledging the uncertainties in HO	
- Beneficiaries' needs	Chang et al. (2007); Jia et al. (2007); Rawls and Turnquist (2010); Taskin and Lodree Jr (2010), Li et al. (2012); Lodree Jr et al. (2012); Noyan (2012); Rawls and Turnquist (2011), Bozorgi-Amiri et al. (2013); Davis et al. (2013); Galindo and Batta (2013a); Garrido et al. (2015); Hong et al. (2015b); Lu (2013); Rawls and Turnquist (2012); Zhan et al. (2014), Alem et al. (2016); Ghezavati et al. (2015); Mohamadi et al. (2016); Rezaei-Malek et al. (2016), Bai et al. (2017); Bastian et al. (2016); Moreno et al. (2016); Tofighi et al. (2016), Chowdhury et al. (2017); Dalal and Üster (2017); Dufour et al. (2018); Mahootchi and Golmohammadi (2017); Ni et al. (2018).
- Supplied commodities	Bozorgi-Amiri et al. (2013); Davis et al. (2013); Moreno et al. (2016); Tofighi et al. (2016), Bai et al. (2017); Mahootchi and Golmohammadi (2017); Ni et al. (2018); Rezaei-Malek et al. (2016).
- Funding uncertainty	Alem et al. (2016).
- Limited or damaged infrastrucrure	An et al. (2015); Noyan (2012); Rawls and Turnquist (2010, 2011); Zhan et al. (2014), Ghezavati et al. (2015); Mohamadi et al. (2016); Verma and Gaukler (2015), Alem et al. (2016); Bai et al. (2017); Moreno et al. (2016); Ni et al. (2018); Tofighi et al. (2016).
4. Choosing appropriate methods	
- Data	See first part of table
5. Incorporating uncertainty in the modeling	
- Objective functions	Paul and Hariharan (2012); Rezaei-Malek et al. (2016); Salmerón and Apte (2010); Sheu and Pan (2014), Chapman and Mitchell (2018); Paul and MacDonald (2016).
- Integrated models	Chang et al. (2007); Mete and Zabinsky (2010); Rawls and Turnquist (2010); Salmerón and Apte (2010), Döyen et al. (2012); Noyan (2012); Rawls and Turnquist (2011, 2012), Bozorgi-Amiri et al. (2013); Galindo and Batta (2013a); Hong et al. (2015b), Ghezavati et al. (2015), Ahmadi et al. (2015); Bastian et al. (2016); Caunhye et al. (2016); Moreno et al. (2016); Tofighi et al. (2016), Paul and MacDonald (2016); Rezaei-Malek et al. (2016), Bai et al. (2017); Elluru et al. (2017), Dalal and Üster (2017); Khalilpourazari and Khamseh (2017); Mahootchi and Golmohammadi (2017), Klibi et al. (2018); Manopiniwes and Irohara (2017); Ni et al. (2018); Rodríguez-Espíndola et al. (2018).
6. Use of enabling technologies for model development and implementation	
- Suitable solution algorithms	Ahmadi et al. (2015); Alem et al. (2016); Burkart et al. (2017); Dekle et al. (2005); Kelle et al. (2014); Li et al. (2012); Lodree Jr et al. (2012); Lu (2013); Salman and Yücel (2015); Verma and Gaukler (2015); Zhan et al. (2014), Döyen et al. (2012); Rawls and Turnquist (2010); Salmerón and Apte (2010), Galindo and Batta (2013a); Hong et al. (2015b); Moreno et al. (2016); Noyan (2012), Bai et al. (2017); Paul and MacDonald (2016); Rezaei-Malek et al. (2016), Chowdhury et al. (2017); Dalal and Üster (2017); Khalilpourazari and Khamseh (2017), Rodríguez-Espíndola et al. (2018).

In this category, we cite the papers that instead of only relying on the traditional objectives from the commercial sector, they include humanitarian aspects such as the psychological cost for the affected population, casualties and fatality cost, and equity in their models' objective function.

- Integrated models

In this category, we introduce the papers that propose integrated models by including interdependency between decisions and by considering more than one phase of disaster management in their scope. To be precise, we cite the papers that model location of distribution centers, inventory prepositioning, and distribution logistics in an integrated model. This type of model is suggested by Gupta et al. (2016). We also cite the papers that consider the location and transportation problem (which are in two different phases of disaster management) simultaneously.

- Suitable solution algorithm

In this category, we introduce papers that propose algorithms for solving large optimization problems in a short time.

5.1. Some findings from Table 8

61 out of 74 of our reviewed papers are presented in Table 8. It shows 83% of our literature address at least one of the methodological concerns introduced in Table 8. Among these papers, a small portion of them (10 papers) address 5–6 out of 9 methodological concerns. It means that these papers are strong papers in POD area in the aspect that they consider several critical items that need to be addressed in every HO research. These papers are as follows: Rawls and Turnquist (2010), Noyan (2012), Galindo and Batta (2013a), Moreno, Alem, and Ferreira (2016), Rezaei-Malek et al. (2016), Tofighi, Torabi, and Mansouri (2016), Alem et al. (2016), Bai et al. (2017), Dalal and Üster (2017), and Ni, Shu, and Song (2018). Among the papers in Table 8, 23 of them present 3–4 of the methodological concerns and 28 of them address 2–1. Hence, the overall conclusion is that future researchers in POD area must consider more of these critical methodological concerns in their work to increase the quality of POD research area.

Now let us discuss which of the critical items introduced in Table 8, are most considered or most neglected by our literature. It

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is important since it will direct us to some future research directions. Collecting field and real data is the most addressed methodological concern by our literature. To be more precise, 40 papers out of 74 papers of our literature, use real and field data instead of hypothetical data in their case studies.

The most neglected methodological issue in our literature is about funding uncertainty. The only paper in our literature that deal with funding and budget uncertainty in its model is Alem et al. (2016). Hence, future researchers in POD research area are strongly encouraged to cover this gap in their future works. The next most neglected methodological concern in our literature is about objective function. To be more precise, only 4 papers of our literature consider humanitarian aspect costs (like psychological costs and casualties and fatality costs) in their models' objectives. It means that most of the papers in POD area only consider traditional objectives that are related to supply-side costs in their proposed models. Hence, future researchers in POD research area are encouraged to cover this gap by considering this methodological issue in their future work. Considering the uncertainties that exist in the supply quantities and assets is another neglected methodological concern in our literature. This fact directs us to another gap in POD research area that is expected to be covered by future researchers in this area.

6. Suggested future research directions

Whereas several types of investigations are comprehensively covered by the surveyed papers, there are other types of research questions that have not been addressed adequately yet in domain of POD. We note that many of the points we make (e.g., tailored models for specific disaster types) apply broadly to the disaster logistics domain and in fact their impact on the broader disaster logistics domain could be far great than their impact on the POD domain. Comments on these broader aspects, however, is outside the scope of this review paper.

We now list the gaps in POD research along with some specific suggestions on ways that they can be addressed:

- Tailored models for specific type of disasters

We believe that there is a crucial need for papers in the POD area that consider preparation for a specific type of disaster. As mentioned earlier in Section 3.2.1, 70% of our reviewed papers claim that their methods are applicable to all types of disasters. This claim seems unrealistic to us and we think these proposed methods may not be easily adjustable to a different type of disasters. Moreover, even the papers that refer to a specific type of disaster, do not comprehensively consider the specific characteristics and effects of that disaster in their modeling approach. This is a gap and should be addressed by future research, in recognition of the fact that different types of disasters have different characteristics and consequences. Hence, they need specific preparation models. For instance, for a predicted hurricane we need applicable models that use predicted winds speed, intensity, and hurricane path, which are predicted by NHC before its landfall, to suggest suitable locations of facilities and a suitable level of supplies and assets to be prepositioned and deployed. However, for a disaster like an earthquake, which is not predictable, there exists no such predicted information prior to its strike. Hence, the preparation process for earthquakes is totally different from the process for hurricanes. Moreover, after an earthquake strike, we expect to have some aftershocks to happen. Therefore, besides preparation for the main earthquake, we also need to prepare for its aftershocks. We do not have this situation in hurricanes. These examples demonstrate differences for only two types of disasters. However, one can extend it for all types of disasters.

Another important gap that we hope future researchers fill is the necessity of considering priorities among supplies for different type of disasters. As mentioned earlier in Section 3.2.1, the type of supplies to be procured and prepositioned for each type of disaster may have different priorities. For instance, in earthquakes, where physical injuries are the first concern, medical supplies and medical teams are in priority to be prepositioned and deployed during the first 72 hours of disaster strike in comparison to food and water. This priority would change in case of disasters like droughts. In droughts, food and water shortage are the first concern. Therefore, since in case of a disaster, the time, budget, and capacities are limited, considering priorities in supplies can help local and national agencies to manage their time and budget effectively to achieve better results for both demand and supply sides. Hence, we encourage future researchers in POD and disaster management area to consider this gap in their work.

A specific suggestion we have is to study prior disasters and the logistical challenges that they posed towards prepositioning of supplies. From studying these impacts, more suitable models can be developed. As an example, we would mention hurricane Maria that struck Dominica and Puerto Rico in 2017. The widespread power outage and shortages in water and fuel were the most critical problems that affected victims (ABC-news, 2017). The majority of Puerto Rico Island's 69 hospitals were left without electricity or fuel for generators which caused lack of medical services to victims (Zorrilla, 2017). In the case of Puerto Rico, a key logistical issue was the lack of truck drivers to move relief items from the port to impacted areas on the island coupled with significant damage to the road infrastructure that made delivery of relief items to remote parts of the island virtually impossible. A further issue was the lack of ability to communicate due to fallen cell towers and lack of electricity. Yet another issue was the fact that since Puerto Rico is an island and since the hurricane impacted the entire island there was no safe place for residents to evacuate to, creating massive demand for relief items after the hurricane made landfall. From a prepositioning perspective, the situation in Puerto Rico could have been positively impacted if communication devices were delivered to remote areas and if relief items were placed at strategic points/locations in remote communities prior to hurricane landfall.

- Lack of papers that consider demand side costs

A significant gap we noticed is that most model objectives are constructed from supply-side costs and rarely include demand-side costs. The first few papers among our reviewed papers that address a demand-side cost in their proposed model objectives are Mete and Zabinsky (2010), Rawls and Turnquist (2010), and Salmerón and Apte (2010). In these papers, the expected unmet demand penalties are considered as a demand-side cost. After these papers, this cost (unmet demand penalties) was the only demand side cost that has been widely considered by our reviewed papers. It reveals the need for papers that consider more types of demand-side costs in their objectives like fatality cost (Paul & Hariharan, 2012; Paul & MacDonald, 2016) and utility level among demand points that measures the benefit level of each demand point (Rezaei-Malek et al., 2016). One more type of demand side cost that we like to mention is the social impact costs of the disasters. A suggested future research direction is to consider the social costs of natural disasters as the cost that should be minimized in the objectives. Almost all of the reviewed papers consider facility setup and maintaining costs, cost of procuring supplies, expected distribution and transportation cost, and generally the costs that are in relation to the money in their objectives. Hence, it is time to investigate the social impacts of natural disasters and to include them in future preparation activities to reduce disaster impacts and make the suggested models more realistic; We note that

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this finding is in the same spirit as the need for studies of deprivation costs (Holguín-Veras et al., 2013) and need for including other factors than cost and demand in the analysis of facility location (Jahre et al., 2016). One of the papers that consider psychological cost for demand side, which is a type of social cost in its proposed model objective is Sheu and Pan (2014). Also, Chapman and Mitchell (2018) proposes a form of deprivation cost (a kind of social cost) in the objective function of its proposed model. As one sees, only a few papers have considered social costs in their proposed model objectives. This reveals a substantial research gap in this area. Hence, we encourage future researchers to include contents such as introducing types of social costs, finding factors that affect these kinds of costs, and finding ways to specify appropriate values for these costs in their works. Also, we would like to suggest investigation of the balance between demand-side costs and supply-side costs in disaster situations, which is a missing concept in the literature. This balance can be reached by using decision making methods or other methodologies, and could greatly help both demand and supply sides approaches, instead of considering only one of them or mostly one of them.

- Prepositioning as a risk management strategy

Prepositioning can also be thought of as a risk management strategy as it balances the need to act in vain (i.e., pre-position in vain) versus the risk of not acting (and not having anything at hand when needed.) One way to do address this is to use unmet demand penalties, as in Mete and Zabinsky (2010), Salmerón and Apte (2010), Rawls and Turnquist (2011), Rawls and Turnquist (2012), Moreno et al. (2016), Tofighi et al. (2016), and Alem et al. (2016). However, risk management can be addressed in many other ways. An example is the potential destruction of prepositioned items as discussed in the paper by Galindo and Batta (2013a). More work in this domain is suggested.

- Combining the prepositioning problem in preparedness phase with the expected cost of the last mile problem in response phase

Research that is not in the prepositioning area can be combined with research in the prepositioning area in meaningful ways. For example, effective prepositioning of supplies and assets in the preparedness phase of the disaster can reduce the cost of last mile delivery in the response phase of the disaster. Thus these two problems can be viewed as a single problem, which aims to optimize both the prepositioning and the last mile delivery simultaneously. There is some work in this area, notably papers by Ahmadi, Seifi, and Tootooni (2015), Stauffer, Pedraza-Martinez, and Van Wassenhove (2016), Morrice et al. (2016), Moreno et al. (2016), Caunhye et al. (2016), Rezaei-Malek et al. (2016), Elluru et al. (2017), and Manopiniwes and Irohara (2017). However, we believe that many aspects (e.g., uncertainty in disaster outcomes) of this combined problem have not been satisfactorily addressed, so it is a fruitful area for future research efforts.

- Reducing the risk of loss by considering reliability

Very few reviewed papers address reliability by resorting to risk measures (like VaR and CVaR) (cf. Bai et al., 2017; Elluru et al., 2017; Noyan, 2012). Taking reliability into account is an important and decisive task in confronting natural disasters which are full of uncertainties and risks. This gap has also been identified by Gutjahr and Nolz (2016) and needs to be filled by future researchers.

- Need for more research on the topic of medical staff and emergency crew prepositioning

Prepositioning of medical staff and emergency crew is a common practice in severe hurricane events, yet to the best of our knowledge, there is no study of this in the current reviewed academic literature except Rodríguez-Espíndola, Albores, and Brewster (2018). Examples of this type of asset prepositioning include recent events like Hurricanes Maria, Florence, and Michael (Alvarez, 2018; FEMA, 2017; Katz, 2018), where these assets were used for search and rescue, assisting in evacuation, and medical cares. Studying this prepositioning problem in more detail is important to provide better outcomes for future hurricane events.

- Need for more realistic modeling

Another suggestion for future research is relaxing unrealistic assumptions assumed by most of papers. For instance, most of our reviewed papers assume identical and independent facility disruptions which are highly unlikely to be a realistic assumption. Another unrealistic assumption that we witnessed in many of the papers is the assumption of infinite available supplies. In other words, these papers seek the number of supplies to be prepositioned (stock level) without considering the limitation in the number of products that can be procured. There are many factors that can affect the quantity of supplies that can be procured, for instance, available time, budget, the quantity of available supplies in different retailers, and production rate of manufacturers. Hence, in a situation of disaster threat, when the time and budget are restricted and uncertain, the uncertainty in the number of available supplies and assets is an important fact that should be considered in POD research. Considering uncertainty and limit in the budget and funding is another neglected fact in POD research area that must be addressed in future research. Considering uncertainty in the infrastructures in evacuation planning is also limited to a small portion of studies (Bayram, 2016). We also witnessed that among our reviewed papers in POD, only around 18% of them consider uncertainty in the infrastructure (like uncertainty in transportation network availability and uncertainty in facilities' damage level). The mentioned unrealistic assumptions simplify the modeling, but make the resultant model far from reality. Hence, future researchers are encouraged to find ways to consider more realistic assumptions while confronting the complexity that these assumptions bring. For proving that almost all of the OR models proposed by academic papers in disaster preparedness area, are unrealistic, it is enough to mention that we could find no model that is used in real disaster situations (like recent hurricane Maria). These proposed models are still not suitable to be used in real emergency situations, because they are not realistic or close enough to reality. Hence, there is still a lot of work that should be done to strengthen the available and future models to be applicable in real disaster situations.

There are two key components to develop realistic models. First, the data needed to run the models must be available and second the data should be based on a realistic case as opposed to random generation methods. One way to do this is to use the disaster simulation tool HAZUS developed by the Federal Emergency Management Agency (FEMA), which simulates hurricane, flood and earthquake disasters in the United States. The software HAZUS is made available to researchers for no cost and can be downloaded from HAZUS (2019). Once the specifications of the disaster event have been specified (e.g., in a hurricane this would be the point of landfall, the wind speed at landfall, and other meteorological characteristics) the software generates damage estimates for the impacted areas, which include percentage of households without water, percentage of displaced households, level of damage to the road infrastructure, etc. These damage estimates can be used to develop realistic data sets related to demand for essential items. Some researchers have used HAZUS to develop case studies. As an example, see the earthquake case study in the paper by Lin, Batta, Rogerson, Blatt, and Flanigan (2011).

- When to start prepositioning?

How many hurricane forecast updates should be obtained before the stock prepositioning starts is also another interesting research question (Pacheco & Batta, 2016; Taskin & Lodree, 2011). Finding the best time to start prepositioning of supplies is challenging for emergency managers in confronting a foreseen disaster. The reason is that for disasters like hurricanes, in which forecast advisory updates are issued every 6 hours, it is expected that the forecast accuracy regarding the hurricane's landfall characteristics improves as we get closer to the time of landfall. Hence, for decreasing the uncertainty and the cost it would bring to us, finding the best starting time for the prepositioning task is a crucial issue that should be further investigated by future researchers. It is worth mentioning that, this issue should be addressed not only for hurricanes but also for all predictable disasters.

- Using social media to better prepare for upcoming disasters

Social media driven decision models have been used effectively in other (non-prepositioning) research efforts. For example, they have been used to debunk rumors that spread during a natural disaster (Gupta, Lamba, Kumaraguru, & Joshi, 2013; Mendoza, Poblete, & Castillo, 2010; Wang & Zhuang, 2018). This filed we believe that significant potential for prepositioning research, as there have been very few studies in using Twitter in the pre-disaster preparation phase. We found that, although less than the response phase, there is a significant amount of information generated on Twitter in disaster preparation like in tweet categorizing (Stowe, Paul, Palmer, Palen, & Anderson, 2016). In a more practical instance, we found there were more than 3000 tweets generated in Florida prior to Hurricane Irma which talked about gasoline shortage. These tweets have the potential to guide responsible agencies to preposition and direct gasoline shortage according to the spatial and temporal demand and shortage predicted by the spatial and temporal distribution of these tweets. The perspective by Merchant, Elmer, and Lurie (2011) shows how it is possible to integrate social media into emergency preparedness efforts. Based on the lack of research in this very interesting and useful area, we would encourage interested researchers to fill this gap in their future work.

7. Summary

In this paper, we reviewed OR/MS journal papers from the year 2000 to the end of January 2018 that worked on assets and supplies prepositioning problem before a natural disaster strike. We categorized the surveyed papers in several different ways to show OR/MS journal contributions in this area (see Section 3.1), trend in number of papers by year and type of disaster (see Section 3.2), and statistics on disaster types considered (Section 3.2.1). We further categorized the papers based on decision variables used (see Section 4), and for each of these categories we provided the structure of optimization models suggested by these papers. We did this by defining their objectives, decision variables, constraints, the type of considered uncertainty if it was applicable, the planning horizon, solution methodology, and case studies (see Tables 2–7 and S1–S3). In addition, we also assessed our current literature based on some of the methodological issues in HO gathered by Kovacs and Moshtari (2018), to see how many and which papers address these critical items in their research (see Section 5). Finally, we highlighted and discussed the gaps we found through reviewing these papers to provide researchers in the POD area with potential future research directions. We believe that following these suggested future research directions will lead to models that are close to reality and applicable to be used in the future natural disasters (see Section 6).

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Supplementary material

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