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Disaster Management: Managing the Calamities Through Operations Research

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Abstract:-Disasters, natural or man-made are large refractory and intractable problems. They are unforeseen, severe and immediate. And thus, they become important circumstances that test the management capability of humankind to successfully protect their populations and infrastructure, to lessen both human and property loss, and to quickly recuperate. Operations Research as a discipline has the ability to answer these dynamic and unique problems and give real time optimal solutions, thus making Disaster Management very suitable for OR research. This research paper aims to give a structured solution oriented study, derived from various Operations Research theorems, about 4 phases of Disaster Management: Mitigation, Preparedness, Response and Recovery. The study will throw light upon various problem areas that arise during these 4 phases and how OR theorems (like Queuing theory, Evolutionary optimisation, Probability assessment and more) practically solve these problems, and when applied reduce their arbitrary nature giving them structured holistic solutions. The limitations to the study being the limitations of various theorems and how they actually respond when put to application in problem areas in real life. Thus, not giving the provision of ideal solution.

I. INTRODUCTION

According to the Centre for Research on the Epidemiology of Disasters (CRED) in 2011, 332 disasters from natural hazards were recorded in 101 countries, causing more than 300770 deaths, and affecting over 244 million people (CRED, 2012).A huge number of dead and billions of dollars of harms flag the presence of huge issues for study by any discipline with the capability of reducing the impacts and improving the response to such events. Disasters are extreme occasions that are characterised by a sudden beginning and have an effect on a large sections of the population in the area they appear. They can be natural such as earthquakes, tsunamis, floods, tornadoes, hurricanes and pandemics, or anthropogenic such as industrial accidents, traffic accidents, terrorist attacks. Therefore, the development of approach for the assessment of future risks and impacts of disaster, their present outcomes and diminish the following is pivotal as well as the decision making process for preparedness and response of disasters is of major significance. Thus, this paper encapsulates the concepts of Operation Research which provide real time optimum solutions to the arbitrary natured disaster problems.

A. Boundaries of the study

To highlight the boundaries of the study three questions need to be answered: What is a disaster? What is OR/MS? And what constitutes disaster operations? The last question is relatively easier to answer. We consider the set of activities that are performed before, during, and after a disaster with the goal of preventing loss of human life, reducing its impact on the economy, and returning to a state of normalcy as disaster operations. The definition of OR/MS on the other hand, is not clear cut. Churchman et al. (1957) defines OR/MS as the application of scientific methods, techniques, and tools to problems involving the operations of systems so as to provide those in control of the operations with optimum solutions to the problems. This study is not limited to a certain kind of event and considers all disaster types that are of interest to the International Federation of Red Cross and Red Crescent Societies (IFRC). So, the research paper revolves around the key concept of OR/MS resulting in proper situations like disaster.

B. Overview: OR and Disaster Management

In the context of disaster management OR can provide solutions that can be crucial for optimal humanitarian assistance deployment such as supply chains, resource allocation etc. Methodologically, OR can complement the tools and methods used in disaster epidemiology in the management of emergency disaster situations. But there is a systematic division to situations attributed to disaster in order to deal with emergency situations effectively since disaster as problem is really vast. So accordingly we can segregate as given below:

Tufekci and Wallace (1998) suggest that emergency response efforts consist of two stages; prevent and post-event response. Pre-event tasks include predicting and analyzing potential dangers and developing necessary action plans for mitigation. Post-event response starts while the disaster is still in progress. At this stage the challenge is locating, allocating, coordinating, and managing available resources. Tufekci and Wallace also suggest that an effective emergency response plan should integrate both of these stages within its objective. They add that separating pre- and post-loss objectives may lead to suboptimal solutions to the overall problem. Emergency management is normally portrayed in terms of four methodical phases: Mitigation, Preparedness, Response, and Recovery. The four-phase approach covers all of the actions described in Tufekci and Wallace classification while providing a more focused view of emergency management actions.

Mitigation is the application of measures that will either prevent the onset of a disaster or reduce the impacts should one occur. *Preparedness* activities set up the group to react when a catastrophe occurs. *Response* is the employment of resources and emergency procedures as guided by plans to preserve life, property, the environment, and the social, economic, and political structure of the community. *Recovery* involves the actions taken in the long term after the immediate impact of the disaster has passed to stabilize the community and to restore some semblance of normalcy.

Table 1lists the typical activities involved in each of these four stages. (Next page)
From the concepts projected above we define the objective and flow of research ahead in the paper as follows:

C. Objectives of the Paper

In this paper we aim to:

- Discuss the problems that arise during the phase of mitigation, preparedness, response and recovery
- Give structured solutions about above mentioned four phases of disaster management
- Check the applicability of the solutions in the real world scenario
- Check which application are being used in the real world

II. TYPICAL ACTIVITIES OF DISASTER OPERATIONS MANAGEMENT

A. Mitigation

- Zoning and land use controls to prevent occupation of high hazard areas
- Barrier construction to deflect disaster forces
- Active preventive measures to control developing situations
- Construction standards to enhance disaster resistance of structures
- Tax incentives or barriers Controls on rebuilding after events
- Risk analysis to measure the potential for extreme hazards
- Insurance to reduce the financial impact of disasters

B. Response

- Activating the emergency operations plan
- Activating the emergency operations centre
- Fatality management
- Evacuation of threatened populations
- Emergency rescue and medical care
- Fire fighting
- Opening of refuges and arrangement of mass care
- Urban search and rescue
- Emergency infrastructure protection and recovery of lifeline services

C. Preparedness

- Recruiting personnel for the emergency services and for community volunteer groups

- Emergency planning
- Development of mutual aid agreements and memorandums of understanding
- Training for both response personnel and concerned citizens
- Threat based public education
- Budgeting for and acquiring vehicles and equipment
- Maintaining emergency supplies
- Construction of an emergency operations centre
- Development of communications systems
- Conducting disaster exercises to prepare workforce and test competencies

D. Recovery

- Disaster debris clean up
- Financial assistance to individuals and governments
- Rebuilding of roads and bridges and key facilities
- Sustained mass care for displaced human and animal populations
- Reburial of displaced human remains
- Full restoration of lifeline services

III. OPERATIONS RESEARCH CONCEPTS AND IMPLEMENTATION SCOPE

In the next section of the paper we introduce the conceptual analysis of various Operation Research methods on which research has been undertaken previously and they prove to be on pragmatic grounds for management of calamity and disaster situations. We aim to present our research in the format of stages of disaster onset and occurrence - classifying the methods used or can be used in the order of stages: Mitigation, Preparedness, Response and Recovery and the scope of their implementation discussed along.

A. Mitigation

Disaster mitigation measures are those that dispose of or diminish the effects and dangers of hazards through proactive measures taken before an emergency or disaster occurs. Mitigation methods can be structural or non-structural. Structural solutions use technological solutions like flood levees. Non-structural measures include legislation, land-use planning and insurance. Mitigation is the most cost-efficient method for reducing impacts of hazards and insurance.

Summarised below are the principle techniques of OR that help in the Mitigation process of disaster Management and Pre-planning:

a). Supply Chain Risk Management

- *Concept:* Supply chain risk management (SCRM) is "the implementation of strategies to manage both everyday and exceptional risks along the supply chain based on continuous risk assessment with the objective of reducing vulnerability and ensuring continuity".

  SCRM attempts to reduce supply chain vulnerability via a coordinated holistic approach, involving all supply chain stakeholders, which identifies and analyses the risk of failure points within the supply chain. .

- *Application:* The applicability of the above process is mainly regarding the availability of the food supplies and essentials before and during disaster and managing it in a way taking the factors of disaster in considerations such that it's least effected and are easily accessible during emergency situations.

SCRM assess the effectiveness of incorporating three types of redundancy practices (pre-positioning inventory, backup suppliers, and protected suppliers) into a firm's supply chain that is exposed to two types of risk: supply risk and environmental risk. Supply risk disrupts an individual provider, while environmental risk makes various providers in a given locality inaccessible. An extra factor is supplier interconnection, where an interruption in one supplier may also disturb other active suppliers. Using the idea of a decision tree to capture diverse disruption scenarios, development of a two-stage mixed-integer programming (two-stage MIP) model as a General Model to address the problem of supplier selection and order allocation under supplier subordination and danger of interruptions. In the General Model, multi-sourcing is the only supplier procedure that the firm carries out. It's quantitatively shown how adding redundancy to the supply chain in different forms, along with contingency plans, can help firms mitigate the impact of supply chain disruptions. An analysis of reliability, risks, dependence, and costs is conducted is used as a strategy to provide insights into supplier selection, demand allocation, and capability development in a supply chain under supply chain risks. Finally, it can be inferred that regionalizing a supply chain is an effective way to mitigate the negative impacts of environmental disruptions on the supply chain.

B. Formulation and Solution of A Multi-Commodity, Multi-Modal Network Flow Model for Disaster Relief Operations

a). Concept

The multi-commodity flow problem is a network flow problem with multiple commodities (flow demands) between different sources and sink nodes. Suppose we have a network of nodes connected by lines. Each line has a particular capacity (aka "bandwidth"), as well as a cost associated with it. There is some traffic flowing along each line (where the flow is bi-directional) consuming some of the bandwidth. The traffic flow is made up of node-to-node

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demands that may go through multiple hops along its route in order to get from origin to destination. We can assume that each possible pair of nodes has some traffic flow between them. The goal is to find the optimal (ie, minimum cost) set of routes through the network for each of those demands.

b). Applicability

Urban evacuation views as a crucial course of action that serves to transfer the maximum number of people and property from the catastrophe zone of the urban region to the safe zone within the briefest conceivable time. Multi-commodity urban evacuation problem (MCUEP) seeks and discovers the re-construction of the traffic routes to be followed in clearing with the portability of at least two sorts of the vehicles permitting two way lanes. Thus this model is used in pre-planning stage to optimise routes in case of disaster.

IV. PREPAREDNESS

Preparedness refers to an extremely solid research based arrangement of moves that are taken as precautionary measures in the face of potential disasters. These activities can incorporate both physical arrangements (such as emergency supplies stores, adjusting structures to survive earthquakes and so on) and trainings for crisis activity. Preparedness is a critical quality in accomplishing objectives and in avoiding and mitigating negative outcomes. "Disaster Preparedness", defined by the UN as involving "forecasting and taking precautionary measures prior to an imminent threat when advance warnings are possible"

A. Inventory Planning

a). Concept

- *Pre-Positioning:* Regional warehouses are strategically located in major transportation hubs.

  A stochastic inventory model can help anticipate the types and quantities of aid supplies to be kept in a pre-positioned facility, minimizing the overall cost of inventory kept. The study of Emmett and Lodree (2011) centred in the local retailer’s inventory management issue that arises upon identification of a possible pre-storm demand surge; estimating the responsive and dynamic strategies over stock level for a fast-moving item. They use the minimax decision criterion (the decision rule that optimizes the worst case scenario that does not require any probabilistic information) for the classic economic order quantity (EOQ) model.

- *Applicability:* Arranging inventories for crisis supplies such as bottled filtered water, non-perishable foods, batteries, and torches can be difficult for retailers situated within the anticipated path of the crisis. The retailer's stock choices are complicated by the innate uncertainty of the crisis forecasts and the corresponding demand predictions.

b). Inferences from the Study of Emmett AND Lodree

The inventory system is formulated based on an underlying economic order quantity framework. Minimax decision rules are developed analytically. Sensitivity analysis is facilitated by both analytic and numerical methods.

The conditions that are helpful to a responsive ordering strategy are constrained supplier adaptability, intense demand surge, and excessive reorder costs; otherwise, the minimax inventory control policy is given by a reactive ordering strategy.

Humanitarian logistics is the other method that defines the solution towards preparedness of disaster management, but the solution orientation provided by the concept of humanitarian logistics is coherently interconnected to next stage of disaster management, which is response, so in the flow of research ahead we will first define Response and then introduce the concept Humanitarian logistics which will be interconnected to the solutions for Preparedness and Response.

V. RESPONSE

Disaster response is the second phase of the disaster management cycle. It comprises of various components, for example; cautioning/evacuation, search and rescue, giving prompt help, evaluating damage, continuing help and the immediate rebuilding of infrastructure. The aim of emergency response is to give prompt help to maintain life, enhance health and support the spirit of the affected population. Such help may extend from giving particular however restricted aid, such as assisting refugees with transport, temporary refuge, and food, to establishing semi-permanent settlement in camps and other locations. It may also include initial repairs to damaged infrastructure.

The focus in the response phase is on meeting the essential requirements of the people until more permanent and supportable arrangements can be found. The main obligation to address these necessities and react to a calamity lies with the government or governments in whose domain the disaster has occurred.

VI. HUMANITARIAN LOGISTICS

A. Concept

‘‘Since disaster relief is about 80 % logistics it would follow then that the only way to achieve this is through slick, efficient and effective logistics operations and more precisely, supply chain management. ’’Van Wassenhove (2006) p. 475

Humanitarian logistics is defined as ‘the process of planning, implementing and controlling the efficient, cost effective flow and storage of goods and materials as well as related information, from the point of origin to point of consumption for the purpose of meeting the end beneficiary’s requirements.

B. Coherence and Linkage with Preparedness and Response:

Logistics assumes a key part in disaster response operations; it fills in as a link between disaster preparedness and response, between procurement and allotment, and between headquarters and the field, and is essential to the efficiency and responsiveness to major humanitarian plans such as health, food, shelter, water and sanitation.

Quickly after the occurrence of catastrophe, humanitarian operations are started with the aim to give quick assistance to victims in various ways, rescuing the individuals who are injured or potentially stranded, gathering and disposing corpses, resource allocation, provision of food aid, shelter and medical care, and re-establishing access to remote areas. In humanitarian actions, delays in conveyance or alleviation can cost lives. Therefore, effectiveness in logistics is an important success factor, because it ensures the smooth flow of goods and services in a complex supply chain.

C. Key Areas in the implementation of Humanitarian Logistics are:

- Procurement: consider the activities relating to supply chain preparation, planning and evaluation, supply chain optimization and pre-positioning of products (allocation problem).
- Storage and handling: operational issues with respect to storage and transport of materials and inventory planning - supply network design, gauging of inventory levels, facilities location (location problem) and personnel distribution.
- Transport and distribution: related with the conveyance of the item to the end client or a point to redispatch – lining of deliveries and distribution flow coordination.

VII. IMPLEMENTATION

The scientific literature related to humanitarian logistics can be divided into three main groups, facility location, inventory management and network flows.
Procurement: Regarding the logistics process of procurement, the existing mathematical models focus on decisions related to supply chain optimization and inventory pre-positioning. The OR/OM techniques applied in these models are discussed as follows:

A. Facility Location:

Facility location research deals with spatial aspects of operations and explores the effects of geographical facility location on factors such as service and response time but also costs.

Facility location problems derive their importance from two factors: their direct impact on the system’s operating cost and timeliness of response to the demand. While the goal of facility location models aiming private sector problems is generally to minimize cost or maximize profit, the models addressing public and emergency services instead focus on user accessibility and response time.
This flow of resources agrees with the four fundamental phases of disaster relief, as identified by Thomas (2002) and Beamon (2004): (1) assessment: minimal resources are required to distinguish what is required, (2) deployment: resource requirements increase to meet the requirement of the time, (3) sustainment: operations are sustained for a timeline, and (4) reconfiguration: operations are diminished, then ended. The length of each stage in the relief cycle fluctuates depending on the disaster characteristics. However, the speed of relief operations amid the primary days of the disaster significantly affects the lives of many people threatened by the disaster. Hence, the ability of a relief organization to prepare and mobilize its resources during the assessment and deployment phases is important to the success of disaster response.

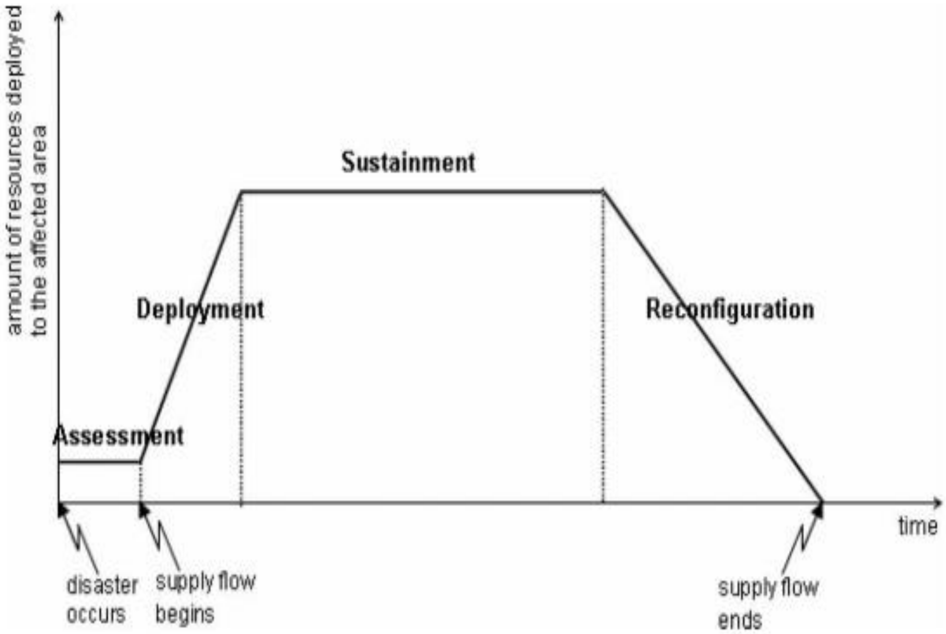

Figure 1. Relief mission life cycle. *Source*: modified from Beamon (2004) and Thomas (2002).

B. Implementation

We consider a distribution system in which a relief organization locates distribution centres to satisfy the immediate needs of those affected by quick-onset disasters, given the uncertainties and resource limitations in a disaster relief environment. Assuming that demand for relief supplies can be met from suppliers and warehouses, finding the optimal warehouse locations and capacities. In their scenarios for disaster location based on historical information they minimise the expected response time over all scenarios for a single event. Since facility locations and the amount of inventory affect relief chain costs and response times, realistic forecasts of potential demand locations and amounts will contribute to the effectiveness and efficiency of facility location and stocking decisions.

C. Network Flows

Concept: In graph theory, a flow network (also known as a transportation network) is a coordinated graph where each edge has a limit and each edge receives a flow. The measure of flow on an edge cannot exceed the limit of the edge. Often in operations research, a directed graph is called a network, the vertices are called nodes and the edges are called arcs. A flow must fulfil the restriction that the amount of flow into a node equals the amount of flow out of it, unless it is a source, which has only outgoing flow, or sink, which has only incoming flow. A network can be used to model traffic in a road system, circulation with demands, fluids in pipes, currents in an electrical circuit, or anything similar in which something travels through a network of nodes.

D. Implementation

Given the existing infrastructure, such as traffic roads, bridges, buildings, and other facilities, may suffer from severe damage due to disaster. Assuming uncertainty related with each road segment's availability, a transhipment network flow is formulated, optimization problem under various types of uncertain situations. In order to express the uncertainty regarding the availability of each road segment, application of the Monte Carlo simulation technique to generate random networks following certain probability distribution conditions. Then, model is solved to obtain an optimal transport strategy for the relief goods. Thus, implementation of a necessary and desirable response strategy for managing emergency cases caused by, for example, various natural disasters. This modelling approach has been applied to the actual road network in Sumatra Island in Indonesia in 2009, when a disastrous earthquake occurred to develop effective and efficient public policies for emergency situations.

Alternately, Ozdamar et al. (2004) developed a network flow model to implement on logistics planning in emergency situations. The model deals with the transportation problem that occurs in the event of natural disasters. Problems occur due to the time-aspect involved in rescue efforts. Supply available only in limited quantities poses also a major issue. They develop a mathematical model that addresses the dynamic time-dependent transportation problem that needs to be solved repetitively at given time intervals during on-going aid delivery. Model outputs are dispatch orders for vehicles waiting at different locations in the area. These orders designate the routes of vehicles including empty trips, pick-ups and deliveries in mixed order and waiting interludes throughout the planning horizon. The model takes into consideration time-dependent supply/demand and fleet size, and facilitates schedule updates in a dynamic decision-making environment.

VIII. RECOVERY

Disaster recovery (DR) involves a set of policies, tools and procedures to enable the recovery or continuation of vital technology infrastructure and systems following a natural or human-induced disaster.

Recovery stage of Disaster Management is planning and management based, we could not discover any specific operations research technique that could give a structured solution. Though planning and Management theories like PDRM *(Practical* Disaster *Risk* Management) and Business continuity planning can be helpful in the process of recovery.

Reference: Project management methodology for post disaster reconstruction, 2008 by Sterling and Marie, conference paper-PMI (Project Management Institute)

IX. SUGGESTIONS FOR THE APPLICATION OF MODELS IN REAL OPERATIONAL CONDITIONS

The experience of mathematicians practicing prevents the application of mathematical OM/OR models in the decision-making for operations processes in response to cataclysmic events. Professionals often complain that mathematical models have such large numbers impediments that they do not reflect the reality of such an intricate procedure as a humanitarian operation for alleviation after a catastrophic event, due to the eccentric nature of the situation, quick response time, demand variability, and the accessibility of information and resources - material and money related (Beamon and Balcik, 2005). Furthermore, professionals fortify that mathematical models tend to be exceptionally complicated and require time and computer resources not available after the occurrence of a disaster.

In any case, in this study, our discoveries suggest the application of OR/OM models on the context of humanitarian logistics can be of great help to the improvement of systems for management decisions in reaction of catastrophic events. However, when building up a mathematical model for humanitarian logistics, certain facets should be considered to expedite its application on the field, on real operational conditions. Hence, the accompanying parts of the models were analysed and suggestions were made to enhance the functionality of the proposed models, regarding:

- Operational costs
- Humanitarian relief parameters
- Support of humanitarian organizations
- Implementation of mathematical solutions

A. Considerations Regarding Operational Costs

In a portion of the models studied, the aggregate operating cost is viewed as a decision variable, as part of the objective function, in others it showed up as a constraint. Nevertheless, in real operations, costs must be considered in two unique conditions by decision makers. In the first, the goal is the minimum cost as striving for operational efficiency, to permit an estimate of the money required for funding (private or government). In the second condition, the estimation of the monetary allowance must be known or assessed, and the estimation quality will directly affect the nature of the alleviation programme with respect to attendance to the demand of the victims. The choice of the model ought to be related with this understanding, or its formulation should permit adaptability as the real condition is known.

In all results considered, costs are important factors in planning and application. Aside from the work of Wyk et al. (2011), the papers do not indicate a routine and the information source to compute the diverse cost components.

For models centred in disaster response, the finding of the costs for transport, handling and storage, and others, becomes extremely complex, so there is the need for a methodical costs estimation, plainly and rapidly because of this circumstances (post-disaster). The use of models planned to the pre-disaster stage permits more time for the determination of appropriate costs, in spite of the fact that using more estimates than facts. In any circumstance, not only the time required for costs estimationis important, yet in addition also the quality, both being key elements for the workability of any mathematical solution.

B. Considerations Regarding Humanitarian Relief Parameters

Because of the characteristics of the objectives of humanitarian activities, the objective function of proposed models ought to include decision variables related with welfare. Notwithstanding the time and the service level, which are the most evident factors that influences welfare, penalties in costs related with the forgo of victims and losings based on the level of care given have also been used.

Regarding the forgo of lives, monetary parameters related with losses were presented by Perez et al. (2010), Holguín-Veras and Jaller (2011) and Wyk et al. (2011), including information from the Department of Transport in South Africa. However, there are still tries to find an ideal solution.

The gathering of data for demand forecasting, including things and amounts to be supplied to the victims, are imperative factors that influence the service level of a relief operation. In these conditions, the models that use weights on the cost components to derive to the choice about resource allocation (Clark and Culkin, 2007) might be the most fitting; considering the need of an accomplished group, in charge for the activity coordination and for the decision making process.

C. Considerations Regarding The Support of Humanitarian Organizations

The works of Balcik and Beamon (2008), Wyk et al. (2011), Mete and Zabinsky (2009), Beamon and Kotleba (2006) and Özdamar et al. (2004), that have the support organizations or take part in programmes concentrated on identifying solutions for the optimization of logistics activities in the humanitarian context, have the upside of supporting for getting resources and information, and for application under field conditions.

There are ongoing projects and organizations such as IFRC, PAHO, PARVAC and SADC that have operational guidelines, experiments, studies and techniques directed to humanitarian aid environment, notwithstanding the practical experience of participation in humanitarian operations. The association with these organizations can be useful in accelerating the way towards developing more appropriate solution, because of the increase in knowledge emerging from a possible collaboration (theory and practice in the field).

D. Considerations Regarding the Implementation of Mathematical Solutions

The display of the steps to execute the solution proposed by mathematical models is a critical thing to be considered for the use of such models in real operations since it permits to assess the level of difficulty, and the requirement for funds and resources required for its utilization in field conditions of humanitarian responses. In any case, the articles presented does not explain how to implement the solutions proposed, which makes the decision of which model to apply more complex and difficult, as it asks for the recognition of the requirements and the application for more assessment of the conditions at the scenario of the calamity response. In this way, imitating the outcomes shown may be compromised due to contrast in the implantation procedure of any model chosen. Furthermore, it convolutes the likelihood of trading experiences and possible upgrades in the standardization of procedures.

X. CONCLUSION

Disaster response quantitative techniques for example operations research answering issues related to public health are imperative instruments for planning effective responses to catastrophes. A lot of modelling methods have been utilized to examine public health disaster reaction decisions. These include statistical analyses, Markov models, epidemiological models, supply chain management models, facility location models, and routing and network flow techniques. Models address a diversity of decision makers (e.g. first responders, public health officials), geographic settings, strategies modelled (e.g. dispensing, supply chain network design, prevention or mitigation of disaster effects, treatment) and outcomes evaluated (costs, morbidity, mortality, logistical outcomes).

The study of articles with the proposition for application of mathematical models to enhance the logistics outcomes in disaster response shows that there remains a gap between what is proposed in the model and what actually happens in the situation of the disasters. There are imperative advances with the inclusion of humanitarian aspects as decision variables in the making of the models. Nonetheless, studies seem scattered, with little coordination between developments, trying to find and present alternatives, yet not reciprocal and, with a few exceptions, with little adherence to field conditions, which is one of the principle focus that may encourage operations managers to use mathematical models proposed. It is possible to link many of those works because they deal with logistics stages (including humanitarian context), but only through a backbone procedure in which they can be applied.

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