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Operations research in disaster preparedness and response: The public health perspective

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Abstract

Operations research is the scientific study of operations for the purpose of better decision making and management. Disasters are defined as events whose consequences exceed the capability of civil protection and public health systems to provide necessary responses in a timely manner. Public health science is applied to the design of operations of public health services and therefore operations research principles and techniques can be applied in public health. Disaster response quantitative methods such as operations research addressing public health are important tools for planning effective responses to disasters. Models address a variety 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) and use a range of modelling methodologies. Regarding natural disasters the modelling approaches have been rather limited. Response logistics related to public health impact of disasters have been modelled more intensively since decisions about procurement, transport, stockpiling, and maintenance of needed supplies but also mass vaccination, prophylaxis, and treatment are essential in the emergency management. Major issues at all levels of disaster response decision making, including long-range strategic planning, tactical response planning, and real-time operational support are still unresolved and operations research can provide useful techniques for decision management.-

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 30 770 deaths, and affecting over 244 million people (CRED, 2012). Disasters are severe events that are characterised by a sudden onset and affect a large fraction 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. Disasters have the specific feature to be unpredictable and have a substantial public health impact in terms of short and long-term adverse-health effects. Therefore, the development of methodologies for the evaluation of the public health consequences as well as for the decision making process for preparedness and response of disasters is of major importance and has drawn the attention of several scientific disciplines such as operations research, the science of decision management.

Operations research (OR) is a scientific area where methods coming, predominantly, from mathematics, computer sciences and economics are employed in decision making processes. The tools developed by OR are used to assess the consequences of alternative decisions of long or short term nature such as strategic planning or operational decisions. Therefore, OR can be seen as the science of resource allocation in an optimal way. In association with disaster preparedness and response and the impact on public health OR can contribute in the evaluation of operational strategies and actions associated with large scale natural disasters. OR can provide guidance on the optimal choice of these strategies and actions under consideration.

Within the framework of public health, operations research is the study of the employment and the optimal use of health services in a community. 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 public health programmes. The ultimate goal is to achieve better managed humanitarian relief programmes and quantitative analysis scientific techniques can contribute to process of informing public health decision making.

In this paper we systematically review operations research approaches used in the crisis management of large scale disasters/emergencies and specifically disaster preparedness and response with respect to public health. We describe the benefits from the use of quantitative methods to the humanitarian assistance arena based on selected examples.

Methods

Search strategy and selection criteria

The PubMed database was exclusively used for the search strategy since our focus was on operational research methods in public health issues related to disasters. Documents were included if there was reference to operational research methods related to natural disasters. An investigation of disaster specific databases such as the disaster portal DisDAT proved to not be appropriate for a methodology review due to poor quality of data, description of methodology, and inconsistency of estimates. The PubMed search was performed for studies published from January,1st, 2000 to May 31, 2012, comprising a period of more than 12 years. Terms used for the search were 'emergency/disaster response or preparedness'. To comply with our goal we restricted the search to methodological work by using terms which represent common methods in

operational/operations research such as mathematical programming and modelling, probability and statistics, simulation, decision theory, optimisation as well as more specific terms such as queuing theory, system dynamics and control theory. We restricted our search to articles in English language that didn't represent a weakness in terms of missing relevant articles. Our preliminary search showed that none of the articles in other languages were of relevance for our review. As mentioned above our work focussed on large scale natural disasters or emergencies with a short term crisis character namely earthquakes, tsunamis, floods, tornadoes, hurricanes and pandemics. Small scale natural disasters, industrial accidents, terrorist attacks and hospital planning were excluded. We also considered pandemics associated with a fast spreading mode of transmission e.g. influenza outbreaks, but not pandemics of a large time scale nature such as HIV/AIDS.
Using the terms emergency/disaster response or preparedness for natural disasters or pandemics 161 articles were screened. 76 potentially relevant articles were retrieved for full text review. 32 papers were excluded due to content e.g. they didn't use any OR typical method that went beyond basic descriptive statistics or the public health and/or the emergency/disaster part was either limited or related to small scale emergencies and thus of secondary relevance for the purpose of this work. 44 were assessed.

For our systematic review of articles listed in PubMed related to our key words 'disasters' and 'public health' we used an automated methodology that allows the search and visualisation of the retrieved bibliography through an intuitive hierarchical clustering method (Consoli et al. 2010). The method produces a graph of document clusters from a distance matrix whereby the number of clusters is not known in advance. The method allows to detect the structure of the articles and to cluster them according to their thematic proximity (Fig. 1).

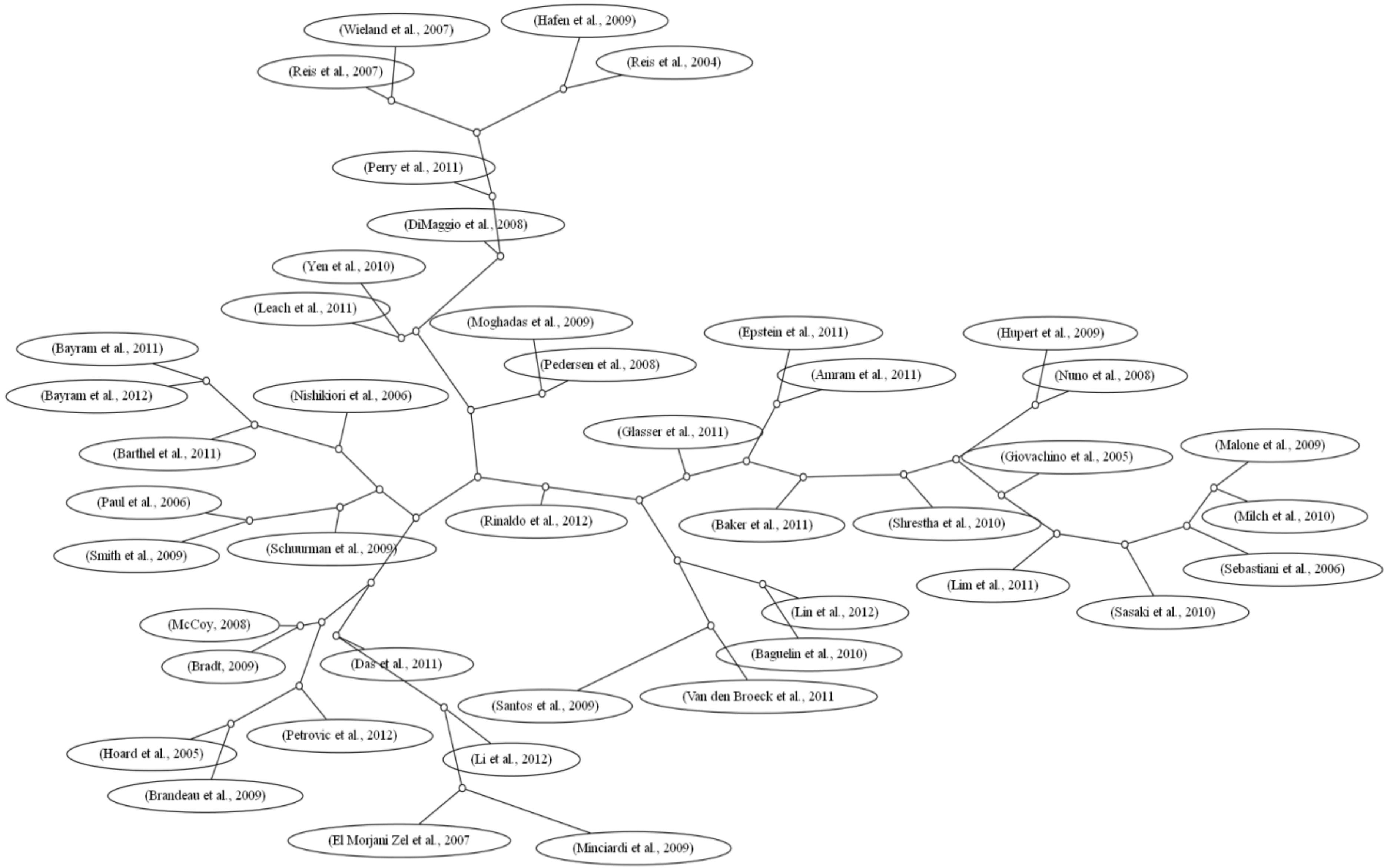

Fig. 1: Clusters of publications related to the combination of the key words disasters and public health as they emerged from the search in PubMed.

Types of disasters

In this review the focus is on natural disasters and the operations research approaches used. Man-made disasters such as population movement, conflicts and technological disasters industrial accidents, transport accidents, are not subject of this report. The approaches are presented as they implemented by type of disaster. In what follows, and before entering into the public heath component of the issue, we present some examples of the use of operations research in disaster relief associated problems from the scientific literature.

Operations research approaches used in natural disasters management

There have been a large number of methods used in disaster operations management. Mathematical programming, heuristic methods, probability theory and statistics, and simulations are some of them. Within the contexts for instance of logistics and supply chain management, quantitative methods were also used in humanitarian logistics to analyse situations, data, and improve performance of the relief chain. Altay and Green (2006) did a literature survey on the operations research work that has already been done in the disaster operations management area. Based on that review, mathematical programming, and heuristic methods were used most often. Probability theory and inferential statistics were used second most frequently with simulations being also one of the most common approaches. Decision theory, and queuing theory were also used in specific cases. De la Torre et al. (2011) present in their article an analysis of the use of operations research models in transportation of relief goods, from the perspective of both practitioners and academics.

Humanitarian logistics

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' (Thomas and Mizushima 2005). Disasters are unpredictable and are often associated with large scale casualties. Thus, humanitarian logistics plays a critical role. The 2004 Indian Ocean Tsunami has shown the challenges associated with relief aid efforts and the importance of humanitarian logistics. There have been a number of publications related to humanitarian logistics in recent years. Alexander (2006) provides an overview of the logistical and organisational components of humanitarian relief. The characteristics of disasters that make response complicated and difficult, the instruments used to respond to disasters and the communication problems together with the conditions that create the chaotic environment at disaster site adversely affecting logistical operations are presented and discussed by Katoch (2006).

The scientific literature related to humanitarian logistics can be divided into three main groups, facility location, inventory management and network flows.

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. In a study on inventory pre-positioning for humanitarian logistics Akkihal (2006) developed a model to determine positions for facilities where goods could be stored and used in the event of a disaster. The approach identifies optimal locations for ware-housing inventories required for the initial development of aid. The model is a linear-programing optimisation approach using historical information on mean homeless people resulting from natural disasters as the weights for the different demand locations. The model minimises the average distance from the forecasted homeless persons to their nearest warehouse. The pre-positioning of relief supplies was also addressed by Balcik and Beamon (2008). Assuming that demand for relief supplies can be met from suppliers and warehouses they find 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. Duran et al. (2011) find an optimal number and location of pre-positioning warehouses given that demand for relief supplies can be met from both pre-positioned warehouse and suppliers. In contrast to Balcik and Beamon (2008) they allow multiple events to occur within a replenishment period and they also allow probability of need for each item to depend on both local conditions and natural hazard type.

Inventory management research is rather associated with estimating item quantities required at various nodes along a supply chain, purchasing quantities, order frequency and maintenance of safety stock levels. Beamon and Kotleba (2006) develop a stochastic inventory control model, that determines optimal order quantities and re-order points for a pre-positioned warehouse responding to a complex humanitarian emergency.

Distribution and allocation of goods is the next step in the logistics chain of decision making. Given the decisions regarding location and replenishment the delivery of goods can be modelled as a network flow. Barbarosoglu and Arda (2004) present a multi-commodity, multi-modal network flow with time windows under consideration of uncertainty in demand, in vulnerability of commodity sources, and in survivability of arcs. 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. The authors implemented the model in a realistic scenario based on the attrition figures of the 1999 Izmit earthquake in Turkey.

Very often needs exceed supply of goods, and relief organisations face the problem of how to distribute the goods in an optimal way. Prioritising the needs of the most vulnerable is a common strategy but even there problems emerge. Operations research approaches try to tackle this issue using routing modelling. A common characteristic of many relief routing models is the investigation of egalitarian or utilitarian policies. In egalitarian policies maximal equality of a measure such as delivery quantity or speed is the goal. Utilitarian strategies maximise the amount of demand satisfied without requiring equality in distribution of goods or access to them.

De Angelis et al. (2007) developed a multi-period routing and scheduling model for transporting humanitarian food aid via cargo air planes. Their model minimises total unsatisfied demand and although it includes constraints that may not lead to equitable solutions such as all beneficiaries receive a minimum amount of goods, it can be used to enforce minimum standards.

In general, for rapid and early response maximising total speed of delivery while delivering the maximum quantity of goods possible is essential. Equality in delivery is more suited to longer-term recovery and development aid where speed is less of a factor to worry about (De Angelis et al. 2007).

Sheu et al. (2005) try to optimise the large scale relief distribution problem with the goal to minimise the number of fatalities. Using fuzzy-optimisation techniques their model classifies the damaged areas based on relief demand and priority and then it optimises the situation where the demand for victims is greater than the available resources.

Operations research approaches related to natural disasters and public health

There have been a series of modelling approaches to inform decision making about responses to public health disasters. The models address a variety of decision makers (e.g. first responders, hospital officials, planners, public health officials), geographic settings (e.g. local, regional, national), decision modelled (e.g. dispensing, inventory/stockpiling, supply chain network design, prevention or mitigation of disaster effects, treatment health care workforce, staffing, transportation) and outcomes evaluated (costs, morbidity, mortality logistical outcomes) and use a range of modelling methodologies. Regarding natural disasters the modelling approaches have been rather limited. Response logistics related to public health impact of disasters have been modelled more intensively since decisions about procurement, transport, stockpiling, and maintenance of needed supplies but also mass vaccination, prophylaxis, and treatment are essential in the emergency management. A review and recommendations for modelling disaster responses in public health can be found in Brandeau et al. (2009).

Natural disasters

- Natural disasters can be classified in five major categories.
- Meteorological: Storms, hurricanes, cyclones, tornadoes, typhoons, heat waves
- Hydrological: Floods, avalanches
- Climatological: Droughts, wildfires
- Geophysical: Earthquakes, tsunamis, landslides, volcanic eruptions
- Biological: Disease outbreaks in humans and animals, famine

Meteorological disasters

Heat waves

Heat waves belong to one of the major public health threats since they can affect an enormous number of people. Typical example is the heat wave of the year 2003 in Europe that caused an estimated 70 000 additional deaths in 12 European countries (Robine et al., 2008). Heat waves affect in particular cities due to the heat–island effect. Projections based on mathematical modelling approaches indicated that heat waves are going to occur more often (IPCC, 2012). Early warning mechanisms are introduced through heat-health action plans introduced by many countries as a consequence of the 2003 heat wave in Europe. They include monitoring of meteorological forecasts and public heath activities to reduce or prevent heat related illness and death. Epidemiological assessments contribute to the quantification of the health effects the identification of risk and confounding factors.

Storms and hurricanes

The health effects of storms and hurricanes include injuries, and mental health issues as well as stress of critical infrastructure facilities such as hospitals and emergency rooms. Storm and hurricane forecasting tools can contribute to preparedness and save lives.

Hydrological disasters

Floods

Floods can lead to disastrous conditions with consequences for public health, and damages to personal property. Loss of life and destruction of critical public heath infrastructure with substantial economic losses is usually the result. With respect to public health increasing cases of drowning and injuries are expected after flood incidences. Mental health effects associated with emergency situations during flood incidences have been documented in the literature (IASC, 2007). There is increasing risk of water- and vector-borne infectious diseases. Disruption of health systems, facilities and services when they are needed most and damage of essential infrastructure such as food and water supplies is another consequence. The Intergovernmental Panel on Climate Change (IPCC) published a report on disasters with projections of the increase in the number of people exposed to floods in 2030 compared to those in 1970 (IPCC, 2012). They calculated that all over the Globe there will be an increase in the number of people exposed to floods. This number ranges from about 1.87 million people in Europe compared to 1.65 million in 1970 to 77.64 million compared to 29.79 million in 1970 in Asia.

One area of employment of quantitative methods in flood management is the crisis management of microbial contaminations. In large-scale floods in urban environments pathogens can be brought into homes and buildings and contaminate water and food supplies with substantial public health risks. The risk of microbial contamination under different environmental conditions can be assessed with mathematical modelling approaches as well as epidemiological approaches (Taylor, et al. 2011, Cann et al., 2012).

Geophysical disasters

Landslides

In association with geophysical disasters landslides have been the least investigated. In a study by Das et al. (2011) the authors assessed the vulnerability of elements at risk to landslides such as buildings, persons inside buildings, and traffic, with a stochastic approach. By defining vulnerability as a stochastic consequence of a landslide that quantifies the potential loss in space, time and hence expressed as a probability, they consider a set of objects vulnerable to landslide, e.g., buildings, persons, vehicles at risk. Their vulnerability depends on the location and time with respect to landslide. Statistical approaches such as logistic regression were used to assess vulnerability of static elements such as buildings whereas Poisson modelling was used to assess vulnerability of dynamic elements such as persons in a building or vehicles on the road. They concluded that vulnerability of elements at risk to landslide varies greatly in space and time. This variation was attributed to the dynamic nature of the elements at risk.

Earthquakes

Response of health care providers to large-scale disasters such as earthquakes with respect to casualty treatment includes logistics issues such as the movement of casualties from the stricken area to hospitals. Fawcett at al. (2000) present a simulation model where using as input the numbers of locations of casualties rescued alive, the scale of pre-hospital care, the post-earthquake hospital capacity and the transport system they model the movement of the casualties. The model predicts the number of casualties that die during that movement and makes some prediction about the health-care system response, e.g. waiting time before treatment. The mathematical model can be used for planning and training.

It is well documented that mortality rates increase with proximity to the epicentre of an earthquake and with increasing earthquake magnitude. Seismic intensity has been identified as the primary cause of mortality and injury during earthquakes, mediated by building damage (Aleskerov et al. 2005). Studies about the role of socio-demographic factors on earthquake vulnerability are rare (Badal et al. 2005). In a combined concept using a house hold survey and observational damage assessment, social and environmental determinants for injury and displacement were investigated by Milch et al. (20120) and statistical modelling approaches were used to explore to what extend seismic intensity, distance to rapture, living conditions and educational attainment affect displacement and injury rates (Milch et al. 2010). The results showed that about 55% of the variability in displacement rates could be explained by the above factors. Living conditions were a strong predictor of injury and displacement, indicating a strong association between risk and socioeconomic factors.

Tsunamis

There has been poor documentation of the health consequences of tsunamis from the public health point of view. In order to describe the distribution of mortality among internally displaced persons during two and a half months after the Indian Ocean tsunami 2004 Nishikiori et al. (2006) conducted a cross-sectional household survey with retrospective cohort analysis of mortality in Sri Lanka. Their findings confirm the plausible notion that most casualties occurred on the day of the tsunami and up to three days after. Starting one week after the disaster and for the two and a half months of the duration of the study no deaths were reported. In a second report and using the same epidemiological approach Nishikiori et al. (2006a) tried to identify the risk factors of the mortality during the same tsunami and therefore the vulnerable population groups. The distribution of mortality in 13 evacuation camps for internally displaced persons and associated risk factors were analysed using logistic regression modelling and generalized estimating equations methods. There was a higher mortality among females and children and elderly compared with adults. Other factors such as being indoors at the time of the tsunami, the house distraction level, and fishing as an occupation were all statistically significant associated with increased mortality.

Biological disasters

Disease outbreaks in humans and animals and their control

Outbreaks of infectious diseases that have the potential of a pandemic can become a major challenge from the decision making and management point of view. Public health interventions for mitigation of an evolving pandemic such as vaccination and drug treatment need to be prepared well in advance. Making the decision about the appropriateness and the dimension of the intervention to achieve optimal protection of public health is a very stochastic process difficult to control. The type of intervention as well its timely production, distribution and assessment during and after administration are governed by complex processes. Quantitative tools such operations research methods can be of major help in this context.

The 2009 H1N1 influenza A pandemic represents a typical example where many public health decisions on how to mitigate the pandemic had to be made quickly and were associate not only with the public health component of the issue but also with the corresponding economics. Vaccination was the dominant public health intervention during the pandemic. An assessment of the effectiveness and the cost-effectiveness of several vaccination strategies in real–time using a transmission dynamic model fitted to the estimated number of cases was performed (Baguelin et al. 2010). The model was employed to generate plausible scenarios under different vaccination strategies. The proportion of these cases by age and risk group resulting in practitioner consultations, emergency rooms visits, hospitalisations, intensive care and death was estimated using existing data from the pandemic. The epidemiological modelling approach was a susceptible, latently infected, infectious, and recovere model with the population being split also into risk groups and a not in a risk group as well as into age groups. The model was fitted using maximum likelihood estimates from official national public health sources. The economic model was based on the burden of disease estimated due to the number of infections predicted by the epidemiological model assuming a proportion to be with clinical symptoms. Each clinical case was linked to health care of clinical end point associated with an age and risk group such as general practitioner consultation, antiviral therapy, hospitalisation, intensive care, death. Each of these clinical and health care endpoints was associated with a cost to the health service and quality of life detriment. Then a net incremental discounted cost per quality adjusted life year (QALY) gained was estimated under different vaccination strategies. The model suggested that it would be effective and cost-effective to vaccinate certain risk groups however, for England, due to considerable number of cases before autumn mitigation of the pandemic through vaccination would be unlikely. This might be different in European countries where the epidemic was not so advanced.

Statistical packages such as FluSurge (developed by the Centers for Disease Control and Prevention in the USA) were used for the same pandemic to estimate the potential surge in demand for hospital-based services (Baker et al. 2011). The modelling tool predicts the surge in demand during an influenza pandemic yielding estimates of the number of hospitalisations and ICU admissions and deaths caused by a pandemic compared to the existing hospital capacity. Based on a web-based survey, the feedback of the model was evaluated to be positive and useful to service planning for local hospitals.

Epidemics spread through contacts and the associated networks and their structure may be of major importance for the design of the optimal use of resources for the control of an outbreak. The specific situation on how to minimize the spread of infection by imposing quarantine, provided there are limited resources, is a typical operations research problem and was addressed by Enns et al. (2012). Depending on their positions in the contact network, individuals or links between individuals may play an important role in the spread of the disease and this affects the control strategies of choice. Instead of the algorithms for interventions such as vaccination that make use of network structure commonly used Enns et al. (2012) propose an alternative method. Knowing which nodes in a network are initially infected and given a limited number of links that can be removed in the contact network, Enns et al. (2012) seek to quarantine the portion of the network containing the infected nodes from the rest of the network. All this is done by leaving the minimum number of susceptible nodes connected to infected nodes through some path in the network. The resource limitations are the limit of the number of links that can be removed. The nodes represent communities, or cluster of individuals with links representing their interactions. Networks of this type are likely to be smaller than network at individual levels. For instance, in global airline networks the vast majority of air travel is associated with a sub-graph of 500 airports (Hufnagel et al. 2004). In this context, the link removal problem may help in the decision on which flights to cancel in order to prevent the spread of respiratory diseases through a network of cities connected by air travel. For the decision on which link to remove, an optimisation problem based on two-way graph partitioning was formulated with the goal to minimise the number of susceptible nodes at risk of infection. The authors present a method for generating near-optimal solutions based on constrained quadratic programming and semi-definite programming. They show how to near-optimally isolate susceptible nodes from infected ones, given a constraint on the number of links that can be removed. They demonstrate that their method performs well in small-world random graphs as compared to optimal solutions found by exhaustive search. The approach could also be used for issues like how to limit the movement of livestock between farms to prevent the spread of zoonotic diseases, or how to change the structure of a city's harm reduction programmes to prevent interactions between geographically disparate clusters of injection drug users and the spread of infectious diseases.

A potential public health response to an influenza pandemic might be mass prophylaxis. An intervention of this type will have to deal with the issue of multiple points of dispensing to deliver counter measures rapidly to the affected populations. The optimal staffing levels at points of dispensing under dynamic and uncertain operational environments can be tackled with Monte Carlo simulation modelling approaches, in this case applied for the option of mass prophylaxis (Hupert et al. 2009). The approach can provide insights into the assessment of the consequences of non-stationary patient arrival patterns on point of dispensing function under a variety of point of dispensing layouts and staffing plans. The simulations predict that points of dispensing functioning under non-stationary patient arrival rates require higher staffing levels that would be predicted using the assumption of stationary arrival rates. Staffing levels have to vary over time to meet changing patient arrival patterns. Dynamical adjustment of staff levels to meet demand is the consequence.

Nuno et al. (2008) developed a stochastic compartment model to investigate whether conditions exist under which non-pharmaceutical interventions alone might prevent the induction of a pandemic virus. The model projected that currently existing staff-visitor interactions and social distancing practices will have to be modified to avoid rapid internal propagation. The model identifies staff re-entry as the critical source of infection, provides estimates of the reduction in risk required to avoid virus introduction and suggests interventions such as protective isolation of staff.

These examples show that fundamental uncertainties in public health disasters can be captured and quantified by modelling approaches. Mathematical modelling and decision support systems can also be used for the management of medical supplies such as blood, vaccine or drug supplies during a pandemic (Kamp et al. 2010, Shrestha et al. 2010, Lin et al. 2012). During an influenza pandemic, optimal dosing and dynamic distribution of vaccines is essential. Given the limited production capacity and delays in vaccine development during a pandemic, the production of antigen-sparing vaccines that allows an increased population coverage but being less efficacious is a reasonable option. The trade-off between the two effects was studied by Wood et al (2009).

Surveillance systems are not robust to shifts in health-care utilisation, due to, e.g., a pandemic, since they do not adjust baselines and alert-thresholds to new utilisation levels, or because utilisation shifts themselves may trigger an alarm. Epidemiological network models that monitor the relationships among different health-care data streams instead of monitoring the data streams themselves may help in improving the stability of surveillance systems (Reis et al. 2007). Historical time-series models of the ratios between each possible pair of data streams are monitored. These ratios do not remain at a constant value but they are assumed to vary in a predictable way according to seasonal or other patterns that can be modelled. The ratios predicted by these historical models are compared with the ratios observed in actual data in order to determine whether aberration has occurred. The advantages of this approach are seen to be in the extra information present in the relationship between monitored data streams to increase overall detection performance and their relational nature makes them more robust to unpredictable shifts. For instance, a localised infectious disease outbreak may take place in a metropolitan area. This may take place during an extraordinary mass gathering event that may cause a broad surge in overall utilisation of health-care. The surge in overall utilisation falsely triggers the alarms of standard surveillance models and thus masks the actual outbreak. At the same time the surge affects multiple data streams similarly, and the relationships between various data streams are not affected as much by the surge. Since the network model monitors these relationships, it is able to ignore the surge and thus detect the outbreak. However, this is based in the assumption that broad utilisation shifts, would affect multiple data streams more or less equally, and would thus not significantly affect the ratios among these data streams. The constructed network models constructed provided better detection of localised outbreaks, than reference time-series modelling approaches. The authors describe the conditions under which this approach can be useful and provide it as an alternative to standard methods (Reis et al. 2007).

The need for surveillance systems to provide early quantitative prediction of epidemic events was met by an approach by Sebastiani et al. (2003). They used a multivariate model for influenza surveillance where they integrated different data streams. They build a dynamic Bayesian network that related pediatric and adult syndromic data in two emergency departments to the standard measures of influenza morbidity and mortality. They also showed how to use the model to forecast the beginning of epidemics as well as peaks of epidemics. For instance, they figured out that the number of respiratory cases in a pediatric emergency department predicted influenza morbidity in the general population as early as 2 weeks in advance and influenza mortality as early as 3 weeks in advance implying that children with respiratory syndromes seen at emergency department may act as sentinels for surges in influenza morbidity and mortality.

Another approach is to model the variance of visit patterns that may enable real-time detection with known, constant specificity at all times. An evaluation of the specificity of autoregressive, surfing, trimmed seasonal, wavelet-based, and generalised linear models applied each to 12 years of emergency department visits of respiratory infections syndromes at a pediatric hospital showed that specificity was a function of the day of the week, month and year of the study (Wieland et al. 2007). Using a detection method based on generalised additive modelling to achieve constant specificity by accounting for not only the expected number of visits, but also the variance of the number of visits, Wieland et al. (2007) found that their approach achieves constant sensitivity at all three time scales and earlier detection compared to the other methods.

Allocation of health-care resources and anticipation of the impact of alternative intervention during a pandemic as part of emergency management can be studied via mathematical modelling approaches. For the cholera outbreak 2010-2011 there have been several predictions from mathematical modelling approaches. An ex post reliability of modelling predictions about the spatial spread of the epidemic was performed by Rinaldo et al. (2012). They considered the impact of different approaches to the modelling of spatial spread and mechanisms of transmission accounting for the dynamics of individuals, susceptible or infected within different local communities. For resurgence of the epidemic waning immunity and rainfall as a driver were considered. Using the Akaike information criterion, the added information provided by each process modelled was measured. A model for the Haitian epidemic and the data sets collected over the two year lasting outbreak were utilised. The model allows drawing predictions on longer-term epidemic from multi-season Monte Carlo simulations by using suitable rainfall fields forecasts. On the basis of their analysis the find shortcomings of past approaches, discuss the transmission mechanisms driven by rainfall, and identify the best-performing models. Despite differences in methods the authors find that modelling of large scale outbreaks is an important tool for cholera epidemic control.

Computational tools that allow large scale simulation of pandemics and corresponding predictions have emerged in recent years. Although the computational tools simulate up to the global scale their predictive capacity is better as one would expect due to the scale of complexity (Van den Broeck et al. 2011). GleaMViz is a typical example of a tool of this type that allows the simulation of pandemic scenarios and assist policy makers in their decision making (Van den Broeck et al. 2011).

In general, mathematical models can provide useful insights into possible future impacts of potential emerging epidemics and how they might be best controlled. However, the results, when in particular refer to global complicated outbreaks such as pandemics need to be viewed more as projections and helping structure thinking about pandemic planning rather than being predictive of the precise effectiveness of different policies (Halloran et al. 2008).

Discussion

Large scale disasters are strongly associated with substantial casualties underscoring the need for effective and efficient public health responses. Quantitative methods including disaster response modelling have become integral part of decision making processes in disaster management. They can help in answering questions such as how should the logistical systems for response to various types of public health disasters be organised? How much hospital-based surge capacity might be needed for potential mass casualty events? What is the most efficient and effective way to rapidly dispense medications or vaccines to large numbers of individuals? (Brandeau et al. 2009). Despite progress in recent years there have been major unresolved issues at all levels of disaster response decision making, including long-range strategic planning, tactical response planning, and real-time operational support.

Disaster response models should be designed to address real-world disaster response problems and should be made available for use by planners who, however, should be in a position of understanding how to use the models and how to interpret the results. This implies a judicious balance between computational complexity and usability. New public health disaster response modelling approaches should evaluate relevant disaster response outcomes that go beyond those considered in traditional cost-effectiveness analyses and explore critical uncertainties. Major issues at all levels of public health disaster response decision making, including long-range strategic planning, tactical response planning, and real-time operational support are still unresolved and operations research can provide useful techniques for decision management. Finally, they should be presented in sufficient detail that their results can be interpreted in a reasonable way. Often, these approaches need to be used for on-going decision making by planners who must customise models to their own needs. Taking into account that many of the planners don't have the necessary expertise major emphasis should be given to the design and reporting of such models. Modelling public health response to disasters is highly heterogeneous in terms of methodologies, outcomes evaluated, and quality of presentation. Operations research and other methodologies are essential in effective public health preparedness planning and response to disasters.-

Conclusions

Disaster response quantitative methods such as operations research addressing public health are important tools for planning effective responses to disasters. Several modelling methods have been applied to analyse public health disaster response 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 variety 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).

Public health disaster response models differ from many other models in that they are designed to support on-going planning scenarios. These range from long-term strategic decisions to immediate-term operational decisions.

Response logistics related to public health impact of disasters have been modelled more intensively since decisions about procurement, transport, stockpiling, and maintenance of needed supplies but also mass vaccination, prophylaxis, and treatment are essential in the emergency management.

Operations research methods used in disaster response can inform public health decision makers on issues such as magnitude of the event, operational response capabilities, supply chain capacity, and robustness, and public health intervention measure effectiveness and guide the decision making process.

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Abstract

Operations research is the scientific study of operations for the purpose of better decision making and management. Disasters are defined as events whose consequences exceed the capability of civil protection and public health systems to provide necessary responses in a timely manner. Public health science is applied to the design of operations of public health services and therefore operations research principles and techniques can be applied in public health. Disaster response quantitative methods such as operations research addressing public health are important tools for planning effective responses to disasters. Models address a variety 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) and use a range of modelling methodologies. Regarding natural disasters the modelling approaches have been rather limited. Response logistics related to public health impact of disasters have been modelled more intensively since decisions about procurement, transport, stockpiling, and maintenance of needed supplies but also mass vaccination, prophylaxis, and treatment are essential in the emergency management. Major issues at all levels of disaster response decision making, including long-range strategic planning, tactical response planning, and real-time operational support are still unresolved and operations research can provide useful techniques for decision management.

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