International Journal of Disaster Risk Reduction 28 (2018) 113–121

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

Informing decisions on the purchase of equipment used by health services in response to incidents involving hazardous materials

Luca Grieco[a,*], Hazel Gleed[b], Stephen Groves[c], Simon Dyer[d], Martin Utley[a]

[a] Clinical Operational Research Unit, University College London, 4 Taviton Street, London WC1H 0BT, United Kingdom
[b] National Health Service England South, York House, 18-20 Massetts Road, Horley, Surrey RH6 7DE, United Kingdom
[c] National Health Service England, Skipton House, 80 London Road, London SE1 6LH, United Kingdom
[d] UK Department of Health, Richmond House, 79 Whitehall, London SW1A 2NS, United Kingdom

ARTICLE INFO

Keywords:
Allocation
Health service
Accident
Queueing
Government
Emergency preparedness

ABSTRACT

Accidents involving release of chemical, biological, radiological or nuclear substances may prompt the need to decontaminate exposed casualties prior to further medical treatment. Health service workers who carry out decontamination procedures wear protective suits to avoid direct contact with contaminants.

We developed an analytical framework based on queueing theory to inform UK Department of Health's decisions on the stock of protective suits that ambulance services and hospitals with emergency departments in England should hold. Our aim was to ensure that such allocation gave an accepted degree of resilience to locally identified hazards.

Here we give an overview of our work and describe how we incorporated information in the public domain about local hazards with expert opinion about the patterns of demand for decontamination associated with different types of incident. We also give an account of how we worked with decision makers to inform national guidance on this topic.

1. Introduction

1.1. HazMat events

Incidents involving release of Chemical, Biological, Radiological, or Nuclear (CBRN) materials can have a significant social and health impact. When caused by human error, technological failure or, for example, extreme weather events, these are commonly referred to as "HazMat" events. Such accidents, as well as malicious incidents (for instance, criminal or terrorist acts), have the potential for significant human losses and environmental damage. North Atlantic Treaty Organization (NATO)'s guidelines for first response [1] give top priority to minimising the number of human deaths. In particular, healthcare workers are required to establish decontamination and triage areas and carry out decontamination procedures in order to end casualties' exposure to the hazardous substance as soon as possible and prior to further clinical treatment. Decontamination is also fundamental to prevent the spread of toxic substances to other people/areas.

1.2. Our project

The work presented in this paper is focused on the problem of deciding how much personal protective equipment is needed at different points within the health system for the system to have a given degree of resilience to HazMat events. In particular, we focused on the provision of special protective suits as worn by healthcare workers during decontamination procedures. Each suit incorporates an internal respiratory system and enables full isolation of its wearer from all hazardous materials considered in this project [2].

Our objective was to determine the stock of such suits that should be held by each ambulance service and each hospital with an emergency department in England.

We were commissioned to work on this problem by the UK Department of Health (DH) through a responsive Operational Research (OR) facility that we provide to them to support health protection policy. The work was conducted in close collaboration with partners at the National Health Service (NHS) England responsible for providing national guidance to ambulance services and local hospitals. In this way NHS England, on behalf of the NHS in England, took on the role of client for the work, with DH as project sponsor.

* Corresponding author.
E-mail address: l.grieco@ucl.ac.uk (L. Grieco).

https://doi.org/10.1016/j.ijdrr.2018.02.036
Received 21 November 2017; Received in revised form 20 February 2018; Accepted 20 February 2018
Available online 02 March 2018

1.3. Operational Research approaches in emergency preparedness

Having sufficient resources in place to cope with a range of potential events lies at the heart of emergency preparedness. NATO's guidelines [1] emphasise the importance of such planning on the part of responding agencies, such as ambulance services, emergency departments in hospitals, police and fire brigades. However, HazMat accidents and malicious CBRN events and their consequences are intrinsically unpredictable and planning decisions need to reflect this. OR methods are particularly suitable to deal with this unpredictability, particularly in relation to informing decisions around resource allocation, taking into account risks in different areas, logistical aspects and budget limits.

Quantitative approaches to support emergency preparedness in general have been developed in the last decades. In 2006, Altay and Green [3] reviewed the literature of OR applied to disaster operations management, defining disasters as any emergency that is not an "everyday emergency". This definition of disaster thus includes HazMat events. The main conclusion by the authors was that while several models have been conceived around disaster preparedness, there is a lack of theory development and of actual application of existing models to real-world cases. We also need a better understanding of what the inputs of such models should be, including event features. The review of Altay and Green [3] was updated in 2013 by Galindo & Batta [4], who observed a substantial progress in the development of case studies albeit with the common drawback of simplifying theoretical models by using limited and unrealistic assumptions. Works dealing with resource allocation for disaster preparedness have been published in several fields of application. Natural hazards constitute the most represented topic, including: approaches based on Stackelberg game [5] or nonlinear mixed integer programming [6] to determine the optimal allocation of shelters for flood evacuation planning; two-phase approaches, i.e. preoperational (resource allocation closer to sites with higher hazards) and operational (during event), to optimise the response to wildfire (or natural hazards in general) across a region [7]; facility location models to allocate fire trucks in a geographical area in order to achieve a certain degree of zone coverage [8]. Preparedness for oil spills has also been the subject of mathematical modelling, for instance in the papers by Iakovou et al. [9] and Belardo et al. [10] dealing with optimal location/capacity of clean up equipment. Facility location models were also published for medical supplies or public services needed following (in the short or medium term) large-scale emergencies [11,12] and to allocate ambulances in order to meet large demand volumes [8]. On the specific problem of preparedness for HazMat or CBRN events, Zaric et al. [13] studied the cost-effectiveness of different strategies for stockpiling and distributing medical supplies for response to anthrax bioterrorism, Lee et al. [14] developed systems for early detection of CBRN incidents and software tools for real-time capacity planning, Berman et al. [15] built an optimisation model to allocate limited emergency resources following identification of a bioterrorist attack on an airport. Discrete event simulation was also used to study specific scenarios of simultaneous CBRN attacks to help the Fire and Rescue Service to better allocate resources across England [16].

Lack of historical data as well as sensitivity of some information owned by decision makers around response models and procedures constitute a challenge for the development of methods to improve preparedness for HazMat events. Moreover, policy makers need to be in a position to use the mathematical models and/or interpret the results before taking decisions and spreading guidelines. Therefore, quantitative approaches towards improving preparedness to such events should be balanced between computational complexity and usability [17].

2. An analytical framework tailored to the national context

The analytical framework we developed (see Fig. 1 for a schematic diagram) was influenced not just by the intrinsic characteristics of the problem at hand but also by the context in which we were working.

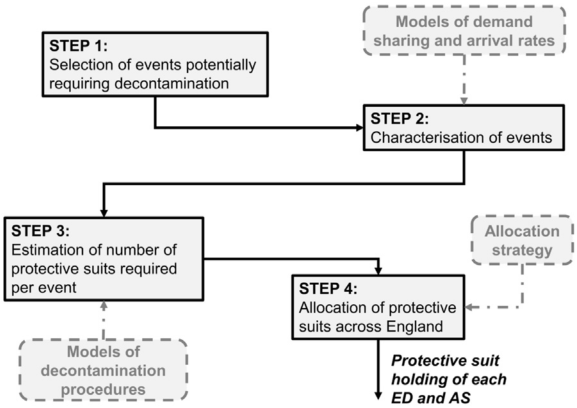

Fig. 1. Approach followed for estimating the number of protective suits required by each ambulance service (AS) and emergency department (ED) across England.

Specifically, our work was influenced by client and project sponsor perspectives on the information available about potential HazMat events and by the nature of the decisions to be made. Moreover, lack of detailed information about event locations and precise estimates of event likelihood led us to follow a precautionary approach for determining the allocation of protective suits. The approach we followed consisted of four steps:

- Step 1 – We selected a list of HazMat events potentially requiring decontamination of casualties exposed to chemical, biological, radiological or nuclear materials.
- Step 2 – We used available information on the nature of these events to estimate the proportions of casualties to be accounted for by different healthcare services, along with the likely pattern of arrivals over time.
- Step 3 – We estimated the demand for protective suits for each healthcare service in response to single events occurring in a given region, based on the expected number of casualties and on the characteristics of the decontamination procedures carried out.
- Step 4 – We determined an allocation strategy allowing each healthcare service responsible for a particular (group of) region(s) to be resilient to HazMat events characterised by a minimum likelihood to happen in that(those) region(s).

In the remainder of this section we give an overview of our modelling work. Full technical details are provided as Supplementary Materials.

2.1. Selection of HazMat events

As a requirement of the Civil Contingencies Act introduced to UK law in 2004 [18], a Local Resilience Forum (LRF) has been formed by key emergency responders in each of the 39 police areas in England. Every LRF is required to maintain a Community Risk Register (CRR), which is a publicly available document reporting a list of accidental events potentially causing mass casualties. The description of events and their impact (health, social, economic and environmental effects) are determined centrally in the UK National Risk Register. Local Resilience Fora have the role of selecting for the CRR those events they consider relevant to them locally and attributing to them a semi-quantitative likelihood estimate by choosing one of five probability levels of each event happening in the area within the next five years. Following advice by project sponsor and client, we took the set of CRRs for England as the starting point for our analysis in order to align our work with the relevant decision processes.

From the Community Risk Registers (CRRs) we extracted a list of HazMat events (Table 1) potentially requiring decontamination. We