A Systematic Review of Public Health Emergency Operations Centres (EOC)

December 2013

World Health Organization

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Acknowledgements

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Executive summary

A public health emergency operations centre (EOC) is a central location for coordinating operational information and resources for strategic management of public health emergencies[1] and events. EOCs provide communication and information tools and services and a management system during a response to an emergency or event. They also provide other essential functions to support decision-making and implementation, coordination, and collaboration.

This systematic review examined peer-reviewed and grey literature in order to document global best practices for effective public health emergency response by EOCs; to identify indicators to monitor EOC performance; to describe risk communication in EOC settings; to outline research needs; and to identify standardised terminology.

The standards and best practices identified will be used to strengthen World Health Organization (WHO) Member State capacity for effective public health response. Analysis of the components of EOCs and their standards and best practices can assist in achieving the basic EOC functions and navigating the complexities of emergency response.

Several categories of EOC function were researched: general EOC function and structure; EOC communication technology and infrastructure; procedures and plans; minimum data sets and standards for operational information; and training and exercises.

A total of 291 studies were examined, and recommendations and lessons learned from the peer-reviewed literature are incorporated throughout the report, organized by category. Standards, guidelines, and best practices are listed in Tables 3 and 4 and referenced throughout the report. Certain qualities were consistently noted as important elements of effective EOC function: collaboration; coordination; communication; harmonisation; respect; cooperation; vertical and horizontal integration; trust; and leadership [5.1.7]. Evidence that these elements are foundational components of effective EOC function spanned grey literature; peer-reviewed literature; quantitative and qualitative studies; and case studies of both effective and ineffective emergency responses. The literature showed that the biggest barriers to EOC function were lack of sufficient communication and coordination. Other impediments existed, and adequate planning was also an essential element, but communication and coordination consistently formed the basis for EOC success.

EOCs are used in a variety of hazards and emergencies, including natural disasters; foodborne disease outbreaks; radionuclear events; bioterrorism; chemical incidents; mass gatherings; blackouts; humanitarian emergencies; and disease outbreaks or pandemics. They are employed at a variety of jurisdictional levels, ranging from field EOCs to local or regional EOCs to national or international EOCs [5.1.2 and Table 2]. Staff and surge capacity were important elements of EOC function in all areas [5.1.3 and 5.1.4]. Incident Command Systems and similar EOC structures were frequently used to organize EOC operations and decision-making [5.1.5 and 5.1.6].

Incorporating lessons learned into EOC plans and function can improve performance. Several performance indicators are used to measure success, although clear agreement on indicators

1 A public health emergency is an extraordinary event that adversely affects the health of human populations and which requires a coordinated response. Such an event may increase morbidity and/or mortality, and/or spread disease, and may be caused by natural disasters, disease outbreaks or pandemics, bioterrorism, radionuclear events, chemical incidents, humanitarian emergencies, etc.

is not seen in the literature. While no current international standards exist for monitoring the function of EOCs, several bodies, including WHO, the 2005 International Health Regulations (IHR(2005)), and the United States of America Centres for Disease Control and Prevention (CDC), provide performance measure indicators [5.1.8].

Best practices for building new EOCs and improving existing ones include recommendations about an EOC's location and physical space requirements, as well as suggested information and communication technology components [5.2.1, 5.2.2, and 5.2.3]. EOCs, whether physical or virtual, also frequently use information and knowledge management software applications [5.2.4]. These systems are increasingly critical for sufficient communication within and between agencies and EOCs during emergency response. The need for backup systems and redundancies is also widely documented [5.2.3].

The need for plans is continually emphasized. This report lays out components and characteristics of an emergency operations plan, providing a suggested structure for plans and procedures [5.3.1 and 5.3.2]. The planning process, and that of conducting a hazard analysis or needs assessment, are also discussed as key steps [5.3.3].

Risk communication is integrated throughout many other foci and categories in the literature. Accurate and timely information sharing that is evidence-based and coordinated is critical. Building on existing relationships and collaboration is particularly effective, both with the media and with other agencies and stakeholders [5.4]. Risk communication is an important component of emergency operations plans and EOC operations [5.4.1].

Operational information and information needs can vary widely in EOC settings, but needs assessments and the use of existing and baseline data are helpful to effective EOC function [5.5.1]. The types of operational information needed by EOCs and information sources depend on the type of hazard or emergency, but follow similar categories, outlined in Sections 5.5.2 and 5.5.3. These data, and the appropriate use of communication technology and systems, are critical to decision-making and response [5.5.4].

Training and exercises form an essential component of emergency response plans and standards [5.6]. Individual training can improve the skills and competencies of EOC staff for specific EOC functions and for cross-functional and interagency skill improvement [5.6.1]. Organizational training and exercises are important both for team and relationship building and for the agency's ability to function effectively [5.6.2].

Future areas of research are recommended in Section 6.6 and include surveillance systems, the legal and ethical issues concerning EOCs, and more in-depth research on risk communication. Several review questions not fully supported by the systematic review are also recommended for future study. These include solutions to surge capacity; the challenges of using information management software; EOC training programmes; and integrating risk communication into exercises.

Finally, international standards and/or guidelines need to be developed in order to: outline a structure for the organization of EOC operations and decision-making; delineate roles and responsibilities for staff and surge staff; list appropriate knowledge management software and ICT in line with messaging, privacy, and security standards; list data collection, analysis, and interpretation processes and systems to be used; and develop consistent schedules and content for training and exercises.

1. List of abbreviations

ACM	Association for Computing Machinery
ANSI	American National Standards Institute
BSI	British Standards Institution
CASP	Critical Appraisal Skills Programme
CASPER	Community Assessment for Public Health Emergency Response
CDC	United States Centers for Disease Control and Prevention
COPSS	Common Operating Picture Software/System
CSA	Canadian Standards Association
DHS	United States Department of Homeland Security
DOJ	United States Department of Justice
ebXML	Electronic Business Extensible Markup Language
ECDC	European Centre for Disease Prevention and Control
EMBASE	Excerpta Medica Database
EOC	Public Health Emergency Operations Centre/Center
EOC-NET	Public Health Emergency Operations Centre Network
FEMA	United States Federal Emergency Management Agency
GCR	WHO Department of Global Capacities, Alert and Response
GIS	Geographic Information Systems
HL7	Health Level 7 International
HTTP	Hypertext Transfer Protocol
IASC	Inter-Agency Standing Committee
ICD-10	International Classification of Diseases, 10th revision
ICS	Incident Command System
ICT	Information and communication technology
IEEE	Institute of Electrical and Electronics Engineers
IEEE Xplore	Digital library of the Institute of Electrical and Electronics Engineers
IHR	International Health Regulations
INFOSAN	International Food Safety Authorities Network
ISO	International Organization for Standardisation

LOINC	Logical Observation Identifiers Names and Codes
MACS	Multiagency Coordination Systems
NFPA	National Fire Protection Association
OASIS	Organization for the Advancement of Structured Information Standards
OCHA	The United Nations Office for the Coordination of Humanitarian Affairs
OSOCC	On-Site Operations Coordination Centre
PAHO	Pan American Health Organization
PHIN MS	Public Health Information Network Messaging System
PKI	Public Key infrastructure
PRISMA	Preferred Reporting of Items for Systematic Reviews and Meta-Analyses
PROSPERO	International Prospective Register of Systematic Reviews
PubMed	Public/Publisher MEDLINE
SNOMED	Systematized Nomenclature of Medicine
SSL	Secure Sockets Layer
UN	United Nations
WHO	World Health Organization

2. Introduction

2.1 Background

The World Health Organization (WHO) Department of Global Capacities, Alert and Response (GCR) established the Public Health Emergency Operations Centre Network (EOC-NET) in 2012. This was done in order to strengthen global collaboration and WHO Member States' capacity for effective public health all-hazards response in line with the requirements of the 2005 International Health Regulations (IHR(2005)).

A systematic review was undertaken in order to: provide understanding of the current global status and best practices of public health emergency operations centre (EOCs); document impediments and gaps; and inform the development of guidance and standards for building, maintaining, and using EOCs for response to public health risks and emergencies. This systematic review aimed to address the components of EOCs and their standards and best practices both for achieving the basic EOC functions and for navigating the complexities of emergency response.

2.2 Review objectives

1. Inform WHO and EOC-NET partners of the current status, gaps, and impediments in building, maintaining, and using EOCs
2. Share global best practices for EOCs for effective public health emergency response
3. Describe the connection between EOCs and risk communication
4. Identify indicators to monitor performance of EOCs
5. Outline research needs for building, maintaining, and using EOCs
6. Identify standardised EOC terminology.

3. Methods

3.1 Summary of review questions & categories

A public health emergency operations centre (EOC) is the central location for coordinating operational information and resources for strategic management of public health emergencies and events. EOCs provide communication and information tools and services and a management system during a response to public health emergencies and events. They also provide other essential functions to support decision-making and implementation, coordination, and collaboration. An EOC is often referred to by other names (1).

Categories of possible hazards or risks included in this review include disease outbreaks or pandemics (e.g., influenza, haemorrhagic fever, meningitis, cholera, smallpox, polio, dengue fever, plague, emerging infectious diseases); bioweapon or bioterrorism events; crises or disasters; chemical safety or toxicology events; radionuclear safety events; food safety events or outbreaks; mass gatherings; and others.

Review questions were grouped into five categories (Section 8.1):

1. General questions
2. EOC communication technology and infrastructure
3. Procedures and plans
4. Operational information minimum data sets and standards
5. Training and exercises.

3.2 Review protocol

The review protocol followed the guidelines of the Preferred Reporting of Items for Systematic reviews and Meta-Analyses (PRISMA), the Cochrane Handbook for Systematic Reviews of Interventions, and the WHO Handbook for Guideline Development. It specified the review's objectives, search strategy, inclusion and exclusion criteria, data extraction methods, and quality assessment. The protocol was registered in the PROSPERO International Prospective Register of Systematic Reviews [2-4].

3.3 Study identification

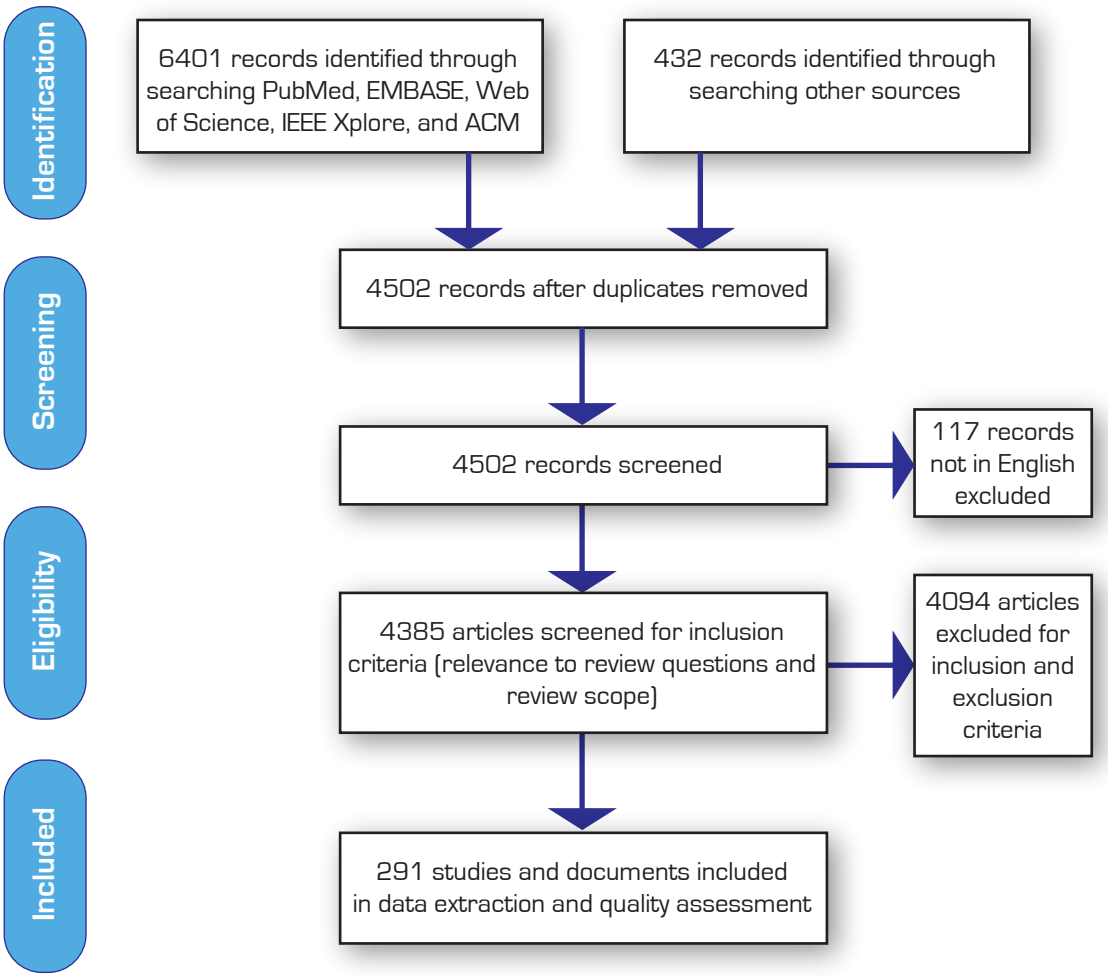
3.3.1 Exclusion and inclusion criteria

All articles published in English between 1 January 1993 and 30 October 2013 that contained both an abstract and full text were included. The abstract requirement was waived for government and industry reports and other grey literature sources. Articles selected for inclusion used various terms to refer to an EOC (e.g., "command and control operations centre," "strategic health operations centre," "command centre," "situation room" and "crisis management centre"). To be included, an article must have provided information relevant to one or more of five pre-

determined review categories (general; information communications technology infrastructure; procedures and plans; operational information minimum data sets and standards; and training and exercise). These categories were developed by WHO and Emory University.

Duplicate articles and those with interventions and/or programme descriptions occurring before 1 January 1993 were excluded. Figure 1 shows the number of records identified during the retrieval process and how many were excluded because they did not meet the criteria detailed here.

Figure 1. **Workflow diagram of the retrieval process for the systematic review of public health emergency operations centres, January 1993 – October 2013**



3.3.2 Publication types

Original peer-reviewed articles, review articles, standards, guidelines, and government and industry reports were included. The types of documents found included descriptive studies and those using qualitative methods of data collection and analysis.

3.3.3 Search strategy & data sources

Exhaustive searches were performed collecting all relevant studies, standards, and reports available during the study period. The following databases were searched: PubMed, EMBASE, Web of Science, IEEE Xplore, and ACM. The following grey literature sources were also searched: WHO, the United States Centers for Disease Control and Prevention (CDC), academic research centres, and the Pan American Health Organization (PAHO). PubMed was searched first; subsequent search strategies were derived from PubMed outcomes and modified for each database. The initial search informed the subsequent search of the grey literature, which included websites of partner organizations and published standards.

A parallel search was conducted in PubMed using additionally identified terms and syntax to identify unique references in order to ensure all relevant articles were included. Five hundred and sixty five references were identified. After applying the inclusion criteria, no additional studies were included in the final review. The full search strategy can be found in Section 8.2. The reference lists of reviews or articles found during the search, or which were known to the authors, were also searched (a technique often called snowballing).

During the search and study selection process, four investigators independently screened and selected studies for possible inclusion. First, titles and abstracts of studies, standards, and reports identified were independently reviewed and pooled for further screening. Second, each reviewer examined the abstracts of the studies, standards, and reports identified in the title and abstract screening process. Each reviewer compiled a list of studies, standards, and reports that met the inclusion criteria.

A second investigator then compared each list; disagreements were resolved by discussion and consensus on studies included and excluded. Final studies, standards, and reports selected were then stratified by category. Some of the final studies, standards, and reports selected were eligible for more than one category, but data extraction and quality assessments were performed only once.

3.4 Data extraction & management

After conducting the search, results were exported to an independent database. All the references were merged, and duplicates were identified and removed. References were managed using EndNote®.

The four investigators independently extracted data using a standardised data collection instrument developed on Google Drive® using Microsoft Excel®. The following elements were collected:

- Setting (country and year)
- Aim/objective
- Study design
- Evaluation method
- Type of hazard, risk, emergency, or event
- Size of population served/studied

- Qualities, components, jurisdiction, and functional capacity of centre
- Standards, requirements, or guidelines included or noted
- Adverse events, challenges, or barriers
- Outcomes, lessons learned, after action report conclusions, best practices
- Recommendations
- Limitations (study & outcome level)
- Bias
- Generalisability.

Assessment of the qualities, components, jurisdiction, and functional capacity of the EOC included information about whether an EOC was public or private; temporary or permanent; operational and at a city, state, national, regional, or local level. It also included the funding source; the chain of command and/or level of oversight; staff size; and the types of public health emergencies to which the EOC was able to respond.

Additional information, where relevant, was extracted in order to include any regional, national, or international EOC standards in use or recommended, as well as their implications for practice or policy.

3.5 Quality assessment

The data and the studies' outcomes were evaluated. Because most studies did not fit the quality assessment standards of clinical quantitative research, the Critical Appraisal Skills Programme (CASP) (5) was used to evaluate the research based on the following criteria:

1. Relevance to review objectives and review questions
2. Clarity of the research question
3. Appropriateness of the study design
4. Sampling
5. Data collection
6. Potential for bias
7. Rigour of data analysis
8. Clarity of results.

4. Results

4.1 Quality assessment analysis

Studies that were more generalisable were given a higher quality rating than those that were not generalisable. Generalisability in this review meant the ability of a study's findings to be applied to other circumstances, emergencies, events, and EOCs. Studies were scored "yes" or "no" for generalisability, or, when certain quality assessment measures were not applicable, a "not applicable" score was assigned.

Many studies included in this review were articles using neither quantitative nor qualitative research methods. Rather, they were case studies, peer-reviewed versions of after action reports, retrospectives of emergency response situations, or governmental reports. For example, documents that retrospectively examined an EOC's response during a particular emergency and described the challenges and lessons learned did not contain data collection or analysis, and therefore could not be evaluated according to these measures. In instances like these, the document was given a "not applicable" score for data collection and analysis methods. Each article was evaluated on the basis of relevance, appropriateness of study design, analysis methods, clarity of results, and generalisability when applicable.

A "COUNTIF" formula in Excel was used to calculate the number of "yes," "no," and "not applicable" responses in each criterion, and their corresponding percentages (Table 1). Based on these results, only the criteria for which less than 50% of responses were "not applicable" were kept: clarity of research questions, appropriate methodology, clarity of findings, and generalisability. The data analysis criterion was also kept, as this is an important marker for those studies that included data analysis.

Table 1. **Quality assessment process results of studies yielded from the systematic review of public health emergency operations centres, January 1993 – October 2013**

	Quality assessment response			
Criterion	**Yes (%)**	**No (%)**	**Not applicable (%)**	**Total**
Clarity of research question	209 (72)	22 (8)	60 (21)	291
Generalisability	202 (69)	37 (13)	52 (18)	291
Clarity of findings	185 (64)	21 (7)	84 (29)	291
Appropriate methodology	136 (47)	15 (5)	140 (48)	291
Appropriate research design	109 (37)	17 (6)	165 (57)	291
Data collection	89 (31)	18 (6)	184 (63)	291
Data analysis	65 (22)	29 (10)	197 (68)	291
Appropriate sampling	58 (20)	11 (4)	222 (76)	291
Researcher bias	27 (9)	34 (12)	230 (79)	291

Because a sum of the "yes" responses and a traditional summary of findings table would not accurately portray study quality and would inappropriately weight the "not applicable" responses, a quality ratio was calculated for each study, and an overall mean quality ratio was derived. Quality assessment responses for the five criteria (clarity of research questions, appropriate methodology, clarity of findings, and generalisability) were coded. "Yes" responses were coded 1, "no" responses were coded 0, and "not applicable" responses were not coded. These scores were summed to produce numerators for each study; "not applicable" responses were not included in this numerator, as they were not given a numerical score.

To calculate the denominator, the "yes" and "no" responses were summed. "Not applicable" responses were excluded from the denominators so they would not artificially weight the ratio scores. The numerator (the sum of all coded "yes" and "no" responses) was divided by the denominator (the total number of applicable criteria, maximum 5) to produce ratio scores for each study. A score of 0 would indicate that a study had all "no" responses for the applicable quality assessment criteria and was of low quality. Likewise, a score of 1 would indicate that a study had all "yes" responses for the applicable criteria and was of high quality. Ratio scores for the 291 included studies ranged from 0 to 1, with a mean of 0.87. This mean indicates that, in the context of a possible "perfect" ratio of 1, the overall quality of the included studies was very high.

4.2 Characteristics of identified studies

A total of 291 studies were included in the review (Table 2). 202 (69%) were from the peer-reviewed literature and 89 (31%) were from the grey literature. Some studies were characterised into more than one review category, jurisdiction, or type of event during the data extraction process. The most frequently reviewed categories were general (157); procedures and plans (124); and operational information minimum data sets and standards (116).

The national level was the most common jurisdiction (123), although many studies did not specify a jurisdictional level (72). Many articles (162) were about general emergency response. Of those specifying a type of hazard, most dealt with disease outbreaks (43) and disasters/crises (29). Not all included studies are referenced specifically in this report, but all may be found in the list of additional studies, standards, and other materials in Section 8.3.

4.3 Identified standards

Standards exist at local, national, and international levels to provide consistency in the building, maintenance, and use of EOCs. Serving as guides or requirements, standards are created by bodies including the American Society for Testing and Materials (ASTM) International; the American National Standards Institute (ANSI); the British Standards Institution (BSI); the Canadian Standards Association (CSA); the InterAgency Board; the Institute of Electrical and Electronics Engineers (IEEE); the International Organization for Standardisation (ISO); the National Fire Protection Association (NFPA); and the Organization for the Advancement of Structured Information Standards (OASIS) (Table 3).

Table 2. **Characteristics of the studies yielded from the systematic literature review of public health emergency operations centres, January 1993 – October 2013**

Type of study		Peer-reviewed (n=202)	Grey (n=89)	Total (n=291)
Review category	General	109	48	157
	Procedures and plans	79	45	124
	Operational information minimum data sets and standards	56	60	116
	Communication technology and infrastructure	72	10	82
	Training and exercise	40	18	58
Jurisdiction	National	84	39	123
	Regional	63	19	82
	Local	61	18	79
	International	21	32	53
	Field	14	6	20
	Not Specified	44	28	72
	Other	4	0	4
Type of hazard, risk, or event	General	99	63	162
	Disease outbreak	34	9	43
	Disaster/Crisis	28	1	29
	Bioweapon/Bioterrorism	12	0	12
	Radionuclear event	11	1	12
	Mass gathering	6	1	7
	Chemical incident	4	0	4
	Foodborne disease outbreak	1	3	4
	Not applicable	5	26	31
	Other	2	2	4

Standards help establish global criteria for emergency response facilities and equipment; business continuity programmes; data exchange; communication systems; incident management systems; risk management; assessment exercises; and responses to specific types of emergencies [6-12] (Table 3).

Large governmental bodies responsible for emergency operations, such as the European Centre for Disease Prevention and Control (ECDC) or the United States Federal Emergency Management Agency (FEMA), recommend standards developed by other organizations, such as ASTM or CSA. Along with standards, governments and organizations rely heavily on guidelines and best practices to inform their work (Table 4). This review lists standards in Table 3 and guidelines and best practices in Table 4. Recommendations and lessons learned from the peer-reviewed literature are referenced throughout the text but excluded from the table of standards.

Table 3. **Standards applicable to the building, maintenance, and use of EOCs**

		General	Communication technology and infrastructure	Procedures and plans	Operational information minimum data sets and standards	Training and exercise
Issuing body	**Standard**					
ASTM	E2601 - 08 Standard Practice for Radiological Emergency Response		x	x		
	E2668-10 Standard Guide for Emergency Operations Center (EOC) Development	x	x			x
	E2770 - 10 Standard Guide for Operational Guidelines for Initial Response to a Suspected Biothreat Agent		x	x		
ANSI	INCITS 398-2008 Information technology - Common Biometric Exchange Formats Framework (CBEFF)		x		x	
BSI	PAS 200:2011 Crisis management. Guidance and good practice	x	x	x	x	x
CSA	Z1600-08 - Emergency Management and Business Continuity Programs	x		x		
IEEE	1512 - Family of Standards for Incident Management Message Sets		x			
ISO	11064-7:2006, Ergonomic design of control centres – Part 7: Principles for the evaluation of control centres		x			
	22324, Societal security – Emergency management – Colour-coded alert		x			
	22322, Societal security – Emergency management – Public warning		x			
	22320:2011, Societal security – Emergency management – Requirements for incident response	x	x	x	x	
	22398, Societal security – Guidelines for exercises and testing			x		x
	PAS 22399:2007, Societal security – Guidelines for incident preparedness and operational continuity management		x	x	x	
	11320:2011, Nuclear critical safety – Emergency preparedness and response	x		x		
	31000:2009, Risk management – Principles and guidelines, for the development of emergency preparedness plans and processes			x		
	IEC 24762:2008 Information technology – Security techniques – Guidelines for information and communications technology disaster recovery services		x	x		
	IEC 27031:2011 Information technology — Security techniques — Guidelines for information and communications technology readiness for business continuity		x	x	x	
NFPA	1600 Standard on Disaster/Emergency Management and Business Continuity Programs 2013 Edition	x	x	x	x	x
	1561 Standard on Emergency Services Incident Management System 2008 Edition	x	x		x	
	1221 Standard for Installation, Maintenance, and Use of Emergency Services Communications Systems		x			
OASIS	Common Alerting Protocol Version 1.2		x			
	Emergency Data Exchange Language (EDXL) Distribution Element, v1.0		x			

Table 4. **Grey literature best practices applicable to the building, maintenance, and use of EOCs.**

Issuing body	Guidance document	Key components
Australian Emergency Management Institute	Australian Emergency Management Handbook Series: Managing Exercises, Handbook 3	• Design individual and organizational training from an evidence base and include thorough assessment and evaluation • Ensure training is meeting objectives and that individuals and organizations are properly prepared for emergency response
California Governor's Office of Emergency Services	SEMS Approved Course of Instruction	• Specify a protocol for when to activate the EOC • Use ICS as the standard all hazards response system • Five primary functions of ICS: command, operations, planning/intelligence, logistics, and finance/administration; only the SEMS Field level uses "command," all other levels use the term "management" • Use unit of command to form authority relationships • Standardized list of titles and roles of EOC functions
Columbia University School of Nursing Center for Health Policy, United States Centers for Disease Control and Prevention, and Association of Teachers of Preventive Medicine	Bioterrorism and Emergency Readiness: Competencies for All Public Health Workers	• Train individuals to do the following: recognize threats and abnormal conditions; access and use communication systems; conduct emergency operations planning; implement specific resources, tools, and procedures; rapid assessment and surveillance; and have a basic familiarity with incident management systems and similar structures
Council of Australian Governments. Working Group on Australian Influenza Pandemic Prevention and Preparedness	National Action Plan for Human Influenza Pandemic	• Commonwealth, State, Territory and local governments must work together • Provide businesses and the community with accurate and timely information • All government levels support business continuity planning • Use the phases of pandemic development to describe the global situation • Trigger point defined for activation of a coordinated response (both inside and outside Australia)
Emergency Management Australia	Australian Emergency Manual Series: Multi-Agency Incident Management	• Model the EOC on an ICS • Ensure that staff are in place in all EOC functions, including leadership and management, operations, information management, logistics, media, safety and security, administration, technology support, and liaison positions • Define roles and responsibilities for Incident Management • Ensure sufficient and accurate information is used for decision-making • Guide for multi-agency response to facilitate national interoperability
	Operations Centre Management	• Provide professional staff with a clear set of responsibilities and expectations based on their disciplines • Ensure that staff are in place in all EOC functions, including leadership and management, operations, information management, logistics, media, safety and security, administration, technology support, and liaison positions • Use standard components recommended for the EOC • Use standard operating procedures and checklists for individual staff responsibilities to indicate who should complete a task, and when and how it should be done • EOC staff, other agencies, community members, and situation reports about the emergency or event are all sources of information during EOC activation • Collect and interpret information on an ongoing basis throughout EOC activation • Allocate resources, activate services and response activities, seek outside assistance, and communicate as needed once information about the emergency has been processed appropriately

Issuing body	Guidance document	Key components
Emergency Management Policy Directorate Public Safety Canada** (**this is the publisher, not the author)	An Emergency Management Framework for Canada	• Formalize the process of coordination • Ensure emergency response plans correspond to a jurisdiction's risk • Develop contact with media and journalists as well as the public prior to an emergency response, to allow enhanced communication during a response • Deliver clear, transparent and accurate information to the public
European Centre for Disease Prevention and Control	Emergency Operations Centre (EOC): ECDC Role in Public Health Event (PHE)	• Use an action committee to determine when to activate the EOC • Ensure EU-wide coordination of risk assessment activities • Communicate risk to constituents, partners, media and the public • Ensure an EOC structure dedicated to Public Health Event management is in place
European Centre for Disease Prevention and Control and Health Protection Agency	Exercise Brown Lagoon	• Use exercises to assess an agency's communication and cooperation skills, and to assess the abilities of individuals to work with new or existing equipment.
Food and Agriculture Organization of the United Nations and World Health Organization (**this is the publisher, not the author)	FAO/WHO Framework for Developing National Food Safety Emergency Response Plans	• Surge staff are needed in six core functional areas: coordination, policy-making, operations, information gathering, dispersal of public information, and hosting visitors • Use clear "trigger points" to drive decision-making, information sharing, or the need to involve other jurisdictions • Develop evidence-based plans in advance with a coordinated effort from multiple stakeholders • Provide an overview of the planning process; in the emergency operations plan, list the intention to maintain and re-evaluate the plan, the goals of the plan, and key EOC positions and responsibilities • Use standard operating procedures and checklists for individual staff responsibilities to indicate who should complete a task, and when and how it should be done • In the emergency response plan, include a map of the EOC layout, contact lists of EOC personnel, standard documentation forms, training and exercise schedules and plans, and a section about de-activation and de-escalation procedures • Consider others' plans and national standards for guidance on preparedness plan development • Specify a protocol for when to activate the EOC • Collaborate with other agencies • Deliver clear, transparent and accurate information to the public • Include risk communication in emergency operations plans • Data may come from national governments, academic institutions and commercial entities
	• Ensure emergency response plans correspond to a jurisdiction's risk	• Collaborate with other agencies, using coordinated messages • Integrate communications staff into EOC activities • Have communications staff establish a relationship with journalists of the intended audience, conduct focus groups, and test sample messages

Issuing body	Guidance document	Key components
Food and Agriculture Organization of the United Nations	Good Emergency Management Practices: The Essentials	• Model the EOC on an ICS • Use clear "trigger points" to indicate decision-making, information sharing, or the need to involve other jurisdictions • Ensure sufficient and accurate information is used for decision-making • Use data visualization tools such as GIS to help collate and interpret information for decision-making • Coordinate early and frequently with others within the organizational structure and at other agencies • Coordinate with the non-governmental organization (NGO) sector • Ensure emergency response plans correspond to jurisdictional risk • Use standard operating procedures and checklists for individual staff responsibilities to indicate who should complete a task, and when and how it should be done • Use an action committee to determine when to activate an EOC • Deliver clear, transparent and accurate information to the public • Do not convey inaccurate information • Use epidemiologic data and assessments to gather information about healthcare system capacity, risk of disease spread, or post-disaster health status • Use monitoring information during an emergency response to analyse how emergency response activities are being implemented, determine what additional activities should take place and what resources are needed, and predict future events
Government of Canada	Federal Emergency Response Plan	• Formalize the process of coordination • Collaborate with other agencies, using officially coordinated messages coming from all agencies to the media and the public • Perform needs assessments with the help of field personnel, designated assessment teams, and those in other sectors • Allocate resources, activate services and response activities, seek outside assistance, and communicate as needed once information about the emergency has been processed appropriately
Inter-Agency Standing Committee	IASC Guidelines: Common Operational Datasets (CODs) in Disaster Preparedness and Response	• Train ICT staff to be familiar with the systems used for emergency response • Types of information needed for a humanitarian response include humanitarian profile data, population statistics, geographic boundaries and places, transportation network data, and other geospatial information • Strengthen data collection processes and systems before EOC activation • Use monitoring information during an emergency response to analyse how emergency response activities are being implemented, determine what additional activities should be done and what resources are needed, and predict future events • Collect data both before and during an emergency response
InterAgency Board	IAB Interactive Standardized Equipment List	• Generic equipment is recommended by the IAB to local, state, and federal government organizations preparing for and responding to all-hazards events, with an emphasis on chemical, biological, radiological, nuclear, and explosive (CBRNE) events

Issuing body	Guidance document	Key components
Organization for Economic Cooperation and Development Nuclear Energy Agency	Experience from International Nuclear Emergency Exercises	• Streamline existing bilateral, multilateral and international agreements to optimize the use of resources • Attempt to use a common language for communicating with other countries • Contact points must be operational at all times and have an appropriate knowledge of English • Emergency staff need a clear understanding of their national and international partners as well as the tasks, concepts and obligations of those partners • Use secure network technology for data transmission • Base first action decisions on safety studies • Include local and national media as partners in the emergency management team • Make relevant messages available to all interested parties in their original form simultaneously and without delay • Design training from an evidence base and include thorough assessment and evaluation
The Ministerial Council for Police and Emergency Management - Emergency Management (MCPEM-EM)	National Disaster Resilience Framework	• Coordinate early and frequently with others within the organizational structure and at other agencies • Coordinate with the NGO sector • Use an 'all-hazards approach' that is comprehensive and which encompasses common components that are needed across all types of hazards
The Sphere Project	Core Standard 4: Design and Response	• Requires a humanitarian response to meet the assessed needs of the disaster-affected population in relation to context, risks faced and the capacity of the affected people and state to cope and recover

Issuing body	Guidance document	Key components
United States Centers for Disease Control and Prevention	Division of Emergency Operations	• Planning, training, exercising, and evaluating to improve emergency response is a continuous process • Coordinates the deployment of CDC staff and the procurement and management of all equipment and supplies needed by CDC responders during their deployment
	Public Health Preparedness: Strengthening the Nation's Emergency Response State by State	• Lists competencies of EOC personnel • Include liaisons from other organizations in the structure of an EOC • EOC personnel must understand the structure of an EOC • Notify other agencies of an event's occurrence, a case of disease, or a public health emergency of international concern
	2008 – 2009 Salmonella Typhimurium Outbreak Response: After Action Report	• Use early and frequent coordination • Use an action committee to determine when to activate an EOC
	Public health preparedness capabilities: National standards for state and local planning	• Use a virtual EOC as a backup location • Use an action committee to determine when to activate the EOC • Perform needs assessments with the help of field personnel, designated assessment teams, and those in other sectors • Collect and interpret information on an ongoing basis throughout EOC activation
	CDC Incident Management System (IMS) and Emergency Operation Center	• Outlines the notification process • Describes roles and responsibilities of key staff • Perform needs assessments with the help of field personnel, designated assessment teams, and those in other sectors • Use an action committee to determine when to activate the EOC • Establish Director's Critical Information Requirements for internal issues and national and global events
	CDC's Emergency Management Program Activities - Worldwide, 2003-2012	• EOC activation can range from partial activation to full activation for a prolonged period of time, depending on the situation
	Budget period 1: Performance measure specifications and implementation guidance	• Measure the performance of an EOC with these indicators: the time it takes staff to report for EOC duty; development of an incident action plan; specifications on how to collect data; and completion of after action reports and improvement plans
	Launching a National Surveillance System after an earthquake – Haiti, 2010	• Add data to an EOC using site surveillance that relies on health system data • Use standardized reporting form(s) during response
	Community Assessment for Public Health Emergency Response (CASPER) Toolkit	• Use statistical and clustering methods to collect location, demographic, health status, and safety data about households and communities in affected areas for a needs assessment

Issuing body	Guidance document	Key components
United States Department of Homeland Security	Target Capabilities List	• All states (i.e., provinces or regions), counties, and cities with populations over 50,000 should have at least one designated EOC and in most cases a backup EOC • Incident Commander leads response activities of the ICS across several sections: command, operations, planning, logistics, and finance/administration • Train ICT staff to be familiar with the systems used for emergency response • Communication tools include mobile and satellite phones and radios, laptop computers and more extensive technologies. Pen, paper, and in-person communication serve as a backup system of communication • Develop evidence-based plans in advance with a coordinated effort from multiple stakeholders. Conduct a hazard analysis or needs assessment to identify what the plans should address • Include hazard-specific appendices in plans to provide information on specific procedural details, protective action, and public information needs • Conduct joint trainings with multiple agencies
	National Response Framework	• Describes roles and responsibilities of community and all partners • Incident Commander leads response activities of the ICS across several sections: command, operations, planning, logistics, and finance/administration • All-of-nation approach necessary for the delivery of response capabilities • Deliver coordinated, prompt, reliable and actionable information to the whole community through the use of clear, consistent, accessible and culturally and linguistically appropriate methods • Integrate all stakeholders into a coordinated operational structure • Provide fatality management services • Stabilize critical infrastructure functions • Provide decision makers with decision-relevant information and the status of the response
	National Summary of Statewide Communication Interoperability Plans (SCIPs)	• Develop and implement National Incident Management System (NIMS) procedures, specific Incident Command System (ICS)-related steps, and any associated qualifications into all standard operating procedures (SOPs) • Develop and promote common nomenclature guidance • Adopt and utilize plain language speech communications in compliance with NIMS requirements • Develop shared statewide or regional radio system supporting multiple Federal, state, and local agencies • Install statewide or regional fixed interoperability channel infrastructure • Train ICT staff to be familiar with the systems used for emergency response • Incorporate interoperable communications into all existing and future training and exercise programmes

Issuing body	Guidance document	Key components
United States Federal Emergency Management Agency	FEMA EOC Assessment Checklist	• Use standard components recommended for the EOC • Communication tools include mobile and satellite phones and radios, laptop computers and more extensive technologies. Pen, paper, and in-person communication serve as a backup system of communication • Protect ICT against physical and cyber attacks
	DHS/DOJ Fusion Process Technical Assistance Program and Services: Comprehensive Preparedness Guide (CPG) 502	• Formalize the process of coordination • EOCs at all levels of government and across functional agencies should be capable of communicating appropriately with other EOCs • Communication systems must be reliable, with built-in redundancies • Prepare a list of capabilities, products, assessments, and reports produced and informational needs/requirements of the EOC • Access EOC data and communicate with EOC staff electronically in a virtual EOC
	Guide for All-Hazards Emergency Operations Planning	• Develop evidence-based plans in advance with a coordinated effort from multiple stakeholders • Provide an overview of the planning process and list the intention to maintain and re-evaluate the plan in the emergency operations plan itself • Provide detail for specific functions in annexes to the plan • Include hazard-specific appendices in plans and provide information on specific procedural details, protective action, and public information needs • Consider others' plans and national standards for guidance on preparedness plan development
	Multiagency Coordination Systems	• Integrate emergency response organizations, agencies and structures
	NIMS Recommended Standards List	• Lists the voluntary consensus standards that support the implementation of the National Incident Management System (NIMS) • Standards describe the development and use of common communication plans, interoperable communications equipment, processes and architecture
United Nations Office for the Coordination of Humanitarian Affairs	Country Level Inter Agency Minimum Common Operational Datasets v1.1	• Collect and analyse basic and geospatial data • Aid Member States in the collection and improvement of baseline data • Categories of necessary operational data include: administrative boundaries, populated places data, social infrastructure data, transportation information, and topographical data • Optional datasets include: marine, terrain, and natural hazard data as well as maps and satellite imagery • Metadata collected by Member States can be shared across a network
	OSOCC Guidelines	• Provide professional staff with a clear set of responsibilities and expectations based on their disciplines • Ensure that staff are in place in all EOC functions, including leadership and management, operations, information management, logistics, media, safety and security, administration, technology support, and liaison positions • Use standard components recommended for the EOC

Issuing body	Guidance document	Key components
United Nations Office for the Coordination of Humanitarian Affairs Regional Office for Asia and the Pacific	Common Operational Datasets for the Management of Humanitarian Information in Asia and the Pacific, v1.0	• Categories of necessary operational data include: administrative boundaries, populated places data, social infrastructure data, transportation information, and topographical data • Data may come from national governments, academic institutions and commercial entities
World Health Organization	Managing Health Emergencies: A Guide for Establishing, Operating and Evaluating an Emergency Operations Centre	• Multi-purpose spaces can be converted into EOCs • Use standard components recommended for the EOC • Train ICT staff to be familiar with the systems used for emergency response • Pen, paper, and in-person communication serve as a backup system of communication • Include a map of the EOC layout, contact lists of EOC personnel, standard documentation forms, training and exercise schedules and plans, and a section about de-activation and de-escalation procedures in the emergency response plan • Use full-scale exercises to test the system comprehensively. Some training allows preparation for known events
	Public health emergency operations centre network (EOC-NET): consultation meeting, 19-20 November 2012	• Define, agree on and implement minimum data sets and data exchange standards • Access EOC data and communicate with EOC staff electronically in a virtual EOC
	Protocol for Assessing National Surveillance and Response Capacities for the International Health Regulations (2005)	• Core response capacities include the requirement for functional command, communication, and control mechanisms, rapid support for the investigation and control of emergencies, availability of a rapid response team, and development of policies and procedures. Indicators of these capacities include the existence of a dedicated operations centre, dedicated multidisciplinary rapid response teams, communication and collaboration during response, existence of guidelines and procedures, and response team training and security
	Public Health Events of Unknown Etiology: A framework for response in the African Region	• Conduct activities and components of the response phase as appropriate to the event and local infrastructure as regards alert management, field investigations and field response • Perform needs assessments with the help of field personnel, designated assessment teams, and those in other sectors
	Emergency Response Framework	• Mobilise existing staff to form an Emergency Response Team within 12 hours • Establish and deliver emergency services within 72 hours • Provide technical assistance as required within seven days • Conduct a needs assessment to determine the scale of the emergency and the urgency of the needed response

5. Discussion

5.1 General

5.1.1 EOC functions

There are several basic functions of an emergency operations centre. As mentioned in the previous paragraph Quarantelli outlines six: coordination, policy-making, operations, information gathering, dispersal of public information, and hosting visitors (15). Formal EOC structures such as Incident Command Systems (discussed below) organize EOC functions into sections that include operations, planning, logistics, and finance/administration (17). Media and risk communication and maintenance of formal liaisons with other agencies are also basic EOC functions (18). Public health EOCs may add public health-specific functions including but not limited to surveillance monitoring, public health data collection and analysis, quarantine, epidemiology and laboratory functions and community mitigation (17, 19-21). Quarantelli notes that there are many types of EOC structures, but that: "what is crucial is that... [staff] be knowledgeable and possess certain decision-making responsibilities" (22). The importance of coordination, communication, management, and information gathering and interpretation are consistent themes throughout the literature (16, 23, 24). Modern technology, complex organizational and governmental structures, and insufficient resources are challenges to achieving Quarantelli's six functions.

5.1.2 Types of risks and hazards

EOCs are used in a variety of hazards and emergencies. In some instances, EOCs are used for drills and exercises or other non-emergency events (25). In emergency situations, EOCs are activated due to: natural disasters; foodborne disease outbreaks; radionuclear events; bioterrorism; chemical incidents; mass gatherings; blackouts; humanitarian emergencies; or disease outbreaks or pandemics – as discussed above and in Table 2. The literature cites protocols of the 2005 International Health Regulations (IHR(2005)) when discussing disease/event detection, and WHO pandemic global alert phases when discussing EOC activation under pandemics (26, 27). EOCs are used in multiple types of jurisdictions, taking forms ranging from field EOCs to local or regional EOCs to national or international EOCs (Table 2).

5.1.3 Human resource needs

While there was reluctance to quantify the number of staff needed for an EOC, given its variance according to jurisdiction, type of hazard, and duration and scale of emergency, the literature did suggest necessary competencies of EOC personnel. Staffing was described as "one of the most critical components of an EOC" (28). Some papers concluded that professionals staffing an EOC should have a clear set of responsibilities and expectations based on their disciplines (29-32), and should be well trained both in general emergency response and in their assigned responsibilities (33, 34). Others stated that there should be staff in place for all EOC functions, including leadership and management; operations; information management; logistics; media; safety and security; administration; technology support; and liaison (31, 32, 35).

5.1.4 Surge capacity

In public health EOCs, surge staff are needed for all EOC functions (15, 36). Identifying surge staff and adequately training them is "paramount to ensur[ing] capacity for an available and trained workforce... [that can] rapidly adapt to different and unfamiliar work patterns" (37). The United Nations Office for the Coordination of Humanitarian Affairs (OCHA) maintains an emergency response roster of 35 staff permanently available if an urgent response is needed; it also has several programmes to identify surge capacity staff in a variety of roles on short notice (38). It was noted that some public health professionals do not view themselves as emergency response personnel and therefore are not prepared for around-the-clock preparedness, or for a role within an EOC (39); this makes training all the more important for an effective EOC.

5.1.5 Structure

The organizational structure of EOCs was mentioned more frequently than physical and staffing needs. The literature showed a strong preference for an Incident Command System (ICS) (17-19, 25, 30, 35, 40-48).

An ICS is a management system used by public health as well as law enforcement, emergency medical services, fire departments, and other bodies that coordinate response activities within a common framework. ICS uses an Incident Commander who leads response activities with a staff with several sections: command, operations, planning, logistics, and finance/administration (49, 50). ICS has many benefits, including a clear command structure, common terminology, the ability to vary the precise structure and goals of the system depending on the situation, the ability to accommodate multiple protocols, and the ability to function in complex responses (40, 45, 51).

The use of ICS within public health settings is relatively recent, and some public health agencies have adopted a modified ICS, such as that used during the 2009 H1N1 influenza pandemic (17). Public health EOCs often include a strong scientific and technical component, which is not traditionally emphasized in ICS (17, 30). Because public health professionals are not traditionally familiar with ICS terminology and structure, several studies recommend ICS training for staff in order to overcome this documented challenge during emergency response in EOCs (39, 52-54).

Even when ICS is not used, an EOC's structure is expected to be defined, standardised, scalable and flexible, and connected to other levels and agencies. Some papers indicated a need for clear "trigger points" to indicate decision-making, information sharing, or the need to involve other jurisdictions (36, 42, 48, 55); others made the point that this structure should be well understood by EOC personnel and should include liaisons from other organizations and agencies (18, 21, 28, 56, 57).

5.1.6 Decision-making, modelling, and implementation

Decision-making is a critical function of EOCs. Rapid but accurate decision-making is extremely difficult, however, as "in the early phase of an accident, there is very little time to make decisions" (58). Authoritative decision-making and EOC leadership were noted as factors in effective response, and a lack of leadership and decision-making were noted as significant challenges (59-65).

The literature suggests that proper preparedness and planning can be an important decision-making tool, as it allows operational decisions to be made under conditions less open to the irrationality and stress of a real-time emergency situation (48, 58, 66). The components and process of developing detailed plans are outlined below.

The literature also notes the importance of sufficient and accurate information for decision-making in order to mitigate "the intense constraints of time and resources" under which EOCs must take action (67). In situations without adequate information, it is difficult to take action and prioritize scarce resources (35, 48, 59, 60, 68). Ensuring enough information is gathered and then communicated in the right ways can facilitate decision-making. Effective decision-making can therefore be the product of effective planning and an effective EOC structure (69).

Decision support systems and modelling can aid EOC leaders and decision makers, if used with the understanding that models are not always perfect and do not always predict accurately (58, 70). Decision-making authorities can use data visualization tools such as GIS to help collate and interpret information to aid decision-making (48, 71, 72). Some EOCs use frameworks such as the Haddon or the Synchronization matrices to analyse a situation and provide practical solutions for response (42, 73).

Modelling can be used as another tool to aid the EOC decision-making process. While the outcomes of a model depend on the inputs, and model design is crucial, simulation and mathematical modelling can be used to explore consequences and capabilities of EOC actions (74-77). It is also important to supplement modelling with practice in order to integrate the model with the decision-making to follow (42, 78). However, the right information and model can provide "actionable information to decision makers... by helping to identify and prioritize areas" during emergency response (72).

Having clear leadership and incident commanders, as part of an ICS or similar structure, is beneficial in making easily implemented and operationalized decisions. Many EOCs and emergency operations plans have triggers that lead to information sharing between EOC sections, with other EOCs, and with agencies (55). EOCs with standardised roles, a defined structure, and well-trained staff provide a formal process for taking action, thereby creating an environment in which necessary actions can be carried out (20, 42, 56). The process of implementing decisions and giving instructions to EOC staff, as well as that of reporting and receiving instructions from EOC leaders, can be detailed in EOC procedures (48).

5.1.7 Best practices

Several features were consistently noted as crucial elements of effective EOC functioning. These included collaboration; coordination; communication; harmonisation; respect; cooperation; vertical and horizontal integration; trust; and leadership (24, 28, 31, 36, 40, 48, 63, 66, 67, 79-102). These features spanned the grey and peer-reviewed literature; quantitative and qualitative studies; and case studies of both effective and ineffective emergency responses.

Communication was considered "a vital component" of response (36, 48, 79-82). Timely information sharing and exchange was noted as informing effective public health decisions and policies (83), being essential for taking action (67, 84), and as the "main function of EOCs" (40). Notifying other agencies of an event's occurrence, a case of disease, or a public health emer-

gency of international concern is, of course, a requirement internationally (26) and within many countries (28, 85), but timely information sharing can also be more informal. Factors such as EOC planning, information technology, and EOC structure and procedures can affect the ability to share information (66, 86-89). However, setting the foundation for plentiful and timely information exchange can facilitate effective and rapid EOC action and response (90-93).

Coordination with others within the organizational structure and at other agencies is touted as critical in emergency responses, during which information changes rapidly. Early and frequent coordination are repeatedly noted as key factors in an effective response (48, 63, 82, 94, 95). As Scanlon says bluntly:

> *"An EOC is an effective way to achieve coordination among agencies responding to a major emergency or disaster. The absence of an EOC seems to encourage the opposite." (96)*

Some have formalized the process of coordination, even going so far as to structure regionalization and partnerships (24, 97-100). Internationally, the International Search and Rescue Advisory Group developed guidelines and a concept for an On-Site Operations Coordination Centre (OSOCC) to improve international coordination (31). Others noted the need to coordinate with other sectors, including the private business sector (101), the healthcare sector (102), and the non-governmental organization sector (48, 82).

5.1.8 Indicators and performance measures

There is no agreement in the literature about indicators to measure the performance and effectiveness of EOCs; development of indicators and metrics was lacking (33, 63, 103). Beck et al. report that "there is a growing need to coordinate and systemize [efforts] to ensure a consistent level of response" and that "there is a clear need for international standards" (63). Nelson et al. point out that the development of standards and accompanying indicators will be difficult "if 'evidence-based' implies the standards of proof that are normally required for clinical and other public health interventions" (78). Though welcomed in principle by decision makers, standards can also pose challenges for those whose work uses language and approaches that vary from the language and approaches of the relevant standards (14).

Many studies examined previous events and the performance of various EOCs' and their strengths and weaknesses; these results have been incorporated throughout this review. Indeed, some note that the incorporation of lessons learned into a jurisdiction's emergency operations plans is more than simply recommended, but is in fact a critical component of the post-event phase. The Canadian Emergency Management Framework includes continuous improvement and both incremental and transformational change as key principles and "underlying beliefs and goals" of the Canadian perspective on emergency management (100). The target capabilities of the United States Department of Homeland Security (DHS) explicitly include the evaluation of plans based on lessons learned from both exercises and actual events (49); and one of Rebmann's key findings was that "examining past disaster responses and incorporating lessons learned into future disaster plans can improve public health preparedness" (52).

Several examples of this improvement process were seen in the literature. North Dakota incorporated lessons learned from past disasters, and improved procedures, staffing, and materials

(104). Sri Lanka established a Centre for National Operations to coordinate responses after the 2004 tsunami (105). New Zealand incorporated lessons learned from a pandemic influenza exercise into its Influenza Pandemic Action Plan, which was subsequently activated, and the recent exercise was credited with the effective response (106). Capacity building activities undertaken after ineffective hurricane response in North Carolina led directly to effective communication and better response after subsequent hurricanes (107).

Nevertheless, there are some objective indicators of success. The United States Nuclear Regulatory Commission provides guidance for emergency action levels for nuclear plant drills and emergencies (108). The Sphere Handbook includes key indicators for coordination and collaboration during humanitarian disasters (13, 70). Furthermore, the IHR core capacities for response state their use as indicators to monitor EOC response. The core response capacities include the requirement for functional command, communication and control mechanisms; rapid support for the investigation and control of emergencies; availability of a rapid response team; and development of policies and procedures. Indicators of these capacities include a dedicated operations centre; dedicated multidisciplinary rapid response teams; communication and collaboration during response; existence of guidelines and procedures; and response team training and security (109). The CDC's funding to state and local jurisdictions specifies performance measures and, in some circumstances, performance targets. Time for staff to report for EOC duty, development of an incident action plan, and completion of after action reports and improvement plans are included as performance measures, along with specifications on how to collect data, but these measures are not universally applied and nor are the accompanying performance targets (110). The WHO Emergency Response Framework has performance standards against which it measures its performance. Time-based performance standards are laid out that commit WHO to taking certain actions within predetermined timeframes. For example, WHO mobilizes existing staff to form an Emergency Response Team within 12 hours; establishes and delivers emergency services within 72 hours; and provides technical assistance as required within seven days – along with many other actions to ensure an effective response (111).

5.2 Communication technology and infrastructure

5.2.1 EOC space

The physical locations of EOCs vary widely. In some cases, EOCs are located in a dedicated space (e.g. the CDC's EOC) (112, 113). More common are multi-purpose spaces that are converted into an EOC when needed. It is suggested that EOCs in multi-purpose locations must be able to be converted and activated within one hour (113). Modular EOCs can be shipped to any location and set up on (for example) a football field, a quality which is advantageous for providing open vertical access and proximity to evacuation centres (114). The United States DHS recommends that all states (i.e. provinces or regions), all counties, and all cities with populations over 50,000 have at least one designated EOC, and in most cases a backup EOC as well (115).

Regardless of the type of location, the literature recommends that EOCs have standard components. Co-locations for essential interdependent functions are recommended for planning and operations, and logistics and finance (113). A separate communications centre is also a common feature of EOCs (116). Some papers concluded that these facilities should have the ability

support robust communications systems featuring networked computers, telephone/fax lines, and display boards, along with backups for these systems (16, 92, 113); and that the facility should also feature backup systems for electrical power and heating/air conditioning (113). It is important that EOCs feature separate meeting rooms for priority discussions, along with a briefing space for visitors and the media (32, 113). Lastly, a common component of EOC facilities is a staging area for air and land transportation (114).

5.2.2 Information and communication technology (ICT)

Rapid changes in information and communications technology (ICT) mean that studies published in the 1990s about technology used in EOCs are now far outdated. There is a wide range of ICT, software and hardware components and systems that support EOC functions; these are increasingly important (117-119). These systems allow EOCs to collect, analyse, interpret, visualize, and disseminate information accurately and quickly, providing a "significant preparedness and response advantage" (120).

EOCs need data collection, analysis, and interpretation systems, communication systems, and knowledge management systems (70). Details of software, equipment, and systems are outlined below; but just as important as the specific systems are their shared characteristics. The literature suggests that ICT must be interoperable and reliable, with backups in place; and it must be well designed and modifiable. Different elements of ICT must also use common vocabulary and terminology, in order that they are able to link with each other. Finally, staff using ICT must be trained and familiar with the systems, so that their use and implementation aids emergency response instead of hindering it (9, 43, 49, 67, 113, 121-125). The importance of these characteristics, and especially that of interoperability, is underscored by Gusty, who points out that the lack of interoperability can make "accessing life-saving critical data impossible for emergency managers and incident commanders" (126).

5.2.3 Equipment and technological components

Basic hardware is an essential foundation of the proper function of ICT in an EOC. Such equipment includes servers; computers meeting the appropriate system and performance requirements; high speed internet; and networking connections. An EOC should also have the ability to adapt its ICT capabilities if additional functionality is needed. Security is also a key concern, and the need to protect ICT against physical and cyber attacks is noted (127-129).

Communications components are especially critical. The literature recommends that EOCs contain an adequate number of telephones and fax machines with secure connection capabilities. Video teleconferencing is commonly found in EOCs, for the purposes of communicating with those in other locations and agencies; and many EOCs also have computer messaging systems for rapid and informal staff communication within and among agencies (although mobile phones are also used for this purpose). EOCs commonly use video displays visible from throughout the main room in order to display multiple feeds for video conferencing, GIS and other visual data analyses, and maps. ICT tools are also used for communicating with those in the field; these tools are most commonly mobile and satellite phones and radios, although laptop computers and more extensive technologies are sometimes also used (16, 49, 59, 62, 68, 92, 104, 129-132).

Backup and redundancy requirements are also thoroughly noted. The literature repeatedly emphasized the need for backup systems and security requirements to ensure EOCs remain functional even if initial systems experience glitches or fail completely. Backup options are important for systems as well as equipment – such backup might include having radios on hand in case telephones are not operable. It is also noted that backup systems and redundancies can be implemented incrementally to balance costs and operational needs. It is pointed out that in the event of multiple systems failures, often "the technology that [works] best [is] the oldest" (128). Paper and pens and in-person communication can be relied on as the ultimate backup system (9, 49, 67, 89, 92, 104, 113, 122, 129, 133).

5.2.4 Information and knowledge management software

The volume of data and information available and used in EOCs can be daunting. Knowledge management systems are a commonly used way to increase and improve information exchange in EOCs. Systems can be custom built or purchased. Software systems mentioned in the literature include Responder Knowledge Base; DisasterLAN; E-Team; WebEOC; SharePoint; AskMeEnterprise; Common Operating Picture Software/Systems (COPSS); WIISARD; and wikis (48, 51, 67, 133-137).

Multiagency Coordination Systems (MACSs) coordinate activities both in the field and in EOCs, and prioritize demands for resources (99). MACSs can formalize the process of multiagency coordination by using specific protocols, often within an ICS structure. MACS can provide support and coordination as well as assistance towards policy decisions; they can also facilitate information sharing between EOCs (93). The goal of a MACS is fully to integrate emergency response organizations, agencies, and structures (138-140).

5.2.4.1 EOC applications and standards

The review suggested that systems should adhere to internationally accepted standard messaging specifications and vocabularies, including HL7, LOINC, SNOMED, and ICD-10; and that they should also use security standards such as ebXML, HTTP, PKI, PHIN MS, and SSL (121).

The systems themselves can range from early warning and detection systems (133, 141) to geographic information systems (GIS) and spatial modelling (72). GIS systems were frequently mentioned as a way in which to display data visually to aid in decision-making. These visualizations are especially important for the public and stakeholders whose functions are less technical and scientific in nature (16, 49, 71, 120, 142-145).

5.2.4.2 Virtual EOCs

The ability to manage information and data through electronic systems is an indispensable component of the modern EOC; some agencies have advanced this concept to incorporate a virtual EOC into their responses.

The concept of a virtual EOC is the creation of a virtual environment to support core EOC functions and enhance knowledge management, inter-organizational communication, collaboration,

and decision-making (148, 149). It is recommended that virtual EOCs use emergency management software; provide remote access to databases and communications; disseminate information; and link individuals and groups who are not in the same location, in order to help improve EOC function (147). Virtual EOCs can also take advantage of shared resources and system capacity (127).

Virtual EOCs can be used to access EOC data and communicate with EOC staff electronically (1, 99, 118). Virtual EOCs can also be used to allow agency staff or other organizations and agencies to participate remotely in EOC activities; to facilitate external communication; to share information with partners and stakeholders; and to document information and processes (WHO 2012 consultation meeting; DHS/DOJ Fusion Center, ASTM standard guide).

Some jurisdictions may decide to use a virtual EOC as a backup 'location' (146). A United States-based organization, Virtual Emergency Operations Center, operates completely in the cloud, collecting and disseminating information and providing support to field personnel (147); and a private sector EOC exists in the United States to coordinate the efforts of the public, private, and non-profit sectors (101). It is clear, however, that these models are not widely used.

5.3 Procedures and plans

5.3.1 Key characteristics of procedures and plans

The literature unequivocally supports emergency operations planning: well-written plans can result in timely and effective implementation of response activities (106). Such plans "[should be] as simple as possible but as complex as necessary" (58). Having a plan does not, however, guarantee that an agency has achieved preparedness (150, 151).

Plans must by definition be developed in advance. It is widely recommended that development be evidence-based, and the result of a coordinated effort involving multiple stakeholders and parties (33, 36, 49, 152-154); it is also recommended that plans consider multiple phases of emergency response, mitigation, preparedness, and recovery, in order comprehensively to address emergency preparedness (22).

Plans frequently use an all-hazards approach that is comprehensive and which encompasses common response components that are needed across all types of hazards. The United States National Response Plan uses this approach to establish a plan "across a spectrum of activities" as well as across different types of emergencies (22, 44, 82, 100, 155, 156). Despite the popularity of the all-hazards approach, some of the literature cautions that plans should correspond to a jurisdiction's risk (48, 100, 157-159).

The literature includes a wide variety of planning guidance, from national-level plans like the United States National Response Plan to guidance that local jurisdictions "should not be expected to develop and coordinate cross-jurisdictional planning... better carried out by a centralized command structure at the state level" (160).

Coordination with other agencies' plans and resources is an important component for jurisdictions to consider (29, 33, 88, 150, 158, 161). The literature suggests that incorporating formal protocols for interacting with other agencies, jurisdictions, and sectors should be part of

all plans (29, 152, 153); and that agencies should also consider that plans will be affected, and sometimes superseded, by other jurisdictions that participate in EOC activation and emergency response (160, 162).

5.3.2 Key components of emergency operations plans

The literature suggests that emergency operations plans should have several standard components: the basic plan; functional annexes; hazard-specific appendices; and standard operating procedures and checklists (163).

The basic plan is a high-level overview document that explains general concepts and assigns broad responsibilities. It cites legal authority for the response as well as the leadership structure. Some papers conclude that the basic plan should also state the general goals of the plan and list key EOC positions and their primary responsibilities; and that this section should give an overview of the planning process and the intentions to maintain and re-evaluate the plan (36, 154, 163).

Functional annexes are organized around providing detail on specific functions of the EOC, including detail on broad tasks, processes, roles, and responsibilities. Functions include but are not limited to direction and control; communications; warning; emergency public information; evacuation; mass care; health and medical services; and resource management (30, 154, 163).

Hazard-specific appendices provide unique operational information for specific types of hazards. Information may include specific detail about procedures, protective action, and public information needs for particular hazards that are not addressed in the functional annexes or anywhere else in the plan. These appendices may list vulnerable populations or high-risk areas, warning or detection systems, evacuation or mitigation and control strategies, and unique planning considerations for a hazard (49, 154, 163).

Standard operating procedures and checklists provide the most detailed step-by-step information about how individual staff should fulfil responsibilities and perform tasks. These responsibilities cover activities throughout the EOC's activation period and identify who should complete a given task, when it should be done, and how it should be done (32, 36, 48).

Finally, plans also include a number of miscellaneous components, including a map of the EOC layout; contact lists of EOC personnel; standard forms for documenting EOC activities; training and exercise schedules and plans; and a section about de-activation and de-escalation procedures (36, 113).

5.3.3 Planning process

Planning is time consuming, and agencies can find it difficult to address a range of hazards comprehensively. Focusing on the process of planning is as important as the plan itself (22, 33, 36). It is also necessary to address operational problems as well as the necessary training and implementation preparations that must accompany plans (33). Although preparedness planning is a detailed and difficult process, the literature suggests that agencies should take advantage of the experience and plans of others, and should also consult national standards (36, 154). Additional experiential knowledge is gained from incorporating lessons learned from previous EOC responses and training exercises into plan development (58, 84, 106).

Several sources recommend conducting a hazard analysis or needs assessment to identify what the plan should address (49). A needs or risk assessment can help an EOC know what type of hazards are most likely to occur, thereby guiding the planning and training processes (164-166). Results of such assessments and analyses can also inform decisions about the level of need for personnel, equipment, and other resources. Mass gatherings are one example of an event for which response will vary widely based on need; a small mass gathering of a short duration will require a smaller EOC, or perhaps none at all, whereas a larger, longer gathering or event will require a more robust EOC response (164).

5.3.4 Activation criteria

Some jurisdictions have protocols specifying when to activate EOCs (36, 40, 167), while others use an action committee or other authority that determines when to activate it (30, 48, 60, 95, 106, 131, 146, 168-170). Depending on the situation, the degree of EOC activation can range from partial activation to full activation for a prolonged period of time (171).

5.4 Risk communication

Risk communication is a broad discipline, the literature for which contains vast amounts of knowledge, best practices, and research. This paper gathers some information about risk communications in emergency response, although this is recommended as a topic for future research. The literature suggests several basic characteristics for risk communication to the public as part of emergency response: communication should be clear and accurate, timely (ideally early), evidence-based (ideally with access to subject matter experts where appropriate), and coordinated.

Risk communication is yet another area for which good existing relationships and collaboration result in more effective emergency response. Several studies state prior EOC contact with media and journalists, as well as with the public, as important factors in successful communication during emergency response (29, 100, 172-174). Collaboration with other agencies is also a key factor, as coordinated messages allow for clearer public consumption of the information presented (36, 172, 175). Canada's Federal Public Communications Coordination Group formalizes this process, officially coordinating messages from all agencies to the media and the public (24).

Clear, transparent, and accurate information is important in order to build trust with audiences (36, 48, 100, 176, 177). The literature recommends being honest and forthcoming where possible, and not conveying inaccurate information (48, 173). Tailoring information, especially highly scientific or technical information, to specific audiences can help align public perceptions with the messages conveyed (176). As Ng and Lean point out, successful risk communication means conveying "complex subject matter... in language that laypeople can understand" (177). This can be accomplished by experts in linguistics and messaging.

Several papers conclude that risk communication should be a component of emergency operations plans (21, 36, 131, 178). Integrating communications staff into EOC activities such as daily briefings, planning, and trainings can create an atmosphere that facilitates information sharing in order to build foundations for communication with the public (174, 175, 178, 179).

Work done before an event occurs, such as establishing a relationship with journalists or the intended audience, conducting focus groups to determine what the public wants to see, and testing sample messages, can facilitate effective risk communications during an event (131, 162, 173-175, 177).

5.5 Operational information minimum data sets and standards

Standards for data sources and common data sets are critical for successful EOC functioning and interoperability. Infrastructure, communication technology, and procedures and plans are the structures and foundations that enable operational information to be collected and analysed for decision-making and response. Data are collected from varied sources using tools such as the Community Assessment for Public Health Emergency Response (CASPER) tool and – in some instances – mobile phones (180, 181). The surveillance systems collecting this information for EOCs are active before, during, and after an emergency, and are responsible for capturing data about population demographics, disease incidence and health status. During an emergency, it becomes important to collect data about healthcare system capacity, risk of disease spread, or post-disaster health status. EOCs collect standardised data during humanitarian responses based on common operational data sets, and use standard information sources during foodborne disease outbreaks, both of which procedures are detailed below (125, 182, 183). Standards for minimum operational information data sets are outlined in the sections below and in Table 4.

5.5.1 Information needs

Information and data needs during EOC activation can vary widely. At the beginning of a response, needs assessments can help incident commanders and EOC leadership obtain situational awareness in order to manage the response and make decisions more effectively. These assessments may be done with the help of field personnel, designated assessment teams, and those in other sectors, such as healthcare professionals (9, 24, 41, 107, 146, 159, 170, 184-186). Needs assessments can determine the scale of the emergency and the urgency of the necessary response (111).

Several tools can be used to conduct needs assessments, such as CASPER, which uses statistical and clustering methods to collect location, demographic, health status, and safety data about households and communities in the affected area (180). Results of needs assessments may be used within an EOC or disseminated to other jurisdictions and agencies, and the media or the public (107). Aung (70) notes not only that needs assessment results can be disseminated to others, but that data from other sources can also be added to one's own data in order to form a clearer picture of emergency responds needs and capabilities. The need for assistance from other jurisdictions can also be determined with the help of a needs assessment, as well as an assessment of the ability of the local community to respond to those needs (41).

While surveillance systems were not specifically within the scope of this review, they are mentioned below as a potential topic for future research. They are also worth mentioning in the context of an assessment of the types of information and systems needed in an EOC environment. Surveillance that captures morbidity and mortality data, disease incidence, and population health

status data can be critical in determining situational awareness and making decisions about response (142). Pre-event data and trends are an important component of surveillance during an emergency response, as are data collected during the response. Even in areas where infrastructure is destroyed or resources are scarce, surveillance systems using mobile phones can be used to collect some data in a standardised way (144, 181). The data collected and used by surveillance are discussed below.

5.5.2 Types of operational information

EOCs can use many types of information during emergency response. This information is needed "to support operations and decision-making for all actors" during emergency response (125). Epidemiologic data and assessments can provide crucial information about healthcare system capacity, risk of disease spread, or post-disaster health status (48, 68, 187). Baseline data collected before an emergency or disaster can be an important factor in the timeliness of a response. If baseline data are not available, resources otherwise used for response or relief efforts must be used to collect and analyse basic and geospatial data (182). Organizations like the UN and WHO are working to help Member States collect and improve their baseline data (182).

The Inter-Agency Standing Committee (IASC) guidelines outline the types of information needed for humanitarian response, including humanitarian profile data, population statistics, geographic boundaries and places, transportation network data, and other geospatial information (125). The OCHA standards for common operational data sets outline five similar categories of data (182, 183):

1. Administrative boundaries include political and administrative boundaries used to organize and aggregate data
2. Populated places data include the point location of cities, towns, and settlements
3. Social infrastructure data include the point location of schools and health facilities
4. Transportation information supports logistical planning and includes roads, rail lines, and airports
5. Topographic data support mapping and spatial analysis.

Optional data sets include marine, terrain, and natural hazard data, as well as maps and satellite imagery (182).

5.5.3 Data sources, collection, and monitoring

Information can be gathered from many sources for use in an EOC. These sources include but are not limited to EOC staff, other agencies, community members, and situation reports about the emergency or event (32).

Data collection for EOC purposes during an event is difficult, but strengthening processes and systems before EOC activation can facilitate data collection and use during it (70, 125).

Data collection during response can be accomplished through direct observation, rapid assessment teams, health system data, population based surveys, and ongoing surveillance systems

(70, 188, 189). Site surveillance that relies on health system data can add to the data at an EOC (190). In the absence of resources or infrastructure, data can be collected in a non-technical but rapid manner if they are collected consistently and thoroughly; systems set up quickly based on needs during emergency response can still be effective for response and decision-making (181, 191).

Established global data sources and information networks can provide information for EOCs to use in determining response activities. EOCs activated for foodborne disease outbreaks can use the International Food Safety Authorities Network (INFOSAN) as a source of information about global food safety issues. Humanitarian disasters can use databases such as the Global Administrative Unit layers and Global Discovery. Metadata collected by Member States can also be shared through the GeoNetwork by end-users (182). It is also noted that national governments are further common sources of data, including geospatial and population data, as are academic institutions and commercial entities (36, 183).

Monitoring information throughout emergency response can be used to make predictions about what is likely to happen next (48). Using and analysing information on how emergency response activities are being implemented and then determining what additional activities should be done and what resources they require are important roles of an EOC (48, 125). While some information used by EOCs can be gathered before an event, like census data, other information can be collected and updated throughout the response to help EOCs continually reassess emergency response activities (125).

5.5.4 Use of operational information

Knowledge management systems, discussed above, can be important sources of information from other parts of an EOC or from other agencies. They can also be helpful in pooling information and displaying it visually to help drive decision-making and action. Virtual EOCs, also discussed above, are another ICT innovation that can provide EOC staff with critical operational information during a response.

Throughout EOC activation, the ongoing collection of information and its appropriate interpretation can help EOC leaders maintain situational awareness in order to respond effectively (32, 48, 146). EOC staff interpret and assess information collected at an EOC in order to determine its relevance, reliability, significance, and implications. Some papers recommend that staff should be trained using EOC standard data fields, and should follow standard procedures for performing this assessment (192, 193). After information has been appropriately processed, EOC leaders can react and respond by allocating resources, activating services and response activities, seeking outside assistance, and communicating as needed (24, 32).

5.6 Training and exercises

Training is "essential for [emergency operations plan] execution" (92) and a major element of many emergency response plans and standards (193-195). For example, FEMA coordinates trainings on Incident Command Systems and their components and awards credentials (25, 43). Training and readiness is a required component of CDC funding for state and local health departments, and critical for Australian emergency management (196, 197).

One criticism of emergency response and EOC training is that the lack of standardisation (in the form of both competencies and curricula) and the lack of emphasis on evaluation or assessment call into question the effectiveness of training methods (196, 198). Individual and organizational training designed from an evidence base and including thorough assessment and evaluation can help ensure training is meeting its objectives and that individuals and organizations are prepared for emergency response (197-199).

5.6.1 Individual training

Training individuals in overall emergency response, as well as in specific functions and roles, is emphasized throughout the literature. Some papers also note the need for cross-functional and interagency training to enhance the ability of individuals to implement the components of communication and collaboration needed in EOC environments (34, 54, 108, 112, 200). Regardless of the need for both all-hazard and hazard-specific training in order to meet the respective needs of both an overall response and specific functions, due to resource constraints there is a widespread emphasis on all-hazard, overall training (37, 195, 196).

Standards for individual training competencies are not consistent. There are some agreed-upon best practices for skills that individuals should have, and therefore be trained to do; these include but are not limited to recognizing threats and abnormal conditions; accessing and using communication systems; conducting emergency operations planning; implementing specific resources, tools, and procedures; rapid assessment and surveillance; and basic familiarity with incident management systems or similar structures (54, 163, 179, 196, 201). Agreed-upon standards, competencies, and curricula are needed to ensure consistent training across jurisdictions and agencies (196, 198).

Training for individual public health professionals can take the form of continuing education courses, government-sanctioned courses (e.g. FEMA certification), organizational exercises (discussed in detail below), and on-the-job training (25, 80, 178). Training that includes a combination of didactic and experiential learning techniques can involve individuals more fully in the skills being taught (34, 196).

5.6.2 Organizational training and exercises

The literature notes the importance of team and relationship building as one of the "primary purposes" of agency trainings (202). Improved communication, cooperation, and collaboration are all notable outcomes of high-quality training (107, 203). Joint training involving multiple agencies is mentioned consistently as an approach to building relationships and improving the likelihood of collaboration and coordination during responses to events (49, 60, 97, 204, 205).

There are several types of agency trainings discussed in the literature. Different training formats achieve different objectives, and agencies may choose formats based on those objectives (53). Orientations and seminars familiarize participants with procedures, plans, and operational information. Drills help participants build, maintain, and evaluate specific skills. Tabletop exercises, hypotheticals/scenarios, and workshops are informal ways in which to discuss hypothetical situations and responses. Functional exercises simulate an EOC experience by presenting a situa-

tion in an interactive exercise with time constraints and limited available information. Full-scale exercises are the most extensive type of training by which to test a system comprehensively. Training can also take place in order to plan for known events, such as mass gatherings (18, 49, 64, 113, 165, 195, 197, 203, 205).

Exercises can assess an agency's communication and cooperation skills as well as the abilities of individuals to work with new or existing systems or equipment. These exercises help individuals become more competent with the systems; help agencies become better at using the systems as part of emergency response; and help expose any need for modifications or improvements to the systems themselves (70, 102, 120, 133, 204, 206).

5.7 Themes and conclusions

Major emergency events in the last two decades have caused authorities to modify emergency preparedness plans, resources, and approaches to emergency response. Many response efforts in this review, therefore, emphasized the need for robust planning and capacity and underscored the importance of Quarantelli's six basic EOC functions (15). As Kendra and Wachtendorf observe:

> *"One key aspect of the response to the 11 September attack is that, although the EOC was destroyed, the emergency management organization was not. Rather, the organization itself exhibited robust, adaptive behavior, demonstrating considerable improvisation, evidence of goal-directed solution-seeking and incorporating resources from diverse sources." (16)*

5.8 Limitations

This systematic review included English-language studies only. To ensure that future research is robust, some non-English studies are listed in Attachment 2, the database of excluded studies. While the authors consulted with several knowledge management specialists to refine the search strategy and review protocol, some literature may not have been included in the search results. There was a risk that the data extraction process could have been biased by potential inconsistencies in individual authors' use of terminology and language.

Furthermore, the quality assessment process was limited by the types of studies included in the review and difficulty in assessing the quality of standards, guidelines, and requirements, especially governmental documents. This weakness was addressed by changing the quality assessment denominator, but quantitatively assessing these types of articles remained challenging.

This review's broad timeframe and the sensitivity of standards and guidelines, especially with respect to ICT, were limiting. Articles included from earlier in the review timeframe (i.e. closer to 1993) referred to technologies of that time period but are now outdated. Often the principles, functions, and components of the article had stood the test of time, but specific technologies or hardware had not.

In addition, major emergency events significantly altered public health emergency response, as well as many of the corresponding standards and best practices. The corresponding updating of standards, guidelines, and procedures did not always result in updated websites, especially at regional or local levels.

Finally, assumptions were made about best practices and guidelines. While some documents clearly stated requirements (e.g. funding prerequisites or independent organizational standards), others only laid out recommendations clearly intended as best practices and guidelines. Still others offered lessons learned and conclusions that aligned with those of others to become de facto best practices. By convention, a preference was maintained for documented standards, but de facto best practices seen repeatedly in the research, especially with regard to informal communication and coordination, were also included as lessons learned from emergency situations.

6. Conclusion

Public health EOCs are physical or virtual centres responsible for the strategic management of public health emergencies (1). EOCs provide support to on-scene response and relief activities. Although the format, structure, and size of individual EOCs vary widely, their role in public health emergency management and response is universally fundamental.

6.1 Current status, gaps, and impediments in building, maintaining, and using EOCs

Given the fast-changing political, environmental and social climate of today's world, EOCs must be adaptable and resilient in order to continue to provide effective emergency response. Listed below are descriptions of how EOCs currently function and the barriers to an improved response.

6.1.1 EOC functions

The requirement for communication and coordination was a central theme in the literature for effective EOC function across all variations in types of systems and software, EOC structures, hazards and risks, planning processes, activation criteria, risk communication strategies, and data collection approaches. The literature showed that the biggest barriers to EOC function were lack of sufficient communication and coordination. Other impediments existed, and adequate planning was also an essential element, but communication and coordination within EOC sections, between EOCs, among agencies, and among jurisdictions consistently formed the basis for EOC success.

6.1.2 Standards

Standards provide consistent guidelines or requirements for the building, maintenance, and use of EOCs. Standards produced help establish global criteria for emergency response facilities and equipment, business continuity programmes, data exchange, communication systems, incident management systems, risk management, assessment exercises, and responses to specific types of emergencies.

6.1.3 Human resource needs

The number of staff needed for a response varies by jurisdiction and according to elements of the emergency. Dedicated staff are necessary across EOC functions, in roles including leadership and management; operations; information management; logistics; media; safety and security; administration; technology support; and liaison positions. All staff should have clearly delineated roles and responsibilities.

Surge staff are also needed for all EOC functions, and should be identified and trained in advance of a public health emergency. A major challenge posed by the use of surge staff is the fact that some public health professionals do not view themselves as emergency response personnel and are not prepared to be called upon to respond at any time.

6.1.4 Decision-making, modelling, and implementation

With limited time and resources, rapid but accurate decision-making is extremely difficult. Proper preparedness and planning can be an important decision-making tool, but sufficient and accurate information is also required. In situations without adequate information, it was difficult to take action and prioritize scarce resources. Decision support systems and modelling can aid EOC leaders and decision makers in decision-making, and they can also take advantage of other tools and frameworks developed to assist situational analysis and aid decision-making.

EOCs with standardised roles, a defined structure, and well-trained staff provide a formal process for taking action and create an environment in which necessary actions can be carried out.

6.1.5 Communication technology and infrastructure

The structure of an EOC should be well defined, standardised, scalable and flexible, and interconnected with other levels and agencies. EOC personnel should be familiar with clear "trigger points" for decision-making, information sharing, or involving other jurisdictions. Many EOCs use an Incident Command System as an organizational structure. If an ICS is used, staff training is recommended in order to overcome documented challenges with ICS terminology and structure.

The physical locations of EOCs vary, ranging from dedicated space to converted multi-purpose spaces to modular EOCs. Regardless of location, EOCs should have certain standard components including communication systems; backup electrical and heating/air conditioning systems; meeting rooms; a briefing space; and a staging area for air and land transportation.

There is a wide range of ICT, software and hardware components, and systems that support EOC functions. These systems allow EOCs to collect, analyse, interpret, visualize, and disseminate information accurately and quickly. The ICT used in EOCs must be interoperable, reliable, modifiable, and have backups in place. In order to be interoperable, ICT must use common vocabulary and terminology, and staff must be trained and familiar with the systems. Lack of interoperability is a major challenge for the technology used in EOCs. Backup systems and redundancy and security requirements are critical for ensuring that EOCs remain functional even if initial systems have glitches or fail completely.

6.1.6 Procedures and plans

Emergency operations plans should be stated plainly. Well-written plans can result in timely and effective implementation of response activities. Having a plan does not, however, guarantee that an agency has achieved preparedness. Plans frequently use an all-hazards approach; but despite the popularity of the all-hazards approach, some literature cautions that plans should correspond to a jurisdiction's particular risks.

Plans must, by definition, be developed in advance, and it is widely recommended that development be both evidenced-based and a coordinated effort involving multiple stakeholders and parties. An emergency operations plan should have several standard components: the basic plan; functional annexes; hazard-specific appendices; and standard operating procedures and checklists. Plans should also include several other miscellaneous components: a map of the EOC layout; contact lists of EOC personnel; standard forms for documenting EOC activities; training

and exercise schedules and plans; and a section on de-activation and de-escalation procedures. All plans should also incorporate formal protocols for interacting with other agencies, jurisdictions, and sectors.

6.1.7 Operational information minimum data sets and standards

Standards for data sources and common data sets are critical for successful EOC function and interoperability. Data are collected from varied sources using a variety of tools. The surveillance systems collecting this information for EOCs are active before, during, and after an emergency and are responsible for capturing data about population demographics, disease incidence and health status. During an emergency, data about healthcare system capacity, risk of disease spread, or post-disaster health status become important to collect.

Information can be gathered from many sources, including but not limited to EOC staff, other agencies, community members, and situation reports about the emergency or event. Strengthening processes and systems before EOC activation can facilitate data collection and use during the event. Data collection during response can be accomplished through direct observation, deployment of rapid assessment teams, use of health system data, population based surveys, and ongoing surveillance systems. In the absence of resources or infrastructure data can be collected in a non-technical but rapid manner if they are collected consistently and thoroughly.

6.1.8 Training and exercises

Training is a major element of many emergency response plans and standards. One criticism of emergency response and EOC training is the lack of standardisation (in both competencies and curricula) and the lack of emphasis on evaluation or assessment.

Individual and organizational training should be designed from an evidence base and include thorough assessment and evaluation to ensure that training meets its objectives and that individuals and organizations are prepared for emergency response.

Individuals should be trained in overall emergency response as well as in specific functions and roles. There are some agreed-upon best practices for training in skills that should be possessed by all EOC staff: recognizing threats and abnormal conditions; accessing and using communication systems; emergency operations planning; implementing specific resources, tools, and procedures; rapid assessment and surveillance; and basic familiarity with an incident management system or similar structures.

There are several types of agency trainings: orientations and seminars; drills; tabletop exercises; hypotheticals/scenarios; workshops; functional exercises; and full-scale exercises. Training should include a combination of didactic and experiential learning techniques to in order to involve individuals fully in the skills being taught. These exercises help individuals become more competent with systems; help agencies become better at using those systems as part of emergency response; and can expose the need for modification or improvements to the systems themselves.

6.2 Global best practices for EOCs for effective public health emergency response

This report listed current standards and guidelines in EOCs; summarized best practices and challenges in building, maintaining, and using EOCs; and identified existing performance indicators. These best practices are summarized in the following findings.

- Use an Incident Command System (ICS) or similar structure to organize EOC operations and decision-making.
- Delineate clear responsibilities and expectations for EOC staff and surge staff in all functions.
- Use knowledge management software and information communication technology as appropriate for sufficient communication. Follow international messaging, privacy, and security standards.
- Undertake a comprehensive planning process and create thorough plans, procedures, annexes, and other materials to facilitate EOC function during periods of activation.
- Incorporate lessons learned from previous EOC responses in order to improve performance, while also working to meet and exceed existing governmental performance measures.
- Implement data collection, analysis, and interpretation processes and systems to ensure EOCs have the information needed for decision-making and response.
- Conduct regular and objective-based trainings and exercises at both the individual and organizational levels to build skills, relationships, and the ability to respond effectively.

6.3 The connection between EOCs and risk communication

Risk communication is integrated throughout an EOCs' functions and activities. Accurate and timely information sharing that is evidence-based and coordinated is critical. Key points:

- Build on existing relationships and collaborations with the media, other agencies, and stakeholders.
- Include risk communication and risk communication specialists in all aspects of emergency operations plans and EOC operations.

6.4 Indicators to monitor EOC performance

Several performance indicators can be used to measure success in EOC function, although clear agreement on indicators is not seen in the literature. The IHR lists indicators of its core response capacities, and some governmental agencies have developed competencies and indicators for measuring performance. The findings suggest adapting existing performance measures to individual EOC and agency use to self-assess performance and progress towards agency goals.

6.5 Standardised EOC terminology

This review found that EOCs have a variety of unstandardised names. Use of consistent language within an agency or jurisdiction can avoid confusing terms. Thus glossaries and lists of terminology should be included in emergency operations plans and trainings.

6.6 Research needs for building, maintaining, and using EOCs

From the gaps in the literature, several areas were identified for future research. Gaps in evidence were identified and require future research.

The field of risk communication is very broad and outside of the scope of this review. While some best practices were included, it is important to explore others more fully.

Legal and ethical issues and concerns were continually indicated as important areas for consideration by jurisdictions when planning for and implementing emergency response. Examples of topics mentioned in various articles throughout the review included individual privacy concerns; jurisdictional coordination and the legal complexities thereof; and legislative solutions that facilitated effective emergency response.

Public health EOCs interact with public health and syndromic surveillance systems and with the healthcare sector at various points. These interactions are tangential to the specific objectives of this review, so they were not included in the scope of the review. They should, however, be noted as important components of overall public health emergency response.

There are several review questions addressed in this report that are not fully answered by the literature. Solutions for surge capacity, the challenges of using information management software, EOC training programmes, and integrating risk communication into exercises are all considerations raised by this review but which are not fully addressed by the literature found in the systematic review process.

As summarized in Section 6.2, several international standards need to be developed, including those which will outline: structures for organizing EOC operations and decision-making; clearly delineated roles and responsibilities for staff and surge staff; suitable knowledge management software and ICT in line with messaging, privacy, and security standards; data collection, analysis, and interpretation processes and systems; and consistent schedules and content for training and exercises.

Finally, while the review covered many countries, jurisdictions, and types of populations, there are some that are underrepresented. The authors suspect that these areas, geographical or topical, do not have a presence in the peer-reviewed literature or prominent grey literature. Although they may be difficult to find, future research should make a specific point to seek out best practices in these areas.

As this review has shown, there are many tangible elements that go into making up an EOC, including procedures and plans; information and communication technology; and various types of systems, equipment and supplies. Underlying the many physical components of EOCs are EOC leaders and staff, and their interaction, communication, and collaboration in order to improve public health.

Continuing to develop guidelines and standards in order to bring more uniformity and consistency to EOC functions and components can improve emergency response efforts.

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8. Appendices

8.1 List of review questions

Review questions were grouped into five categories:

1. General questions
2. EOC communication technology and infrastructure
3. Procedures and plans
4. Operational information minimum data sets and standards
5. Training and exercises.

General questions:

1. How are public health EOCs used? What are the core functions of public health EOCs?
2. What are the risks and hazards that public health EOCs deal with?
3. What models, best practices, and case studies exist on how risk communication is carried out in countries?
4. How is risk communication integrated into EOC function?
5. What are the key business processes (i.e. the common workflow of decision-making and implementation) in EOCs?
6. What are the human resource needs for a functional EOC (telecommunications, operations manager, information management, situation analysis, logistics, operations, etc.)?
7. What are solutions to surge capacity for an EOC during an emergency response/crisis?
8. What are the major challenges in building, maintaining, and using an EOC for public health emergency response?
9. What indicators can be used or collected to describe and monitor a functional public health EOC?
10. What regional, national, and international standards, good examples, or models exist related to EOCs, including the four technical areas?
11. What are the core components of the above standards?

Communication technology and infrastructure:

1. What equipment, technology, and infrastructure (hardware and software) are used in the EOC that deal with public health emergencies?
2. What are the types of information management software used in the EOC?
3. What are the challenges and gaps of using information management software in a public health EOC?
4. What are the core components of equipment, technology, and infrastructure (hardware and software) of a public health EOC?

5. What are the tools for a virtual EOC in the circumstance when a physical EOC is collapsed?
6. What are the ICT problems associated with using an EOC for public health response?

Procedures and plans:

1. Are there plans and procedures in place for risk communications?
2. What international standards on public health emergency management procedures and plans exist?
3. What are the common components in a public health emergency response plan?
4. What are the barriers to complying with plans and procedures in public health emergency response or emergency management?
5. What operating procedures and plans are used in a public health EOC?
6. What criteria are used to determine EOC activating levels (i.e., partial or full activation)?
7. What are the key common components in an EOC operating procedure/plan?
8. What are the barriers to complying with plans and procedures in an EOC?

Operational information minimum data sets and standards:

1. What are the information needs and challenges to the effective functioning of a public health EOC?
2. What types of information are included in EOC operational information for public health emergency response in an "all hazards" approach (e.g., outbreaks or pandemics, bioweapon or bioterrorism events, crises or disasters, chemical or nuclear events, or mass gathering)?
3. What are the sources of operational information in a public health EOC?
4. What is the role of an EOC in monitoring health emergency information?
5. How is operational information used?
6. What are the typical problems regarding collecting and using EOC operational information?
7. What are the typical problems regarding data redundancies and duplication?
8. How is risk communication messaging developed and disseminated from the EOC?
9. What are the key components of risk communication information in a public health EOC?
10. Is media and social media monitoring carried out systematically to gauge public concerns and fears, as part of the communications response?

Training and exercise:

1. What are the roles of an EOC in a public health response exercise?
2. How is the EOC used for training staff for effective public health emergency response?
3. What are the challenges of using an EOC for training and exercises?
4. What EOC training programmes exist? What are the specific EOC's training programmes?

5. What are the core components for an effective EOC training programme?
6. Is risk communications integrated into the health response exercises?

8.2 Search strategy for each database searched

See Tables S1-S5.

Table S1. PubMed search strategy

Category	Search	Terms
Overall search terms	**1**	(((«Public Health Practice»[Mesh]) AND «Emergencies»[Mesh]) AND «Disaster Planning»[Mesh])
	2	Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety) AND («Emergency Operations Center» OR «Emergency Operations Centre» OR «Command and control operations center» OR «Command and control operations centre» OR «strategic health operations center» OR «strategic health operations centre» OR «Command center» OR «command centre» OR «Communication center» OR «Communication centre» OR «Disaster management center» OR «Disaster management centre» OR «situation room» OR «crisis management center» OR «crisis management centre»)
	3	Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety) + Keywords found below in 20-79
	4	(((«Public Health Practice/organization and administration»[Mesh])) AND ((((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh])))) OR ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh]))))) OR («Civil Defense/organization and administration»[Mesh]))
	5	(((Public health practice OR civil defense))) AND ((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh])))) AND ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh]))))
	6	((«Public Health Practice»[MESH]) AND «Disasters»[Mesh]) AND («Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh] OR «Civil Defense/organization and administration»[Mesh])
General	**7**	«Emergency Operations Centre»
	8	«Emergency Operations Center» AND Disaster Planning[MeSH]
	9	«Command and control operations center»
	10	«Command and control operations centre»
	11	«Strategic health operations center»
	12	«Strategic health operations centre»
	13	«Command center»
	14	«Command centre»
	15	«Communication center»
	16	«Communication centre»
	17	«Disaster management center»
	18	«Disaster management centre»
	19	«Situation room»
	20	«Emergency room» AND Disaster Planning[MeSH]
	21	«Emergency center» AND Disaster Planning[MeSH]
	22	«Emergency center» AND Public Health[MeSH]
	23	«Emergency center» AND Public Health[MeSH] AND Disaster Planning[MeSH]
	24	«Emergency centre» AND Disaster Planning[MeSH]
	25	«Emergency centre» AND Public Health[MeSH]
	26	«Crisis management center» AND Public Health[MeSH] AND Disaster Planning[MeSH]
	27	«Crisis management centre» AND Public Health[MeSH] AND Disaster Planning[MeSH]
	28	1-6 AND (Risk Management[MeSH] OR Risk Factors[MeSH])
	29	1-6 AND Risk Communication
	30	1-6 AND Safety Management[MeSH]
	31	1-6 AND (Practice Guidelines as Topic[MeSH] OR Benchmarking[MeSH])
	32	1-6 AND Organizational Case Studies[MeSH]
	33	1-6 AND (Health Communication[MeSH] OR Emergency Medical Service Communication Systems[MeSH] OR Communication[MeSH])
	34	1-6 AND (Decision Making[MeSH] OR Decision Making, Organizational[MeSH])
	35	1-6 AND (Health Plan Implementation[MeSH] OR Regional Health Planning[MeSH])
	36	1-6 AND Organization and Administration[MeSH]
	37	1-6 AND Telecommunications[MeSH]
	38	1-6 AND Operations Research[MeSH]
	39	1-6 AND ((Surge Capacity[MeSH] OR Capacity Building[MeSH]) OR Surge Capacity)
	40	1-6 AND Epidemiological Monitoring[MeSH]
	41	1-6 AND (Guidelines as Topic[MeSH] OR Guideline Adherence[MeSH])
	42	1-6 AND (Policy[MeSH] OR Organizational Policy[MeSH] OR Public Policy[MeSH] OR Policy Making[MeSH])
	43	1-6 AND Needs Assessment[MeSH]
	44	1-6 AND Health Resources[MeSH]

Category	Search	Terms
Information communication technology	**45**	1-6 AND Information Systems[MeSH]
	46	1-6 AND (Information Management[MeSH] OR Health Information Management[MeSH] OR Intergrated Advanced Information Management Systems[MeSH])
	47	1-6 AND (Text Messaging[MeSH] OR Internet[MeSH])
	48	1-6 AND Telecommunications[MeSH]
	49	1-6 AND Software[MeSH]
	50	1-6 AND (Computers[MeSH] OR Technology[MeSH])
	51	1-6 AND (Health Communication[MeSH] OR Emergency Medical Service Communication Systems[MeSH] OR Communication[MeSH])
	52	1-6 AND Computer Communication Networks[MeSH]
	53	1-6 AND Information Science[MeSH]
	54	1-6 AND Organization and Administration[MeSH]
	55	1-6 AND User-Computer Interface[MeSH]
	56	1-6 AND Database Management Systems[MeSH]
	57	1-6 AND (Construction* OR Infrastructure*)
Procedures and plans	**58**	31, 32, 35, 36, 38, 41, 42
	59	1-6 AND Standards*
	60	1-6 AND (Terminology* OR Lexicon*)
	61	1-6 AND Methods*
Operational information minimum data sets and standards	**62**	45, 46, 51, 54
	63	1-6 AND Operations Research[MeSH]
	64	1-6 AND (Decision Making[MeSH] OR Decision Making, Organizational[MeSH])
	65	1-6 AND Epidemiological Monitoring[MeSH]
	66	1-6 AND Computer Security[MeSH]
	67	1-6 AND Interoperability*
	68	1-6 AND (Minimum Data Sets* OR Data Elements*)
	69	1-6 AND (Information Content Standards* OR Standardization*)
	70	1-6 AND (Operating Procedures* OR Operations* OR Logistics*)
Training and exercise	**71**	1-6 AND Education[MeSH]
	72	1-6 AND Staff Development[MeSH]
	73	1-6 AND Education, Public Health Professional[MeSH]
	74	1-6 AND Professional Role[MeSH]
	75	1-6 AND Inservice Training[MeSH]
	76	1-6 AND Capacity Building[MeSH]
	77	1-6 AND Training*
	78	1-6 AND Human Resources*
	79	1-6 AND Exercises*

Category	Search	Terms
Parallel search strategy	**80**	(Centres[TIAB] OR Centers[TIAB] OR offices[TIAB] AND Centre[TIAB] OR Center[TIAB] OR office[TIAB] OR EOC[TIAB] OR room[TIAB] OR rooms[TIAB] OR facility[TIAB] OR facilities[TIAB]) AND («Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh] OR «Disaster Planning/standards»[Mesh] OR «disaster planning»[TIAB] OR «disasters»[TIAB] OR «disease outbreak»[TIAB] OR «disease outbreaks»[TIAB] OR «Disease Outbreaks/legislation and jurisprudence»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh] OR pandemics[TIAB] OR epidemics[TIAB]) Filters: Abstract available; Publication date from 1993/01/01 to 2013/12/31; English NOT ((((((((«Public Health Practice»[Mesh]) AND «Emergencies»[Mesh]) AND «Disaster Planning»[Mesh])) OR (Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety) AND («Emergency Operations Center» OR «Emergency Operations Centre» OR «Command and control operations center» OR «Command and control operations centre» OR «strategic health operations center» OR «strategic health operations centre» OR «Command center» OR «command centre» OR «Communication center» OR «Communication centre» OR «Disaster management center» OR «Disaster management centre» OR «situation room» OR «crisis management center» OR «crisis management centre»))) OR ((((«Public Health Practice/organization and administration»[Mesh]))) AND ((((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh]))) OR ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh]))))) OR («Civil Defense/organization and administration»[Mesh])))) OR (Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety))) OR ((((public health practice OR civil defense))) AND ((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh]))) AND ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh])))))) OR (((«Public Health Practice»[MESH]) AND «Disasters»[Mesh]) AND («Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh] OR «Civil Defense/organization and administration»[Mesh]))
	81	«Crises Room»[TIAB] OR «crises rooms»[TIAB] OR «emergency operations centre»[TIAB] OR «emergency operation center»[TIAB] OR «situation room»[TIAB] OR «emergency operation centre»[TIAB] OR «emergency operations center»[TIAB] OR «National Emergency Operations Centre»[TIAB] OR «Nationale Alarmzentrale»[TIAB] OR «Centrale nazionale dall arme»[TIAB] OR «Centrale nationale d alarme»[TIAB] OR «National Disaster Management Center»[TIAB] OR Nationale Alarmzentrale AND «[TT] OR « AND Centrale nazionale dall arme AND «[TT] OR « AND Centrale nationale d alarme AND «[TT] OR « AND Emergency Operations Center AND «[TIAB] OR « AND Emergency Operations Centre AND «[TIAB] OR « AND «control operations center»[TIAB] OR «control operations centre»[TIAB] OR «strategic health operations center»[TIAB] OR «strategic health operations centre»[TIAB] OR «Command center»[TIAB] OR «command centre»[TIAB] OR «Communication center»[TIAB] OR «Communication centre»[TIAB] OR «Disaster management center»[TIAB] OR «Disaster management centre»[TIAB] OR «situation room»[TIAB] OR «crisis management center»[TIAB] OR «crisis management centre»[TIAB] Filters: Abstract available; Publication date from 1993/01/01 to 2013/12/31; English NOT ((((((((«Public Health Practice»[Mesh]) AND «Emergencies»[Mesh]) AND «Disaster Planning»[Mesh])) OR (Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety) AND («Emergency Operations Center» OR «Emergency Operations Centre» OR «Command and control operations center» OR «Command and control operations centre» OR «strategic health operations center» OR «strategic health operations centre» OR «Command center» OR «command centre» OR «Communication center» OR «Communication centre» OR «Disaster management center» OR «Disaster management centre» OR «situation room» OR «crisis management center» OR «crisis management centre»))) OR ((((«Public Health Practice/organization and administration»[Mesh]))) AND ((((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh]))) OR ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh])))))) OR («Civil Defense/organization and administration»[Mesh])))) OR (Public Health AND (Disasters OR Risk OR Civil Defense OR Disease Outbreaks OR Bioterrorism OR Chemical Safety OR Toxicology OR Radioactive Hazard Release OR Food Safety))) OR ((((public health practice OR civil defense))) AND ((((«Disaster Planning/methods»[Mesh] OR «Disaster Planning/organization and administration»[Mesh]))) AND ((«Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh])))))) OR (((«Public Health Practice»[MESH]) AND «Disasters»[Mesh]) AND («Emergency Medical Services/organization and administration»[Mesh] OR «Disease Outbreaks/organization and administration»[Mesh] OR «Civil Defense/organization and administration»[Mesh]))

denotes a keyword

Table S2. EMBASE search strategy

Search	Terms
1a	Public health'/exp AND 'emergency'/exp AND 'disaster planning'/exp
1b	Public health'/exp AND ('emergency'/exp OR 'disaster'/exp)
2	Public health service'/exp AND ('disaster'/exp OR 'risk'/exp OR 'civil defense'/exp OR 'biological warfare'/exp OR 'hazard'/exp)
3	Public health'/exp AND ('disaster'/exp OR 'risk'/exp OR 'civil defense'/exp OR 'epidemic'/exp OR 'biological warfare'/exp OR 'chemical safety'/exp OR 'toxicology'/exp OR 'nuclear accident'/exp OR 'food safety'/exp)
4	Public health practice'/exp AND ('disaster planning'/exp OR 'emergency'/exp OR 'disease outbreaks'/exp OR 'civil defense') NOT 'emergency department' NOT 'hospital'
5	Public health service'/exp OR 'civil defense'/exp AND ('disaster planning'/exp OR 'emergency health service'/exp)
6	('Public health service'/exp AND 'disaster'/exp) AND ('emergency health service'/exp OR 'epidemic'/exp OR 'civil defense'/exp)
7	«Emergency Operations Centre»
8	«Emergency operations center»
9	«Emergency Operations Center» AND «Disaster Planning»
10	Command and control operations center
11	Command and control operations centre
12	Strategic health operations center NOT surgery
13	Strategic health operations centre NOT surgery
14	«Command center»
15	«Command centre»
16	«Communication center»
17	«Communication centre»
18	«Disaster management center»
19	«Disaster management centre»
20	«Situation room»
21	«Emergency room» AND Disaster Planning
22	«Emergency center» AND Disaster Planning
23	Emergency center AND Public Health NOT hospital
24	«Emergency center» AND Public Health AND Disaster Planning
25	«Emergency centre» AND Disaster Planning
26	«Emergency centre» AND Public Health NOT hospital
27	«Crisis management center» AND Public Health AND Disaster Planning
28	«Crisis management centre» AND Public Health AND Disaster Planning
29	Public health'/exp AND 'emergency'/exp AND 'risk management'/exp
30	Risk communication' AND 'public health'/exp
31	Safety'/exp AND 'public health'/exp AND 'emergency'/exp
32	Quality control'/exp OR 'practice guideline'/exp AND 'public health'/exp AND ('emergency'/exp OR 'disaster'/exp)
33	Public health service'/exp AND 'disaster planning'/exp
34	Public health service'/exp AND 'emergency health service'/exp NOT 'emergency department'

Search	Terms
36	('System analysis'/exp OR 'epidemiological monitoring'/exp OR 'computer security'/exp) AND ('public health'/exp AND ('disaster'/exp OR 'risk'/exp OR 'civil defense'/exp OR 'epidemic'/exp OR 'biological warfare'/exp OR 'chemical safety'/exp OR 'toxicology'/exp OR 'nuclear accident'/exp OR 'food safety'/exp))
37	System analysis'/exp OR 'epidemiological monitoring'/exp OR 'computer security'/exp AND 'public health'/exp
38	1a AND «Information System»
39	1b AND «Information System»
40	2 AND «Information System»
41	3 AND «Information System»
42	4 AND «Information System»
43	5 AND «Information System»
44	6 AND «Information System»
45	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('computer' OR 'computer interface' OR 'computer program')
46	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('technology' OR 'communication software')
47	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('database' OR 'medical information system' OR 'medical information')
48	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('communication protocol' OR 'emergency health service facilitated communication' OR 'mass communication')
49	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('education' OR 'medical education' OR 'vocational education' OR 'education program' OR 'emergency medical services education')
50	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('staff training' OR 'In service training' OR 'capacity building')
51	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND ('personnel management' OR 'professional standard')
52	(1a OR 1b OR 2 OR 4 OR 5 OR 6) AND («human resources»)

Table S3. Web of Science search strategy

Search	Terms
1	«Public health» AND emergency AND «disaster planning»
2	Public health'/exp AND ('emergency'/exp OR 'disaster'/exp)
3	Public health AND preparedness
4	Public health service'/exp AND ('disaster'/exp OR 'risk'/exp OR 'civil defense'/exp OR 'biological warfare'/exp OR 'hazard'/exp)
5	Public health'/exp AND ('disaster'/exp OR 'risk'/exp OR 'civil defense'/exp OR 'epidemic'/exp OR 'biological warfare'/exp OR 'chemical safety'/exp OR 'toxicology'/exp OR 'nuclear accident'/exp OR 'food safety'/exp)
6	Public health practice'/exp AND ('disaster planning'/exp OR 'emergency'/exp OR 'disease outbreaks'/exp OR 'civil defense') NOT 'emergency department' NOT 'hospital'
7	Public health service'/exp OR 'civil defense'/exp AND ('disaster planning'/exp OR 'emergency health service'/exp)
8	('Public health service'/exp AND 'disaster'/exp) AND ('emergency health service'/exp OR 'epidemic'/exp OR 'civil defense'/exp)
9	«Emergency Operations Centre»
10	«Emergency operations center»
11	«Emergency Operations Center» AND Disaster Planning
12	Command and control operations center
13	Command and control operations centre
14	Strategic health operations center
15	Strategic health operations centre
16	Command center AND public health
17	«Command centre»
18	(Communication center AND public health) AND (emergency or disaster)
19	«Communication centre»
20	«Disaster management center»
21	«Disaster management centre»
22	«Situation room»
23	«Emergency room» AND Disaster Planning
24	«Emergency center» AND Disaster Planning
25	Emergency center AND Public Health
26	«Emergency center» AND Public Health AND Disaster Planning
27	«Emergency centre» AND Disaster Planning
28	«Emergency centre» AND Public Health NOT hospital
29	«Crisis management center» AND Public Health AND Disaster Planning
30	Crisis management center
31	«Crisis management centre» AND Public Health AND Disaster Planning
32	«Public health» AND emergency AND «risk management»
33	Risk communication AND public health
34	Risk communication AND public health AND emergency
35	Public health AND preparedness AND guideline
36	Public health AND preparedness AND standard
37	«Public health emergency» AND «training»
38	«Public health disaster» AND «training»
39	«Public health emergency» AND «technology»
40	«Public health disaster» AND «technology»
41	«Public health emergency» AND «communication»
42	«Public health disaster» AND «communication»

Table S4. IEEEXplore search strategy

Search	Terms
1	Incident command center
2	Public health disaster
3	Public health emergency
4	Public health emergency communication
5	Public health emergency data
6	Public health emergency equipment
7	Public health emergency functions
8	Public health emergency information management
9	Public health emergency infrastructure
10	Public health emergency international
11	Public health emergency management
12	Public health emergency management plan
13	Public health emergency model
14	Public health emergency operation
15	Public health emergency operation center
16	Public health emergency plan
17	Public health emergency protocol
18	Public health emergency response
19	Public health emergency risk communication
20	Public health emergency software
21	Public health emergency staff
22	Public health emergency standards
23	Public health emergency surge capacity
24	Public health emergency technology
25	Public health emergency telecommunication
26	Public health emergency training
27	Public health preparedness
28	Public health response
29	Public health response challenge
30	Virtual emergency operation center

Table S5. ACM search strategy

Search	Terms
1	Public health emergency
2	Public health response
3	Public health preparedness
4	Emergency operation center
5	Emergency preparedness
6	Public health preparedness AND emergency response
7	Public health emergency AND response

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