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Public health delivery in the information age: the role of informatics and technology

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Abstract

Aim: Public health systems have embraced health informatics and information technology as a potential transformational tool to improve real-time surveillance systems, communication, and sharing of information among various agencies. Global pandemic outbreaks like Zika and Ebola were quickly controlled due to electronic surveillance systems enabling efficient information access and exchange. However, there is the need for a more robust technology to enhance adequate epidemic forecasting, data sharing, and effective communication. The purpose of this review was to examine the use of informatics and information technology tools and its impact on public health delivery.

Method: Investigators searched six electronic databases. These were MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL) Complete, Cochrane Database of Systematic Reviews, COMPENDEX, Scopus, and Academic Search Premier from January 2000 to 31 March 2016.

Results: A total of 60 articles met the eligibility criteria for inclusion. These studies were organized into three areas as (1) definition of the term public health informatics; (2) type of public health surveillance systems and implications for public health; and (3) electronic surveillance systems functionality, capability, training, and challenges. Our analysis revealed that due to the growing expectations to provide real-time response and population-centered evidence-based public health in this information-driven age there has been a surge in informatics and information technology adoption. Education and training programs are now available to equip public health

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CONFLICT OF INTEREST

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ETHICAL APPROVAL

This study is a systematic review that involves no human or animal subjects. Therefore, no ethical approval was pursued.

students and professionals with skills in public health informatics. However, obstacles including interoperability, data standardization, privacy, and technology transfer persist.

Conclusion: Re-engineering the delivery of public health is necessary to meet the demands of the 21st century and beyond. To meet this expectation, public health must invest in workforce development and capacity through education and training in informatics.

Keywords

public health; public health informatics; informatics; information technology; management information system

INTRODUCTION

The discipline of public health is tasked with the responsibility to protect and improve the health of communities through the provision of effective and efficient education, healthy lifestyles as well as disease and injury prevention. Based on this foundation, the field has seen many achievements over the years. These include the rise in life expectancy and reduction in maternal and infant mortality and chronic diseases like cancer, cardiovascular, and workplace-associated injuries. However, to effectively address public health challenges in today's global economy, practitioners and researchers need reliable and timely information which facilitates evidence-based decision-making. In addition, better communication and improved information management resources/tools to track and analyze epidemics or threats to accelerate response for early warning systems are also required.¹ This is necessary because the advancements in globalization have not only led to the faster movement of goods and services but also has created opportunities for the spread of diseases and other public health threats. Adequate preparation for these threats and events is paramount to avoid panic and safeguard the protection of the whole population. One way to ensure this is through the application of informatics and technology in public health delivery.

Application of informatics and information technology in public health

Over the last two decades, public health and medical care systems have embraced information technology (IT) as a powerful revolutionary tool for engagement, change enhancement, improvement, and health promotion. Public health agencies use various information systems to improve real-time surveillance systems, prompt effective communication of warning systems, data collection, and sharing of information.^{2,3} According to the disease control priorities project (DCP2) report, global pandemic outbreaks such as severe acute respiratory syndrome (SARS), and the influenza A (H1N1) were contained through the application of rapid surveillance and response network systems.^{2,4} Despite these successes, there is a need for more advanced technology that focuses on effective collaboration among public health agencies and with other partners to promote adequate epidemic forecasting and communication.⁵

One of the goals of healthy people 2020 is to improve public health and strengthen the US national security through global disease detection, response, prevention, and control strategies.³ Global health is important, since the health of the US population is affected by public health threats and events that happen across the world. Examples include the Zika and

Ebola viruses outbreak that began in 2014, the 2009 H1N1 influenza, and the 2003 SARS epidemic.³ These outbreaks have shown that there are no borders for deadly pathogens. Moreover, the explosion in the number of emerging and re-emerging infectious and communicable diseases calls for investment and development of informatics infrastructure to facilitate swift identification, monitoring, management, and containment of global epidemic. As accurately argued by Duchin,⁶ Zika and Ebola have exposed the weaknesses in our public health system not only in terms of insufficient investment for preparedness, response to disease outbreaks, and other health threats but also the public health systems' readiness and response capacity.⁶

In support of this argument, the World Business Council for Sustainable Development (WBCSD) noted that 'nearly everyone agrees that the way we manage health today is unsustainable'.⁷ It costs more than we can afford and delivers less than we expect.⁷ If the current public health system is to flourish in the coming age of uncertain resources and increased demand, then it requires redesign and implementation of new systems that are both not sustainable and reliable in real-time.^{8,9} To be prepared and respond to outbreaks like Zika, Ebola, H1N1, SARS, and similar re-emerging diseases and disasters, we need to invest in the existing public health system and strengthen its information system infrastructure.

Furthermore, Bell et al.¹⁰ noted that the response to the Ebola outbreak was problematic due to poor health infrastructure, lack of geographic and cultural familiarity with the disease, and distrust in government and healthcare workers. The major lessons these outbreaks are the need of effective systems to detect and stop infectious disease threats, stronger international surge capacity partnership, improving infection prevention and control in healthcare settings, IT systems, rigorous training of healthcare workers and scientists, as well as development of faster reliable laboratory tests and genetic analysis methods.^{10–12} In addition, there is the need for a well-prepared global response systems and action strategies that should include short-, medium-, and long-term plans on how to address threats and contain future epidemic outbreaks.

Similarly, it is necessary to establish and maintain a solid foundation that consists of core functions for a strong public health emergency response before a crisis occurs.⁶ Contingency plans should include robust surveillance and strong collaborative systems that enable easy communication with public health agencies and experts.⁶ In addition, the use of incident management framework is paramount for health emergency response. As a result, public health agencies and the medical care system must proactively engage governmental and non-governmental stakeholders to maintain robust health information systems and disaster management plans along with surge capacity. Nonetheless, this can only be achieved through the implementation and availability of an operational information system. Hence, the purpose of this systematic review was to evaluate the development and use of informatics (public health informatics (PHI)), and IT tools and its impact on public health delivery.

METHODS

Data sources

The authors searched six major scientific electronic databases. The search strategy focused on issues relating to public health and informatics or technology use over the last decade (2000–2016). Investigators identified studies in MEDLINE, Cumulative Index to Nursing and Allied Health Literature (CINAHL) Complete, Cochrane Database of Systematic Reviews, COMPENDEX, Scopus, and Academic Search Premier. The studies were retrieved using combinations of the following Medical Subject Headings (MeSH) terms only: *public health* AND *informatics* OR *public health informatics* AND *information technology* OR *management information systems*. We also systematically reviewed the reference lists of articles retrieved. The year of publication was limited to January 2000–31 March 2016. The earliest publication date of 2000 was selected because the term ‘Public Health Informatics’ was entered into the MeSH during that time.

Inclusion and exclusion criteria

Our inclusion criteria were studies on the use of informatics and technology and its impact on public health delivery between the years 2000 and 2016. We excluded studies that were not published in English and those that focused solely on medical or healthcare delivery or health technologies such as electronic medical/health records (EMRs/EHRs), computerized physician order entry (CPOE), clinical decision support system (CDSS), and healthcare automation systems.

Study selection and data extraction

The investigators examined the titles and abstracts of the identified citations and applied a screening algorithm based on the inclusion and exclusion criteria described above. Each paper was rated as ‘relevant’ or ‘not relevant’ by the investigators. Next, the authors collected the following information from each ‘relevant’ article: objective, type of information system, impact on public health delivery, and conclusions.

RESULTS

Since the publications of the two Institute of Medicine (IOM) reports *To Err is Human: Building a Safer Health System* and *Crossing the Quality Chasm: A New Health System for the 21st Century*, IT has been embraced as an integral resource for achieving quality care delivery and improvement (public health and medical care services). While healthcare IT is not only limited to electronic health records (EHRs), this systematic review revealed that most of the studies focused on this area and how the use of health informatics and IT is changing medical care or clinical decision-making. The initial comprehensive literature searches using the combination of keywords identified 47,523 studies. Based on the selection and exclusion criteria established, 60 studies remained eligible (see Figure 1).^{1,13–71} These studies were further divided into three categories: (1) definition of the term PHI;⁶⁹ (2) type of public health surveillance (PHS) systems and implications for public health (23 studies);^{13,14,19,21–23,25,27,29,32,34,41,44,45,47–49, 55,58,61,65,67,71} and (3) electronic

surveillance systems functionality, capability, training, and challenges (37 studies).
1,15–18,20,24,26–28,30,31,33,35–40,42,43,46,50–60,62–64,66,68–70 See Tables 1 and 2 for details.

Definition of the term PHI

The term PHI was defined in 1995 by Friede et al.,⁷² and also Yasnoff et al.⁶⁹ in 2000 as the systematic application of information and computer science and technology to public health practice, research, and learning.^{69,72} The term was formally entered into the MeSH in 2003. Since then, PHI has evolved as a specialized discipline within public health with a focus on the use of informatics and IT to engage communities and individuals in behavioral, socio-cultural, and environmental lifestyle changes to promote health and wellbeing.^{69,72} In addition, the growing expectations to provide population-centered public health delivery, have led to increasing adoption of informatics and IT systems to provide faster and more efficient services. This push has also created a need for public health to place a high priority on the development and applications of new technologies to facilitate evidence-based public health delivery along with effective and efficient management of health programs and project.⁷³

Type of PHS systems and implications for public health

Informatics and IT tools have the potential to influence almost every aspect of the public health sector. Telemedicine and rapid syndromic surveillance systems are used to improve access to health services, quality of care, overall quality, and wellbeing of the community.^{1,13–15,17–19,21–30,32–59,62–71,74} These benefits notwithstanding, public health, like the medical care sector, has lagged behind the banking and aviation industries, in the adoption of IT.⁷⁵ However, since the establishment of the Office of the National Coordinator for Health Information Technology, by the U.S. Department of Health & Human Services in April 2004, to promote health IT, the field of public health has undergone a lot of transformation.⁷⁵ For instance, over the last decade, numerous investments have been made in IT surveillance systems to support public health management.

Boom et al.¹³ examined the Houston – Harris county immunization information system (IIS) after Hurricane Katrina. They reported that the ability to link the registry to the Louisiana immunization network immediately after the disaster enabled a reduction in the duplication of immunization administered to children resulting in a cost saving of over US\$26.5 million. In addition, the IIS backup systems prevented the distraction of all medical charts and enabled providers in Houston, Texas, and Louisiana, to deliver efficient and effective care to children and their parents. Due to the success of the IIS, Michigan Care Improvement Registry added hazard module functionalities to capture medication and mass immunization during an epidemic.¹³ Using public health England emergency department syndromic surveillance system (EDSSS), Hughes et al.³² investigated the factors contributing to respiratory pathogens and emergency room attendance. Results revealed that the EDSSS provides real-time better early warning activity than laboratory surveillance. Findings also highlight the need to triangulate laboratory surveillance systems with the EDSSS to increase monitoring, planning, and response to acute emergency room services.³² Similarly, Derby et al.¹⁹ evaluated the Arizona Poison and Drug Information Center (APDIC) database to assess its ability to improve foodborne disease outbreaks (FBDOs). After analyzing 68,433

suspected foodborne calls, of which 2922 were suspected of human exposure from Pima County, they concluded that although the APDIC helped to avoid duplication of cases reported, the system is limited in its ability to provide real-time foodborne illness data¹⁹ (See Table 1).

The traditional PHS systems continue to play a tremendous role by enabling public health sector to detect and respond to outbreaks. Nonetheless, to meet the public health demands and needs in today's information age, new surveillance systems are necessary.⁷⁶ As a result, to strengthen health promotion and disease prevention, state and local public health departments are collaborating with health agencies, organizations, and institutions around the world to implement various forms of integrated automated/electronic surveillance systems to effectively track and detect diseases, disasters, and other bioterrorism attacks. For example, the U.S. Centers for Disease Control and Prevention (CDC) in conjunction with the Department of Homeland Security have developed the BioSense and other information systems to coordinate disaster response among federal, state, and local public health agencies.^{14,44,47,48} Since its implementation, these systems have helped detect, monitor, report, and evaluate many public health incidents (Table 1). These include respiratory problems associated with the southern California wildfires, gastrointestinal disease outbreak at a U.S. Department of Defense base, rash illness among elementary school students, as well as other communicable and waterborne outbreaks (Table 1).^{22,23,44,48,55,77} Table 3 provides further examples of syndromic surveillance systems currently in use around the world for public health threats.^{13,14,34,44,62,68,78–81}

Electronic surveillance systems functionality, capability, training, and challenges

Well-developed and functioning IT systems have the potential to help public health officials make timely decisions during any disaster. It is crucial that surveillance systems are designed to provide public health personnel with the needed skills to predict, detect, manage, communicate, and disseminate outbreak information among all agencies and decision-makers (Table 2). Buckeridge and colleagues^{16,17} evaluated the algorithms of the bio-event advanced indicator recognition technology (BioALIRT) and the simulation model of the anthrax epidemic injection in Norfolk, Virginia. The authors reported that both the BioALIRT and the anthrax systems accurately improve the timeliness of outbreak detection and progression of the disease, but it lacks the ability to successfully track movement across different locations (Table 2).^{16,17}

Similarly, Heisey-Grove et al.³⁰ examined the impact of PHI in enhancing the Massachusetts hepatitis C surveillance reporting system. According to the authors, more than 8000 new cases of hepatitis C are reported annually. Prior to the implementation of the new system, local health departments (LHDs) had to manually complete a four-page case-report form, which took at least 7 min to complete. However, the implementation of the Massachusetts virtual epidemiologic network (MAVEN) Web-based system resulted in timeliness of hepatitis C reporting.³⁰ Henao et al.³¹ analyzed CDC's 10 state health departments' FoodNet surveillance system and concluded that though the system has helped improve food safety in the US, it is also critical to ensure rapid access to clinical data and facilitate surveillance and epidemiologic research informatics capacity such as geographic information system linkage.

The electronic surveillance system early notification of community-based epidemics (ESSENCE) was developed to track higher-than-expected visits to the emergency room, and sale of pharmaceutical products.³³ Analysis of the system by Hurt-Mullen and Coberly³³ revealed that the longitudinal data collected enable epidemiologist to identify hotspots for community outbreaks. Nonetheless, continuous modification of the system is needed to distinguish between important public events requiring urgent attention and statistical anomalies (false alarms).³³

The next important issue is public health information system architectural design and capability.^{24,38,40,43,46,50,51,53,54,59,60,70} Mirhaji,⁴⁶ Ortega et al.,⁵⁰ Reeder et al.,⁵¹ and Yih et al.⁷⁰ examined the state of electronic PHS conceptualization, design, analysis, and implementation in the US and concluded that the evolution of the Internet has tremendously changed public health delivery. However, due to the complexity of PHS data collection, electronic surveillance systems should be designed to enable reusing data and sharing.

Another development is a surge in the number of public health schools and programs providing professional-level educational degrees from bachelor to Doctor of Philosophy (PhD) and Doctor of Public Health (DrPH). This has also led to changes in entry requirements, core competencies in learning, practice, and teaching for schools of public health and programs.⁶⁹ To meet the 21st century needs, demands, and characteristics of the population some scholars have argued public health programs must include courses in informatics.^{1,36,37,39,69} Yasnoff et al.,^{1,69} noted that ‘the need for new and improved information systems for public health is growing because of new challenges related to antibiotic-resistance, emerging infections, and chemical and biological terrorism’.⁶⁹ Consequently, the authors suggested that public health professionals should have deeper skills and knowledge in informatics to effectively make the appropriate decision concerning PHS systems development and management.^{1,69} Others argued that public health agencies should collaborate with educational and training institutions to coordinate development of tailored informatics competencies (continuing education) for current professionals to reflect technological changes.^{36,69,82–85} This training should meet variety of needs ranging from basic informatics skills for current and future professionals to a more specialized informatics and information system management skills.^{1,86} Currently, the delivery of PHI education and training varies from short-term in-service training to long-term academic education including certificates, diplomas, first degrees, graduate degrees, and postgraduate training.^{1,69} Again, Yasnoff et al.,⁶⁹ Norris and Brittain,⁸⁶ commented that the mode of these training programs varies greatly depending on the individual or organization’s education and or training requirements.^{69,86} The CDC PHI fellowship-training program established in the mid-1990s continues to evolve. The main goal of this 2-year program is to provide training and experience to public health professionals in applying computer and information science skills to real public health problems.^{1,69} The training also provides fellows the opportunity to work with experienced mentors in the field of PHI, thereby enhancing their understanding of global health issues, learn development of effective partnerships, and improving the health of poor communities through the application of health informatics and IT^{1,69} (See Table 2).

Effective and efficient public health delivery can be sustained only on readily available IT. Real-time response to natural disasters and those due to bioterrorists require a well-equipped integrated information system. Despite the benefits of health informatics and IT, there are obstacles to consider during the design and implementation of such system. One of such issues is implementing interoperable and reusable systems.⁵¹ While some believe costs associated with hardware and software acquisition are no longer an issue,^{84,85} system and data standardization remain a problem.^{69,85} Standardization can lead to design and development costs reduction, increase integration, and facilitate the collection of meaningful aggregate data for quality improvement necessary for policy development.^{69,87,88} However, due to complexity, diversity, and needs of each public health unit and agency, maintaining technological standards has become more difficult.

Another challenge is data and information sharing across organizational and jurisdictional boundaries.^{36,39,43,68,85} Historically and following the example of the medical system, public health agencies have designed information systems that are often maintained in many different forms and incompatible. This has resulted in duplicative and fragmented systems that hindered the ability of allied public health officials to access them.^{37,69} Interoperable information systems for both routine and emergency functions such as biosurveillance, outbreak management, and electronic laboratory reporting are essential to public health work and practices. Interoperable information systems are also critical because the capability to exchange information across, and among organizations will lead to early detection, faster response times, and early intervention to improve the public's health during any disaster.⁶⁸

Ethical and procedural issues for managing and safeguarding public health data also need consideration. IT is perceived as a double-edged sword. Thus, whatever is done to make integrated, comprehensive information system more easily available for laudable and worthwhile purposes is likely to create new opportunities for misuse.^{69,85} The currently available public use data and statistics can play an increasingly important role in advancing progress on major public health threats. As noted by Bell et al.¹⁰, surveillance data are often collected without informed consent. These issues can be safeguarded through the use of ethical research frameworks, adequate design and support of PHS systems and responsible access control.⁸⁹ It is important that adequate security measures are put in place to maintain data and information security and confidentiality, to prevent any form of breach and to reassure the public that their information is safe (Table 2).^{1,37,39}

DISCUSSION

Public health is the science and art of preventing disease, prolonging life, and promoting health through the organized efforts and informed choices of society, communities, and individuals. The focus is to prevent injuries, outbreaks, and diseases through surveillance of cases and the promotion of healthy behaviors.⁹⁰ Within this function is prevention as a primary goal for improving population health and quality of life through collaboration with different agencies and organizations to facilitate development of policies and programs to optimize interventions for healthy community.³⁷ Hence, availability of and access to 'up-to-date' robust information system is crucial to public health practice, services, and delivery. It

is obvious that the traditional paper-based surveillance systems are not efficient in providing timely information for public health action. Health informatics and IT system provide transformational tool to ensure efficient information access and exchange. Over the last two decades, public health, and the medical care systems have invested increasingly in IT and communication systems. Globally syndromic surveillance and biosurveillance systems are being developed and implemented (see Table 3). For example, the Pennsylvania Electronic Disease Surveillance System was used to track and isolate *Salmonella* quickly.⁸⁰

Benefits derived from the implementation of a well-functioning health information and IT systems include better communication and collaboration across all public health and clinical specialties, prompt access to accurate clinical and demographic information, and reduction or prevention of human errors for automated processes.^{87,88} Despite these benefits, certain areas represent grand challenges for public health practice and delivery. These include the development of coherent integrated national public health information systems, integration between public health and clinical care and pervasive concerns about the impact of IT on confidentiality and privacy. To encourage data harmonization, documentation, and investigation, rigorous system standardization should also be considered.^{37,69,76}

According to Lumpkin,⁹¹ federal and state public health information systems in the US have been developed in three ‘waves’.⁹¹ The first wave began with the independent development of state and federal systems that could not exchange data. The second wave was supported by federal funding to develop state-level systems capable of exchanging data using standards in building independent – and therefore costly – state systems. The last wave focused on reducing costs through the integration of ‘the benefits of state-level system development with the tools of software reuse’ and a requirement that ‘each system that is developed must be standard based’.⁹¹ As the use of informatics and PHI grow, strategies must be put in place toward a reusable design of information systems to promote technology transfer, and effective functioning of public health agencies, and the health system as a whole.⁵¹ This means public health, as a field and discipline of focus, should encourage and demand high-quality informatics education and training systems with a focus on building recognition of the importance of informatics. The goal of public health education should be the preparation of students for the future, by creating an environment that supports the teaching of PHI, competencies, and skills necessary for the future.

Limitations of the review

Several limitations are associated with this study. To start with, the review was limited to only studies published in the English language. This means, we might have excluded potential articles that were indexed in other languages or not available in the electronic databases searched. We assumed this explains why the majority of the eligible studies included in the review were conducted in the US. In addition, the published date was limited from January 2000 to 31 March 2016. Because the field encompasses many areas and is very interdisciplinary in nature, it is not possible to review without bias. Despite these limitations, this review has drawn attention to how informatics/technology has helped address some of the major issues and challenges in public health for the last two decades. In addition, this

review has revealed the importance and crucial role health informatics and IT are playing to reshape public health delivery to ensure a healthy society.

CONCLUSION

To the best of our knowledge, this is the first evidence-based systematic review of the literature solely dedicated to the role of informatics and IT and its impact on public health delivery. Through a comprehensive literature search, the authors identified 60 articles. This review provides an in-depth overview of how public health agencies are using informatics and technology, benefits, challenges, and opportunities. There is no doubt that to most effectively serve and improve communities' health in this information age and beyond, requires a strong PHI infrastructure. To meet this expectation, public health must invest in workforce development and capacity through education and training in PHI. As noted by the IOM's Committee on Quality Healthcare in America, 'information technology must play a central role in the redesign of the healthcare system if a substantial improvement in quality is to be achieved in the coming decade'.⁹² As a result, re-engineering public health courses, learning competencies, skills, and practices represents the next phase in public health.^{73,76}

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Figure 1.
Flow diagram on application of selection criteria established for studies included in review

Table 1:
Type of public health surveillance systems and implication for public health

Author/source	Type of information system	Purpose of study/system	Findings/impact on public health
Boom et al. ¹³	immunization information System (Houston - Harris County immunization Registry)	Description of the Houston - Harris County immunization Registry's experience after Hurricane Katrina	Effective and efficient preparation for responses during public health emergencies
Bradley et al. ¹⁴	Centers for Disease Control (CDC) BioSense Early Event Detection	initiative to advance early detection by providing the standards, infrastructure, and data acquisition for near real-time reporting, analytic evaluation and implementation, and early event detection support for state and local public health officials	Foster relationships and communication among local, state, and federal public health officials, and facilitate information exchange regarding data sources, analytics, monitoring practices, and other aspects of early event detection and situational awareness
Derby et al. ¹⁹	The Arizona Poison and Drug Information Center (APDiC) and The Foodborne Disease Outbreaks (FBDOs) System	Evaluate the ability of APDiC's data collection system to provide early detection of FBDOs and to recommend ways to improve FBDO surveillance efforts by integrating the two surveillance systems	Poison control centers might improve public health syndromic surveillance for foodborne illnesses because they capture early, real-time symptom data from the broadest possible range of sources (i.e. callers with mild to severe illness)
Espino et al. ²¹	Real-Time Outbreak and Disease Surveillance (RODS)	To accelerate deployment of computer- based syndromic surveillance	This project hopes to accelerate the deployment of real-time public health surveillance by lowering costs, increasing reliability, preventing vendor lock-in, and ensuring software customizability
Fan et al. ²²	The Alberta Real Time Syndromic Surveillance Net (ARTSSN)	(1) To improve upon traditional paper- based, fragmented public health surveillance using a centralized automated system; (2) enhance routine public health surveillance through effective use of existing Provincial Electronic Health Record data for earlier detection of cases, clusters, outbreaks, and trends of communicable disease, injury and environmental hazard exposure; and (3) track the effectiveness of public health interventions	ARTSSN provides richly integrated information on a variety of health conditions for early detection of and prompt action on abnormal events such as clusters, outbreaks, and trends
Fan et al. ²³	Automated Mortality Surveillance System (MSS)	To enhance surveillance monitoring of the H1N1 at local and regional levels to support evidence-based decision-making by physicians and public health authorities	The new system provided public health officials with timely information regarding the impact of H1N1 mortality the Kingston, Frontenac, Lennox & Addington (KFL&A) region with weekly updates
Flamand et al. ²⁵	Dengue Fever Surveillance System	To improve early detection of outbreaks and a better provision of information to health authorities	The system enabled health authorities to detect outbreaks and provided real-time information
Graber and Smith ²⁷	Rate-Based Statewide Surveillance System	To describe results from a pilot surveillance system for carbon monoxide poisoning	Establishing state-based public health surveillance for carbon monoxide (CO) poisoning is feasible and essential for guiding prevention and control efforts
Heffernan et al. ²⁹	New York City's First Syndromic Surveillance Systems	To assess the syndromic surveillance system	The syndromic surveillance system helped improve detect communitywide outbreaks and reassurance during high- profile public events
Hughes et al. ³²	The Emergency Department Syndromic Surveillance System (EDSSS) in England	To understand the factors driving respiratory attendances at emergency departments (EDs) in England	EDSSS provides additional intelligence about different categories of attendance, highlighting pressures in particular age groups, thereby aiding planning and preparation to respond to acute changes in EDs, and thus the health service in general
Hutwagner et al. ³⁴	CDC Early Aberration Reporting System (EARS)	Provide local and state health departments with a tool to assist in the best application of often-limited resources during epidemiological investigations of important public health events	EARS can be used with a variety of data sources to produce outputs that enable the users to determine how many resources and personnel they can invest in investigating specific aberrations

Author/source	Type of information system	Purpose of study/system	Findings/impact on public health
Lewis et al. ⁴¹	National Capital Region (NCR) Disease Surveillance Network	Description of the NCR Disease Surveillance Network as an example of cooperation and potential for regional surveillance activities	System provides users with a means to measure health of communities using real-time tracking disease-surveillance data
Lombardo et al. ⁴⁴	The Electronic Surveillance System for the Early Notification of Community-Based Epidemics (ESSENCE ii)	A prototype syndromic surveillance system for capturing and analyzing public health indicators for early detection of disease outbreaks	ESSENCE ii has provided excellent performance with respect to the framework and has proven to be a useful and cost-effective approach for providing early detection of health events
Mandl et al. ⁴⁵	Syndromic Surveillance System	The design and deployment of the first wave of syndromic surveillance systems, is intended to serve as a guide for informaticians, public health managers, and practitioners who may be planning deployment of such systems in their regions	Syndromic surveillance is another modality that clearly has a role in detecting and monitoring bioterrorism as well as other outbreaks and public health problems
Mnatsakanyan and Lombardo ⁴⁷	Electronic Surveillance System for the Early Notification of Community-based Epidemics (ESSENCE)	To highlight a prototype decision-support model	Great improvement in both the sensitivity and specificity of the detections
Naumova et al. ⁴⁸	The integrated Forecasts and Early eNteric Outbreak Detection System (iNFERNO)	The description of the integrated Forecasts and Early eNteric Outbreak System	Although the system is under development, its potential has been demonstrated through successful use of emergency department records associated with a substantial waterborne outbreak
Shea and Lister ⁵⁵	BioWatch Program	Collect airborne particles onto filters, which are subsequently transported to laboratories for analysis	BioWatch in urban areas may serve as an effective deterrent to potential bioterrorists
Sosin ⁵⁸	National Syndromic Surveillance System	To provide a common framework to evaluate syndromic surveillance systems	The framework for evaluating syndromic surveillance systems provides a focal point for evaluating and understanding syndromic surveillance systems for terrorism preparedness and outbreak detection
Tang ⁶¹	National Health Information Infrastructure (NHII)	Provides the underlying information utility that connects local health providers and health officials through high-speed networks to national data systems necessary to detect and track global threats to public health	Accelerate development and wide-scale deployment of electronic public health surveillance systems, computer-based patient records, and disaster-response information technologies. Such efforts hold the greatest potential to protect our citizens from disaster and to deliver the best healthcare if disaster strikes
Wagner et al. ⁶⁵	The National Retail Data Monitor (NRDM) For Over-The-Counter (OTC) Healthcare Products	(1) To enlist participation of retailers to achieve 70% coverage of OTC sales nationally; (2) influence the industry toward real-time data collection; (3) obtain supplemental information needed for spatial analysis, adjustment for promotional effects, and maintenance of UPC analytic categories (e.g. liquid cough medications); (4) promote and develop this type of surveillance practice; (5) achieve fault and load tolerance; and (6) develop detection algorithms for the data	NRDM data-utility approach reduces the effort required for health departments to monitor sales of OTC healthcare products
World Health Organization ⁴⁹	Communicable Disease Surveillance System (Guide to monitoring and evaluating)	Two key functions to (1) provide early warning of potential threats to public health and (2) program monitoring functions which may be disease specific or multi-disease in nature	The recommendations should be used as a basis on which to plan improvements of the surveillance system. Routine monitoring and follow-up evaluations should continue as scheduled
Xue and Liang ⁶⁷	Public Health Emergency Information System (PHEIS) in China	To investigate the ongoing development of PHEIS	By using the functional coupling framework, some insights were provided regarding China's post-SARS public health emergency responses from a process re-engineering perspective
Yih et al. ⁷¹	Syndromic Surveillance System	Evaluation of a real-time ambulatory care-based syndromic surveillance system in four metropolitan areas of the United States	The system was able to detect true clusters of illness but none was of public health interest

Table 2:
Electronic surveillance systems functionality, capability, training, and challenges

Author	Type of system design	Aim of system/study	Main issue(s) addressed	Conclusion
Bravata et al. ¹⁵	Bioterrorism Surveillance System	Evaluate the potential utility of existing surveillance systems for illnesses and syndromes related to bioterrorism	Review of surveillance systems for early detection of bioterrorism-related diseases	Few surveillance systems have been specifically designed for collecting and analyzing data for the early detection of a bioterrorist event
Buckridge et al. ¹⁶	The Defense Advanced Research Project Agency (DARPA) sponsored project called the Bio-event Advanced Leading Indicator Recognition Technology (BioALIRT)	To improve the timeliness of outbreak detection (1) identifying new nontraditional data sources with early alerting potential and (2) develop and evaluate outbreak detection algorithms for surveillance data	Synthesize and description of major themes in research on detection algorithms conducted through the BioALIRT project	Surveillance for rapid outbreak detection should move from analyzing a single time-series to analyzing covariate and spatial information collected from multiple data sources
Buckridge et al. ¹⁷	Simulated an Anthrax Epidemic Injection Model	To design a simulated anthrax epidemic injection model that accounts for the complexity of the background data and enables sensitivity analyses based on uncertain disease-agent characteristics	Requirement for the design and evaluation of an epidemic simulation model	The model successfully addresses the limitations of existing simulation approaches by accounting for factors such as spatial mobility and disease modeling knowledge base
Buehler et al. ¹⁸	Syndromic System in relation to Bioterrorism	Consider the mix of hypothetical factors that may affect the detection of epidemics attributable to CDC category A bioterrorism agents	The role of syndromic surveillance in detecting a bioterrorism-related epidemic	Efforts to detect bioterrorism epidemics at an early stage should not only address the development of innovative new surveillance mechanisms but also strengthen resources for diagnosis and enhance relationships between clinicians and public health agencies
Doyle et al. ²⁰	The Public Health Surveillance Knowledgebase (PHSKb™)	Improve the sensitivity, timeliness, and quality of surveillance data through improved electronic data interchange. Second, to describe the creation of the PHSkb	Description of the initial creation of the PHSkb	The PHSkb provides integrated, extensible, and interoperable system architecture component to support notifiable disease surveillance
Flamand et al. ²⁴	Dengue Fever Surveillance System in French Guiana	Assessment of the contribution of the data mining method to the understanding of factors associated with the dissemination of infectious diseases and their spatiotemporal spread	Application of contextual sequential pattern extraction techniques to enable early warning of dengue outbreaks in French Guiana	Utilization of the data mining approach essential to analyzing disease-surveillance data on a temporal and a spatial scale in relation to climatic, social, and environmental variables
Fricker and Rolka ²⁶	Syndromic Surveillance System	Address current challenges in syndromic surveillance system	Statistical issues in electronic biosurveillance	Electronic biosurveillance systems and the analytical methods have the potential to improve public health surveillance, not only for bioterrorism, but also to improve responsiveness to natural disease outbreaks
Graber and Smith ²⁷	Pilot Surveillance System for Carbon Monoxide (CO) Poisoning	Describe results from a pilot surveillance system for carbon monoxide poisoning	To describe the development of a state-based surveillance system for unintentional, non-fire-related CO poisoning using a combination of existing data sources, analyzed using standard public health methodology	Establishing state-based public health surveillance for CO poisoning is feasible and essential for guiding prevention and control efforts
Hanrahan et al. ²⁸	Wisconsin's Public Health Information Network (WI-PHIN) - Information System for Childhood Cancer Surveillance	Description of information system to support environmental public health tracking in Wisconsin	Development of an information system for environmental childhood cancer surveillance	This information system can serve as the foundation for building a comprehensive system to assess environmental cancer etiology while extending the method to tracking other environmental exposure and disease relationships

Author	Type of system design	Aim of system/study	Main issue(s) addressed	Conclusion
Heisey-Grove et al. ³⁰	Massachusetts Department of Public Health Disease Surveillance System for Hepatitis C	Improve timeliness and completeness of reporting and case follow-up of hepatitis C.	Assessment of the Massachusetts hepatitis C surveillance system	Implementation of the system has resulted in an increase in timeliness of reporting and receiving completed form
Henao et al. ³¹	CDC Foodborne Diseases Active Surveillance Network (Food Net)	To better measure the frequency of enteric infections and their effects on society	Achievements of the FoodNet from 1996-2015	FoodNet has helped improve food safety in the United States
Hurt-Mullen and Coberly ³³	Electronic Surveillance System for Early Notification of Community-Based Epidemics (ESSENCE)	Describe the framework for daily evaluation of ESSENCE data	General principles of the use of syndromic surveillance	Careful development of an evaluation and response framework is necessary to assess whether the use of syndromic surveillance systems requires excess work to distinguish between statistical anomalies and important public health events
Jossanan et al. ³⁵	Heat Wave Syndromic Surveillance System in France	(1) Give the public authorities 3days' prior warning that a heat wave may occur, in order for the National Heat Wave Plan (NHWP) measures to be put into operation and (2) modifying the behavior of people, health institution, and health authorities with regard to high summer temperatures	To determine relevant indicators related to health effects of heat waves and evaluate the ability of the system to monitor variations in the activity of emergency departments over time	System allowed the collection of data in real-time and the subsequent optimization of the response by public health agencies
Karras et al. ³⁶	Public Health Informatics Education	Description and assessment of PHI curriculum development since the 1990s	PHI Curricula Development and Evaluation	Need for all PHI training schools and institutions to coordinate development of curricula to facilitate standardization in competencies areas
Koo et al. ³⁷	Challenges and opportunities offered by Public Health Informatics	Examination of public health as a professional discipline for informatics	Fundamental nature of public health and grand challenges	The application of information science and technology in public health practice provides untapped opportunities to improve the health of the population
Krause et al. ³⁸	Electronic Surveillance System (SurvNet) for Infectious Disease Outbreaks in Germany	Provide timely and easily retrievable epidemiologic information exchange on outbreaks at the local, state, and national levels	To describe the system, and present epidemiologic aspects of reported outbreaks, and also to discuss the strengths and weaknesses after 5 years of practical use	SurvNet may be a useful tool for other outbreak surveillance systems because it minimizes the workload of local health departments and captures outbreaks even when causative pathogens have not yet been identified
Kukafka ³⁹	Public Health Informatics Career Development	Proved examples of how informatics is being applied to health promotion activities	The role of health informatics in disease prevention health education and health promotion	Health promotion and disease prevention practices in public health can be dramatically transformed by use of informatics tools and methods
Kulldorff et al. ⁴⁰	Real-Time, Geographic, Early Outbreak Detection Systems	(1) Set benchmark for rigorous evaluation of the statistical power of early outbreak detection and (2) estimate and compare the power of prospective temporal and space-time scan statistics	Power calculation for evaluating disease outbreak detection	Temporal scan statistic performs substantially better at detecting a city-wide outbreak, when compared with a space-time
Liang and Xue ⁴²	Public Health Emergency Response Information System (PHERIS) in China	Facilitate disease surveillance, detection, reporting, and response	(1) Review of emergency response information systems and (2) analyze the weakness of China's old public health system and describes the design and functionalities of PHERIS from both technical and managerial aspects	China recognizes that surveillance and detection of disease outbreaks is a critical part of the solution and a dynamic system incorporating command, action, and supporting components is needed to manage emergencies. The ongoing development of PHERIS will provide a complete package for China to rapidly detect emergencies, effectively share critical information among key stakeholders, and competently manage emergencies

Author	Type of system design	Aim of system/study	Main issue(s) addressed	Conclusion
Lober et al. ⁴³	Information System Architectures for Syndromic Surveillance	The essential architectural components of a syndromic surveillance information system and discuss existing and potential architectural approaches to data integration	The role of data elements, vocabulary standards, data extraction, transport and security, transformation and normalization, and analysis of data sets in developing disease-surveillance systems	Public health informatics and computer science research in data-integration systems can supplement approaches recommended by public health informatics network and provide information for future public health surveillance systems
Mirhaji ⁴⁶	Public Health Surveillance Systems (PHS) with emphasis on Syndromic and Bioterrorism System	To examine the conceptualization, design, analysis, and implementation	Significance of a translational approach to the problems of public health informatics	To streamline the collection and integration of public health information, it requires the development of a culture and infrastructure to enhance meaningful integration knowledge and information across organizations
Ortega et al. ⁵⁰	IBM's Public Health Information Affinity Domain (PHIAD) in Mexico	A prototype that leverages the latest information technology standards and infrastructure for the public health community	To retrospectively examine the public health policies put in place in Mexico City	PHIAD can be deployed to provide a bridge technology that enables clinicians and public health officials to share disease data using standards-based, real-time electronic transactions without upgrading their legacy systems
Reeder et al. ⁵¹	Public Health Information System Design	Proposal for the creation of PHI reusable information system	Reusable knowledge design in PHI system and standard	Identification and consistent use of rigorous system design will move the discipline of PHI forward
Reis et al. ⁵²	Automated Epidemiological Geotemporal Integrated Surveillance system (AEGIS)	To provide real-time population health monitoring in the state of Massachusetts	Description of the evolution of the design over time in response to the challenges of a regional and national integration environment	Results indicated the need for robustness when designing public health information system
Savel et al. ⁵³	Public Health Grid (PHGrid)	Description of architectural framework for a Public Health Grid	Data grid aspect of grid computing	PHGrid has the potential to overcome technical, cultural, and financial obstacles existing public health information systems by improving the availability accuracy and timeliness of critical health data
Scotch et al. ⁵⁴	Public Health Grid Applications using Web 2.0 Mashup Technologies	To assess the feasibility of using Web 2.0 technologies to develop complex public health applications	The development and use of Web 2.0 technologies including Yahoo!	Web 2.0 applications are reasonable environments for rapid prototyping; they are not mature enough for large-scale public health data applications
Shmueli and Burkom ⁵⁶	Modern Biosurveillance System	Monitoring of time series for early alerting of anomalies to stimulate investigation of potential outbreaks	Statistical challenges in monitoring modern biosurveillance data and description of the current state of monitoring in the field	Lack of application to modern biosurveillance raises attention to one of the main barriers to statistical involvement in the field
Siegrist and Pavlin ⁵⁷	Bio-Event Advanced Leading Indicator Recognition Technology (BioALIRT) Biosurveillance	Develop data sources, technologies, and prototypes for monitoring nontraditional data sources that enable public health authorities to detect terrorist release of a pathogen or toxin at the earliest possible moment	Determine whether automated detection algorithms can reliably and quickly identify the onset of natural disease outbreaks that are surrogates for possible terrorist pathogen releases, and do so at acceptable false-alert rates (e.g. once every 2–6weeks)	Due to minimal data exist for an actual biologic attack, determining how quickly an algorithm might detect such an attack is difficult. However, application of these algorithms in combination with other data- analysis methods to historic outbreak data indicates that biosurveillance techniques for analyzing syndrome counts can rapidly detect seasonal respiratory and gastrointestinal illness outbreaks
Sosin ⁵⁸	National Syndromic Surveillance System	Describe the status of performance measurement of syndromic surveillance systems and ongoing challenges in system evaluation	Framework for evaluating Syndromic Surveillance Systems	Evaluation requirements should be simplified and standardized to allow comparisons across systems and across outbreak detection approaches
Stoto et al. ⁵⁹	Syndromic Surveillance	(1) To introduce the statistical issues in syndromic surveillance, (2) describe and	Use of statistical methods in syndromic surveillance	Although an increasing number of statistically sophisticated detection algorithms have been developed,

Author	Type of system design	Aim of system/study	Main issue(s) addressed	Conclusion
Surjan et al. ⁶⁰	The Protege ontology editor with RDF	illustrate approaches to evaluating syndromic surveillance systems and characterizing their performance, and (3) evaluate the performance of a couple of specific algorithms through both abstract simulations and simulations based on actual data	Development of conceptual framework for public health indicators	there is a limit to their efficacy. However, syndromic surveillance systems can help public health to build relationships with hospitals and other entities in their communities to get access to data
Tokars et al. ⁶²	BioSense US National Surveillance System	To create a core ontological model that is able to represent public health indicators	Describe and evaluates modifications of C2 algorithm as well as its potential benefits, and limitations to improve its performance	The Protege ontology helps improve data comparability in the system Findings can be used to improve both early event detection and situation awareness because accurate recognition of unusually high counts is needed for both uses
Uscher- Pines et al. ⁶³	Public Health Syndromic Surveillance	Receives data from various sources and makes them available for public health use	To describe current syndromic surveillance system response protocols in health departments from eight diverse states in the United States and to develop a framework for health departments to use as a guide in initial design and/or enhancement of response protocols	Due to the lack of guidance, limited resources for development of response protocols, and few examples of syndromic surveillance detecting previously unknown events of public health significance, health departments have not prioritized the development and refinement of response protocols. Systems alone, however, are not effective without an organized public health response
Wagner et al. ⁶⁴	The Real-Time Outbreak and Disease Surveillance (RODS) Project	Allows for earlier detection of epidemics and more timely public health response, due to lack of reliance on clinicians for recognition and active reporting of disease clusters to public health departments	Experience of the RODS project in collecting and analyzing patient chief complaints	Free-text chief-complaint data are useful in public health surveillance and can be obtained in real-time for modest cost
Wilson et al. ⁶⁶	Heuristic Model for Biological Detection Events	Test whether early detection of outbreaks can be achieved through statistical analysis of chief- complaint data (or other routinely collected data)	Strategy for rapid response to pandemic influenza is to identify the first focus of human-to-human efficient transmission of the H5N1 influenza virus	This approach could aid global public health officials and national political leaders in responding to biological threats of international public health significance
Yan et al. ⁶⁸	Syndromic Surveillance Systems	A model designed to enable rapid detection and assessment of biological threats that may require swift intervention by the international public health community	A comprehensive survey of state-of-the-art syndromic surveillance research and system development efforts from the perspective of information science and technology	Although syndromic surveillance systems have been developed and deployed in many state public health departments, there is an urgent need to create a cross-jurisdictional data-sharing infrastructure to maximize the potential benefit and practical impact of syndromic surveillance
Yasnoff et al. ⁶⁹	Public Health Informatics (PHI)	A case study comparing three state-of-the-art syndromic surveillance systems	Need to utilize informatics applications to enhance public health activities	Application of PHI principles provides unprecedented opportunities to build healthier communities
Yasnoff et al. ¹	Public Health Informatics (PHI)	To identify how PHI can improve public health delivery	To develop national agenda for PHI	Implementation of this consensus agenda will help promote progress in the application of information technology to improve public health
Yih et al. ⁷⁰	The National Bioterrorism Syndromic Surveillance Demonstration Program	Development of a national agenda for PHI	Assessment of the National Bioterrorism Syndromic Surveillance Demonstration Program	Data files created by this system are also directly usable by health departments and are compatible with the emerging standards of CDC's BioSense initiative. This allows healthcare organizations to make their data directly available to local and national health agencies if they so choose

Table 3:

Examples of global syndromic surveillance systems

type of syndromic design	objective/function	Agency/host country
EpiCom - Berndt et al. ⁷⁸	To provide information exchange for reporting and tracking outbreaks and to alert public health officials	Florida Department of Health - USA
The Louisiana immunization Network for Kids Statewide (LINKS) - Boom et al. ¹³	To track immunizations/vaccinations of children	Louisiana Department Health of and Hospitals - USA
Early Aberration Reporting System (EARS) - Bradley et al. ¹⁴ and Huiwagner et al. ³⁴	To monitor bioterrorism	U.S. Centers for Disease Control and Prevention - USA
Electronic Surveillance System for Early Notification of Community-Based Epidemics (ESSENCE) - Lombardo et al. ⁴⁴	To monitor infectious disease outbreaks at military treatment facilities worldwide	Department of Defense - USA
Kentucky Preparation and Response on Advanced Communications Technology (PROACT) - McKinney et al. ⁷⁹	To aid volunteer and evacuee coordination efforts	University of Kentucky - USA
National Health Service (NHS) Direct Syndromic Surveillance - Yan et al. ⁶⁸	To monitor infectious and noncommunicable diseases	Operated by National Health Service (NHS) of UK
The Pennsylvania Electronic Disease Surveillance System (PA-NEDSS) - Sandt et al. ⁸⁰	To improve the timeliness of disease reporting and also provide access to complete and accurate public health data for the Commonwealth	Pennsylvania Department of Health - USA
BioSense - Tokars et al. ⁶²	To expedite event recognition and response coordination among federal, state, local, and local public health and healthcare organizations	CDC and the Department of Homeland Security - USA
Early Warning Outbreak Recognition System (EWORS) - Yan et al. ⁶⁸	Collects data from a network of hospitals and provides technical approaches to distinguish epidemic from endemic diseases	Association of South East Asian Nations
Alternative Surveillance Alert Program (ASAP) - Yan et al. ⁶⁸	Monitors gastrointestinal disease trends by analyzing over the counter (OTC) anti-diarrheal and anti-nausea sales data and calls to telehealth lines	Health Canada
Association of South East Asian Nations - Yan et al. ⁶⁸	Daily analysis of acute respiratory syndrome	Korea
Experimental Three Syndromic Surveillances in Japan - Yan et al. ⁶⁸	To analyze OTC sales data, outpatient visits, and ambulance transfer	National Institute of Infectious Diseases - Japan
Australian Sentinel Practice Research Network (ASPREN) - Yan et al. ⁶⁸	To collect and report data on selected conditions such as ILI for weekly statistical analysis	The Royal Australian College of General Practitioners, the Department of General Practice, University of Adelaide, Australian Government Department of Health and Aging
influenza-Like illness (ILI) Surveillance in France - Yan et al. ⁶⁸	To collect medication sales and weekly office visit data to provide forecasts of influenza outbreaks	European Center for Disease Prevention and Control - France
HealthMap - international Society for Disease Surveillance (ISDS) ⁸¹	To monitor disease outbreak monitoring and real-time surveillance of emerging public health threats	Boston Children Hospital - USA
Suite for Automated Global Electronic bioSurveillance (SAGES) - ISDS ⁸¹	Collection of modular for electronic disease surveillance	Johns Hopkins University Applied Physics Laboratory - USA
Trip S - ISDS ⁸¹	To increase the European capacity for real-time or near-real-time surveillance and monitoring of the health burden of expected and unexpected health-related events	European Commission through Executive Agency for Health and Consumers