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IS-DRIVEN PROCESS REENGINEERING: CHINA'S PUBLIC HEALTH EMERGENCY RESPONSE TO THE SARS CRISIS

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ABSTRACT

A process reengineering perspective suggests that public health emergency response requires a low degree of mediation and a high degree of collaboration. Employing a functional coupling framework, this paper analyzes China's former public health processes and describes the ongoing development of the public health emergency information system (PHEIS) in China. Five problems of the former public health processes are identified, which have largely limited China's ability to respond to public health emergencies efficiently and effectively. The structure and functions of PHEIS are described, and the facilitation of PHEIS as part of China's public health process reengineering is explained. In addition, this paper discusses implications for future public health emergency information system development.

INTRODUCTION

In recent years, a number of microbial threats greatly endangered global public health. One of the most publicized global public health crises was severe acute respiratory syndrome (SARS) whose outbreak and rapid spread in more than 25 countries in early 2003 claimed numerous lives and caused tremendous economic losses (Hughes 2003). It is predicted that new pathogens, originating either naturally or from bioterrorism, will continue to emerge and cause new public health emergencies (Hughes 2003). Response to public health emergencies should be regarded as a global issue, and an orchestrated worldwide coordination is needed. Particular attention should be paid to developing countries that have relatively fewer resources to deal with public health emergencies.

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China was the most seriously affected by SARS. Among the 8,445 cases reported to the World Health Organization (WHO), 5,327 (63%) were from China (WHO 2003). After employing effective control measures, China was able to contain the outbreak in a relatively short time (Pang, Zhu, and Xu 2003). Nonetheless, the rampant outbreak in the early stages resulted in chaos and exposed the fragility of China's public health information systems. Reflecting on lessons learned from the SARS crisis, the Chinese government realized that there were flaws inherent in its former public health systems and started making large scale changes to improve the processes of public health operations. The leader of the Ministry of Health (MOH) admitted that the MOH was unprepared for the surge in cases that resulted in an escalation of public health hazards and the consequent visibility of weaknesses in the system. Following the SARS outbreak, the MOH neither instituted a timely and unified mechanism for collecting, processing and reporting relevant epidemic information nor did it provide clear-cut instructions or effective guidelines to control the epidemic. The MOH leader also recognized that lacking a reliable and valid system of information collection, surveillance reporting and contact tracing, relevant agencies could not compile statistics on SARS. This precluded the ability to report accurate figures to higher authorities in a timely manner.

Recognizing that its inefficient and anachronistic public health policies were problematic, China attempted to undertake reengineering initiatives to streamline the inefficient processes. One of China's major efforts was to allocate more than two billion dollars to build a public health emergency information system (PHEIS). The purpose of this paper is to investigate the ongoing development of PHEIS. Drawing on business process reengineering (BPR) theory, the paper analyzes the weakness of the former public health system, describes the design and functionalities of PHEIS, and provides suggestions on how to improve PHEIS. The intent of this paper is to explore (1) the deficiencies in the pre-SARS public health information system at the time of the SARS crisis, (2) the critical design considerations of

CONTRIBUTIONS

This paper makes a contribution to IS research by investigating public health emergency responses in China from a process reengineering perspective and exploring how the implementation of an emergency response information system can help reengineering inefficient public health processes.

This is one of the first studies to examine the impact of IS on public health emergency responses from a theoretical perspective. The functional coupling framework on which this paper is based enhances the conceptualization of complex relationships among various actors and processes during emergency situations. This paper shows that this framework can be adapted to the context of public health emergency response. The framework facilitates the diagnosis of existing public health systems and helps to understand how information technologies can be employed to resolve those problems.

This research pertains to a crucial issue - public health emergency response. China's responses to the SARS crisis are investigated and results are presented. Given China's important role in protecting global public health and the lack of information regarding China's public health emergency response initiatives, this paper will be significantly informative.

This research should be of interest and geared to the academic community, public health administrators, and other researchers in the area of IS for crisis response and management. The functional coupling framework in the context of public health emergency responses should draw considerable attention from this audience. This research should interest practitioners responsible for designing, implementing, and using emergency response information systems in various environments.

PHEIS, and (3) the potential use of a functional coupling framework to analyze processes associated with public health emergency information systems.

LITERATURE REVIEW

The purpose of this section is to review development projects and research studies on emergency information systems and to use past information to inform the current research. Given that a large portion of past research and development on emergency response systems has been conducted in the United States because of terrorist attacks (Kohane 2002; Lober *et al.* 2002; Teich, Wagner, Mackenzie, and Schafer 2002; Wagner 2002), the scope of our literature review covers primarily the project reports and research articles published there. In order to identify the relevant literature, we searched academic databases including ABI, PubMed, IEEE Explore, and ACM Digital Library. The search was performed using different combination of such keywords as "public health," "crisis," "emergency system," "emergency response," "surveillance," "bioterrorism," "information technology," and "information system." We also collected information from the official websites of organizations including the Centers of Disease Control and Prevention (CDCs), the Agency for Healthcare Research and Quality (AHRQ), and the Health and Human Services (HHS), which have sponsored emergency response information systems initiatives.

The criteria used to assess the relevance of citations address issues of responding to emergencies by using information technologies. The system development projects are about information systems designed to cope with public health emergencies. The research articles also address issues of information systems in the public health area, but articles on general emergency information system design are included since we believe that the general design principles can be applied to the public health field as well. The two authors used the criteria to decide whether or not to include a citation in this literature review. Each author read the selected articles independently, and then compared their findings to ensure that they agreed on the key points. These points concern information systems development in the domain of public health. In this section we will review major IT development and research initiatives in the United States. It should be noted that this review does not represent a comprehensive coverage of the entire body of research and practice relating to public health emergency information systems.

Motivated by a series of naturally occurring and human-made disasters, federal and state governments, as well as private companies, have implemented various initiatives to create coordinated systems for surveillance, detection, and response. Given the wide recognition that the application of information technology (IT) provides previously unfathomed opportunities to improve public health practice (Board of Directors of the AMIA 1997; Koo, O'Carroll, and Laventure 2001; Yasnoff, Overhage, Humphreys, and LaVenture 2001), many of these initiatives have sought the assistance of IT. According to the AHRQ, there exist 217 information technologies and decision support systems of potential use in the event of a bioterrorist attack or other public health emergencies (AHRQ 2002). One of the most important applications of IT is in public health surveillance. This encompasses the ongoing systematic collection, analysis, and interpretation of health-related data for use in planning, implementing, and evaluating public health practice (Teutsch and R.E. Churchill 2000; Thacker and Berkelman 1988). Some examples include a national retail data monitor, which was designed to collect and analyze sales of over-the-counter health products to detect outbreak of disease (Wagner, Robinson, Tsui, Espino, and Hogan 2003); a clinical data warehouse, which was used for hospital infection control (Wisniewski *et al*. 2003); a data mining surveillance system, which can provide sophisticated capability to control hospital infection and public health (Brossette *et al*. 1998); and a real-time outbreak and disaster surveillance system, which was utilized for early detection of disease outbreaks (Tsui *et al*. 2003).

In order to integrate isolated information systems that support communications for public health labs, the clinical community, and state and local health departments and to capitalize on the potential for a cross-fertilization of data exchange, some national level projects were implemented in the U.S. for early detection of public health threats. The Public Health Information Network (PHIN) is a framework created by the CDC. Based on defined data and vocabulary standards and strong collaborative relationships, the PHIN enables consistent exchange of response, health, and disease tracking data between public health partners. PHIN is composed of five key components: detection and monitoring, data analysis, knowledge management, alerting, and response. Other federal initiatives include: (1) the National Electronic Disease Surveillance System (NEDSS), which promotes the use of data and information system standards to advance the development of efficient, integrated, and interoperable surveillance systems at federal, state and local levels (CDC 2004), (2) the BioNet, a national network of public health laboratories and federal food regulatory agencies helping the CDC to rapidly detect and determine possible links between disease agents during terrorist attacks (CDC 2003), and (3) the National Health Information Infrastructure (NHII), an initiative set forth to improve the effectiveness, efficiency and overall quality of health and health care in the United States, a comprehensive knowledge-based network of interoperable systems, and the set of technologies, standards, applications, systems, values, and laws that support all facets of individual health, health care, and public health (HHS 2004). These national level initiatives focus on data integration and standardization that intend to facilitate information sharing among various healthcare partners and enables early detection of threats.

Prior research addressed various issues related to the design of public health emergency response information systems. Currently, an integrated disease surveillance framework has been proposed for rapidly detecting, tracking, and managing public health threats (Popovich, Henderson, and Stinn 2002). This contains six functions: data collection, detection, alert and early warning, resource planning, response assessment and evaluation, and investigation and modeling. A decentralized public health emergency response system was proposed which gives states responsibility for collecting and disseminating all necessary information and coordinating surveillance and response (Leifer, Grasso, and Freilich 2003). According to this model, systems in different states would be compatible using common data standards and the federal government could oversee a national network. Other researchers contended that state and local health departments should build dual- or multiple-use public health information infrastructures (Kun and Bray 2002), so that public health information systems would be able to respond to, and detect not only, bioterrorism, but infectious human and animal disease outbreaks, chemical spills or leakages, food and water contamination scenarios as well. Based on experiences of the "Emergency Management Information System and Reference Index" (EMISARI) at the Office of Emergency Preparedness (OEP), Turoff (2002) asserted that "an emergency system must be viewed as a structured group communication system where the protocols and communication structures are provided, but there is little content about a particular crisis situation except as an integrated electronic library of external data and information sources" (p. 30). As a consequence, the design of emergency information systems should focus on the group communication process by accommodating how humans collect, contribute, and utilize data in a time-urgent manner (Turoff 2002). Given that Turoff's remark is about generic emergency response information systems, it is applicable to public health emergency responses. It suggests that public health emergency response information systems can also be viewed as structured group communication systems. Turoff, Chumer, Van de Walle and Yao (2004) have articulated five criteria for the design of such a group communication system: metaphors, roles, notifications, context visibility, and hypertext. The criteria largely focus on system interface design and assume the existence of communications networks and computing technologies and focus on the software and interface design features.

The extant literature has provided an exploration about how to respond to public health emergencies by leveraging the power of IT. However, the majority of prior studies are based on experiences in the US. Given that a public health emergency could easily spread across countries and pose a global threat (e.g., the SARS outbreak), the scope of research on public health emergency responses should be extended to include developing countries which are more susceptible to epidemic diseases. China is the country where SARS caused the most serious damage; hence its initiatives of developing public health emergency response systems were important enough to make a case. In the next section, a general process reengineering framework is described which can be used to illustrate how China's public health processes were reengineered by means of information systems.

THEORETICAL FRAMEWORK

An emergency information system can be viewed as a specialized group decision support system (Turoff, Chumer, Van de Walle, and Yao 2004) which entails not only certain IT artifacts, but specified processes in accordance with functionalities of the system. It is a moot point whether IT artifacts serve processes or vice versa. Although much IS research assumes IT artifacts to be the ultimate goal of organizational IT projects (e.g., critical success factor studies of IS implementation), the IS literature also recognizes that complex IT systems such as enterprise systems can serve as an enabler of business process reengineering (Hammer and Champy 1993; Larsen and Myers 1999). In other words, an information system has dual roles in certain contexts: it can be the means (method), or it can be the end (objective). Similarly, public health information systems have dual roles. In the context of public health emergency response, we contend that implementing information systems is not the ultimate goal; rather, it is a means by which processes are improved and optimized. Therefore, we focus on examining how China's public health processes are reengineered by means of PHEIS.

Since emergency response information system is a relatively new research area, there are few theoretical developments. In this paper, we employed a functional coupling framework of business processes developed by Teng, Grover, and Fiedler (1994). We argue that this framework is applicable by assuming that the characteristics of business processes and emergency response processes have significant similarities in terms of how goals are attained. A business process refers to a set of logically related tasks performed to achieve a defined business outcome (Davenport and Short 1990), while an emergency response process could also be viewed as a set of related tasks performed to achieve an outcome, that is, to cope with the emergency. Both processes face a challenge of integrating different tasks so that they are orchestrated to achieve a common goal. Therefore, the functional coupling framework developed for business processes could fit in the context of emergency response processes and provide a useful conceptualization.

Certain management researchers have observed that a process can be redesigned to achieve maximum performance gains (Hammer 1990). Business Process Reengineering (BPR) refers to "the critical analysis and radical redesign of existing business processes to achieve breakthrough improvements in performance measures" (Teng, Grover, and Fiedler 1994). A business process encompasses a set of participating functions and tasks, and BPR is usually enabled by IT applications that modify how these participants are coupled to each other to attain dramatic performance improvements. The functional coupling framework depicts the coupling patterns among different participants of business processes (Teng, Grover, and Fiedler 1994). Two critical dimensions are conceptualized in the framework to capture the characteristics of a business process: degree of mediation and degree of collaboration. A process with a high degree of mediation involves a large number of steps in a sequential manner, while processes with a low degree of mediation require that most of the participants contribute directly, often simultaneously, to the final outcome. For the degree of collaboration dimension, the participants in a process, regardless of the pattern of mediation, may exchange information with each other and make mutual adjustments to facilitate the accomplishment of process outcomes. Depending on the extent of such information exchange, one can identify processes having a higher or lower degree of collaboration. This gives rise to a framework that delineates four general process patterns: high-mediation/low-collaboration, high-mediation/high-collaboration, low-mediation/low-collaboration and low-mediation/high-collaboration as shown in Figure 1.

In order to illustrate the four process patterns, an example is provided for each.

1. In the high-mediation/low-collaboration pattern, infectious disease cases were reported to the MOH by going through a series of governmental agencies. There was no coordinated effort for this reporting.
2. A scenario for the high-mediation/high-collaboration pattern is that while the physician, lab, and pharmacy work together to provide medical care to patients, a number of steps have to be processed sequentially during the care provision.
3. The low-mediation/low-collaboration pattern characterizes the process where physicians conduct research on SARS in a largely independent manner and exchange little information with each other.
4. The low-mediation/high-collaboration pattern is the desirable pattern for emergency response which requires many groups of people to participate in the activity directly and cooperatively.

In the context of emergency responses, the low-mediation/high-collaboration pattern is likely to generate the best performance. A low degree of mediation is desirable because emergencies need to be handled in a time urgent manner. A high degree of mediation would delay response time, since critical information has to go through many intermediate participants before it ultimately reaches decision makers. However, a high degree of collaboration is needed because emergency response is a complex process whose outcome is dependent of the joint effort on the part of a variety of participants. Prior research suggests that an emergency system needs to define roles, develop collective understandings, and maintain effective coordination (Bigley and Roberts 2001; Turoff, Chumer, Van de Walle, and Yao 2004). An emergency system can only be successful when there is effective collaboration among all participants because of the interplay of uncertainty factors. Therefore, measures need to be taken to decrease the degree of mediation and increase the degree of collaboration. However, low-mediation/high-collaboration does not mean no-mediation/all-collaboration. In an emergency situation, too many collaborative relationships may cause inefficiency. For the sake of control, mediation should not be totally removed, given that a certain degree of mediation is essential to exercise centralized commands.

The functional coupling framework postulates that the *degree of mediation* can be reduced by application of shared information resources such as central databases and imaging technologies and the *degree of collaboration* can be enhanced by application of communication technologies such as telecommunications networks, e-mails, and groupware. In essence, both shared information resources and communication technologies are utilized to support efficient and effective communications among various participants of a certain process. The former shortens the communication distance and the latter broadens the communications scope. Both are indispensable in public heath emergency response systems. According to Edward Baker, assistant US Surgeon General, "... the major public health challenges since 9/11 were not just clinical, epidemiological, technical, issues. The major challenge was communication. In fact, as we move into the 21st century, communication may well become the central science of public health practice."

METHODOLOGY

Given the complexity of China's PHEIS and the lack of previous research on this topic, a case research method was employed for this study. Interviews with two professors at Health Science Center of Beijing University, three healthcare informatics experts, and six healthcare IT practitioners were conducted to collect data for this research. The interviewees were chosen because of their experience and knowledge, and their availability for interviewing. The two professors have research interests in public health emergency response, and they are

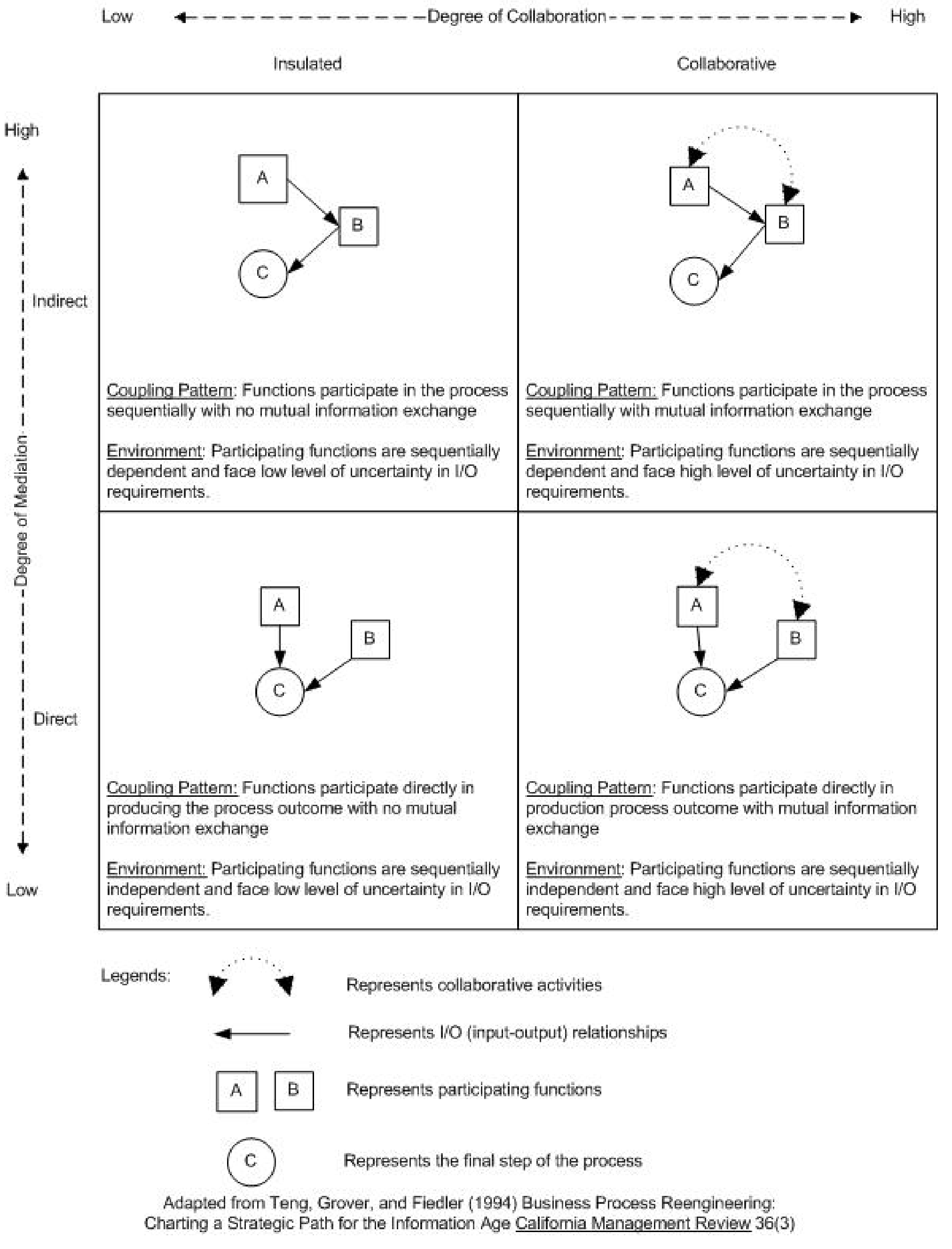


Figure 1. The functional coupling framework

highly informed with regard to the government's PHEIS initiative because of their connection with MOH officials who graduated from Beijing University. The three healthcare informatics experts are from large hospitals and have joint expertise in health care and information technologies. The six IT practitioners, working in IT firms that specialize in developing healthcare information systems, have many years of technical experience. These three groups of interviewees provided opinions from the academic, professional, and technical perspectives, forming a relatively comprehensive view of China's public health information systems. The number of interviewees in each group was subjectively determined and largely depended on their accessibility.

Semi-structured interviews were conducted by the first author. Based on each interviewee's availability either a face-to-face or a phone interview was carried out. The interviewees were asked to identify problems with the former public health information system, to discuss how to solve the problems, and to provide information regarding the ongoing PHEIS project. Notes were taken during the interviews.

Additional documents were reviewed to retrieve pertinent information. These documents included government IT policies and regulations, meeting minutes, reports, development plans, media reports, and news. The credibility of the governmental documents is guaranteed since they were either obtained from government officials or downloaded from official government websites. The quality of media reports and news is likely to be questionable due to political influences. Nevertheless, this is not considered a problem since the triangulation method was employed in this study. Triangulation is a widely accepted case research method which requires collecting data from multiple information sources and posits that multi-source data will corroborate each other and increase validity (Yin 2003). Using the triangulation method, we only included information that appeared to be consistent in multiple sources. We discarded conflicting information. Each author read the interview notes and additional documents, and performed case analysis independently. We then compared individual results of the analysis and achieved consensus through debates. The remainder of this paper addresses the analysis of the data collected from interviews and documents.

PROBLEMS WITH PRE-SARS PUBLIC HEALTH PROCESSES

China's former public health information system (PHIS) has a four-layer hierarchical structure: county, city, province, and central government (Figure 2). The primary objectives of the system are disease surveillance and monitoring. Major public health data collected by the system include an epidemiology report, disease surveillance, cause of death statistics, food hygiene, environmental hygiene, school hygiene, women and children hygiene, professional hygiene, and public health resource allocation. The outbreak and spread of SARS uncovered five deficiencies inherent in the PHIS, which are summarized as follows:

Disease reporting and surveillance could not be carried out in a timely manner. Due to the hierarchical structure of China's PHIS, disease surveillance data were reported by following a bottom-up path and the reporting was performed on a ten-day or monthly basis. Despite the establishment of a virtual private network in 2000 for electronically transmitting disease surveillance data among the four layers of the PHIS, communication between the PHIS and the sites where public health raw data were collected was performed by snail mail or telephone. In addition, surveillance reports had to be approved by relevant officials at each layer before they could move up to the next layer. As a result, the reporting cycle time was prolonged and local officials' interference effected the accuracy of the reports. During the SARS event, it took an average of eight to nine days to report a SARS case from the patient's location to MOH, and three to four days to report a diagnosed SARS case from a hospital to MOH. The delayed reporting contributed largely to the rampancy of SARS in China.

The coverage of the PHIS was relatively small. The network of the PHIS comprised a variety of centers of disease control and prevention (CDC) which were at the county and above levels. Although these organizations were able to shape a national net where public health information could be exchanged in real time, the mesh was too big to catch timely disease information. Health care organizations at the grassroots level are usually the sites where public health emergencies occur; however, these organizations were not part of the PHIS network. As shown in Figure 2, epidemic information generated at the town and village level hospitals was reported manually by filling out a reporting card and mailing it to the CDC.

The information flows in care-providing organizations were inefficient. When a public health emergency occurs, it is critical to gather accurate information regarding available medical resources such as empty hospital beds, transportation, physicians on call, care givers medical devices and equipment, medication and preventive equipment, so that the emergency situation can be managed to the maximum. Because of the inefficient inter-organizational information sharing in China's hospitals as well as poor communication between hospitals and disease control organizations, the admission and transfer of SARS patients during the SARS epidemic became chaotic.

The public health regulatory system was insufficient. In China, only a few regions have established regulations to mandate and monitor the development and use of public health information systems. There was no unified regulation at the national level to ensure the efficient application and use of IS in disease surveillance and public health.

There was no standardized national platform for public health information exchange. China did not invest in the development of health information standards, coding schemes, and communication protocols. Although information systems had been widely used by health care providers, disease control and prevention organizations, and health management authorities, health information was confined inside boundaries of these entities and effective health information sharing could not be easily realized due to the nonexistence of a standardized platform.

Using the functional coupling framework, we can easily see that various players participate in the disease reporting process indirectly, with many intermediate steps, and a sequential flow of electronic and paper documents. This leads to a high degree of mediation which negatively affects timely communications, thus causing delay of appropriate responses to emergencies. In addition, the lack of inter-organizational information sharing signifies a low degree of collaboration which makes it difficult to share knowledge, allocate resources, and coordinate group activities. For instance, during the SARS crisis, due to ignorance of the outbreak of SARS, a large hospital in Beijing treated SARS patients as without taking appropriate quarantine measures, causing rapid nosocomial infection. The spread of SARS in this large hospital soon grew out of control and the entire hospital had to be quarantined for over a month. If alert information on SARS had been received from sister hospitals or the CDC, the situation could have been avoided.

These five deficiencies have fundamental implications for the containment of the SARS epidemic. First, if the epidemic information had been reported in a timely and accurate manner, the government would have paid stricter attention to this issue and SARS would have been identified sooner. Second, if healthcare organizations were more connected electronically, the reporting of suspicious SARS cases from the grassroots level would have been rapid thus precluding unnecessary morbidity. Third, had the information flow in care-providing organizations been more efficient, the SARS patients would have been better cared for with more available medical resources, thereby resulting in fewer mortalities. Fourth, if a sufficient public health regulatory system were in place before the SARS crisis, more disciplined disease surveillance and monitoring would have been exercised and earlier detection of SARS would have been possible. Finally, if a standardized national public health information platform had been established, information exchange regarding epidemic and emergency response data would have been easier and faster, which would have contributed to a better containment of the SARS crisis.

The pre-SARS deficiencies suggest that China's public health processes exhibited a high degree of mediation and a low degree of collaboration in response to the sudden outbreak of SARS. It appears that in order to cope with public health emergencies, the degree of mediation needs to be decreased and the degree of collaboration increased. According to the functional coupling framework, information systems can be used to achieve the process transformation. The next section describes China's PHEIS initiative and discusses how this IS project overcome the past deficiencies in public health processes.

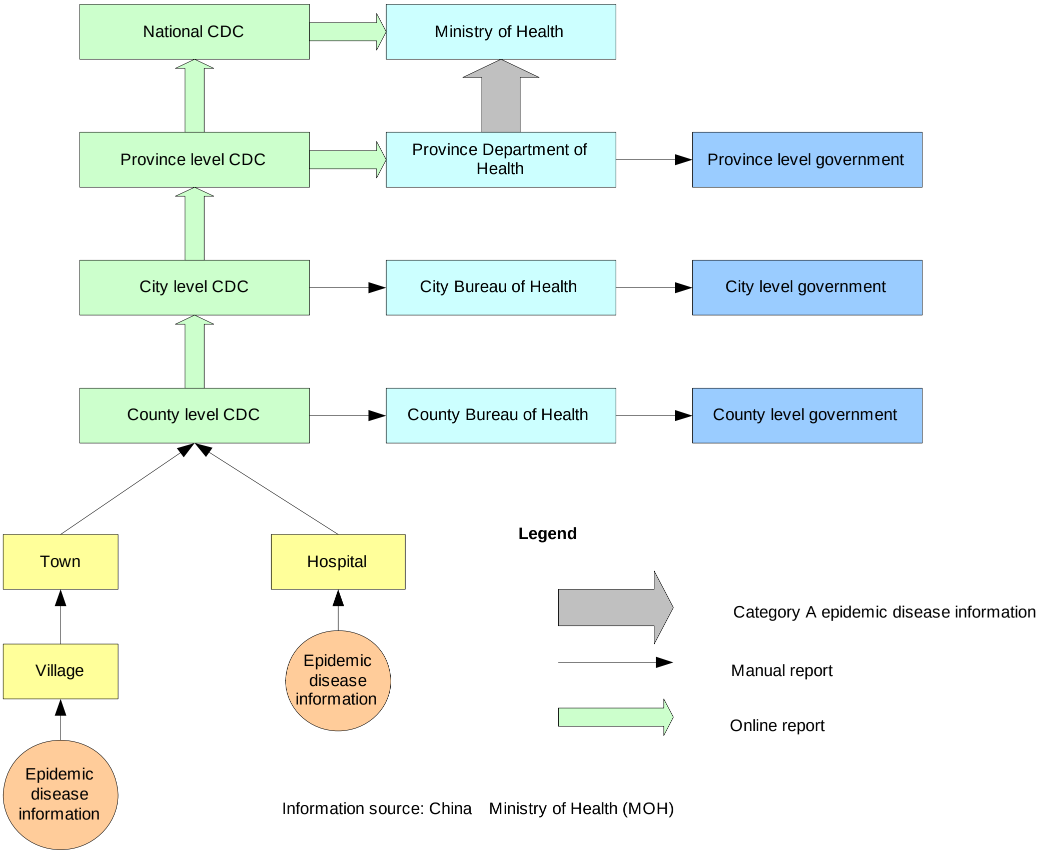


Figure 2. China's pre-SARS public health reporting systems

DESCRIPTION OF PUBLIC HEALTH EMERGENCY INFORMATION SYSTEM (PHEIS)

The development of PHEIS involves extensive efforts in constructing four components: (1) a surveillance system, (2) a command center, (3) an action system, and (4) a supporting system. Figure 3 illustrates relationships among these four components and their functional characteristics.

PHEIS development plan

The design, development, implementation, and use of PHEIS are controlled and guided by the MOH. Specifically, an IS leading team consisting of the Health Minister and major leaders of the MOH is in charge of the national public health IS development. This IS leading team organizes expert teams to develop PHEIS and lead subordinate organizations such as CDC to implement it. The first priority of the PHEIS project is to build a SARS surveillance system, so that potential SARS resurgence can be controlled. Meanwhile, other components of PHEIS will be developed to support public health.

The IS leading team has planned to complete the PHEIS project within three years. The PHEIS project encompasses three phases. The first phase, which ended at the end of 2003, mainly aimed to meet the requirements of dealing with SARS and to build the foundation for the future development of public health information systems. During this phase, CDC and health care organizations at the county level or above and some health care organizations at the village level have deployed SARS reporting systems and established SARS clinical examination and alert systems. The SARS reporting system is a secure Web-based application which allows users to report SARS cases electronically to a central database. In addition, the disease

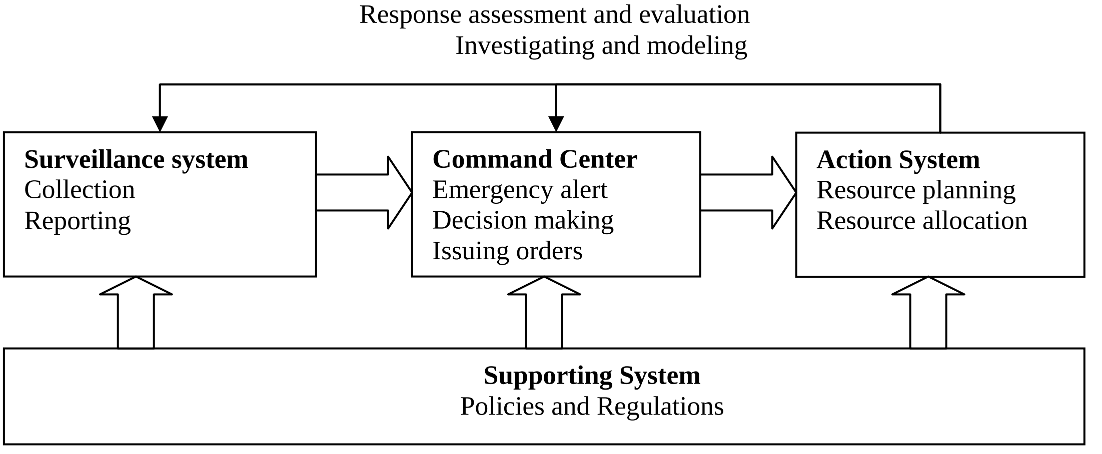


Figure 3. China's Public Health Emergency Information System (PHEIS)

surveillance system and the command center were designed in this phase and preparations were made to roll out the development of these systems.

The second phase is planned to be finished at the end of 2004. One of the major objectives in this phase is to build a national computer network infrastructure to support public health data exchange. A five-layer and three-level computer network will be constructed to connect health administrative agencies, CDC, and health care organizations at the national, province, city, county, and village levels. Another major objective of this phase is to complete the development of the disease surveillance system so that the online reporting system not only covers SARS but other epidemic diseases. Moreover, this phase will develop some national public health databases which can be used as knowledge bases for healthcare providers when they encounter public health emergencies, and to start and partially complete the development of the command center.

The third phase will be completed at the end of 2005. The objective of this phase is to finish development of PHEIS and realize information sharing and coordination among relevant organizations so that the public health emergency plan can be handled efficiently and effectively.

Surveillance system

The objective of the surveillance system is to replace periodic manual reporting with online reporting to meet the requirements of emergency alert and response. A standard national public health emergency reporting platform with an underlying central database will be implemented (Figure 4). Starting in 2004, authorized reporting individuals and organizations can report online. Health administrative agencies and CDC will be able to download reports of local epidemic events and public emergencies in real time. In order to facilitate public health surveillance, CDC at the city and county levels will develop infectious disease and public health risk factor databases. Regular updates will be made to these databases on the basis of surveillance reports and epidemiological investigations. Given that many Chinese health care workers lack the ability to use computers, training will be given along with the development of the surveillance system.

Command center

The command center integrates public health, disease surveillance, medical care, and health regulation information by using the Internet platform. It intends to use advanced information technology and management tactics to expedite the necessary information during public health emergencies. The system will monitor the entire emergency process with such functions as data collection, crisis determination, decision support, command, deployment, real time communication, and onsite support. The purpose is to make the most appropriate response to an emergency in the shortest time so that available resources can be effectively and efficiently allocated. The systems in the command center comprise three application platforms and seven subsystems (Liang and Xue 2004). The three application platforms are information, professional service, and decision-making. The seven subsystems are database system, geographic information system, remote sensing system, analysis and prediction system, virtual reality system, decision support system, and search and query system. The three platforms and the seven subsystems need to share information or exchange data on a regular basis. They are integrated together so that they can support the public health emergency response.

Action system

The action system is an important component of PHEIS. Under normal circumstances, this system is utilized to manage public health, provide medical services, facilitate emergency room services, and conduct telemedicine and other health activities. It is closely linked with healthcare, emergency rescue, and CDC institutions. Once a public health emergency occurs, the action system will report relevant information to the command center and execute orders from the command center to allocate resources such as hospital beds, medications, resuscitation equipments, telemedicine services, long distance training and other healthcare services. The action system will connect information systems implemented in organizations who participate in the emergency response process. The electronic linkage among these organizations will largely enhance the degree of collaboration of the emergency response process and facilitate the achievement of optimum emergency response outcomes.

Supporting system

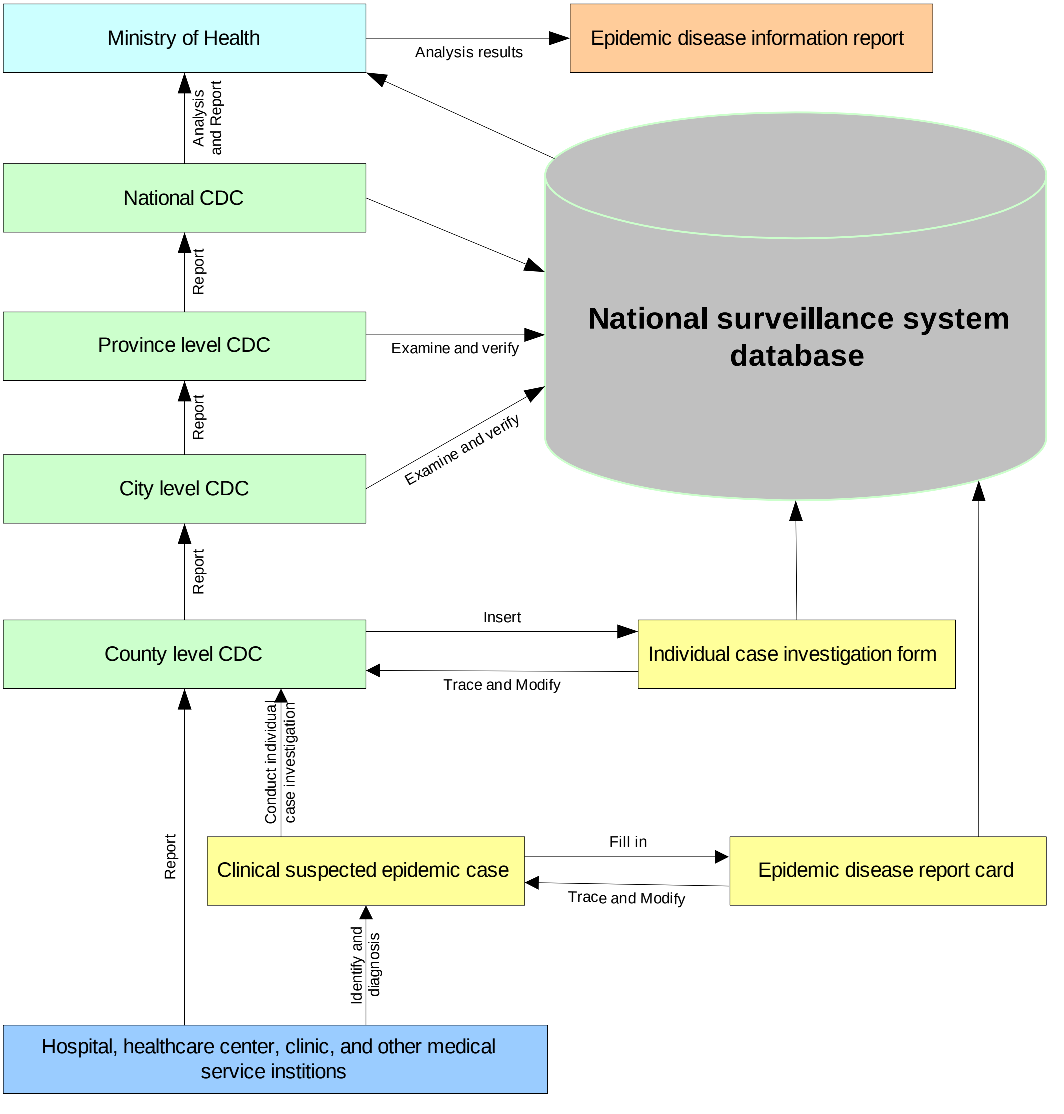
The supporting system is primarily a public health regulatory information system. The purpose of this system is to monitor the behavior of health care administration bodies and health care organizations in fulfilling their legal obligation of protecting public health. The supporting system requires the establishment of public health regulatory LAN and central databases at the provincial and national levels. All the public health supervising agencies need to connect to the two LAN through the national public data network. A standardized format of regulatory reports will be developed. Online reporting and digital data collection methods will be explored.

PROCESS REENGINEERING DRIVEN BY PHEIS

The development and implementation of PHEIS can be viewed as an IS-driven process reengineering undertaking. By leveraging IT, China will attempt to reduce the degree of mediation and augment the degree of collaboration of the public health process so that its emergency response ability is strengthened. In Figure 1, China moves from the top-left to the bottom-right cell.

One major improvement of PHEIS over the former system is the reduction in the degree of mediation. Traditionally, China exercised a strict central-control system and every task had to get approval from an administrative agency before it was performed. The local CDC and other organizations participated in the disease reporting process indirectly, with many intermediate stops, and a sequential flow of paper and electronic documents. After reengineering, the high degree of mediation will change with the help of a shared database and telecommunications networks. Reporting activities will no longer be dependent on the flow of documents. Instead, every health administration body, CDC, hospital, clinic, or other healthcare organization can participate in the process directly by communicating with the shared database. Many intermediate stops formerly required for the public health emergency data have been removed. This process, embedded in PHEIS, indicates a radical change which hopefully will lead to dramatic improvement of emergency response outcomes.

The collaboration enhancement is another critical improvement that PHEIS brings. The command center, action system, and supporting system provide an environment in which all actors involved in public health



Information source: China Ministry of Health

Figure 4. China's current public health reporting system

emergency can easily engage in collaborative efforts. In accordance with what is suggested by the functional coupling framework, China is developing telecommunications networks and shared databases to make it easier to establish collaborative relationship among various public health players. A high degree of collaboration helps players identify their roles, accomplish their jobs, and switch roles without making mistakes, especially under pressure in an emergency condition.

Specifically, the five deficiencies identified earlier could be overcome as a result of the implementation of PHEIS. First, the epidemic surveillance and reporting were carried out more quickly after the surveillance system was implemented. Second, a "five-layer and three-level" network structure is being developed as the underlying infrastructure for PHEIS, which forms a nation-wide information network connecting local users. Third, the command center and action system require healthcare organizations to build intra- and inter-organizational systems to improve information flow, so that critical information can be shared efficiently during public health emergencies. Fourth, when the supporting system of PHEIS is in place, appropriate public health emergency response processes will be codified and enforced. Finally, the PHEIS project puts considerable emphasis on the development of standards. Research on Chinese versions of health standards has already started. Given China's economic imbalance, it is unlikely that China will have the same system configuration in all regions regardless of their financial affordability. Hence, PHEIS will encompass heterogeneous local systems and system integration will continue to be a problem. PHEIS underscores the importance of standards and this will benefit China's public health IS development in the long run.

As a part of the supporting system, the State Council enacted an ordinance on public health emergency response, which codified such issues as emergency preparedness and response. According to this ordinance, when a state of public health emergency is declared, a national incident command center will be created to centrally direct emergency response activities. Local incident command centers will also be created in the involved provinces. The leaders of the State Council and provincial governments will become incident commanders who have the authority to make critical decisions. For example, one decision regards medical resource allocation. Assisted by PHEIS, the incident commander can decide how to efficiently allocate limited resources. During the SARS crisis, many hospitals did not have enough isolation wards to quarantine SARS patients and those in whom SARS was suspected, nor did they have enough infectious disease specialists to treat those patients. The incident commander designated some hospitals which had necessary resources to be "SARS hospitals" and sent all the SARS patients to these hospitals. It should be noted that hospital administrators were not expected to handle this inter-hospital problem. It was the incident commander who had the power to accomplish the job. Using the functional coupling framework, the process of transferring patients between hospitals can be seen as having low mediation and high collaboration. PHEIS is instrumental in making this happen. On the one hand, PHEIS allows first responders, hospitals, and CDC to report directly to the incident commander in real time, resulting in a low degree of mediation. On the other hand, PHEIS enables hospitals to exchange information efficiently in the course of emergency response, facilitating a high degree of collaboration.

The state ordinance on public health emergency response changed the process of epidemic reporting. It requires the utilization of the surveillance system of PHEIS to perform online reporting. The CDC provided training to healthcare professionals on how to use the surveillance system. Before the system went live on October 10, 2003, the CDC organized several rounds of rehearsals to test the system performance. The ordinance requires a SARS case or a suspicious SARS case be reported online within two hours after it is identified. Compared with the past eight to nine days reporting time limit, the online reporting process is clearly a dramatic improvement.

DISCUSSION

Critical enablers of PHEIS

The successful development of PHEIS depends on several critical enablers. First, the development of PHEIS is initiated by China's central government. The MOH issued detailed plans to direct the development and passed regulations to force the implementation. The emphasis of the central government largely legitimizes the efforts of local governments and healthcare organizations in developing PHEIS. Second, China paid a high price to learn what serious damages could be caused because of failing to respond to a public health emergency appropriately. Hence, while anticipating tremendous socio-technical challenges, China made a firm commitment to reengineer its public health system so that future public health emergencies could be managed competently. Finally, PHEIS has stable sources of support. Most investments come from national and local special funds supported by the government. The central government will appropriate about two billion U.S. dollars for the PHEIS project. Some private companies also provided support. For example, Cisco donated networking hardware, installation, and three years' technical support, which corresponds to about 2.5 million dollars, for building China's public health computer networks.

Obstacles for PHEIS

The development of PHEIS is an ongoing process. There are a few obstacles that need to be taken into account during the development process. Anticipation of possible obstacles will not only help the development of PHEIS, but give direction to future system development.

First, the economic development in China is unbalanced. While developed provinces have the financial and technical capability to implement PHEIS, underdeveloped provinces might not be able to do the same because of the lack of IT infrastructure and other resources. Second, health information standards such as HL7 and DICOM are not available in China's public health information systems. Experience in the US has suggested the important role of using the HL7 standard for public health surveillance (Tsui *et al*. 2003). With a wide range of data sources in PHEIS, technical standards should be developed to avoid confusion and facilitate information sharing. Third, the relationship between PHEIS and local health information systems is unclear. Some parts of China have established regional or community health information systems and some hospitals implemented hospital information systems. How to integrate these information systems poses a challenge. Fourth, China's healthcare system does not require a unique patient identification number. In the process of disease surveillance, it is possible that the same patient is reported many times, thus distorting the accuracy of surveillance data. Fifth, the information system management ability in China's healthcare organizations is at a relatively low level and there are huge discrepancies between regions and organizations. As a consequence, health information integration at the national level is very difficult.

Finally, it needs to be noted that the sociopolitical context in China could compromise the effective implementation of the processes embedded in PHEIS. At the beginning of the SARS crisis, the Chinese government attempted to cover up the truth. As SARS' morbidity and mortality kept climbing and domestic and international pressures increased, China changed its stance dramatically and fired two top officials, the health minister and Beijing's mayor, to demonstrate its determination in dealing with the SARS crisis responsibly. This story is cited because it suggests that political influences permeate health systems. They can affect the pre-SARS public health processes, as well as the post-SARS processes. Thus, it is advisable to pay attention to sociopolitical issues that might have a significant effect on the implementation of PHEIS.

Implications for Future Development

The development of PHEIS yields some implications for the future development of similar systems. One implication is that the functional coupling framework can be used to analyze existing processes to identify which dimension could be improved by reengineering. In China's situation, both the degree of mediation and the degree of collaboration need to be modified. For other countries, it is possible that only one dimension needs to be modified. The functional coupling framework provides an environment that facilitates determining the strategic path of transforming existing public health emergency response processes.

Mediation and collaboration problems can be solved by leveraging advanced information technologies by using the functional coupling framework. Yet simply applying information technologies might not be a total solution. As China's experiences suggest, without suitable health information standards, the power of advanced information technology cannot be brought into full play. Emergency response is about timely information transfer and accurate information interpretation. If two systems are not using the same standard, information transfer will be problematic. Standardization has long been a challenge for healthcare researchers and practitioners. Western countries have made substantial progress in this area. In order to learn from western health information standards, China is translating HL7 and DICOM specifications. The functionality of China's PHEIS is limited by the lack of standards. It is important to note that PHEIS does not have to be uniform in all regions and institutions in China. Given the heterogeneous economic development across regions, a workable PHEIS using a mixture of solutions is intended that would collectively be an improvement over the pre-SARS system. Such a system may consist of many incompatible local systems where data exchange is difficult. Therefore, future system development should emphasize the critical role of standards.

In addition to data standardization, another important consideration during any emergency response is the accuracy and the quality of the information. With reduced mediation and increasing collaboration via PHEIS, how can one be sure that the information received is accurate? In an emergency environment, when people work under a great deal of pressure, the chance of making mistakes is increased. The information sender is more likely to send inaccurate information, and the information receiver is more likely to overlook the inaccuracy of the information. The price of sharing inaccurate information during an emergency would be considerably high. Therefore, it is important for emergency response information systems to monitor data quality. The development of PHEIS does not emphasize the importance of data quality monitoring. For future system development, it is highly recommended that a quality assurance component be incorporated which allows monitoring of data quality through efficient and effective mechanisms. For continued academic research on emergency response, it will be interesting to examine how information systems can increase data quality and collaboration efficiency among different players.

CONCLUSION

This article examined issues relating to the development of China's public health emergency information (PHEIS) system. By using the functional coupling framework, some insights were provided regarding China's post-SARS public health emergency responses from a process reengineering perspective. China's former public health system had five problems: (1) timeliness, (2) insufficient networking with local users, (3) inefficient information flow, (4) inadequate regulatory oversight, and (5) lack of a standardized information platform. We illustrated that those problems led to a high degree of mediation and a low degree of collaboration. We also demonstrated how PHEIS helped overcome the five problems and enabled China's public health processes to become less mediative and more collaborative, thus more responsive to emergencies.

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