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Design and prototype of a mechanism for active on-line emerging/notifiable infectious diseases control, tracking and surveillance, based on a national healthcare card system

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A B S T R A C T

Timeliness is a critical issue in preventing the spread of emerging/notifiable infectious diseases, such as severe acute respiratory syndrome (SARS) or avian influenza (bird flu). Current computerized surveillance systems in many countries have demonstrated their usefulness in detecting specified communicable-diseases. However, the off-line, daily or weekly data reporting mode induces a time lag in data collection, transmission, processing, and responses. This paper proposes an on-line real-time mechanism, named EDICTS, for emerging/notifiable infectious diseases control, tracking and surveillance. It is based on the on-line health IC card system and works at the registration process of primary care practices and emergency departments. Hence, should a disease defined by CDC (Center for disease control) be detected at the registration station, EDICTS responds in real time. Note that EDICTS is a mechanism; it is CDC that determines the policy and activates it. A prototype is designed and implemented on a simulated environment of the Taiwan’s national health insurance IC card system. The proposed policy and rules are defined according to the CDC regulations. Timely, sensitive and cost-effective, EDICTS complements the existing successive level of CDC reporting system as a fast-response control channel.

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1. Introduction

From May to December of 2003, an outbreak of severe acute respiratory syndrome (SARS) caused a public panic in Taiwan. A report showed that Penghu pilot health IC card experimental system\([1–4]\) responded quickly and effectively to the contact information about SARS suspects, the clinics they had visited and the patients who were in the same hospitals. The contact information was sent to Taiwan’s bureau of national health insurance (TBNHI) and joined with a database to get the lodging and affiliations of those people for CDC to conduct further examination and isolation processes\([5]\). The efficacy and effectiveness of the Penghu health smart card system motivated this research, since the mechanism could be further generalized to be an on-line surveillance system to automatically monitor a variety of emerging/notifiable infectious diseases (ENID), such as SARS and avian influenza (bird flu), if health IC cards were nationally distributed.

Since timeliness is critical in preventing the spread of ENIDs and quick responses to the (possible) occurrence of ENIDs reduce infections to people and to medical institutions, many countries have their own formal mechanisms and policies for reporting and controlling such diseases. For example a 24 h delay is allowed for a medical institution to voluntarily report a suspect case to CDC in Taiwan. However, such a 24 h delay may cause infection to other people and the...
medical institutions that a SARS or avian influenza patient contacted or visited. Thus, a mechanism to help to reduce the spread of community infection and to decrease public panic is important.

This paper proposes a mechanism, named EDICTS, for emerging/notifiable infectious diseases control, tracking and surveillance, which is based on the on-line national health IC card system. A national health IC card system includes health IC cards, an IDC (IC card data center), which stores all IC cardholders’ information, PoPs (point of presence) in each medical institution and a health network that interconnects IDC and all PoPs. Generally a PoP is located at the register station, the first line of all primary care practices and emergency departments. A PoP consists of a smart card reader, a personal computer connected to the health network, and related software such as HIS (healthcare information system) and smart card application programs. It is assumed that each cardholder would show his or her card to a medical staff at the registration and that CDC defines the policies and checking rules for the patterns of emerging/notifiable diseases, which are called edicts, for EDICTS. Once CDC decides to enable EDICTS, CDC informs IDC. Upon receiving edicts from CDC, IDC disseminates them to each PoP via the network. The EDICTS residing in each PoP updates the policy. Then EDICTS at each PoP automatically monitors such clinical cases (suspect case—symptomatic cases only, not confirmed yet) by constantly checking the patterns, entered by medical staff, of patients’ visits. EDICTS acts in both sending information to IDC and to alerting the first-line medical staff, if a case should appear.

Note that a policy defines “what will be done", while a mechanism defines “how to do something", as given in [6], and that “The separation of policy from mechanism is important for flexibility.” [6]. Only the epidemiologists in CDC determine when to enable/disable EDICTS and define the rules and patterns for ENID.

EDICTS is designed to work in parallel with, not to replace, the current ENID reporting system. It serves as a fast-response control and tracking channel for ENID. EDICTS puts emphasis on preventing secondary transmission from sporadic cases and common source outbreaks. The follow-up diagnosis requires multiple test results and rigorous procedures.

EDICTS checks two kinds of information. One is the most recent medical treatment records stored in smart cards. The other is the current medical record that is to be stored into the card. In the Taiwanese national healthcare insurance IC (NHI-IC) card system (NHICS), each NHI-IC card carries the six most recent patient visits and medical treatment history. A card reader, associated with a PoP, reads the history data and sends it to EDICTS. EDICTS checks this data with CDC edicts. If there is a match, EDICTS writes a suspect case mark into the card and sends an alarm signal immediately and automatically to the PoP’s user interface. Hence clinicians are advised to refer to the suspect case description for further details of the symptoms and signs of ENID. Meanwhile the abnormal case is uploaded to IDC via the network. CDC thus has fast first-hand responses and is to able to set in motion the standard operating procedures. CDC could use the reports from EDICTS to know the contact information of the suspect cases, and therefore control and track the distribution of the ENIDs.

Some computerized surveillance schemes have been established to detect the outbreak of ENIDs worldwide. Their goals are to collect information, to identify the causative viral strains, to rapidly assess related morbidity and mortality, to predict the situation, and to redistribute certified information [7–10]. EDICTS was designed neither to detect nor to predict the outbreak of infectious diseases, though such extension is possible. EDICTS could be regarded as the mechanism to invoke after CDC has analyzed the information and determines that an emerging/notifiable disease outbreak is possible.

Sensitivity, specificity, and timeliness are important metrics in evaluating public health surveillance systems. Developers use these metrics to assess data quality and timeliness as well as more difficult questions such as which outbreaks may be detected, and how early they can be detected. EDICTS runs at each PoP, which is the best time and place to detect, report and alert staff, if there should be any cases. By the on-line (intranet) communication between each PoP, IDC and CDC, both IDC and CDC have the real-time responses from PoPs. Thus EDICTS completes a timely, sensitive and cost-effective ENID control, tracking, and surveillance systems.

The paper is organized as follows. Section 2 summarizes the background of the system. It is followed by the system design objective in Section 3 and technical description in Section 4. Section 5 is a status report of the system. Discussion and conclusions are in Sections 6 and 7.

2. Background of EDICTS

A computer-aided ENID surveillance system is essentially a system to help CDC experts make right decisions by gathering information on ENID occurrences and spread, hence to control, track, and surveillance of ENID. In the last decade, substantial investments have been made in surveillance systems for early detection of natural infectious disease clusters and of intentional acts of bioterrorism. Previous studies demonstrate that surveillance is useful in detecting specified communicable diseases. Such systems include the sentinel provider system (USA) [12], sentinel physician networks (European countries) [13], influenza surveillance system (Japan) [14], Australian sentinel practice research network (Australia) [15], epidemiological surveillance networks (France) [16], electronic point-of-sale (EPOS) pharmacy (England) [17], infectious diseases surveillance system (Japan) [18], ambulatory-care-based syndromic surveillance system (USA) [19], real-time syndrome surveillance (Canada) [20], and infectious disease prevention and control system (Germany) [21].

A categorization of computerized ENID surveillance systems by the timeliness of their response is shown in Fig. 1. Most of these systems set the types of diseases under surveillance, and report the number of diseases covered, the geographical area covered, and the population covered. However, the time delay allowed is from 24 h to a week, except that [18,20], and the proposed EDICTS are on-line. There is generally one-way communication, i.e. from medical institutions to CDC, and only EDICTS is real-time and with automatic reporting, while [20], for example, is done manually and by telephone.
The implementation of an “All-In-One” Taiwanese NHI-IC card came into effect on 1st July 2003 in metropolitan and local community hospitals. The infrastructure was fully operational on a national scale and the first phase of implementation went into effect at the beginning of 2004. TBNHI constructed IDC to manage and maintain the NHICS database and a full-time bidirectional service network (the TBNHI intranet) for connecting all PoPs to IDC [22]. Moreover, the Taiwanese experience with SARS in 2003 proved that the health IC cards can play an important role in delivering solutions to healthcare providers and patients. The NHI-IC card carries a visually and electronically readable identifier to speed access to patient information. This leads to reductions in paper work, administrative costs and entry errors. The standard operations of using IC cards at the time of registration, at the doctor’s side, and in the information infrastructure serve as a sound basis for better, faster delivery in the ENID reporting system. Moreover, the current practice of a surveillance system needs a real-time mechanism for quick spreading epidemic diseases. EDICTS is thus an appropriate mechanism that utilizes the NHICS infrastructure, in accordance with CDC policy, to deliver real-time response to ENID.

3. Design objective

With the implementation of NHICS, which works in an interconnected network, with a common platform, standardized data, exchange protocol and centralized database, and SARS surveillance experience of Penghu pilot project, EDICTS was designed to be timely, sensitive, flexible and cost-effective. EDICTS should be controlled by CDC, which decides when to enable/disable EDICTS. For increased timeliness, EDICTS should operate on-line, gets the directives from CDC and report to IDC automatically. To be sensible, should EDICTS at the PoP side detects a suspect case, EDICTS sends a message to the user interface to instantly alert the medical professionals, marks the case’s information in the NHI-IC card, and then transmits both the case’s and medical provider’s information.
to IDC and CDC. To be flexible, EDICTS is designed to be only a mechanism and it is up to CDC to determine the policies and rules, as in [6]. To be cost-effective, EDICTS is designed be operational with the current national health IC card system. Only software upgrading is required for the medical institutions, with no extra hardware costs.

The EDICTS conceptual block diagram is shown in Fig. 2. EDICTS is decomposed into EDICTS-CDC, EDICTS-IDC, and EDICTS-PoP as software components for CDC, IDC and PoPs, respectively. From the epidemiological point of view, CDC has authority over EDICTS, which is authorized by CDC to be a front-line guard in the prevention and control of ENID. The rapid and universal policy reach each PoP in the network greatly assists CDC in its aim to track and contain infectious diseases.

4. EDICTS technical description

4.1. Taiwan’s NHICS architecture outline

Taiwan’s NHICS architectural outline is shown Fig. 3, consisting of three subsystems, NHI-IC card data center (IDC), a transport network (an intranet built as a virtual private network) and PoPs [23]. The block diagram of a PoP configuration is shown in Fig. 4.

In Fig. 4, generally three different NHI-IC cards—a health insurance card (HC, readable and renewable for a NHI enrollee), a health professional card (HPC, assigned to a health professional) and SAM (for mutual authentication between HC and HPC) are required to have a NHI medical service. HIS is maintained or renewed according to the regulations from NHI. Outpatient services require the presence of IC cards, and HIS calls the standard necessary functions of the control software (CS). CS implements the standard interface that connects the PoP to the IDC and exchanges data between them. CS is maintained by TBNHI, and can be downloaded free from the TBNHI website [24]. CS has versions for MS Windows operating system, MS-DOS, SUN Solaris, Core UNIX, Linux, OS-2. CS calls a hidden standard interface driver (IFD) via RS-232 or RS-485 serial port that connects to a card reader. IFD interface calls are also defined by TBNHI.

The assumptions of EDICTS are that: (1) there is, or will be, a nation wide health IC card system connected by a network; (2) each card must be shown and read at the beginning of the outpatient procedure; (3) each card has some specific or reserved field to store the card holder’s recent medical history. The proposed policy and rules are defined according to the CDC regulations. Major components of the NHICS are NHI-IC cards, PoPs, IDC and a health insurance service network that connects all registered hospitals and healthcare providers. Based on the authors’ experiences of the Penghu health IC card project from 1996 to 2003, EDICTS functions well. The advantage of the proposed approach is that the infrastructure of NHICS is already deployed and only software enhancements to PoPs and IDCs are required. The programs on the IC cards need not change, and the HIS requires only minor modification, i.e. to take signals from EDICTS. The key component to be modified is the CS that originally serves as a standard application interface for smart cards. A TBNHI contracted company maintains the CS, and it is upgradeable from the website of TBNHI, via the VPN. The deployment cost of this would be low, since it can be done with the current upgrade/maintenance workflow.

4.2. The requirements of taking infectious precautions into the NHICS

The goal of outbreak detection is to distinguish an aberrant pattern from a normal one. Early detection of the suspect infectious case and handling by quarantine triage is the rule of thumb in reducing the spread of community infection. EDICTS in NHICS requires:

(1) A mechanism for the CDC to inform TBNHI. The later informs IDC, which then informs all the PoPs in medical service sites that use EDICTS.

(2) CDC and TBNHI define standard operating procedures for the specified diseases, such as SARS, novel influenza, scrub typhus, rabies, anthrax, and so on. TBNHI should make the procedures available to all PoPs.
Fig. 3 – Taiwan’s NHIICS architectural outline.

Fig. 4 – The block diagram of point of presence (PoP).
(3) CDC and TBNHI should invite experts to convert infectious diseases symptoms to comparative quantitative patterns and define the checking rules into electronic forms, such as XML files and text descriptions. EDICTS-PoP is given the former information to check for in an outpatient's record before or at the patient's registration process. This checking process should be automatic.

(4) If PoP detects a match between the defined patterns and the patient history on the IC card, it should write a mark into a suspect patient's HC card. This is to prevent cross infection to other clinics.

(5) Responses to TBNHI are required. The medical staffs would perform standard procedures defined by CDC and TBNHI. PoP responds to IDC and immediately uploads the patient's records to IDC on-line. They should be processed automatically without the medical site's intervention.

(6) To be adaptable to different infectious diseases, IDC is able to remotely download the necessary components to PoP via NHI VPN, such as new versions of CS and quantitative symptom patterns for one or more infectious diseases.

(7) IDC should facilitate quick collection of responses from PoPs and give EDICTS-IDC access to medical histories and possible contacts of suspect cases. From this information it is able to give references to CDC to proceed with orders for seal-off triage.

(8) An across-the-board IDC data warehouse is needed for the on-line surveillance mechanism to complete the transmission tree for individuals at higher risk of ENIDs through their occupation, close contact and medical history, or by travel to, or residence in affected locations.

(9) EDICTS-PoP should be operated with as little help from HIS (or HIS providers) as possible.

4.3. Scenario for SARS

WHO defines clinical evidence for SARS for surveillance purposes as an individual with documented fever greater than
38°C (100.4°F). A SARS patient is not infectious, either with coughing and breathing difficulties, until he or she has a fever, which is thus taken as the definition of a suspect case. The modified outpatient scenario with EDICTS enabled is described in Fig. 5.

5. EDICTS status report

EDICTS is implemented in a simulated NHI-IC card execution environment. EDICTS prototype block diagram is shown in Fig. 6. The characteristics of the EDICTS prototype are as follows:

1. Based on TBNHI standardized CS and card reader interface APIs.
2. Real card readers were used. Java card applets that conformed to SAM, HC and HPC specifications were developed, based on open card framework (OCF) and Gemplus RAD III Java card development system.
3. PoP and IDC communicated via simple object access protocol (SOAP) operating in open web standards. CS is added with EDICTS-PoP package. In the simulation of monitoring SARS suspects, the implemented class file size was 3kB.
4. EDICTS-PoP was fitted to the EDICTS scenario and sifted medical institution code (MIC) from HC outpatient records according to the incubation period.

EDICTS simplifies disease monitoring by defining two phases—a normal and an emergency phase, defined in CS API and represented by a data structure, a CDC alarm-token, in EDICT-PoP. In the emergency phase, IDC would send an alert-set-true event, download symptom quantitative patterns and update the medical institution status table (MIST). EDICT-PoP detects the event and switches to enable EDICTS automatically; EDICTS is then able to detect the infectious diseases as defined. An example screen from the EDICTS user interface on a PoP is shown in Fig. 7.

The algorithm of the EDICT-PoP is as follows.

Procedure Background Checking;

Do {

If Insert-HC-card() {
    outpatient-registration(); /* such as in an outpatient registration process */

    \( HCPI \) = read(HC.Personal Information); /* read personal information from the HC card */

    If (\( CDC\_Alarm\_Token \) == true) { /* if CDC alarms the EDICTS */

        \( PQD \) = Input(Patient-Quantitative-Data); /* read patient records and data */

        \( SQP \) = read(Symptom-Quantitative-Pattern); /* read CDC defined symptom data */

        If Compare(\( PQD.SQP \)) { /* compare personal data with CDC defined data*/

            If ICD-9-symptom-check() { /* use International Classification of Diseases, ninth revision (ICD-9) codes symptom to check */

                HIS_alarm(); /* should there be a match, alert HIS */

                Mark_HC(suspect case); /* put a mark on HC, as a suspect case */

                \( MIC \) = read(Medical Institution Code); /* get medical institution code number */

                Upload_IDC(\( HCPI, MIC \)) /* send the code to IDC */

            }

        }

    }

} While (1)
Fig. 6 – The EDICTS prototype block diagram.

Fig. 7 – An example screen from the EDICTS user interface on PoP.
6. Discussion

The main question addressed by this study is whether the spread of ENIDs is able to be controlled and traced back quickly and efficiently. With the assistance of EDICTS, the answer is ‘yes’. EDICTS suggests that an on-line full-time dedicated network is necessary for real-time data collection and transmission. In addition, a smart card as a medical identifier and storage media to provide a technical solution for accurate data processing and tracking patient pathways is also needed.

The benefits from the proposed new outpatient procedure embedded in an on-line surveillance mechanism are:

1. Automatically identifying suspect cases.
2. Protecting the medical professionals. An immediate alert is issued to the medical staff who are in close contact with the suspect case so that they can take the necessary precautions.
3. The new cross-the-board IDC data warehouse would provide information for analysis of the sources and routes of infection, either in hospitals or communities. This valuable information could also be used for future epidemiology studies on contact histories, possible contact histories and possible transmission routes, and for control and tracking the spread of the disease. Take SARS, for instance. If a SARS suspect were identified, IDC would generate reports on the patient’s medical and hospitalization history, as well as his/her personal data, such as information on family members, place of employment and address. CDC could use this information to trace the source of infection and perform control and quarantine measures. Also, this information could be released to all healthcare institutions as a reference to make early preparations for further outbreaks.

Many countries have deployed, or are going to deploy, smart IC cards in their healthcare systems. Three main objectives of such actions are to reduce in social security operating costs, to increase quality of care, and to fight against fraud. For years these systems have demonstrated their practical benefits in the public health domain. The potential of health IC card in ENID control, tracking and surveillance is still not widely applied yet, although the concept of ENID surveillance in primary care practice and emergency departments is not new. Additionally, EDICTS puts emphasis on complete first-line surveillance data collection, transmission and process in each health IC card patient visit under CDC domination.

EDICTS prototype monitors and tracks various CDC notifiable syndromes by ICD-9 code for faster transmission and less comparison time compared with text descriptions. But each syndrome generally has a corresponding case definition, a diagnostic group (a list of ICD-9 codes for validation studies), and a complaint group (a list of chief complaints being monitored) [17]. ICD-9 code has better accuracy and sensitivity than chief complaints. However, whether appropriate health decisions can be made by ruling out chief complaints is still a matter of choice between complexity and completeness, so a text file consisting of chief complaints for each suspect case for comprehensive review could be added to EDICTS to assist in CDC check up.

If a surveillance system is designed only to detect rare outbreaks or bioterrorism, its use and budget may be cut if no events occur [11]. However, EDICTS is designed to help clinicians, public health officials, and researchers automate existing data collection processes and provide new transmissions of data. It would be thus be more likely to be maintained and improved. EDICTS adds no extra network or system hardware, and EDICTS introduces a low overhead to regular outpatient procedures to perform further checking if the system is enabled.

7. Conclusions

EDICTS is a malleable and adaptable system based on the health IC card system. It surveys ENID, under the control of CDC, and responds in real-time. A prototype of EDICTS based current Taiwan’s NHICS is designed and developed to demonstrate its feasibility.

The sustainability of surveillance systems will depend on whether their usefulness justifies cost. If there is no ENID or biologic terrorism attacks, its use and budget may be diminished or even cut. EDICTS is a useful surveillance tool that requires low introduction/deployment cost and technology threshold if there is already a smart card system in place. It operates with minimal staff effort and it requires no any extra hardware devices. In the future, CDC could share the data collected from EDICTS with epidemiologists and medical institutions to promote best practice for prevention, screening, and efficiently. With the assistance of EDICTS, the answer is ‘yes’. EDICTS suggests that an on-line full-time dedicated network is necessary for real-time data collection and transmission. In addition, a smart card as a medical identifier and storage media to provide a technical solution for accurate data processing and tracking patient pathways is also needed.

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