Intelligent Infection Surveillance System to assist the Control of Healthcare-Associated Infections

Nan-Chen Hsieh [1] Jui-Fa Chen [2] Hsin-Che Tsai [3]

[1] Department of Information Management, National Taipei University of Nursing and Health Sciences
Taipei 112, Taiwan, ROC
nchsieh@gmail.com

[2] Department of Computer Science and Information Engineering, Tamkang University
New Taipei City 251, Taiwan, ROC
alpha@mail.tku.edu.tw

[3] Department of Computer Science and Information Engineering, Tamkang University
New Taipei City 251, Taiwan, ROC
shin@live.com

Received 18 September 2015; Revised 2 December 2015 ; Accepted 18 December 2015

Abstract. Healthcare-Associated Infections (HAI) are important quality indicators of healthcare, a leading cause of mortality and morbidity worldwide, and contributors to lower medical quality and increases in medical costs. Based on the definition and determining criteria of healthcare-related infections stipulated by Taiwan's Centers for Disease Control, Department of Health, we created a program for an HAI determining rule, as well as an HAI monitoring system environment. With a data warehouse and data mining techniques as the core, we integrated all HAI-related data as analytical information for the purpose of decision-making. Key decision information was presented visually in a dashboard. In this way, infection control professionals are able to peruse abundant HAI information through a visual interface at anytime, anywhere. Traditionally, operation is done manually through continuous monitoring and automatic surveillance management. Decision makers can assess measuring indicators in real-time, which is critical to the management of HAI. This also allows HAI control professionals to cross-analyze and understand potential infection trends, and assist hospitals in developing a suitable HAI monitoring mechanism. By using the developed system, we can discover healthcare-related infection abnormalities earlier and provide infection control professionals with the ability to check on and conduct pre-decision analyses.

Keywords: Healthcare-Associated Infections, Healthcare Information Technology, Automatic Surveillance.

1 Introduction

Healthcare Information Technology (HIT) is able to reduce mistakes in medication and diagnosis, help medical professionals obtain patient information in a timely manner, shorten wait times, and improve care quality for patients [1-3]. The common HIT system can help practitioners input medical advice and record prescriptions and medications; electronic medical records can catalog and maintain patients' personal health records, including medical records, inspection reports, and medical images [4]. HAI is one of the major factors leading to patient death and morbidity, as well as a substantial increase in the cost of medical care alongside a reduction in quality of medical care. Zhan and Miller [5] created a database from 28 states, approximating a 20% stratified sample of acute-care hospitals in the United States, and found that infection due to medical care was associated with 9.58 extra days, US$38,656 in excess charges, and 4.31% attributable mortality. The highest infection rates were in intensive care unit (ICU) patients. [6].

In order to create a patient-centered environment, improve the completeness of care, and increase the efficiency of monitoring care quality, an increased penetration of HIT in the care process is recommended [7]. In the medical informatics field, the use of electronic data has been found to improve the efficiency and accuracy of control HAI [8]. Surveillance has been described as an essential component of an effective infection prevention and control program, and has been shown to lead to decreases in infection rates. Surveillance of HAI is important for monitoring and measuring the burden of disease, evaluating risk factors, monitoring temporal trends, and identifying emerging and reemerging infections of changing severity. Raw data in hospital information systems is quite complex, thereby making its association with HAI difficult to locate. Traditional HAI surveillance relies on the manual review of suspected cases and tabulation of basic summary statistics. These measures are time consuming and resource intensive [9, 10]. Therefore, infection control professionals cannot readily uncover from raw data and directly identify patients at high-risk of HAI.

Traditional HAI surveillance is extremely labor intensive and tends to be performed within point prevalence surveys, which is also resource intensive [11]. Moreover, HAI surveillance often relies on the application of complex infection definitions and judgment procedures, and varies between different kinds of infections [12]. With an increasing emphasis on medical quality management, novel HAI surveillance methods must be efficient, reliable, and transferable. Emerging HIT can help to meet these challenges. Modern HIT can facilitate the automated collection of HAI-related data. The developed intelligent surveillance system of this study can meet these requirement and be recognized as a potential driver of medical quality improvement [13]. Several research have focused on the creation of data warehouses for the surveillance of HAI [14-17]. Koller et al. [18] compared the studies of conventional surveillance and automated surveillance approaches, and found that a sensitivity of 100% could be achieved when systematic errors were rectified. Automated surveillance was highly concordant with the manual surveillance method, and several studies have described knowledge-based computer algorithms.

Objectives of this study are described as follows: (1) Building a dedicated HAI database; (2) Developing an HAI system consisting of two main modules: an automatic infection surveillance module and an HAI representation module; (3) Developing a dashboard system to visually represent critical information for HAI surveillance.

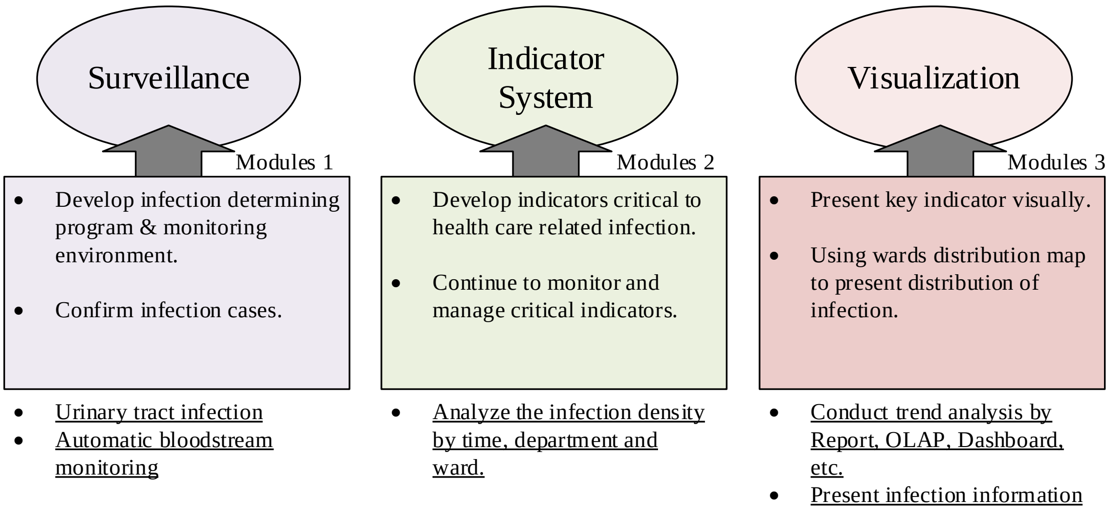

Fig. 1. Conceptual Framework

Using HIT for HAI control can reduce processing time and manpower, and fulfill real-time monitoring purposes [19]. In order to effectively execute infection monitoring, this research splits the infection control work into three modules, as shown in Fig. 1. Modules 1 and 2 were created for automatic monitoring mechanisms and indicator systems, respectively, and Module 3 was designed as a visualized module for critical HAI information representation. In addition to presenting key indicators by means of visualized charts. Key information was presented on the map for the reference of infection control professionals when making decisions.

2 HAI data Requirements

This study employed a four-stage design to develop the HAI Indicator System. The whole procedure of the developed system was divided into four main stages. Our methodological approach is illustrated in Fig. 2, and comprises the following four stages: Indicator, Integration, Implementation, and Deployment.

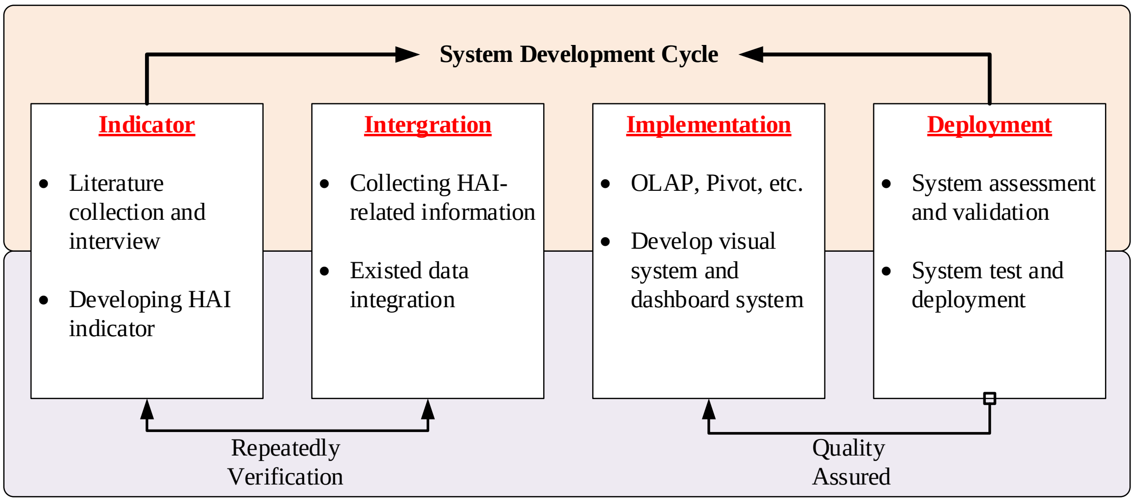

Fig. 2. System development approach

First, an indicator for the system to define issues and prepare data was developed. Data was analyzed and compiled through literature collection and interviews to develop system indicators for HAI. Second was existing data integration to collect HAI control data and integrate heterogeneous data, after which the operational definition for the indicator was set. Upon completion of the previous two stages, information was utilized to commence visualization system design and implementation. The final stage was system deployment; the system was promoted and implemented during this stage. The system was tested and deployed in HAI control rooms, and feedback was collected from directors at all levels.

Analyses and interviews were conducted in order to understand administrators' requirement. These requirement were then converted into information to benefit administrators' decision making processes. Literature information was gathered, discussed, generalized, and analyzed, then interviews were conducted with infection control professionals. Thereafter, key indicators were drafted, ultimately meeting the HAI assessment of this research. Fig. 3 shows a Flowchart for HAI indicator development.

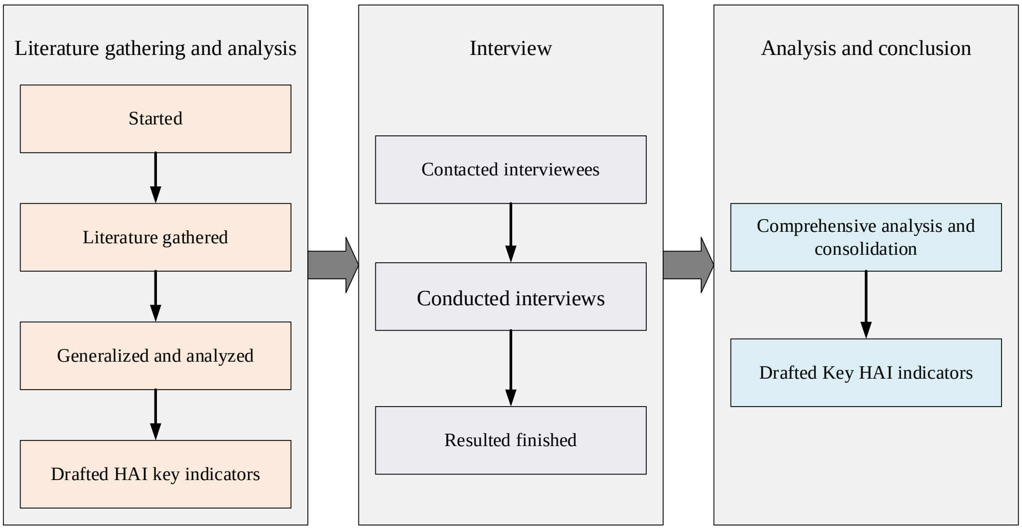

Fig. 3. Flowchart for HAI indicator development

2.1 Literature gathering and analysis

Gathering and analysis focused on developing HAI indicators. The gathered and mastered literature was relevant to "HAI monitoring indicators" and "bacteria species."

(1) **HAI monitoring indicators.** We found development and suggestions for HAI indicators, analyzed and compiled the data, and drafted preliminary HAI monitoring indicators.

(2) **Bacteria species.** We discussed the bacteria species that had most frequently been seen in hospitals over the past ten years in Taiwan and abroad. Common bacteria species were divided into two types by medical centers and district hospitals for analysis and compilation of different aspects.

2.2 Interview

Interviews with professionals were conducted on preliminarily drafted indicators using unstructured questionnaire. We focused on the interaction between researcher and interviewer to gather information, just like day-to-day dialog. In this way, we were able to obtain an understanding of how the infection control indicators are currently being applied in hospitals. Moreover, professionals were asked to select suggested and cited infection control indicators and define their definitions and common bacteria species rankings. The most common bacteria species in medical centers and district hospital ICUs were selected through researching monitoring reports spanning 2003 to 2011, published in 2011 by Taiwan's Centers for Disease Control (CDC), Department of Health (DOH). After interviews with professionals, ICUs with the most serious HAIs were selected for a detection range. The most common bacteria in urinary tract infections (UTI) and bloodstream infections (BSI) were selected, as shown in Table 1.

Table 1. The most common bacteria species in BSI and UTI in ICU

Bloodstream infection	Urinary tract infection
Acinetobacter baumannii	Acinetobacter baumannii
Pseudomonas aeruginosa	Pseudomonas aeruginosa
Coagulase negative staphylococcus	Yeast
Candida sp.	Candida sp.
Escherichia coli	Escherichia coli
Enterococcus sp.	Enterococcus sp.
Klebsiella pneumoniae	
S. maltophilia	
Enterobacter cloacae	
Staphylococcus aureus	

2.3 Analysis and Conclusion

Upon conclusion of interviews, a comprehensive analysis was undertaken over the results, and an indicator evaluation was developed in reference to the results of literature analyses. Regarding HAI monitoring indicators, according to the professional suggestions, UTI and BSI were selected. Based on these two types of infections, Indicators, Aggregated Cubes, and a Dashboard were developed, as shown in Fig. 4.

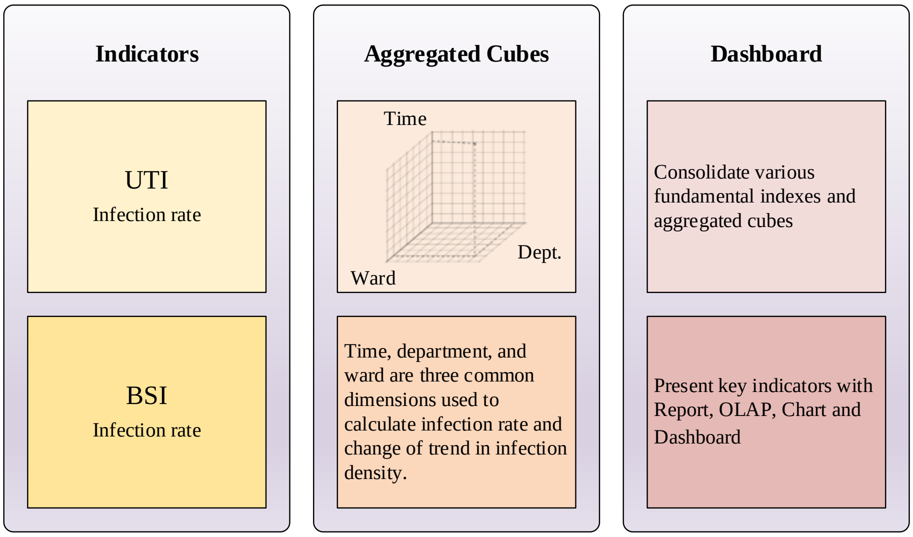

Fig. 4. Flowchart for HAI evaluation indicator development

Indicators. Infection incidence and infection density of UTI and BSI were adopted as items for fundamental indicators. UTI and BSI reference definitions of healthcare-related infections published by Taiwan's CDC, DOH serve as criteria for determining infections.

- **Aggregated cubes.** Aggregated cubes consist of three common dimensions among hospitals - time, department, and wards. The aspects of each measure are designed to provide alerts and improvement opportunities for consideration. They are used to calculate the infection rates of urinary tracts and bloodstreams and changes in trends of infection density.
- **Dashboard.** Various fundamental indexes and aggregated cubes were consolidated to present information with a dashboard.

3 HAI Control Database and Indicator System Requirements

Monitoring of HAI is usually reviewed artificially by professionals, and infection is determined in accordance with HAI criteria. Then, infected patients are admitted and their data is entered into a database. Finally, patients' data is sent to infection controllers to be double-checked. Regarding the manual infection control operating procedure, in case of infection, refer to Fig. 5, where HAI monitoring is shown as having a set of operating procedures. However, clinically, there are still subjective conditions that must rely on infection controllers' personal experiences for determination.

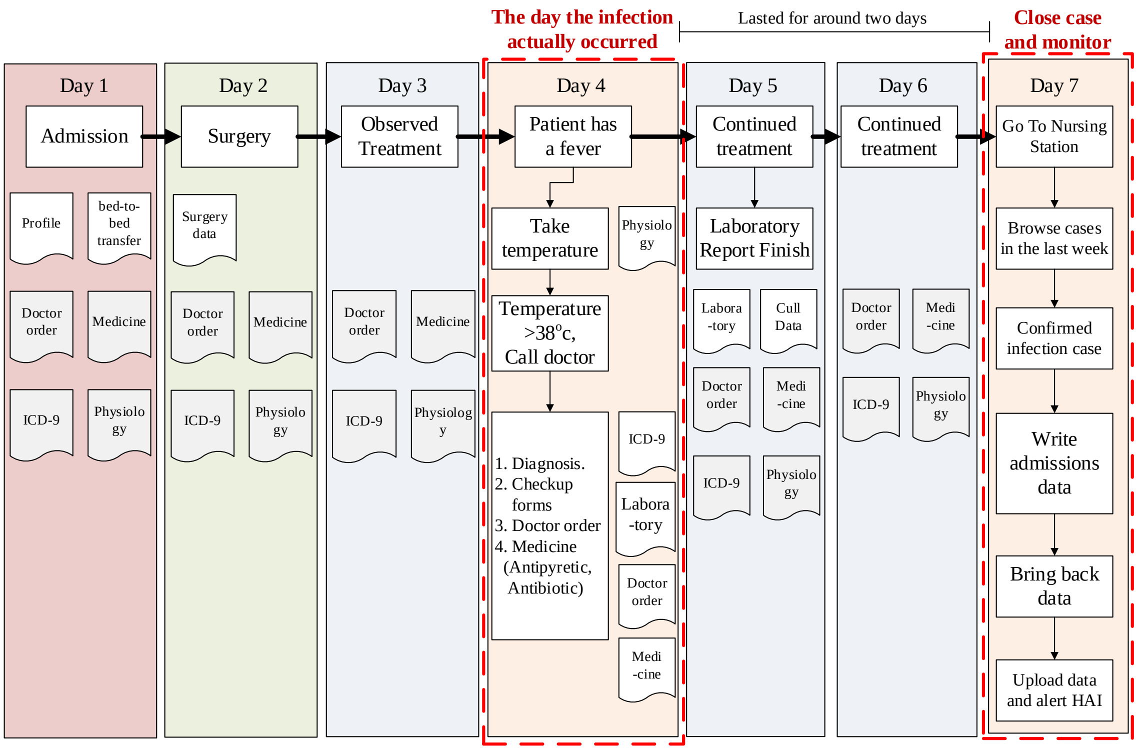

Fig. 5. Flowchart for HAI evaluation indicator development

Currently, within the infection control artificial operating process, there is usually a difference in the time between patients practically being infected to being admitted via infection controller for monitoring. HAI is unlikely to be found as a timely process. As patient severity has increased in recent years, infection control nurse workloads have gradually increased. This study actively determined the occurrence of infection using existing data in the hospital's information systems to decrease errors while infection controllers made a determination and gathered data. This can prevent a cluster outbreak nosocomial infection in a timely manner.

Data source retrieval. Infection control-related data drafted by infection controllers, as well as requirements proposed by hospital information personnel, was combined with existing data in hospital information systems. We also gathered infection control-related data files, including sick lists, basic data files, bed/department transfer data files, inspection and check reports, treatment and doctor's advice files, medication data files, diagnostic code data files, and biological data files. The data was converted and integrated in order to monitor HAI occurrence.

Data integration. We proceeded with the following three steps – confirm data transfer need, pre-data transfer preparation, and execution of data transfer. A relational database was also adopted.

(1) Confirm data need. We gathered infection control files on a daily basis, including sick lists, basic data, bed/department transfer data, inspection and check reports, treatment and doctor's advice files, medication data, diagnostic code data, and biological data.
(2) Data integration preparation. After the target data was confirmed, we began to create a database. This included related data sheets, and relations between these sheets were established in accordance with principles. By excluding repeating and discordant dependency, every attribute needed to relate to an index key. Every data sheet described an entity type (e.g. patient, doctor's advice, medication, etc.), began to write a file transfer program, and tested its accuracy to ensure that no data was lost during the process of data transfer.
(3) Execute data transfer. After the end of pre-transfer operations, export, import, and transformation were conducted using Data Transformation Services (DTS). This was to transform source files to SQL Servers. The integrity and accuracy of the data was verified after the transfer, and the development of the system then proceeded.

The purpose of setting an evaluation goal was to have a comprehensive understanding of the needs in decision-making and indicators of organization. Moreover, it attempted to improve upon healthcare-related infections and understand healthcare infection tendency. From that point, we could proceed to provide a reference for common standards and information technology personnel in stock-taking fields of the database in the information system.

3.1 Indicator Definition

After infection evaluation indicators were set, specific criteria for definitions of formulae were required, including selection of numerator and denominator. In general, the indicators of general display adopted were infection rate (No. of infected persons / No. of hospitalized (discharged) persons) × 100% and infection density (No. of infected persons / No. of days of stay) ×1000‰. The entire healthcare-associated infection rate can be used to evaluate the general situation of HAI and rationality of distributing hygiene resources. However, in regards to healthcare-associated infection rate, number of hospitalized (discharged) persons served as the denominator. Uncorrected patients were considered different problems of risk. In a healthcare associated infection rate, number of days of stay served as the numerator. The healthcare-associated infection rate corrected the problem of days patients were hospitalized. Therefore, the infection rates of BSI, UTI, and infection density were chosen as base indicators.

Infection rates were calculated as follows (Table 2):

(1) Total infected persons: accumulative total of persons who were infected after being hospitalized during the monitored period (excluding persons who had been infected during hospitalization)
(2) Total hospitalized person-times: accumulative total of persons who were hospitalized every day during the monitored period

Table 2. Infection rate of each part in hospital

Indicator	Calculations
BSI	(Total of person-times infected by bloodstream / total of hospitalized person-times) *100%
UTI	(Total of person-times infected by urinary tract / total of hospitalized person-times)*100%

- Number of person-times hospitalized when they were going through the hospitalization procedure after emergency treatment. However, those who had not gone through the hospitalization procedure after emergency treatment were calculated into emergency treatment person-times.
- If patients changed departments during the period of hospitalization, they were merely counted one hospitalized person-time; if they changed beds, one additional hospitalized person-time after bed change

was counted. In cases where they returned to the bed from which they came, if they did not go through the hospitalization procedure again, they were not counted twice.

- When there was a shortage of chronic general beds and acute general beds were borrowed, they were counted into hospitalized person-times in chronic general beds. On the contrary, when there was a shortage of acute general beds and chronic general beds were borrowed, they were counted into hospitalized person-times in acute general beds.
- Beds used by day-care, such as beds for use in the daytime in the Department of Psychiatry, were not counted in hospitalized person-times.

Infection density is calculated as follows (Table. 3):

(1) Total infected person-times: accumulative total of person-times infected after being hospitalized during the monitored period

(2) Total days of stay: accumulative total of person-days every day during the monitored period; only inpatients who had gone through the hospitalization procedure were counted. Only admission was counted; discharge was excluded. Persons who were admitted and discharged on the same day counted as one day of stay.

Table 3. Infection density of each part in hospital

Indicator	Calculations
BSI	(Total person-times infected by bloodstream / Total hospitalized person-times)* 1000‰
UTI	(Total person-times infected by urinary tract / Total days of stay)* 1000‰

- When patients changed departments or beds during the period of hospitalization, if the original bed was kept, the person-days of stay for these two beds were counted at the same time. If the original bed was not kept, only the person-days of the newly occupied bed were counted.
- When there was a shortage of chronic general beds and acute general beds were borrowed, they were counted into the person-days of stay in chronic general beds. On the contrary, when there was a shortage of acute general beds and chronic general beds were borrowed, they were counted into the person-days of stay in acute general beds.
- Beds used during day-care, such as beds for use in the daytime in the Department of Psychiatry, were not counted in hospitalized person-times.

3.2 Definition of Aggregated Cube

The Aggregated Cube was used to calculate change of trend in monitored infection rate and infection density with three different dimensions frequently used in hospitals – time, department, and ward. Relations between the three could determine dimension hierarchies. In this study, data sheets had two dimension hierarchies: the time analysis dimension and department ward analysis dimension. The time analysis dimension, as shown in Fig. 6, monitored frequencies on a constant basis daily, weekly, monthly, quarterly, and yearly.

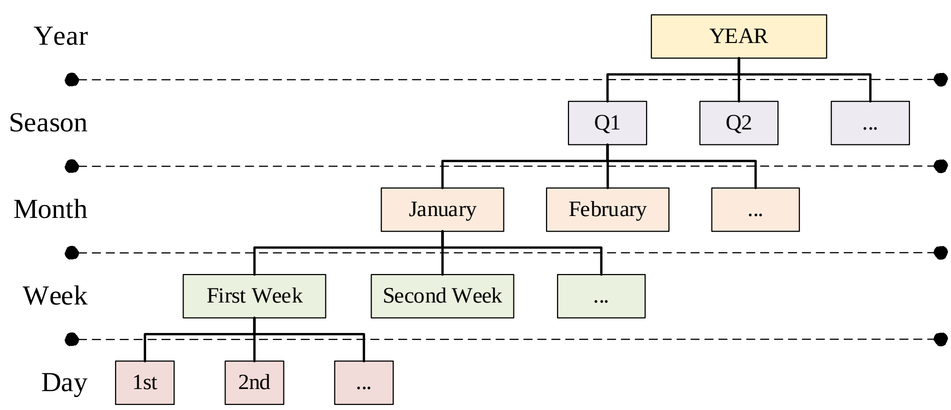

Fig. 6. Time analysis dimension

The department ward analysis dimension, as shown in Fig. 7, was used in the surgical department, medical department, department of gynecology and pediatrics, otolaryngology department, emergency, etc., and totaled 60 departments. Ward dimension included comparing and monitoring 89 wards.

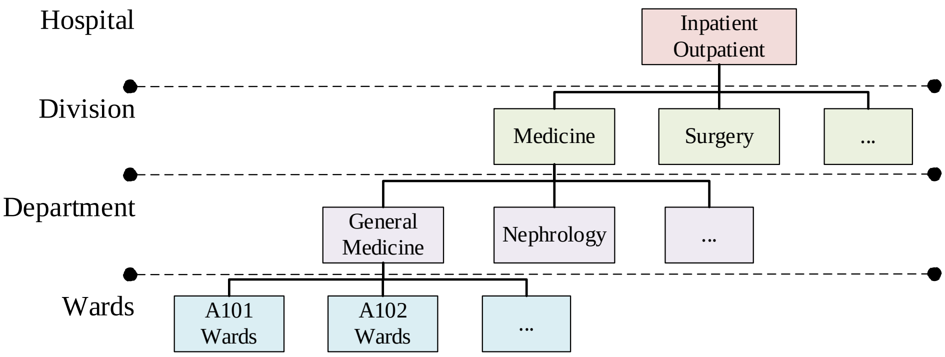

Fig. 7. Department ward analysis dimension

4 HAI Control System Implementation

The HAI control system architecture is shown in Fig. 8 and described in detail below. The first tier is the Infection Detection Tier. According to HAI definitions published by the CDC, DOH, an infection surveillance program was created. The second tier is the Index System Tier, which includes basic indexes and aggregated cubes used to calculate BSI and UTI. The third tier is the Visualized Interface Tier, which was designed to present all indexes to users with Report, OLAP, Charts, and Dashboard. Then, it presents patients who were infected or relevant bacteria species.

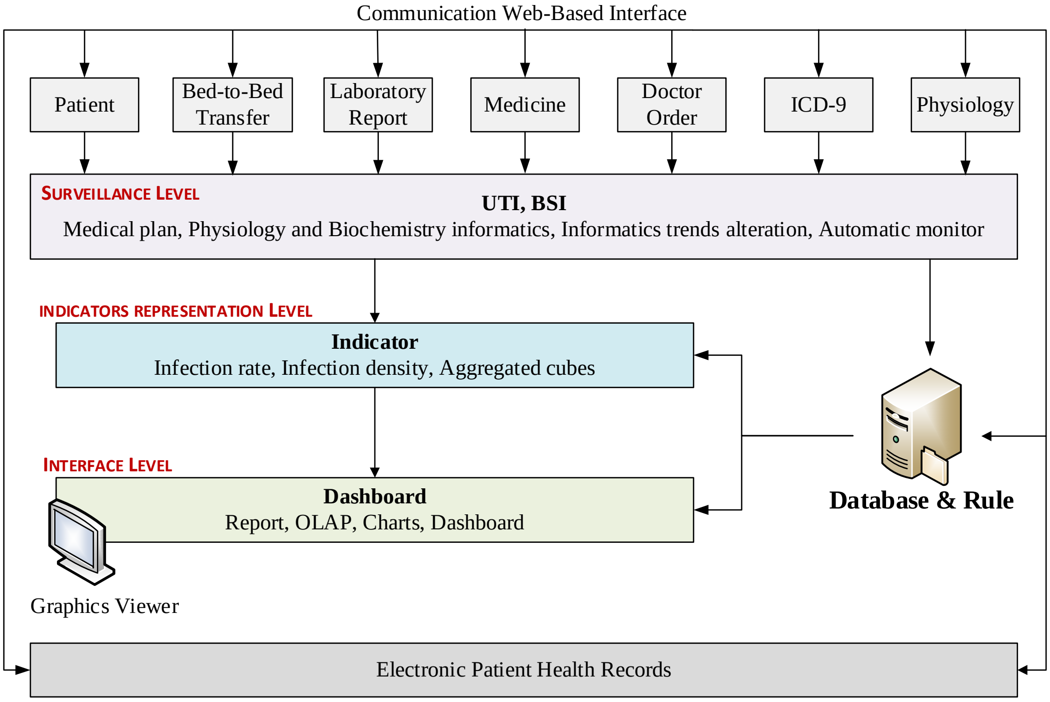

Fig. 8. HAI System architecture

Patient files imported to hospitals were integrated to extract infection-related data for data transfer. Then, according to HAI definitions, a program determination was conducted to automatically detect patients with UTI and BSI. This infected patient-related data was imported to the database to present infected person-times in the form of a report.

The design process is described in detail below:

- **Step 1:** Conceptual design of surveillance decision trees. The structure of the decision tree is similar to a binary tree, which has a root node; each node has a left and right child node. The decision tree's nodes store not only numeric values, but also text. If a node is a numeric value, then the value of the left node must be smaller than the right node. We designed the tree structure as database fields to record the relationship between nodes.
- **Step 2:** Decision tree design. We employed a depth-first traversal algorithm to implement the recursive call of the decision tree.

4.1 BSI Automatic Monitoring Regulation Rule

The automatic monitoring system included BSI monitoring as shown in Fig. 9. The determination rules will be described below respectively.

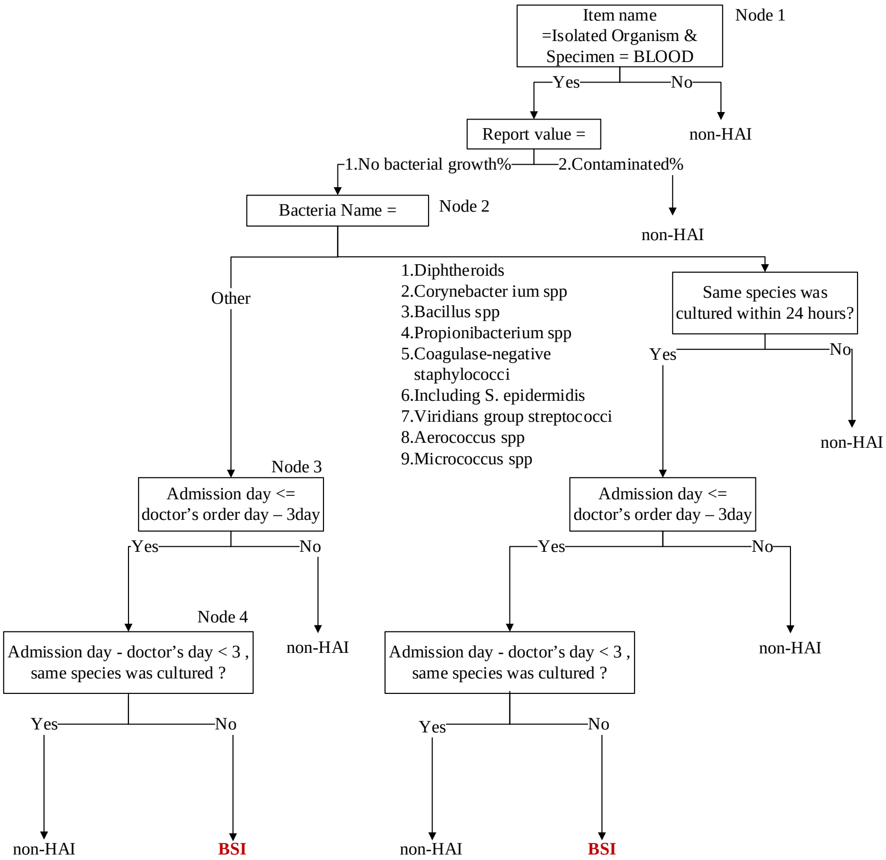

Fig. 9. BSI monitoring rule

- **Determination Node 1:** At least a set of blood had been cultured to confirm the infectious agent. The infectious agent was not related to other infected parts. Therefore, in the inspection report, we identified an inspection item named "Isolated Organism" with a "Blood" specimen. Program conditions were designed as [Inspection item name] = "Isolated Organism" and [Specimen] = "Blood". Blood culture had two types: one was a species with infectious agents and the other a result of being bacteria-free. Therefore, we needed to exclude the bacteria-free result. The program conditions were designed as "inspection report value" <> "No bacterial growth" and [inspection report value] "Contaminated".
- **Determination Node 2:** Determined if the bacteria name was diphtheroids, Corynebacterium spp, Bacillus spp, Propionibacterium spp, coagulase-negative staphylococci, including S. epidermidis, viridians group streptococci, Aerococcus spp, or Micrococcus spp. If one of the aforementioned, then it was determined if the same species was cultured within 24 hours.
- **Determination Node 3:** Determined if the patient had been hospitalized for over 48 hours. The program was designed as [admission date <= advice created date -3 days]. Then, subsequent determination proceeded.

- **Determination Node 4:** Excluded existing or latent infection at admission. The program was designed as determining [admission date – advice date < 3 days has same species]. If determined to be an existing or latent infection at admission, it would not be counted into HAIs.

4.2 UTI Automatic Monitoring Rule

The automatic monitoring system included UTI monitoring as shown in Fig. 10. The determination rules will be described below respectively.

- **Determining Node 1:** Urine culture colony count ≧ 10000/ml, with no more than two species of microbes cultured. Program design was [Colony Count] >= 100000 and Count [Isolated Organism] < 2.
- **Determining Node 2:** Urine culture colony count fell between ≧ 1000/ml and ≦ 10000/ml, with no more than two species of microbes cultured. Determined if leukocyte esterase or nitrite was positive or pyuria (non-centrifugal urine regular check WBC ≧ 10/mm3). Program design was [Colony Count] >=1000 and [Colony Count] ≦ 100000, and [Nitrite] = ‘ + ’ or [WBC/PUS] ≧ 10.
- **Determining Node 3:** Determined if the patient had a fever or overly low body temperature. Then, the advice issue date from the patient’s inspection report was retrieved. Next, the patient’s bio-information file was searched three days before and after the advice issue date to find [VATAL SIGNS type] as TMP. And [Value 1] > 38 or [Value 1] < 36. If one of the items was found, it would be determined a symptom of UTI.
- **Determining Node 4:** Determined if the patient had been hospitalized for over 48 hours. Program design was [admission date <= advice issue date -3 days], then proceeded to subsequent determination.
- **Determining Node 5:** Excluded existing or latent infections at admission. Program design – determined [admission date – advice date < 3 days – if it has the same species]. If yes, it was considered an existing or latent infection and not counted into HAIs.

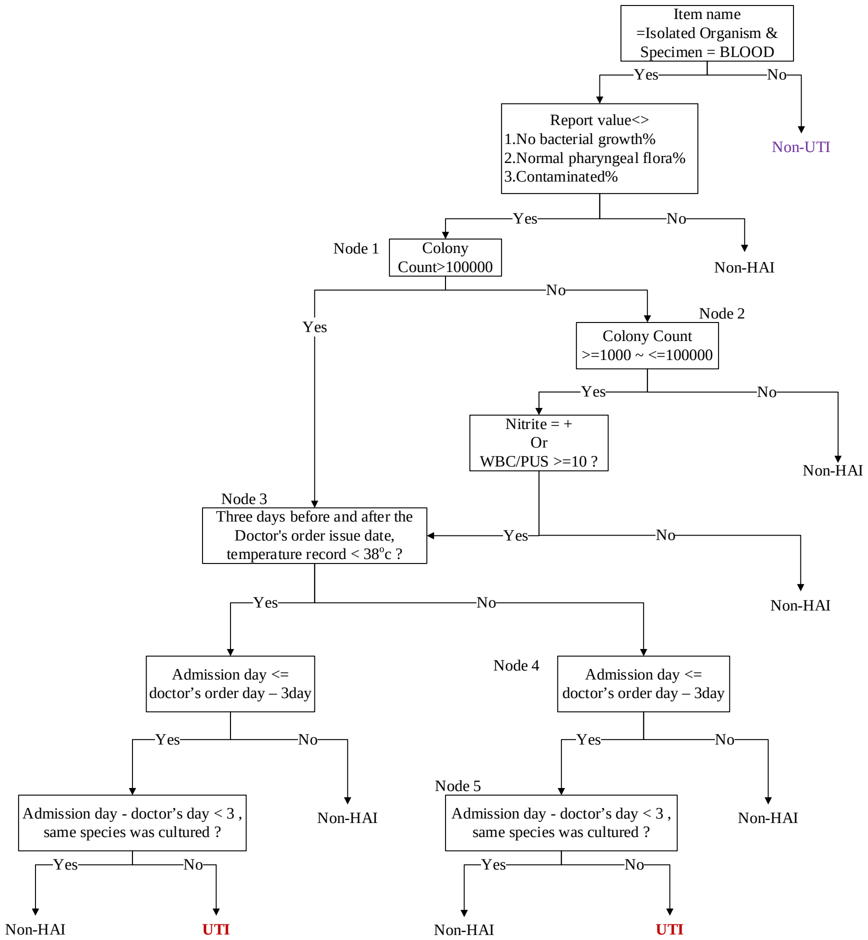

Fig. 10. UTI monitoring rule

The decision tree logic judgment is in Step 3 and on the next page the respective sample code is shown; decision tree judgment logic is used to determine the case time of results output. The judging process will call their code, and when the node type is "results" it will output UTI. If node type or node location cannot be found, it will output "Non-HAI".

Example is a Computer Program.

```
Function RecursiveTree(String parentnode, String LeftOrRight)
IF(readnote)
{
  Switch nodetype
    Case Question:
          readEvaluate
          If(Judgment value at LeftRule)
                       RecursiveTree(node,Left)
          Else If(Judgment value at RightRule)
                       RecursiveTree(node,Right)
          Else
                       Response ''Non-HAI''
          Break;

    Case Dimensions:
          ReadEvaluate
          If(Judgment value <=LeftRule)
                        RecursiveTree(node,Left)
          Else If(Judgment value <=RightRule)
                        RecursiveTree(node,Right)
          Else
                        Response ''Non-HAI''
          break;
    Case Result
          Response ''UTI''
          break;
    Default:
              Response ''Non-HAI''
              break;
}
Else
{
  Response ''Non-HAI''
}
End
```

4.3 System interface

The Visualized Interface Tier presents key indicators with Report, OLAP, Chart, and Dashboard, respectively.

(1) **Report output.** Report data was used to show requirement data in a two-dimensional table. System allowed user to choose a data range, report options, and infection parts for multi-dimensional dynamic query and hierarchical analysis. Infection person-times, infection rate, and infection density were compiled to allow the user to further check patients' related information and infection case information record sheets.

(2) **Online Analytical Processing.** An online analysis concept was utilized to present chart analysis data. An analysis on infection person-times, infection rate, and infection density using date, department, and ward was conducted. Finally, through online data analysis reports, infection person-time charts, infection density curve diagrams, bacteria species distribution charts, and gender and age distribution charts, an infection comparison was presented. An online data analysis report was made through the date dimension, and monitoring began for the entire hospital's infection rate and infection density. The user could narrow data to month, department, ward, etc., to allow the infection controller to monitor from large scale to minute details and identify units with worse infection control.

(3) **Charts.** Infection person-time charts provide three dimensions–date, department, and ward–to act as main observation objects. From the point of time dimension, it was found that UTI person-times were more general than BSI person-times every month. Only one month's BSI increased abnormally. The infection density curve showed its infection trend as times changed, and highlighted the infection peak period. In addition to helping controllers effectively monitor infection rates, this also allowed clinical personnel without statistical concepts to rapidly understand the trend of change in infection rate. When

infection density increased abnormally in the hospital, an investigation would be undertaken over the cluster outbreak event and effective infection control measures would be adopted, as shown in Fig.12 and Fig.13. An infection bacteria species distribution chart allowed infection controllers to check the distribution of bacteria species in different parts. By way of distribution charts, infection controllers could see at a glance which species were the most numerous in healthcare-related infection, and whether bacteria species had an outbreak increase.

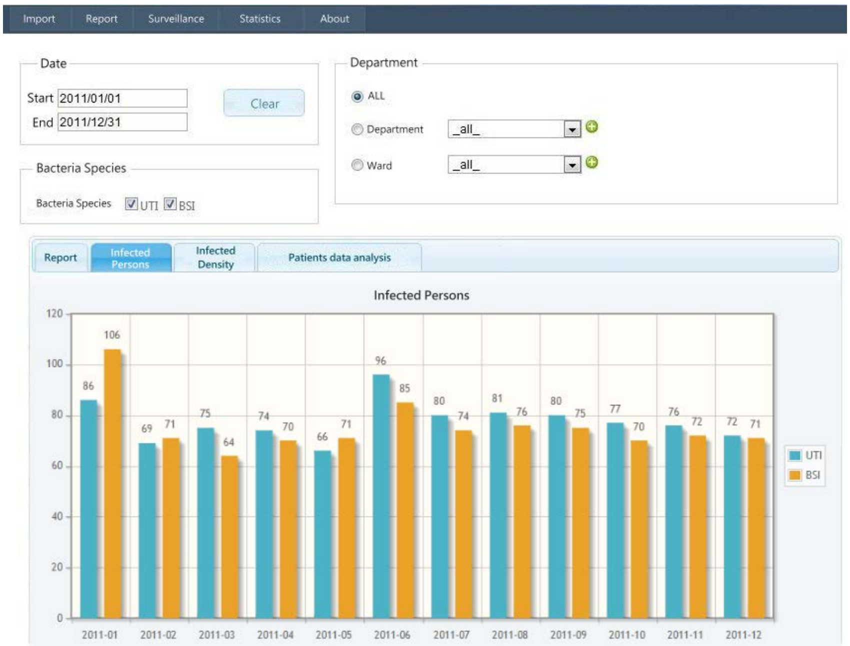

Fig. 12. Infected Persons chart

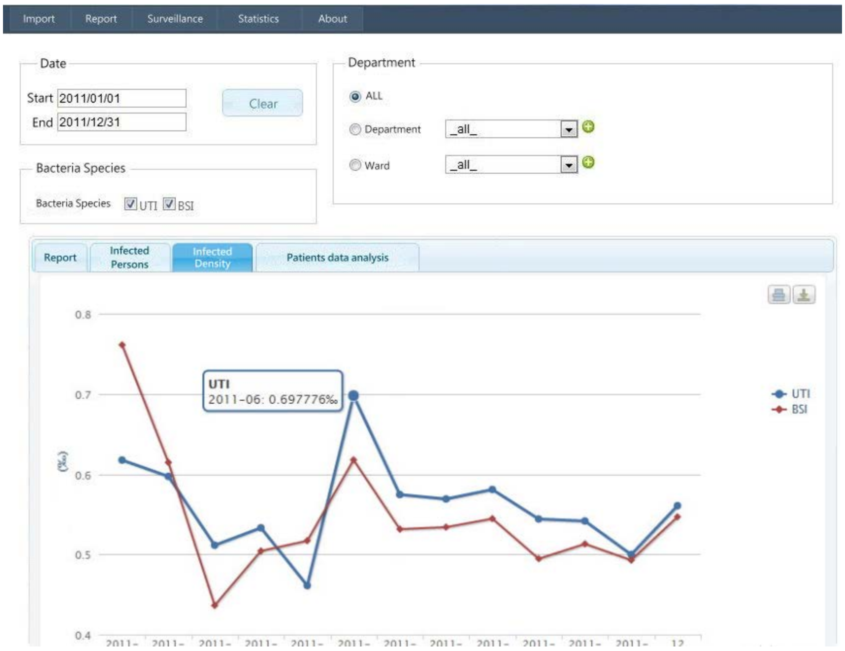

Fig. 13. Infected Density chart

(4) **Dashboard.** Dashboard's dynamic visualized interface can quickly communicate huge and complicated data with users and concentrate large quantities of data within a single chart on one page. It can intuitively develop infection evaluation indicators and assist high-ranking managers to define, present, monitor, follow-up, analyze, and manage all key indices and immediately control the most important level in the data. It allows the user to quickly understand how infections are taking place and more

effectively measure and manage the state of infection. This research used HAI threshold values as a key indicator. In Fig. 14, each unit's infection density of the past three years was averaged; these values are shown in red, yellow, and green for their meanings. Green was defined as within the threshold value and stands for a normal infection density. Yellow was defined as exceeding the threshold value by one standard deviation and stands for a higher infection density, with which the unit should submit an improvement solution. Red was defined as exceeding the threshold value by two standard deviations and stands for an infection density exceeding standard. The unit should work together with the infection control room to submit an infection control improvement solution.

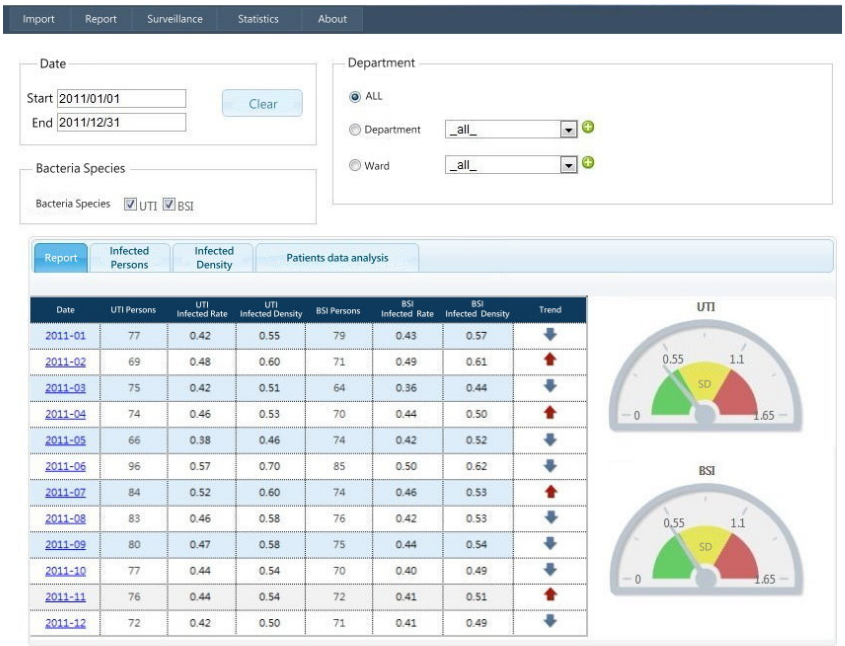

Fig. 14. Dashboard for infection trends

5 Results and Discussions

HAI is a major factor causing reductions in patient treatment quality and increases treatment cost. In addition to assisting with information gathering, storage, analysis, and report, information technology may also engage in quality improvement through continuous monitoring and management. This allows the decision-maker to utilize large quantities of complete information to cross-analyze and grasp its trends. This is reduce potential mistakes, enhance monitoring ability, and hold back a cluster breakout nosocomial infection in a timely manner.

The contribution of this study is to develop an intelligent infection surveillance system for the monitoring of HAI. Compared to traditional HAI surveillance that relies on the manual review of suspected cases and tabulation of basic summary statistics, the developed system provides an automatic surveillance mechanism and uses information technology for infection control that can aid infection control staff in finding HAI in a timely manner. Thereby, it enhances the effectiveness of infection recognition, improves patient safety, and reduces the workload and cost of HAI. Moreover, the built system represented indicators in the form of Report, OLAP, Chart and Dashboard. A visualized geographic information system interface presented critical information on maps to help infection control staff make decisions and prevent the cluster of nosocomial outbreaks. This study merely employed bacteria as a reference variable and mapped a possible HAI situation by means of bacteria propagation. In the future, if nurse's work schedules or antibiotics can act as a reference variable, it is believed that the effectiveness and accuracy of HAI can be further enhanced and controlled.

Acknowledgement

This research was partially supported by Ministry of Science and Technology, R.O.C. (MOST104-2221-E-227-001).

References

[1] D. W. Bates, M. Cohen, L. L. Leape, J. M. Overhage, M. M. Shabot, T. Sheridan, "Reducing the frequency of errors in medicine using information technology," *Journal of the American Medical Informatics Association*, Vol. 8, pp. 299-308, 2001.

[2] D. Liu, N. G. Castle, "Health Information Technology in Nursing Homes," *Journal of Applied*, Vol. 28, pp. 38-58, 2009.

[3] M. Y. Wu, W. Y. Huang, "WSN-based Health Care Management Platform for Long-Term Care Institutions," *JCIT: Journal of Convergence Information Technology*, Vol. 7, pp. 303-311, 2012.

[4] B. A. Hamilton, "Evaluation design of the business case of health information technology in long-term care : Final report," Baltimore2006.

[5] C. Zhan, M. R. Miller, "Excess length of stay, charges, and mortality attributable to medical injuries during hospitalization," *Journal of the American Medical Association*, Vol. 290, pp. 1868-1874, 2003.

[6] S. K. Fridkin, S. F. Welbel, R. A. Weinstein, "Magnitude and prevention of nosocomial infections in the intensive care unit," *Infectious Disease Clinics of North America*, Vol. 11, pp. 479-496, 1997.

[7] B. Chaudhry, J. Wang, S. Wu, M. Maglione, W. Mojica, E. Roth, S. C. Morton, P. G. Shekelle, "Systematic review: impact of health information technology on quality, efficiency, and costs of medical care," *Annals of Internal Medicine*, vol. 144, pp. 742-52, May 16 2006.

[8] R. S. Evans, R. A. Larsen, J. P. Burke, R. M. Gardner, F. A. Meier, J. A. Jacobson, M. T. Conti, J. T. Jacobson, and R. K. Hulse, "Computer surveillance of hospital-acquired infections and antibiotic use," *Journal of the American Medical Informatics Association*, Vol. 256, pp. 1007-1011, 1986.

[9] S. E. Brossette, A. P. Sprague, W. T. Jones, S. A. Moser, "A data mining system for infection control surveillance," *Methods of Information in Medicine*, Vol. 39, pp. 303-10, 2000.

[10] W. E. Trick, B. M. Zagorski, J. I. Tokars, M. O. Vernon, S. F. Welbel, M. F. Wisniewski, C. Richards, R. A. Weinstein, "Computer algorithms to detect bloodstream infections," *Emerging Infectious Diseases*, Vol. 10, pp. 1612-1620, 2004.

[11] H. M. Glenister, L. J. Taylor, C. L. Bartlett, E. M. Cooke, J. A. Sedgwick, C. A. Mackintosh, "An evaluation of surveillance methods for detecting infections in hospital inpatients," *Journal of Hospital Infection*, Vol. 23, pp. 229-242, 1993.

[12] T. Haustein, P. Gastmeier, A. Holmes, J. C. Lucet, R. P. Shannon, D. Pittet, S. Harbarth, "Use of benchmarking and public reporting for infection control in four high-income countries," *The Lancet Infectious Diseases*, Vol. 11, pp. 471-481, 2011.

[13] L. R. Peterson, S. E. Brossette, "Hunting Health Care-Associated Infections from the Clinical Microbiology Laboratory: Passive, Active, and Virtual Surveillance," *Journal of Clinical Microbiology*, Vol. 40, pp. 1-4, 2002.

[14] M. Apte, M. Neidell, E. Y. Furuya, D. Caplan, S. Glied, E. Larson, "Using electronically available inpatient hospital data for research," *Clinical and Translational Science*, Vol. 4, pp. 338-345, 2011.

[15] L. Garcia Alvarez, P. Aylin, J. Tian, C. King, M. Catchpole, S. Hassall, K. Whittaker-Axon, A. Holmes, "Data linkage between existing healthcare databases to support hospital epidemiology," *Journal of Hospital Infection*, Vol. 79, pp. 231-235, 2011.

[16] A. Tinoco, R. S. Evans, C. J. Staes, J. F. Lloyd, J. M. Rothschild, P. J. Haug, "Comparison of computerized surveillance and manual chart review for adverse events," *Journal of the American Medical Informatics Association*, Vol. 18, pp. 491-497, 2011.

[17] C. Bellini, C. Petignat, P. Francioli, A. Wenger, J. Bille, A. Klopotov, Y. Vallet, R. Patthey, G. Zanetti, "Comparison of automated strategies for surveillance of nosocomial bacteremia," *Infect Control Hosp Epidemiol*, Vol. 28, pp. 1030-1035, 2007.

[18] W. Koller, A. Blacky, C. Bauer, H. Mandl, and K. P. Adlassnig, "Electronic surveillance of healthcare-associated infections with MONI-ICU--a clinical breakthrough compared to conventional surveillance systems," *Stud Health Technol Inform*, Vol. 160, pp. 432-436, 2010.

[19] M. S. van Mourik, A. Troelstra, W. W. van Solinge, K. G. Moons, M. J. Bonten, "Automated surveillance for healthcare-associated infections: opportunities for improvement," *Clinical Infectious Diseases*, Vol. 57, pp. 85-93, 2013.