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# The design and evaluation of an antimicrobial resistance surveillance system for neonatal intensive care units in Iran

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ABSTRACT

*Introduction:* Neonatal intensive care units (NICUs) have complex patients in terms of their diagnoses and required treatments. Antimicrobial treatment is a common therapy for patients in NICUs. To solve problems pertaining to empirical therapy, antimicrobial stewardship programs have recently been introduced. Despite the success of these programs in terms of data collection, there is still inefficiency in terms of analyzing and reporting the data. Thus, to successfully implement these stewardship programs, the design of antimicrobial resistance (AMR) surveillance systems is recommended as a first step. As a result, this study aimed to design an AMR surveillance system for use in the NICUs in northwestern Iranian hospitals to cover these information gaps.
*Methods:* The recommended system is compatible with the World Health Organization (WHO) guidelines. The business intelligence (BI) requirements were extracted in an interview with a product owner (PO) using a valid and reliable checklist. Following this, an AMR surveillance system was designed and evaluated in relation to user experiences via a user experience questionnaire (UEQ). Finally, an association analysis was performed on the database, and the results were reported by identifying the important multidrug resistances in the database.
*Results:* A customized software development methodology was proposed. The three major modules of the AMR surveillance are the data registry, dashboard, and decision support modules. The data registry module was implemented based on a three-tier architecture, and the Clinical Decision Support System (CDSS) and dashboard modules were designed based on the BI requirements of the Scrum product owner (PO). The mean values of UEQ measures were in a good range. This measures showed the suitable usability of the AMR surveillance system.
*Conclusion:* Applying efficient software development methodologies allows for the systems' compatibility with users' opinions and requirements. In addition, the construction of interdisciplinary communication models for research and software engineering allows for research and development concepts to be used in operational environments.

## 1. Introduction

The discovery of antimicrobial agents in the 20th century resulted in better control strategies for bacterial infectious diseases and led to a dramatic decrease in related morbidity and mortality. Unfortunately, antimicrobial resistance (AMR) arose in clinical environments after this discovery, and this resistance increased rapidly in the 1990s. Currently, most microbial infections are exacerbated by AMR [1]. In most cases, AMR-related infections require long-term treatment; this treatment comes at a high cost and requires longer hospitalization and more patient–doctor visits [2]. In developing countries, AMR is an important factor in the management of infections [3].

The implementation and monitoring of intervention systems to optimize the efficiency of existing or accessible antimicrobial agents is critical, as the development of new agents has been extremely slow in the past 20 years [4]. Recently, antimicrobial stewardship programs (ASPs) were introduced. To successfully implement ASPs, the responsible organizations first recommend the strengthening of the AMR surveillance systems' design [5,6]. In 2013, the World Health Organization (WHO) reported that only 33 of 133 studied countries had

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comprehensive systems for the surveillance of AMR [7]. In recent years, local, regional, and national AMR surveillance has been performed in some countries and WHO-covered regions. Despite the success of these programs in terms of data collection, inefficiencies remain concerning analyzing and reporting these data. Such inefficiency and the lack of standardized methods for collecting, analyzing, and reporting AMR data by local, regional, and national management results in the inability to map a worldwide picture of AMR trends and events.

In 2015 and 2016, the WHO published the Global Antimicrobial Resistance Surveillance System (GLASS) in various axes to establish a uniform foundation for the development of AMR surveillance systems across countries. GLASS aimed to support a standardized approach in collecting, analyzing, and reporting AMR data on a global level. The system focuses on the support of local activities and decisions, as well as national and regional operations [8,9]. Thus, it requires global collaborative strategies; elsewhere, national and international data have been missed, and the monitoring strategies have failed [10]. Due to the importance of AMR surveillance and the implementation of surveillance systems integrated with national and global surveillance systems, 68 members of the World Health Assembly confirmed a global operational AMR combat plan in 2015. One of the core objectives of this plan was to reinforce evidence-based management via global surveillance.

Neonatal intensive care units (NICUs) have complex patients in terms of their diagnoses and required treatments. Antimicrobial treatment is a common therapy for patients in NICUs. To solve problems pertaining to empirical antimicrobial therapy, ASPs were recently introduced. Continuous planning is required in NICUs to obtain comprehensive descriptions of infants' required treatments. The United States Centers for Disease Control and Prevention (CDC) established a campaign consisting of 12 steps to prevent AMR during treatment. However, these steps were not developed specifically for use in NICUs [11].

As mentioned above, antimicrobial therapy represents an important treatment for patients in NICUs. Considering the lack of specificity in terms of the clinical signs of infection in infants, as well as the effects of severe infection and its rapid spread across systems, healthcare providers must perform rapid treatment rather than waiting for lab results, for example, from antimicrobial susceptibility tests. Because of the vulnerability of infants to a variety of pathogens, a combination of antibiotics is used; however, this pattern of treatments leads to AMR [12]. Thus, this study aimed to design an AMR surveillance system for use in the NICUs of northwestern Iranian hospitals. This system considers the core elements of biosurveillance systems, including data collection, analysis (statistical and intelligent), and reporting (using dashboards and geographical information systems [GIS]) modules. The developed system is fully compatible with GLASS.

## 2. Materials and methods

This developmental study follows from previous descriptive studies conducted by our research team that determined the important axes of AMR surveillance systems. A knowledge, attitude, and practice (KAP) study [13,14] was used to propose, design, and describe the architecture of an AMR surveillance system based on business intelligence (BI) indicators. In the current study, an AMR surveillance system for use in NICUs was designed in accordance with the Scrum methodology proposed by Hicks and Foster [15]. The designed system was a pilot implementation based on our proposed national framework [13], which we adapted to NICU departments. This framework is a comprehensive model for implementing AMR surveillance systems in all clinical domains by using the recommended requirement analysis methods.

The study was conducted at the Iranian Ministry of Health, while the system was designed and evaluated at Tabriz University of Medical Sciences. The Koodakan, Taleghani, and Alzahra educational hospitals were selected for implementation of the system, as they have fully equipped NICUs. Alzahra Hospital has 50 NICU beds, while Taleghani Hospital has 25, and Koodakan Hospital has 25. On average, 900, 1200, and 1700 annual infant admissions are registered at Taleghani, Koodakan, and Alzahra hospitals, respectively.

In this study, first, an innovative architecture for the implementation of biosurveillance systems was recommended. Then, to apply both knowledge discovery and visualization methods, the BI requirements were extracted by an interview with a Scrum PO using a predesigned reliable and valid checklist [16]. Some intelligent algorithms were applied based on the extracted requirements [17]. Next, the system was designed and implemented. Some initial results from data gathered in the system were described. Statistical and intelligent analysis on collected data were performed to extract the resistance rate and level multidrug resistance. We applied statistical diagrams and association rule mining in the dashboard and CDSS module to extract frequent itemsets. The Apriori and naïve Bayes algorithms were implemented in the core of the CDSS module.

Finally, the AMR surveillance system was evaluated according to the users' experiences. In addition, the usability of the system was assessed quantitatively via the user experience questionnaire (UEQ) [18], which was completed by 11 skilled users in three pediatric hospitals. The system was then compared with other systems.

## 3. Results

### 3.1. AMR surveillance content and axes

The results of the focus group discussion held in the previous KAP study are shown in Fig. 1. We determined seven major AMR surveillance topics in eight managerial axes, as follows: surveillance methods in AMR, priority specimens, priority samples, priority pathogens and microbial agents, test methods and reporting scheduling, and recommended datasets and reporting protocols/tools. Other important axes, such as the information flow and priority pathogen/antimicrobial combinations, were not included due to the high volume of other content included. More details are available in Safdari et al. [19].

### 3.2. The BI requirements of the AMR surveillance system

A checklist was developed by our research team to extract the BI requirements. Table 1 shows the results of the requirement analysis of the AMR surveillance system for use in NICUs. These requirements were embedded in the software modules. This table shows part of the product backlog determined in Scrum for Research (SCORE).

In the current study, the SCORE methodology was used to follow agile development, and the Scrum framework was customized based on the limitations of the research team. Nine iterative and incremental steps were defined in the final methodology.

### 3.3. System architecture

The major modules of AMR surveillance systems are the data registry, dashboard, and decision support modules. The data registry module includes a minimum dataset and special data elements (for enhanced surveillance), with the aim of collecting data quickly and accurately. This module was constructed in Microsoft Visual Studio 2015 with the Windows Presentation Forms, Language Integrated Query (LINQ), and Model-View-Controller (MVC) in a three-tier architecture. Based on the selected architecture, the data access tier, business tier, and user interface (UI) tier were coded for each sprint. The data model was designed and mapped in SQL Server 2012. Fig. 2 shows a screenshot of the final data registry module. Access control policies were implemented based on different actors. Furthermore, the data were recorded in the seven following categories: admission, risk factors, assessment, interventions, disease and diagnosis, lab and examination, and discharge. This module includes basic reports using the search toolbox.