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Introduce an Enhanced Hospital Information System Reference Architecture with ATAM Evaluation

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Abstract—**Hospital information system, as an integrated system consists of complex, diverse, and heterogeneous information systems, which supports all clinical, administrative, and financial activities of patients; therefore, it faces interoperability problems, which is a critical feature of data sharing and integration. In this regard, a reference architecture will be presented for the integration of different systems in the hospital which comprises system, information and software architecture. This architecture emphasizes interoperability with eight layers of user interface and application, services, data collection and storage, integration, external application systems, communication and information infrastructure, management, and security/privacy, based on service orientation. It will be evaluated by ATAM method, based on ten scenarios. It shows the presented architecture will satisfy all functional and non-functional requirements such as interoperability between different information systems, reduction of information redundancy and development cost and time, scalability and accessibility.**

Keyword: Reference Architecture, Evaluation, Hospital Information System, SOA, Interoperability, ATAM, Integration.

Article type: Research Article

I. Introduction

Hospital Information System (HIS) is defined as the socio-technical subsystem of a hospital, which supports all financial/official and clinical activities of patients using various and heterogeneous information systems [1]; The primary goal of it is collaborate, share and interoperate with other systems in order to optimize development, reduce costs, Redundancy of information and errors. therefore, due to this variety and heterogeneity (in terms of programming language, operating system, database, the type of hardware and software), HIS has faced a lack of interoperability; The problem of interoperability represents an obstacle to HIS due to the heterogeneity and complexity of the management of health care and healthcare institutions [2-4]. Therefore, there is no data or process sharing, and each system stores and manages its data, which leads to data integrity issues and decreases the effectiveness of data for decision-making and analysis. In addition, it leads to high operational costs due to the increased need for maintenance [5].

However, it should be noted that HIS, not only is integrated but leads to improving efficiency, customer satisfaction, error reduction, communication between

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employees increase, and service effectiveness increase with low cost and time, also must provide accurate information to all patients in a cost-effective way, to facilitate accurate and immediate decision making [6-9]. So successful development of HIS depends on information systems integration inside and outside the hospital [10]. Therefore, there are different types of different architectural models for health information systems; in the following, some of these models will be briefly introduced.

Xi Luo et al. [11], presented the design of a hospital operation management system using business and financial integration, whose main goal is to improve the efficiency of service quality in the hospital through patient management, planning, resources, financial, and reporting modules. Gazzarata et al. [12], had designed an SOA-based platform to support clinical data sharing. This platform is used to collect, store and share clinical data, providing capabilities such as data standardization, security, access control, and identity management. Also, this platform can exchange data between different organizations and institutions.

Garises et al. [5], presented a reference architecture for big data infrastructure in the Namibian health information system. This architecture is inspired by two key concepts, service orientation and virtualization, based on the Lambda architecture, which consists of five components: data provider, router, process, and storage engine, system grouper/aggregator, and data consumer. Delgado et al. [13], presented the xIPAMS architecture, which is an abstract architecture based on FAIR aspects. This architecture has modules like User Application, Workflow Process Management, Authentication Service, Content Service, Authorization Service, Search Service, Policy Service, Protection Service, Reporting/Tracing Service, and Certification Authority.

Benedict et al. [14], proposed a reference architecture for integrating patient pathway systems into patient portals. In general, modules are divided into three categories: core modules, path-specific modules, and path-related modules. Celesti et al. [15], presented an architecture based on OAIS for managing big health data in health information systems using cloud technologies, whose implementation approach is NOSQL. Lu X et al. [16], Architecture presented the hospital information system architecture, which focuses on three aspects of data integration, workflow integration, and functions integration.

Braghin et al. [17], presented the CAR2X architecture, which is a modular and scalable web-based application that is open source and integrates different types of services, processes, and data used in a healthcare system; and Wambura [18], also added the clearance component architecture to CAR2X, which is a 4-layer structure that includes a database, DBMS-independent services, several libraries for the correct behavior of the fourth layer, and a set of components for managing processes and workflows.

Hsieh et al. [19], presented the integration steps of the hospitalization information system with other components of NTUH like; LIS, PIS, and RIS, whose architecture includes four layers of FRONT END, protocol, middleware, and BACK END. Konstantinidis et al. [20], presented an architecture for development of clinical information systems that is performed by the iterative software engineering method, which includes five layers such as; presentation, application or program, business, data access, and persistent storage.

Ziminski et al. [21], proposed a hybrid HHIEA architecture that integrates several HIS by using a variety of architectures. This architecture includes five data layer gateway, ID management, HIE management, security layer, and health service gateway. Nijeweme et al. [22], presented the design of an e-health reference architecture based on interoperability in primary healthcare organizations. This architecture includes four layers of display services, functional services, middleware services, and data services.

Tummers et al. [23], presented the reference architecture of health information systems based on four perspectives of context, analysis, layering, and deployment. Grimson et al. [24], SynEx and Synapses projects can be considered as the first mature approach to federal health records that is open-source. Brown et al. [25], presented VISTA, which provides open-source clinical, administrative, and financial functions for Veterans Health Administration hospitals and clinics.

Moshiri et al. [26], presented an integrated hospital information system architecture focusing on clinical information systems (CIS) based on the interoperability model, which includes three architectural models: reference, software and information.

However, it is very important to provide an appropriate architecture to meet the needs of the system. In this regard, the architecture presented in the study [26] was investigated, and it was found that its evaluation and implementation is difficult due to three architectural models. Therefore, this paper intends to present an improved architecture based on presented architecture in [26]. This reference architecture will be based on SOA, which facilitates communication between diverse and heterogeneous financial and clinical information systems so that accurate and on-time information is available to healthcare providers. In this regard, in order to make the improved architecture suitable, it will be evaluated before implementation using the ATAM scenario-based method; In addition, this evaluation method emphasizes non-functional requirements that have the greatest impact on system architecture and can be implemented in four main stages and nine phases.

The structure of the article is as follows; in section II, concepts such as hospital information systems, interoperability, software architecture, reference architecture, and evaluation will be introduced. In section III will present an overview of the related works that have been conducted in the field. In Section IV, the research method employed in this study will described. The proposed architecture will be presented in detail in section V. Section VI will focus on the evaluation of the proposed architecture. In section VII, a comprehensive discussion of the findings and implications of the study will be provided. The conclusion drawn from the study and suggestions for future research will be presented in Section VIII.

II. Background

A. Hospital Information Systwm (HIS)

According to Figure 1, the term hospital information system refers to the concept of independent information systems which focus on integrated support such as; patient registration, transmission, reception, discharge, and other official, clinical, and financial functions. The main aim of HIS is to improve the quality and management of clinical care and hospital healthcare in clinical processes, analysis, and costing based on activities. One of the main HIS advantages is also patient care improvement and cost decrease; moreover, it can improve the quality of patient care by increasing the timeliness and accuracy of administrative records and information. In addition, HIS standardization improves cost control through efficiency and productivity betterment, and increases patient information security. Thus, HIS is expected to provide the exact information to the right people, in the right place, at the right time, and in the right way to improve patient care by evaluating data and making appropriate decisions [7, 10].

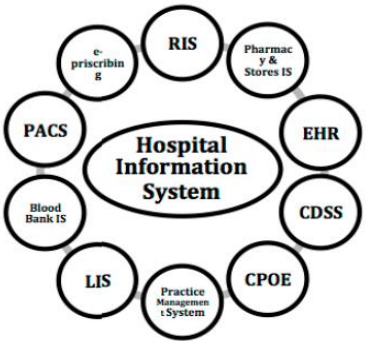

Figure 1. Shows integrated HIS [10]

B. Interoperability

Interoperability is one of the essential factors in the health area, which indicates the ability of information systems to communicate, exchange data, and use exchanged data. It emphasizes four technical, syntactic, semantic, and process dimensions and is considered the main prerequisite of integration [7, 10]. Because, integrity is a critical aspect (while coping with related data and information with geographically distributed organizations), which enables environmental intelligence by providing communication between Information Technology (IT) components inside and outside the organization [27].

- **Technical interoperability:** It refers to the connection between computers and includes subjects like technical infrastructure, technical architecture pattern, data exhibition, secure services, data exchange, connect and access services, and communication technologies.
- **Syntactic interoperability:** It is associated with the format of messages exchanged among different applications and systems. The message sender and receiver encode and decode data in a message using syntactic rules specified in some grammar. Syntactic interoperability issues arise when the sender's encoding rules are incompatible with the receiver's decoding rules.
- **Semantic interoperability:** It ensures that the exact framework and meaning of exchanged data and information are comprehended and have a sensible meaning. In other words, what is sent must be something that can be understood. Some problems arise when the message sender and receiver have different conceptualizations or representations of entity types, properties, and values from their subject domains.
- **Interoperability of processing or organization:** This is the highest level of interoperability, which examines the possibility of integrating processes and business flows beyond the organization's boundaries. Its success requires success in the three previous levels. Therefore, it deals with the compatibility between the business requirements of the cooperating parties described through business objectives, business rules, and organizational policies. Moreover, they must have a common concept of provided services and the field in which these services are used.

C. Software Architecture

Software architecture is the first step in information system development that shows how to solve the problem and how to build the system; it's also a critical and successful factor in expanding complex systems and provides the evolution of the system. It can be ensured by designing and choosing the appropriate architecture that the functional and non-functional requirements of the system are met. It's an important point to choose architecture appropriately, because changing it after design costs a lot. It should be mentioned that the way system components organize expressed by architecture is called Pattern. So Pattern can be assumed as a set of rules that dominates an architecture, which Pattern used for architectural limitation, coordination, and cooperation of architects, by focus on specific qualitative features and examining analytical models, predicts the effect of special decisions and architecture change. The most important architectural Patterns are Layer, Component-based, Publisher/Subscriber, Model-View-Controller (MVC), Service Orient (SOA), Enterprise Service Bus (ESB), Microservice (MSA), Data Warehouse, Federation, Replication, Centralization, and Cloud Computing [28, 29].

D. Reerence Architectural (RA)

In today's software development landscape, the complexity of software has been increasing, necessitating efficient and effective software design processes. This, coupled with the need for seamless interoperability between systems, has led to a growing role for reference architectures in the software design process. Reference architectures are designed to facilitate system design and development across multiple projects. While there is no universally accepted definition for software reference architectures, they can be understood as reference models that define the division of functionality and data flow between different components. In essence, a reference architecture maps this reference model onto software elements that work together to implement the defined functionality, along with the data flows between them.

This comprehensive definition acknowledges the generic nature of reference architectures while emphasizing their software-specific characteristics. It encompasses the essential architectural elements that should be incorporated into the design and recognizes the existence of various types of software reference architectures [30].

*E. **Evaluation***

Information system architecture evaluation and analysis to recognize the possible risks, validation of quality requirements in design, and reduce the risk of failure in system implementation, which include four approaches: scenario-based, mathematical-based, simulation-based, and experience-based reasoning [31]. Among the proposed methods, the scenario-based approach is simpler and more flexible, and it can be executed at different stages of the software development process in which the system architectural capabilities are evaluated based on a set of demanding scenarios [32]. It describes the qualitative characteristic understandably and determines whether the architecture can implement the requested scenario. Among the methods mentioned in this approach are: SAAM, ALMA, SAAMCS, ESAAMI, ATAM, ALPSM, SACAM, ASAAM, DOSAM, SBAR, SALUTA, CBAM, and FAAM [33].

III. Related Work

This section include summarizes the works related to the study regarding architecture evaluation by ATAM method.

Gumbo et al. [34] Presented a hospital information system architecture implemented in Nigeria. This system is responsible for maintaining and handling the electronic patient record and producing various reports for health management and research goals. The architecture of this system is two-layered (data server and user program). The purpose of using ATAM here is to evaluate the performance of the system.

Zeinali et al. [35] Presented a conceptual model of interoperability in health information systems which based on the HSB approach and works as an integrated infrastructure to facilitate interoperability. The purpose of using ATAM here is to evaluate the non-functional requirements of interoperability and extendibility, which shows that the adoption of web service technologies is an effective way of interoperability between health information systems.

Asosheh et al. [36] Proposed a framework for combining service-oriented architecture and cloud computing with ERP. ATAM evaluation method is used, to evaluate this framework based on the non-functional requirements, comprehensiveness and maintainability, which shows the implementation of this framework could have a great effect on increasing the speed of data interaction between independent software systems with lower cost, greater availability, and higher security.

Setareh et al. [37] presented a cloud computing architecture for integration of hospital information systems. This architecture is based on service-oriented architecture, which enables easy access for all system components, including service providers and organizations. To evaluate the proposed model, the ATAM evaluation method was used, which showed that the use of cloud computing technology is an effective way to integrate health information systems.

Putrama et al. [38] Presented the data center architecture to organize and coordinate the information received from different systems. The evaluation of this architecture, which is ATAM method has been used based on non-functional requirements such as access, security, performance, compliance, modifiability and reliability, which concluded that meeting the requirements related to strength, ease of implementation and maintenance of the system requires improving security and reliability.

Szwed et al. [39] Reported the application of ATAM method for primary evaluation of dynamic map architecture. A dynamic map is a complex information system that consists of spatial databases and stores static and dynamic data related to urban traffic. According to the complexity of the system, the size and importance of its services compared to other subsystems with two scenarios was done by ATAM, which showed different stakeholders agree with the proposed system architecture (including adaptability and changes with limited costs).

Lee et al. [40] described the evaluation and improvement of the VAN-Core system architecture, which requires 24/365 performance for online credit card transaction services. The purpose of evaluating this system architecture by the ATAM method based on requirements such as performance, security and safety, operability, usability is to indicate risk reduction strategies for the identified risks and propose architecture improvements.

IV. Methology

In this research, an improved Hospital Information System Reference Architecture (HIS-RA) was presented based on the Pros-RA process [41], which according to Figure 2, includes four stages; selecting and reviewing information sources, identifying the requirements of the reference architecture, designing the architecture, and evaluating. In the following, the way to perform these four steps for HIS-RA is explained.

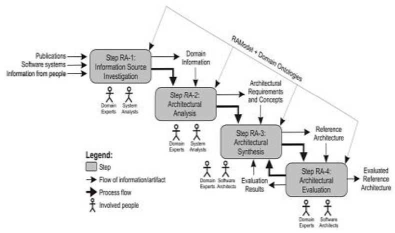

Figure 2. Steps to create a reference architecture [41]

1) Selection and review of information sources

Due to the complexity, diversity, and heterogeneity of different types of information systems in the hospital, which has led to interoperability problems, various types of integrated architecture of information systems in the field of health, interoperability frameworks, and evaluation methods were collected, and Survey.

2) Architectural analysis

A list of different types of requirements (functional and non-functional) was identified in line with the integration of HIS [10, 26, 42, 43], then this list was checked by several information technology specialists in the Nikan and Imam Khomeini Hospitals in Tehran by consensus of experts, which led to the deletion, addition and modification of the final requirements in Table 1.

3) Architectural synthesis

Indeed, a reliable HIS-RA is needed because it can provide; integrate medical information, protect data privacy and secure sharing, provider control over data, real-time traceability of data operations, facilitate accountability, and different medicine inter-institutional interoperability so that information is available in an accurate and timely manner. Therefore, the proposed architecture in Figure 4 emphasizes the of interoperability and is based on SOA, which briefly provides the following: supports the development of service systems, helps modularization, structure, and better maintenance of information systems, is reusable, and supports the evolution of systems.

4) Architectural evaluation

As mentioned, for architecture evaluation before implementation, the scenario-based approach is suitable because it is simpler and more flexible and can be implemented in different stages of the software development process. In this research, the ATAM method, which is one of the types of scenario-based approaches, was chosen to evaluate HIS-RA, because it emphasizes the non-functional requirements that have the most impact on the system architecture, and usually includes three groups of participants, including project decision makers, architecture stakeholders and the evaluator Team. In this research, project decision makers are the authors of the study; Architecture stakeholders include healthcare providers, software engineers, developers, and IT and medical informatics professionals; and the evaluator team is, two groups of project decision makers and architectural stakeholders. Therefore, the evaluation Team has employed different people to evaluate HIS-RA, which include a telecommunication engineer, three medical informatics experts, two information technology experts, a system architect, a software engineer, a doctor, and a nurse. They used the steps shown in Figure 3 for HIS-RA.

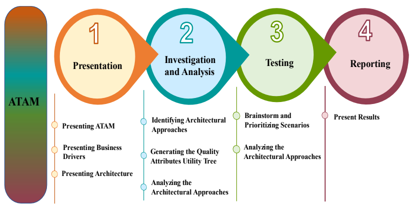

Figure 3. ATAM method

4-1) First stage: presentation

This stage, is done to ensure that all participants (project decision makers, architectural stakeholders, and the evaluator team) are aware of the stages of the evaluation method and includes three phases:

- **Phase 1: Presenting ATAM**. Includes the provision of ATAM. First, the team leader describes the ATAM evaluation to the participants and tries to clarify their expectations and answer their questions.
- **Phase 2: Presenting Business Drivers**. Includes current business motivations. The project leader explains what business goals motivate the development effort and what effects the primary motivations have on architectural quality.
- **Phase 3: Presenting Architecture.** Includes architecture presentation. The desired architecture is described and focuses on how to deal with the business drivers set in the previous step.

4-2) Second stage: Investigation and analysis

At this stage, the architecture analysis is performed, which consists of three stages.

- **Phase 4: Identify architectural approaches.** It describes the highlights of architecture.
- **Phase 5: Generating the Quality Attributes Utility Tree.** Objectives and qualitative characteristics are identified by creating a utility tree to determine the level of scenarios, then the triggers and responses are noted and prioritized.
- **Phase 6: Analyzing the Architectural Approach.** Architectural approaches goal is meeting non-functional requirements, are analyzed and points such as sensitivity and trade-off analysis, are identified.

4-3) Third stage: testing and re-analyzing architectural approaches

At this stage, a bigger set of scenarios, is extracted from the Team of stakeholders, and by using the voting mechanism, the scenarios are prioritized and analyzed by the stakeholders, which includes two phases:

- **Phase 7: Brainstorming and prioritizing scenarios.** Stakeholders provide a large group of scenarios then the ATAM evaluation team prioritizes the scenarios.
- **Phase 8: re-analysis of architectural approaches.** Here, Phase 6 is repeated, including a broader set of scenarios developed based on additional approaches, sensitivity and trade-off analysis.

4-4) Fourth stage: Reporting

In this stage, the outputs are reported in writing and include one phase:

- **Phase 9: Current results.** The evaluation team presents the results of the evaluated results in summary.

V. PRESENTING HOSPITAL INFORMATION SYSTEM REFERENCE ARCHITECTURE (HIS-RA) PROPOSED

As it was said, architecture as a creative process determines the components of the system and the relationship between them, which should represent its requirements [31]. In this regard, different types of HIS-RA integration requirements were identified in two functional (1-3) and non-functional () sections (Table 1). Therefore, the improved HIS-RA is a reference architecture that shows a high-level view of the different hospital information systems in Figure 1 and the connections between them. It also considers goals such as the ability to develop and expand, use new tools, flexibility in requirements and increase interactions between these systems and users as design priorities. HIS-RA is based on SOA and uses two approaches, ESB and MSA. In this way, in addition to having SOA features, it has many advantages, including easy scalability, the possibility of using different technologies, and flexibility. For communication between services, ESB does it through messaging and MSA does it directly using API MSA [44-46].

TABLE I. HIS-RA REQUIREMENTS

Functional Requirements and Non-Functional Requirements
1) **Integration**: The ability of the information system to exchange information and use the services of other information systems. • Supporting the coding system of the health system • Interaction with insurance and administrative/financial systems • Defining special rules and processes • Old and new information system interaction
2) **Expandability**: It defines the software and hardware features of the system such as standards, programming language, etc., for further development. ○ Adding new components to the system
3) **Efficiency:** It shows the ability to avoid wasting energy, money and time in doing the work and producing the desired system. • **Performance**: It is related to the response time or responsiveness of the system. In fact, it can be said that the desired time for the system to respond to several events in a period. ○ Response of all systems to departments and the patient • **Scalability**: refers to the ability of integration technologies to supply high performance to accommodate growing future loads and increasing demands.
4) **Monitoring**: Data tracking at different levels of data production, storage, process, and display. • Determining the exact start and end time of the service • Tracking and following the status of processes
5) **Dependability**: It reflects system reliability, which means the user's confidence that the system will perform as expected and not fail during regular use. • **Reliability:** Reliability denotes the techniques and protocols which are practiced in integration technologies to ensure all transmitted data by sender to receive at end point and the order of packets that are sent is preserved. • **Accessibility:** refers to the ability of users to access and use network resources and services regardless of their physical or cognitive abilities. ○ Access to the list of patients ○ Receiving the electronic prescription ○ Location-oriented requests
6) **Maintainability**: refers to the ability of information system components and software applications to allow changes without causing any problems in other systems. Integration technologies should aim for solutions which could be easily maintained.
7) **Security/Privacy**: The degree of probability that the system can resist accidental or intentional attacks and prevent unauthorized access to people's information.
8) **Usability**: The use of the system should be simple and in such a way that it has the minimum user error. • Providing outputs with different structures
9) **Flexibility**: refers to the capabilities of integration technologies toward rapid adjustments. For example, modifications of software engineering with minimum effort, operational and functional capabilities in various computing environments.
10) **Real-time**: describes the ability of integration technologies to support transactions that require up to the second data latency. Data latency identifies how current information needs to be.
11) **Complexity**: refers to the implementation difficulty of integration technology from the technical viewpoint. The complex integration approaches increase development and maintenance costs, so they may not be preferred.
12) **Maturity**: refers to well-tested, established, and mature integration technologies. The more mature technology is a better solution because the software developers, engineers, and analysts can provide successful implementations.
13) **Portability**: describes the software solution that is developed for one platform and could be easily executed on different platforms. Portability is related to the concept of standards and provides an important role in the cost-effectiveness of information systems.

Thus, HIS-RA with layers such as communication and information infrastructure, data collection and storage, service layer (basic, operational, value-added, and technical), integration, security/privacy and management, external systems, and user interface and application were presented in Figure 4. That list should not be seen as a completed set due to the possibility that the clinical and financial context can require additional modules.

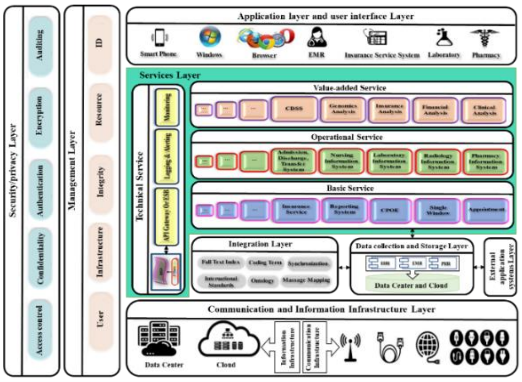

Figure 4. Hospital information system reference architecture (HIS-RA)

1) **Application layer and user interface:** The application layer shows the place of deployment and access to the services introduced in the service layer. The user interface also shows how users access the system and gives the user the possibility to control their next tasks. MVC architectural pattern is considered for communication between clients to server requests.
2) **services layer:** includes basic, operational, value-added and technical services; Basic services such as reporting, identification, electronic prescription, EHR, EMR, and PHR are the main components that; can be reused in other services; Operational services support the main parts of the hospital's ongoing operations, which include various types of clinical and financial information subsystems (Figure 1) and follow the layered and MVC architecture pattern, value-added services such as pharmaceutical analysis, clinical analysis, telemedicine system, CDSS use operational and basic services as the implementation platform in the field of business logic. The technical service layer also includes the API/ESB gateway (establishing communication between systems in the form of messages and directly by REST), monitoring (tracking operations and services), and logging and warning (logging of entries and warning notifications), which; are applied to other services.
3) **External application systems layer:** includes the old systems that already existed in the collection and also includes other organization systems.
4) **Data collection and Storage layer:** clinical, demographic, and financial information of patients in each information systems database is collected by this layer and finally placed in the virtual data center. Based on its importance for the hospital, the collected information is stored in three architectural patterns: Federation, Replication, and Centralization. Generally, after integration, this layer puts data in three electronic records structures EMR, PHR, and EHR
5) **Integration layer:** acts to establish integrity and reliability of processed or stored data. In this layer, several components are used such as; ontology, message mapping, coding terms, and standards. Ontology, is used to represent knowledge as a collection of concepts in a domain and to define relationships between concepts. Message mapping is responsible for histology between different standards. Global standards include a variety of types like; ICD 10, SNOMED, LOINC, and HL7. Sync, supports periodic sync and on-demand sync. Terminology coding is one of the most important aspects of hospital information systems to coordinate with international organizations and unify people's understanding of medical diagnoses and processes to exchange information with other systems [47].
6) **Communication and information infrastructure layer:** It has two information and communication parts, which include wired (cable and optical fiber) and wireless (Internet networks, Ethernet, Wi-Fi,

and server virtualization) communication infrastructure. In fact, it is the general platform for implementation and communication between systems, which is used as the main foundation of services in all departments. The information infrastructure sector is also used to store, process and transfer information, which requires two data centers and cloud computing including software as a service, platform as a service, and infrastructure as a service to realize this [9]. It should be noted that one of the data centers with storage equipment is inside the hospital and the other uses a large data center that exists at the national level and in the country, which has a backup mode for the information and services available in HIS.

7) **Security/privacy layer:** In general, security refers to the ability of a system to resist attacks and unauthorized access, which at reference architecture four types of security layers for infrastructure, services, applications, and API Gateway are considered. Privacy is also the right and desire of a person to control the disclosure of information related to his health. Generally, this layer includes components such as; access control, confidentiality, authentication, comprehensiveness, non-repudiation, encryption, and auditing [48].
8) **Management layer:** It manages the communication between the layers and distribution of components and their activity in the entire network. It also provides integration between each component's goals to achieve comprehensive interoperability. This layer includes identity management, resource management, integrity management, access management, infrastructure management, and user management.

VI. HIS-RA EVALUATION

The results of the evaluator group for evaluation of HIS-RA by ATAM, which is early scenario-based evaluation method in four stages and nine phases are as follows:

1) *First stage of HIS-RA evaluation results*

Considering the complexity and variety of hospital information systems, HIS-RA was presented for information systems interaction the hospital, which concentrates on interoperability and it's based on SOA. Among the benefits of HIS-RA are: Increased efficiency in service delivery, improvement in healthcare provider decision-making for prediction, diagnosis, Act, and treatment, a decrease in development time and costs, and a decrease in information redundancy. Meanwhile, extensibility, flexibility, reusability, interoperability, security, and monitoring which cost a lot to the hospital, are easily supported by HIS-RA. Thus, to ensure the suitability of the presented architecture to meet the HIS integration requirements (Table 1), it is necessary to evaluate it before implementation. Based on this, the ATAM scenario-based evaluation method is used for HIS-RA evaluation in four stages and nine implementation phases due to its earliness, emphasis on non-functional requirements, and applicability in all stages of system development.

2) *Second stage of HIS-RA evaluation results*

Among the identified approaches in providing HIS-RA could be mentioned SOA with two ESB and MSA approaches, interoperability, efficiency, monitoring, security, privacy, extensibility, reliability, and usability. So in considering these HIS-RA approaches and requirements, a utility tree can be created. In Figure ۵, this tree has several levels; the first level of that is the root; the second level includes all types of HIS-RA requirements; the next tree's level, is related to every requirement detail, Such as interoperability which has technical, syntactic, semantic, process and business dimensions; for instance, the technical component itself includes two sub-components of interaction and communication and standard support. The other requirement implemented in the utility tree is efficiency, which includes two components of Performance and scalability. Finally, the last level of the utility tree is leaves which includes scenario issues; Presented scenarios by evaluator Group are located in Table ۲ and are answered according to HIS-RA. These scenarios were proposed based on integrated analysis requirements, which include sensitivity and trade-off analysis of HIS-RA. Among these things, it can be mentioned; adding new service, access control, tracking actions, destroying routers, developing HIS, and collaboration between experts.

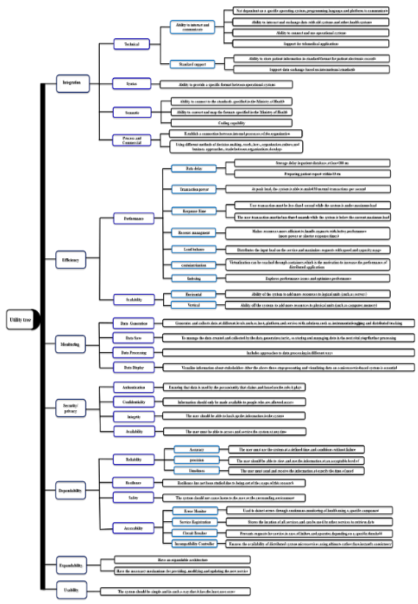

Figure 5. Utility tree of HIS-RA

3) *Third stage of HIS-RA evaluation results*

After re-examining the HIS-RA scenarios, the evaluation team approved the ten scenarios presented in Table 2 as the final scenarios, because they covered all the determined leaves in the utility tree. In the following, the evaluation team, prioritized the scenarios based on the level of importance (for the Stockholders) and the degree of difficulty (in terms of implementation), using the relative value method (more and less) in Table 3. This prioritization was done based on identified approaches in the previous stage, such as integration, security, accessibility, and efficiency, which are more important.

TABLE II. SCENARIOS PROPOSED FOR HIS-RA EVALUATION

Scenarios	Scenarios Questions?	Answer Scenarios
Scenario No.1	Increasing the workload of the hospital physically (bed, computer) and logically (memory, CPU)	According to the communication and information infrastructure layer in Figure 1, it is possible to virtualize servers and physical equipment, without any server or service failure
Scenario No.2	Providing integrated services for physicians (PIS, LIS, RIS, CDSS, CPOE)	Since the hospital services include LIS, PIS, and RIS have access to the information of other services such as EHR, EMR, and PHR, so according to the data center in the infrastructure layer in Figure 4, patient information in the shortest possible time based on the standards approved by The Ministry of Health is given to the relevant departments. Because communication and interaction between services is possible through API.
Scenario No.3	Tracking medical malpractice due to the wrong prescribing wrong drug	Due to the integrity of the services available in the hospital, in addition to the patient's prescription in the PIS, any action by the doctor and nurse to inject or take medicine for the patient is also recorded. Therefore, in case of negligence or mistake, according to the monitoring capability in the architecture technical service layer of Figure 4, it is possible to administratively and legally follow up on who is responsible.
Scenario No.4	Unauthorized access to patient records	According to the authentication features (username and access level) and logging services in the architecture of Figure 4, the system prevents unauthorized people from entering, and the person's action at the entrance, is recorded.
Scenario No.5	Service availability for healthcare providers (The user must use the system flawlessly at any time and place and be able to send, receive and view information)	According to the infrastructure layer in the architecture of Figure1 data center is located inside the hospital, which provides faster access to the generated and collected information; But if the system has a problem and its response is disturbed, this problem is detected by the monitoring capability (architecture of Figure 4), and the request for faster response, is sent to the data center
Scenario No.6	Failure of servers due to reasons such as fire or failure	Virtualization or cloud technology, is used to store information according to the communication and information infrastructure layer in the architecture of Figure 4. In addition, two data centers with all storage equipment (such as servers, switches, and routers) have been considered for the hospital, one of these centers is located inside the hospital, and the other is outside the hospital for quick access by users, which generally it is used critically. In this way, the problem is identified and reported to the API Gateway through the monitoring capability, so the provision and access to the services, are transferred to the external data center.
Scenario No.7	The ability to integrate services at the organizational level	The attending physician can access the patient's EHR. In addition, if the target hospital has the necessary technology and facilities, the physician can also access the patient's EMR and PHR according to the specified access level. This possibility is determined according to the patient ID management in the management layer and the API capability in the architecture of Figure 4.
Scenario No.8	Add new service to HIS	According to the API capability in the architecture of Figure 4, which is the communication interface between different services and applications, if a new system is added to the current collection, the system regardless of the programming language, operating system, platform, type of hardware and software, it can connect to heterogeneous systems. In addition, based on the integration layer in the architecture of Figure 4, the old and new systems can exchange information together based on the global standards set by the Ministry of Health. In addition, it is possible to easily add a user-friendly way to the list of hospital services using MVC in the implementation.
Scenario No.9	Collaboration between doctors with different specialties	According to the provision of integrated services in the hospital and the doctor's access to HER, EMR, and PHR in the application layer of the architecture of Figure 4, it is visible from the last patient status. The patient's clinical information collected from different systems is transformed into understandable concepts for all three doctors by components such as the global standard service approved by the Ministry of Health, and the message mapping in the architectural integration layer of Figure 4.
Scenario No.10	System development (such as setting up a telemedicine service)	Through the API in the architecture of Figure 4, telemedicine services can be established within the hospital's own data center or externally.

TABLE III. PRIORITIZE SCENARIOS (HIGH PRIORITY SCENARIO: H AND LOW PRIORITY SCENARIO: L)

Scenarios	Scenarios Questions?	HIS-RA Architectural Approaches	Importance	degree of difficulty
Scenario No.1	Increasing the workload of the hospital physically (bed, computer) and logically (memory, CPU)	• Efficiency • Maintainability	H	H
Scenario No.2	Providing integrated services for physician	• Integration • Monitoring • Reliability • Efficiency	H	H
Scenario No.3	Tracking medical malpractice due to wrong prescribing wrong drug	• Monitoring Security\privacy	H	L
Scenario No.4	Unauthorized access to patient records	• Integration • Monitoring • Security\privacy	H	L
Scenario No.5	Service availability for health care providers	• Monitoring • Reliability • Efficiency Security\privacy	H	H
Scenario No.6	Failure of servers due to reasons such as fire or failure	• Efficiency • Security\privacy • Reliability	H	L
Scenario No.7	The ability to integrate services at the organizational level	• Integration • Security\Privacy	H	H
Scenario No.8	Add new service to HIS	• Integration • Usability • Expandability • Efficiency • Maintainability • Flexibility	H	L
Scenario No.9	Collaboration between doctors with different specialties	• Integration • Usability • Security\Privacy	H	H
Scenario No.10	System development (such as setting up a telemedicine service)	• Integration • Expandability • Efficiency • Security\Privacy • Maintainability	H	H

4) Fourth stage of HIS-RA evaluation results

The evaluation of HIS-RA, which emphasizes the integration of HIS, according to the analysis of the integration requirements and the sensitivity and trade-off analysis identification, was carried out with ten scenarios. In such a way that the increase in the workload of the hospital and the failure of the servers by the communication and information infrastructure layer; providing a unified service to the doctor by the integration layer and API; tracking medical malpractice by monitoring capability; Unauthorized access control by security layer, management, monitoring, logging and alerting; service availability by application layer and user interface and API; The ability to integrate services at the organizational level by the security layer, external systems, integration and API; adding new service to HIS by communication and information infrastructure layer, application and user interface, integration, security and API; The ability to collaborate between doctors through the data collection, and storage layer and integration; and the development of the system can also be answered by the communication and information infrastructure layer, integration, API, external application systems, security and management. In short, HIS-RA supports things such as; system development and evolution, modularity, integration, intelligence, and reusability.

VII. DISCUSSION

Integrated information and services provided by health information systems are very important, because they play a critical role in providing the right care to the right person at the right time, and their main goal is to provide easy and equal access for entities involved in providing health services [5]. Health information systems such as HIS have problems providing qualified and integrated services to patients due to the use of diverse and heterogeneous information systems. Therefore, the only possible solution is to provide a reference architecture for the integration between these systems because the reference architecture is used to facilitate system design and development in projects such as HIS integration where there are multiple information systems [30]. Based on this, HIS-RA was presented to integrate different information systems in the hospital. HIS-RA as the improved architecture of the study [26] includes 8 layers of communication and information infrastructure, data collection and storage, service layer (basic, operational, value-added and technical), integration, security/privacy and management, external systems, and It is a user interface and application that focuses on interoperability and is based on SOA. Therefore, considering that the architecture meets the requirements of the systems, the review in Table 4 shows the compatibility of HIS integration requirements with the dimensions of interoperability.

Because the provision of safe and efficient care depends on the interoperability and information exchange between different systems, therefore, it is important to pay attention to technical, syntactic, semantic, and organizational interoperability dimensions in healthcare information systems [49]. As mentioned, the last level of interoperability refers to organizational interoperability, for this reason, technical interoperability with a focus on communication and infrastructure connections is considered as its foundation; Therefore, all the requirements that are in line with organizational interoperability also cover technical interoperability. In interoperability, not only the establishment of communication and connections but also the ability to understand information is of great importance. Because the information exchanged without common mean and concept for both the sender and the receiver leads to an increase in errors. Therefore, the requirements of Integration, Performance, Accessibility, Reliability, Real time, Maturity and Portability imply syntactic and semantic interoperability; because syntactic and semantic interoperability focuses on the structure and understanding of meanings. In this way, a common and unified view of terms is created for organizations involved in providing health care services. As a result, it should be said that the requirements are based on different dimensions of cooperation.

As mentioned, the reference architecture for the integration of health information systems such as HIS is very little, but in this research, we tried to use similar works.

As mentioned, the current study (improved HIS-RA architecture proposed in Figure 4) is derived from the architecture presented in the study [26] .This study focused on the CIS due to the use of three reference architecture models for software and information, it was difficult to evaluate and implement it. In light of this challenge, the authors of this research decided to present an improved HIS-RA architecture by combining the components of these three architectural models that focus on clinical and financial information systems. Thus, the layers of information and communication infrastructure, services, security and application in HIS-RA represent the reference architecture described in the aforementioned study [26]. Similarly, the layers of integration, data collection and storage, and external application systems in HIS-RA correspond to the information architecture identified in the same study [26] As well as the application layer and the user interface and management in HIS-RA, it shows the architecture of the software presented in the study [26].

TABLE IV. SURVEY HIS-RA REQUIREMENTS WITH INTEROPERABILITY DIMENSIONS

Requirements / Interoperability	HIS-RA Requirements														
	Expandability	Integration	Scalability	Performance	Accessibility	Maintainability	Monitoring	Reliability	Security/Privacy	Usability	Flexibility	Real time	Complexity	Maturity	Portability
Technical interoperability	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Syntactic interoperability		✓		✓	✓			✓				✓		✓	✓
Semantic interoperability		✓		✓	✓			✓				✓		✓	✓
Organization interoperability	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓

In the study [23], the reference architecture of health information systems is presented based on the perspectives of context, analysis, layering, and deployment; The proposed architectural model has also presented the integration of HIS based on basic, technical, operational, added value, security and privacy, communication and information infrastructure, integration, management, and data storage services; and like study [16], it emphasizes on data, workflow, and functions to create integration in the whole process of the hospital.

According to the study [12], [5], [14], [19], [22] and [26] the service-oriented architecture was chosen as a development platform to connect distributed applications. Two service-oriented approaches, namely MSA and ESB, have been used for communication between services, which is established directly through API Gateway and indirectly or through messages via ESB. The main task of ESB is to deliver messages to the intended recipient of the message, and the recipient can process it and provide the appropriate responsiveness in a way that covers syntactic and semantic integrity [44]. MSA has also become the latest trend in software development, which, according to the component concept, turns the application into a set of small and independent services, and with the help of API Gateway protocols, communication between services is established with non-identical platforms and databases. Its most important advantages are agility, autonomy, scalability, resilience, and easy continuous deployment [45].

In the study [5] and [15], they proposed the concept of virtualization in the cloud and the proposed architecture also uses cloud services in the communication and information infrastructure layer, because moving to the cloud is used as a solution to improve accessibility, flexibility, and reduce costs in hospital information systems [50].

In the study [13], to share information in several organizations, FAIR aspects, namely Findability, Accessibility, Interoperability, and Reusability are emphasized. The proposed architecture also provides integration the hospital's information systems by emphasizing the aspect of interoperability. In addition, according to the service-oriented concept, it can be reused, and according to the technical services, the management layer and the communication and information infrastructure layer also take into account the aspects of accessibility and findability.

Study [20], is the logical separation presented for CIS program development based on object-oriented architecture, but program development in the proposed architecture is similar to [11] and [26] based on layered architecture pattern; in addition, component-based, service-oriented pattern were also used. At the same time, similar to the study [26], it considers the MVC pattern for the user interface and how to connect the user and the server. This architectural pattern is more of a software design pattern. It is a framework for building web applications and facilitates the achievement of appropriate software quality. The use of MVC in software development makes the flexible, transparent, reliable, and scalable. It is also widely used for the development of iOS and dynamic web applications, and today it is one of the most important architectures for software development [51].

Study [21], HHIEA hybrid architecture, uses different types of architectural patterns such as layered, component-based, publish/subscribe, and ESB for the integration of multiple HISs. According to the service-oriented concept, the proposed architecture uses a combination of architectures such as service-oriented (its two elements are ESB and MSA), publishing/sharing, unified, centralized, replication, component-based, and a layer that enables the integration of different treatment centers.

Studies such as [17], [18], [24], [25] and [26] are open source that aim to integrate different information systems in organizations into a single system. But the logic considered for the proposed architecture is a reference architecture that enables technical, syntactic and semantic interactions between different hospital systems and organizational interoperability. Of course, the use of open source software is also allowed in this architecture.

The difference in the proposed architectural model compared to other architectural models is considering the requirements set for integration. Therefore, to create interactivity, interoperability should be considered in the data, service, process, and business of the hospital, and the dimensions of interoperability (technical, syntactic, semantic, and process) should be applied according to each entity.

Thus, data interoperability includes finding and exchanging information from heterogeneous databases, and in addition, it can store data on different devices with different operating systems and database management systems [52]. For this reason, the dimension of syntactic interoperability concerning grammar and the dimension of semantic interoperability were used to understand the data correctly in the integration and storage layer. The integrity layer is for managing and establishing data integrity, which includes services such as ontology, message mapping, synchronization, and coding for data integrity; the storage layer also stores three EMR, EHR, and PHR formats with the help of a Federation, Replication and Centralization architecture pattern.

Interoperability in services includes identifying, combining, and creating functions with different applications, for this reason, the dimension of technical interoperability was used in the programs and infrastructures connecting systems and services [52]. Considerations related to technology are included in the layer of technical services and communication and information infrastructure that enables direct communication of services. Communication between services in the reference architecture is done by API. In addition to that, in the technology-related infrastructure section, the use of two data centers in the hospital has been proposed, which increases productivity and access to HIS services.

In line with the interoperability of processes and the possibility of inter-organizational communication (business), it should also be stated that to communicate between different organizations in the health system, their processes must be integrated. The possibility of process integration examines the workflow beyond the boundaries of an organization. Therefore, its success requires technical, syntactic, and semantic interoperability. This interoperability includes the ability of organizations to effectively communicate and meaningfully transfer data, use different information systems with different types of infrastructures and graphical environments, and different policies [52]. REST protocol has been used in the proposed architectural model for inter-organizational communication, and also enables communication with external organizations by the necessary standards. REST is one of the protocols used in API that can establish communication between different information systems regardless of the type of operating system, programming language, type of hardware, and software.

The proposed architecture tries to overcome organizational, technological, and conceptual obstacles of the hospital based on the dimensions of interoperability; In such a way that the syntactic and semantic difference of information that is created as a result of conceptual problems can be solved by the integrity and storage layer of the proposed architecture; Problems related to communication and information infrastructure that arise in line with technological barriers are supported by the communication and information infrastructure layer and technical services; And using the security and management layer is also to overcome the problems related to access control, which is created according to the definition of responsibilities and authorities and leads to organizational problems.

In the following, it will be checked if there is alignment between the requirements and the architecture [53], in this regard, the evaluation of the architecture provided Like studies [34], [35], [36], [37], [38], [39] and [40] by the ATAM scenario-based method was carried out in 4 stages and 9 implementation phases. The scenario-based approach is simple and can be implemented at different stages of the system development process and has different evaluation methods such as SAAM, FAAM, ESAAMI, ATAM, and SBAR. Since it is better to evaluate the architecture before implementation, among the evaluation methods, only SBAR and ATAM are early. Therefore, according to Table 5, the ATAM method was chosen to perform the architecture evaluation because it is early, its purpose is to meet the system requirements, and it emphasizes the non-functional requirements that have the greatest impact on the system architecture.

TABLE V. SURVEY OF ATAM AND SBAR EVALUATION METHODS [33]

Evaluation Methods / Metrics	ATAM	SBAR
Presentation	The ATAM evaluates software architecture for multiple quality attributes, such as availability, maintainability, security, etc. The method has been developed to maintain a trade-off among quality attributes. The main objective of ATAM is to analyze how software architecture satisfies quality requirements efficiently.	It drives the architecture redesign for reliability and performance quality attributes. The main goal of the method is to introduce an iterative process of quality evaluation and architecture transformation. The method uses four architecture evaluation techniques: scenario-based, mathematical modeling, simulation, and experience-based.
Methods goal	Sensitivity and Trade-off analysis	Software Architecture reengineering to achieve quality attributes
Evaluation approaches	Integrates questioning and measuring techniques	Multiple approaches
Applicable project stage	After Software Architecture/detailed design or iterative improvement process	System extension or reengineering stage
Quality attributes	Multiple quality attributes	Multiple quality attributes
Stakeholders' involvement	All relevant stakeholders	Software architect
Method's activities	Nine activities in four phases	Three activities carried out iteratively

In the ATAM method, the ability of the presented architecture for HIS integration with ten scenarios proposed based on the application tree was evaluated by the evaluator team (consisting of research researchers and architectural stakeholders). The evaluator group determined the scenarios which applied to architecture and how the architecture responds to them. It should be noted that in the structure of responding to the scenario, changes were made in the improved architecture, for example, scenario 6 caused the architecture to be revised and the discussion of virtualization was considered. Therefore, according to the finalization of the scenarios in phase 7, according to the identification of risky, sensitive, and breakable points of HIS-RA in phase 6, the evaluation group stated that the architecture presented before implementation, the ability to meet the requirements of the integration of HIS-RA It has the RA and provides the necessary integration between information systems in the hospital, which makes information available to the stakeholders in a unified manner, the most important achievement of which is saving patients' time, improving quality, reducing redundancy, and reducing the cost of development and maintenance. It also increases efficiency and accessibility.

VIII. Conclusion And Future Work

The improved reference architecture in this research was presented to facilitate the implementation and simplify the evaluation, which focuses on the integration of diverse and heterogeneous financial and clinical information systems. In this regard, the evaluation done using the ATAM method showed that HIS-RA has the ability of integration and cooperation between different information systems in the hospital. Consequently, data is presented to doctors in an integrated manner, resulting in time savings, improved quality, and reduced information redundancy; and also this approach reduces development and maintenance costs while enhancing efficiency and accessibility. For future work, we also plan to provide the information exchange framework (based on the standards in this field such as OpenEHR, CDA, and the third version of HL7) and the security/privacy architecture of HIS-RA.

Abbreviations

HIS: Hospital Information System.
RA: Reference Architecture.
HIS-RA: Hospital Information System-Reference Architecture.
PIS: Pharmacy Information System.
LIS: Laboratory Information System.
RIS: Radiology Information System.
CDSS: Clinical Decision Support System.
MVC: Model-View-Controller.
SOA: Service Orient Architecture.
ESB: Enterprise Service Bus.
MSA: Microservice Architecture.
VISTA: Veterans Health Information Systems and Technology Architecture.
SynEX: Synergy on the extranet.
HHIEA: Hybrid Health Information Exchange Architecture.
xIPAMS: x, for any kind of content, Information Protection And Management System.
SAAM: Scenario-based software architecture analysis method.
SAAMCS: SAAM for Complex Scenarios.
ALMA: Architecture Level Modifiability Analysis.
ESAAMI: Extending SAAM by Integration in the Domain.
ATAM: Architecture-based Trade off Analysis Method.
ALPSM: Architecture Level Prediction of Software Maintenance.
SACAM: Software Architecture Comparison Analysis Method.
ASAAM: Aspectual Software Architecture Analysis Method.
DOSAM: Domain-Specific Software Architecture Comparison Model.
SBAR: Scenario Based Architecture Reengineering.
SALUTA: Scenario-based Architecture Level Usability Analysis.
CBAM: Cost Benefit Analysis Method.
FAAM: Family Architecture Analysis Method.
UI: User Interface.
FAIR: Findability, Accessibility, Interoperability and Reusability.

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Author Contributions

All authors participated in the content preparation phase of the paper. AA will be responsible for the results of this research as the Corresponding Author. Data collection by FM and architectural analysis were done by FM and AA. Architectural interpretation was carried out by AA and FM. The integrated architecture HIS evaluation process was also carried out by FM, AA and FH. Finally, all authors reviewed the manuscript and provided final approval.

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All data generated or analyzed during this study are included in this published article.

Ethics Approval and Consent to Participate

In this study, neither patient data was reported nor did patients participate in the research, so informed consent was not required. The ethical code approved by the Research Ethics Committee of Tarbiat Modares University is also based on this. (Code of Ethics IR.MODARES.REC.1399.078).

Consent for Publication

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Competing Interests

There is no competing interest between the authors of the article.

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