Medical Information System Development: Practical Aspects

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Abstract. This paper deals with the development of the medical information system for automation blood transfusion station operations such as: accounting and availability monitoring of qualified blood in the storage, accounting of donors, monitoring of temporary and permanent blood-donating termination. The functional and software requirements are listed in the paper. Data domain modeling and system design were obtained on the base of the Kamyanske Blood Transfusion station (Dnipropetrovsk region) data and input requirements. The target audience of the information system are blood transfusion station employees. Object-oriented data domain analysis allows describing the functional features of a specific data domain in terms of classes, class objects, and their interactions. The results of data domain analysis are presented in the mathematical form. The scientific significance consists in developing an approach to utilization of system analysis, object-oriented and functional modelling of the data domain for the purpose of architectural design of the specific medical information system. Practical relevance of the proposed solutions results in creation of a multiple-use software product that is a source of and a tool for further development. Interface design has been focused on determining a set of form controls providing minimum user's physical effort towards required result and maximum level of protection against user's mistakes. The example of standardized and unified interface prototype is also presented.

Keywords: medical information system, blood transfusion station, object-oriented data domain analysis

Introduction

Rapid development of information technologies results in their introduction into various areas including information processes automation in health-care. The main purpose of information systems is acceleration and optimization of information processes involving data acquisition, storage, and processing. Information systems intended for automation of health care institutions, medical personnel workplaces, and business processes conducted during various phases of medical care are called medical information systems (MIS) [1]. The MIS is a hardware-and-software integrated complex as a set of software tools and databases, the most important functions of this system are improvement of medical care and optimization of management decision-making in health care system [2].

Research topic of this article is the process of information system for blood transfusion station development as a special type of MIS. Proposed decisions describe the process of donors registering and accounting, availability of blood and its components, and donation prohibition at blood transfusion stations. The main phases of automation of blood transfusion station operation are as follows:

- data domain analysis required to determine functional features of interactions between actors, characteristics of static and dynamic objects, document structures and document flow schemes;
- design of database structure, system architecture, and user interface prototype accounting for user profiles and data access rights;
- software implementation of design solutions;
- software debugging and testing;
- information system commissioning.

The scientific significance consists in developing an approach to utilization of system analysis, object-oriented and functional modelling of the data domain for the purpose of architectural design of a specific MIS.

1.1 Related Works

Introduction of web-oriented and LAN-based MIS's made it possible to automate medicine accounting processes in drug stores, create digital references and ontologies for medicines and diseases, develop digital patient records, create robotized drug stores, implement remote interaction between doctors and patients by means of telemedicine tools, etc. Such researchers as O. Chaban, O. Boyko, K. Kopnyak, V. Stepanov analyze in their papers [3-5] the current state of MIS introduction in Ukraine and other countries. They address the issues of health care digitalization, as well as the problems linked to creation of a uniform medical-informational space. The papers by researchers S.V. Tymchyk, S.M. Zlepko [6], S.V. Kostishyn, T.I. Ovcharuk, A.A. Ovcharuk compare such MIS's as: C-hospital, Digital Hospital, TherDep, and Medialog against a number of criteria. One of the most prospective problems nowadays is development of expertise and advisory diagnostics systems for supporting treatment decisions, this problem is addressed by the following Ukrainian researchers [7-11]: T. Hryhorova, M Iepik, N.I. Melnikova, O.V. Kravchenko, K.V. Steblina and others. Artificial intelligence and neural network technologies are widely used in development of automated medical diagnostics systems. In addition to MIS added to the Ukrainian nationwide health care automation projects E-health [12] such as: Helsi, Medics, Medstar, nHealth, SimplexMed, Health24, Askep.net, Skarb, Ukrmedsoft, MedInfoService, Medikit, MedAir, information technologies can also be utilized in personalized web-oriented services or mobile applications providing user-patients with useful information.

Considering a hard political situation in the country, blood services have become one the most important strategic health care services, digitalization of these services is one of priorities for efficient management of blood assets and donors accounting in general. Automated information systems provide means for integrated digitalization of blood collection, examination, storage, and distribution, significantly improving production safety and efficiency, introducing additional quality control stages, and allowing fast informing the management. Paper [13] describes digitalization and blood bar-codding at Zaporizhzhya Regional Blood Transfusion Station. The authors of paper [14] have developed a blood donor companion system in the form of Android app used for blood donation planning accounting for individual nuances and health state, as well as for getting information regarding actions before and after donation.

Despite the large number of research papers devoted to the development of MIS, automation of processes related to the provision of medical services remains an actual scientific and practical problem especially important for Ukrainian medical system.

Proposed Data Domain Model

2.1 Functional and Software Requirements

The target audience of the MIS are blood transfusion station employees. For implementing the distributed data access mechanisms, the system can be divided into the following functional modules:

- record-keeping module dealing with processing the blood-donors records;
- doctoral activities module intended for keeping the results of examinations and prescriptions;
- laboratory module responsible for registering the results of donors' analyses;
- module for blood accounting, passporting, and quarantine issues.

The functional modules correspond to the organizational structure of the blood transfusion station, allowing to automate the following information processes:

- accounting and availability monitoring of qualified blood in the storage, which includes accounting of all blood donations, considering the dates of these donations, as well as donor blood type and rhesus. Blood and its components are accounted per blood type and rhesus using absolute and relative values;
- accounting of donors including recording the data regarding all their visits, keeping the electronic records of donors and reserve donors;
- monitoring of blood-donating termination, both temporary and permanent, considering the time intervals of such pauses;
- report generation regarding donors with absolute contraindications, which are not allowed to donate blood or its components.

Input functional requirements were formed on the base of the Kamyanske Blood Transfusion station (Dnipropetrovsk region) data. The generalized main functional and software requirements for the application package of the MIS under development are as follows:

- all data, accompanying documents, and reports should be developed based on the information stored in the database of the MIS;
- the user interface should be implemented as a Window – Image – Menu – Pointer (WINP) interface in the form of hierarchical menu, with input or search fields, functional buttons triggering specific actions when pressed, and tabular representation of the data from the database;
- the user dialogues should allow efficient users training regarding general principles of system interaction, and be available in utilization. The software product should be experienced user-oriented;
- the MIS should provide the means for adding, modification, erasing, and searching for reference and input data, as well as for output data generation;
- depending on data access level, the MIS should provide the medical personnel with the following information: blood amount available in the storage; information on active and healthy donors; information on donors who are not allowed for blood donation and the reasons for such temporary/permanent exclusion; the system should allow producing printed forms of medical documentation and certificates.

The MIS should process the data in multi-user mode utilizing the client-server technology, as well as in interactive mode, i.e. generate the output information by executing dynamic inquiries to the database. A database designed using the object model of the data domain should be an integral part of the MIS.

2.2 Object-Oriented Data Domain Analysis

According to the software engineering standards the life cycle of the MIS, like for any software product, consists of five phases: data domain analysis, design, software implementation, testing and operation. An object-oriented analysis was used for analyzing the data domain. Object-oriented analysis of the data domain allows describing the functional features of a specific data domain in terms of classes, class objects, and their interactions as a model of information, labor, financial, and material flows [15]. Data domain data were analyzed and presented by the data domain model, which mathematical form, can be represented as follows:

$$D=\langle K, R, BP\rangle, \tag{1}$$

where D is a data domain limited by the requirements of the task to be automated; $K=\{k_1,\ldots,k_N\}$ is a multitude of classes of the data domain; $R=\{r_1, r_2, r_3\}$ is a multitude of relations type between classes: «one-to-one», «one-to-many» and «many-to-many» connections, $r_\xi= \{1 – 1{:}1;\ 2 – 1{:}N;\ 3 – N{:}N\}$; $BP=\{bp_1,\ldots,bp_3\}$ is a multitude of data domain business processes. Each data domain class is defined as:

$$K=\langle O, P, TK, TP\rangle, \tag{2}$$

where $O = \{ o_1,\ldots,o_N \}$is a multitude of instances of the k_i class; $P = \{ p_1,\ldots,p_N \}$ is a multitude of properties of the k_i class, $TK = \{ tk_1, tk_2, tk_3 \}$ is a multitude of the k_i class types: static class type 1, which is implemented in the MIS as simple data domain directories; static class type 2, which is implemented in the MIS as multi-table data domain directories; dynamic class type 3, which is implemented in the MIS as data domain input documents. $TP = \{tp_1, tp_2, tp_3\}$ is a multitude of the k_i class p_i property types: constant-by-convention $tp_1 \rightarrow const$; dynamic tp_2; calculation-related ones tp_3. Based on (1)-(2), it is possible to specify predicates that describe the structure of data domain classes and business-processes. The predicate, named *class_type*(K, TK), determines a simple correspondence between the k_i class and its tk_ξ type. A multitude defining this predicate can be described as follows:

$$M^{ct}= K \times TK \supset \{ (k_i, tk_\xi)\}| \ \forall\ k_i \in K,\ \exists!\ tk_\xi \in TK. \quad (3)$$

Based on (3), there is a single tk_ξ class type for each k_i class. This allows to create classes multitudes of similar type:

$$KS=\{k_i\ |\text{class\_type}(k_i,1)\};\ KM=\{k_i\ |\text{class\_type}(k_i,2)\};\ KD=\{k_i\ |\text{class\_type}(k_i,3)\}, \quad (4)$$

where KS – is a multitude of simple directories; KM – is a multitude of multi-table directories; KD – is a multitude of input documents. The predicate, named *single_directories*(K, R), sets KS classes. A multitude determining the predicate *single_directories*(K, R) is defined as follows:

$$M^{sd}= K \times R \supset \{ (k_i, r_1)\}|\ \ k_i \in KS. \quad (5)$$

The predicate, named *multi_directories*(K, $\bar{K}$, R), sets KM classes. A multitude determining the predicate is defined as follows:

$$M^{md}= K \times \ \bar{K}, \times R \supset \{ (k_i,\ \bar{k}_t, r_j)\}|\ \ k_i \in KS,\ \ \bar{k}_t \in\ \ \bar{K},\ \ \ \bar{k}_t \in KS \cup KM,\ r_j \in R, \quad (6)$$

where $\bar{K}$ – is a multitude of the child classes, which is joined with parent class by the relation type r_2 or r_3.

In order to fill in dynamic type classes data, it is necessary to use date from simple and multi-table directories. The predicate, named *input_doc*(K, R), sets KD classes. A multitude determining the predicate is defined as follows:

$$M^{id}= K \times R \supset \{ (k_i, r_j)\}|\ \ k_i \in\ KS \cup KM,\ r_j \in R. \quad (7)$$

KS, KM and KD multitudes joining sets a multitude of the data domain classes M^K:

$$M^K=KS \cup KM \cup KD. \quad (8)$$

Static type classes of the data domain include those whose property type is constant by convention. The predicate, named *property_type*(P, TP), determines a simple correspondence between the p_i property and its tp_ξ type. A multitude determining the predicate *property_type*(P, TP), can be represented as follows:

$$M^{pt}= P \times TP \supset \{ (p_i, tp_\xi)\}| \ \forall\ p_i \in p,\ \exists!\ tp_\xi \in TP. \quad (9)$$

Based on (9), there is the only one type tp_ξ for each property p_i.

The main purpose of static type classes existence in the MIS is decreasing the number of manual data input operations, replacing manual input with more efficient data fetching from the database via the elements of the graphical forms. Multiple use of static type classes during creation of dynamic type instances and their unambiguous representation in the database increases data reliability, as well as data input speed and correctness. The main static type classes are: the types of donors, healthcare institutions, medical personnel, territorial subordination hierarchy, blood types and rhesus, temporary donation prohibition, absolute contraindications, etc.

The data of dynamic type classes is the main information source for the database. The frequency of creating dynamic type instances is unknown and depends on the environment conditions. The main dynamic type classes are donors, reserve donor record, blood donation assignment, examination certificate, donor benefit medical note, etc. The selection of the classes and their properties depends on the task to be automated. Also, the analysis approach, as well as the end-users of the information services provided by the software product should be considered. As for the described data domain, the following roles have been determined that are given different data access privileges, for the data stored in the database or generated by the MIS: donors, medical registrars, laboratory doctors, station doctors.

Object-oriented analysis has also allowed decomposition of data domain business-processes. It made it possible to determine the set of mandatory actions and event triggering conditions, where their execution is influenced by the environment. The predicate, named *b_process*(*BP*, *K*), describes interactions between classes joined by the bp_i business-process. A multitude determining the predicate *b_process*(*BP*, *K*), can be represented as follows:

$$M^{bp} = BP \times K \supset \{ (bp_i, k_j)\} | \; bp_i \in BP, k_j \in K. \tag{10}$$

The object-oriented analysis of the data domain and data normalization rules allow transition to relational database design according to the following flow: data domain entity → class → database table. Database functions for creation, deletion, storage, and data search are to be implemented for all entities of the data domain.

2.3 User Interaction Algorithm

Considering the nuances of information flows and the list of functional requirements set for the MIS, the following algorithm for user interaction has been made up:

1. A potential donor applies to the registry desk of the blood transfusion station where he/she confirms his/her identity with a valid document.
2. The medical registrar searches for applying person’s record in the database.
3. In case the database contains no such record, the registrar enters the person’s data into it, namely – information on person’s ID, occupation/study, registered and actual residential addresses. Otherwise, the MIS returns donor’s record containing the exhausting information about the donor, e.g. whether he/she has donated in the past 2 months, and whether there are contraindications against donation. After that, the

registrar creates reserve donor record and prints donor form. The fields in the donor record and donor form are automatically filled with the donor information.

4. The Reserve Donor Record is given to the donor, then he/she is directed to medical examination. Before examination, the donor should fill the form at the backside of the Reserve Donor Record, the answers should be confirmed with the personal signature of the donor.
5. Determination of blood donation qualification. The laboratory doctor conducts the required tests, makes corresponding entries into the Reserve Donor Record, and directs the donor to the doctor who analyzes the donor form and enters information on examination results. Based on medical test and examination results, the doctor determines whether the donor is qualified for blood donation. In this case, a medical examination note is issued that is automatically filled with the information on examination date, the reason of donation prohibition, prohibition term, examination results, etc. In case the donor is well-qualified for donation, the doctor enters the amount of blood to be donated and issues blood donation assignment and medical note about donation.
6. Blood donation. Having a blood donation assignment, the donor donates blood, the results should be written to the donor record.
7. Passporting and quarantine storage of the donated blood. Based on the data on completed donations and complying with the regulations, the donated blood is quarantine-stored for a specific period, after that the blood well-qualified for utilization in medical institutions is to be pasportised.

The developed data flows diagram, which also describes the algorithm of user interaction with MIS and its components, is shown in Figure 1 within the Business Process Management Notation (BPMN). BPMN allows to describe graphical notation for mapping business processes as data flows diagram.

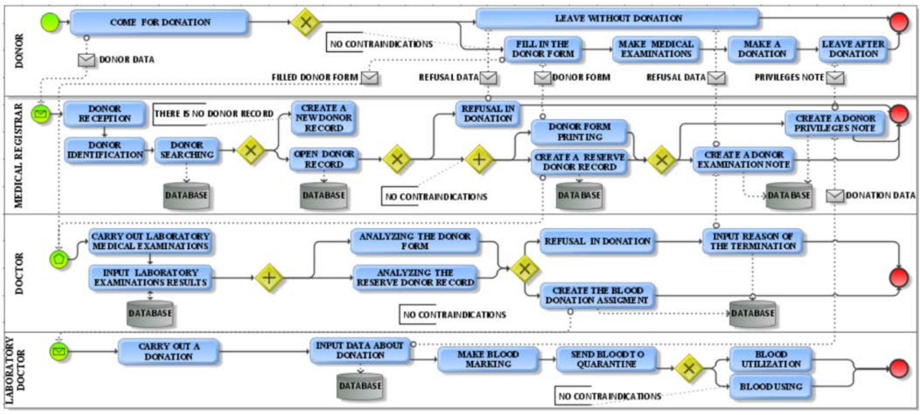

Fig. 1. Data flows diagram (Source: own work)

The pools in the figure 1 display the available actions for each group of data domain actors. Users accesses to the database for performing data input operations and obtaining the queries results are presented as data flows.

Results

In the course of system implementation three-level Model – View – Controller (MVC) architecture has been utilized, thus the MIS is composed of data storage, business-logic, and visualization levels. Data storage level has been implemented using relational database mechanisms, with the database designed accounting for data normalization rules. The business-logic level has been implemented as stored procedures and views, both in the database and at the application level. The visualization level has been implemented as a set of user forms intended for interaction with the MIS, the forms being designed according to Window – Image – Menu – Pointer (WIMP) graphics standard. All user forms have been design using a single style and accounting for standardization and unification requirements.

On the base of data domain functional and object models the main components of the proposed MIS were developed. They are as follow: reference sources (simple and multi-table directories), input (digital documents) and output (data fetched from the database) information. The interaction of data domain actors is documented according to approved forms, such documents are legal evidence of donation. The output information is generated based on input parameters of database queries; this information contains the data fetching results regarding:

- the amount of blood available at the storage per blood types, rhesus, etc.;
- the number of people having absolute contraindications against blood or its components donation for a specific period of time;
- the number of people under temporary prohibition of blood or its components donation, as well as the time intervals of such prohibition;
- the total number of donor’s visits to the blood transfusion station regardless of whether blood donation has been completed;
- the total number of blood donations for each donor.

Usability is one of the main quality criteria for the user interface developed, the criteria it is assessed against are as follows [16]: easy learnability, ergonomics, number of user mistakes, subjective satisfaction with operation, memorability level. Ergonomic level of the developed interface has been assessed as a total degree of convenience that depends on intellectual effort and decision-making speed. The efficient implementation of interface usability mechanisms influences competitiveness of the application compared to existing ones, its marketing attractiveness as a commercial software product, and popularity. Taking into account the analysis of existing MIS having similar functionality, interface design has been focused on determining a set of form controls providing minimum user’s physical effort towards required result and maximum level of protection against user’s mistakes. WIMP standard has been used for user interface implementation. One of characteristic features of this standard is that user-computer dialog is conducted using windows, graphic menus, cursor, and other elements [17]: all operations with applications, files, and documents are to be performed in windows; applications, files, documents, devices, and other items are represented as icons that transform into windows when opened; all operations with the objects are to be performed using menus that is the main control; the mouse serves as the main controller. The graphic form for input data document Reserve Donor Record is shown in Figure 2 as an example of proposed standard interface of the MIS.

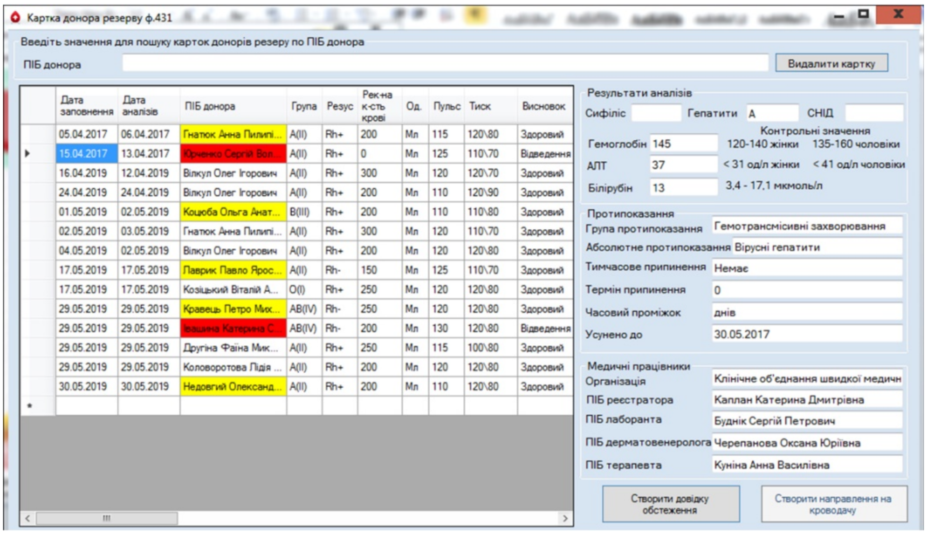

Fig. 2. Ukrainian language user interface prototype (Source: own work)

To meet the interface usability criteria, all graphic forms of the digital documents have been divided into four areas:
1 – search input area for accelerating selection of required values form the database;
2 – MIS reference area for decreasing incorrect inputs and keyboard use;
3 – visualization area for digital document display;
4 – functional panel area where buttons are located, the buttons are used for running user dialog scenarios.

To satisfy the user with the application, all graphic forms have been designed using reasonable color scheme and consistent font, the overall appearance decreases user's effort as to processing the data displayed on the form. Other features improving interface usability include blocking wrong user actions, automatic input validation, and use of signal colors.

Practical relevance of the proposed solutions results in creation of a multiple-use software product that is a source of and a tool for further development. Suggested practical usefulness of proposed design solutions includes the following:

- Acceleration of information processing during registering and servicing the donors due to generation and database-storage of reference information regarding data domain;

- Ensuring reliability and display-ability of database data for each donor at any moment for the purpose of reporting to the management or monitoring authorities;
- Reduction of inefficient manual data processing operations and the number of incorrect inputs due to automatic input validation;
- Optimization of information processes and improvement of managing decision-making in general.

Unlike MIS described in [13,14] proposed system provides multiuser distributed data access and automates information processes from the donor arrival for donation to determining the suitability of blood for use.

Conclusions

This paper deals with the development of the MIS for blood transfusion stations based on functional requirements of the Kamyanske Blood Transfusion station (Dnipropetrovsk region). Accuracy and coordination in medical staff activities in blood transfusion institutions are of primary importance, since they directly influence the health, safety, and anonymity of donors and recipients; reducing losses due to monitoring blood expiration dates; optimization of the number of donations and blood amounts, as well as efficient distribution of blood among medical institutions.

The actuality of the MIS development is an improvement of donors and recipients' services, as well as of medical staff and blood services working conditions due to automation of information processes. The proposed solutions are integral components of the process of creating a uniform information space in Ukrainian health care for the purpose of strengthening the public health and ensuring civil rights in health care. In addition, they conform to the National Blood System Development Strategy approved by the Cabinet of Ministers of Ukraine No. 120-p of Feb 20, 2019. The strategy emphasizes the need in creation of a unified national donors' registry and digital MIS in health care institutions for the purpose of monitoring blood assets circulation.

The results of the object-oriented and functional data domain analysis are presented by the means of the mathematical model. Suggested mathematical model defines classes, its objects, properties, types and relation between them. In the order to represent data domain futures the predicates logic have been used.

The developed data domain models are generalized and universal and can be applied to the MIS development not only for the Kamyanske Blood Transfusion station but also for others similar medical institutions. Introduction of the MIS will result in the following:

- improvement of donors accounting process;
- toughening supervision over medical prohibitions (exclusion from donations);
- minimization of human factor;
- maximum acceleration of operations along with protection from mistakes;
- simplification and optimization of keeping all accompanying documentation;
- acceleration of donor search per blood type, rhesus, phenotype, etc.

Development and introduction of the information system will accelerate information processing and ensure accuracy, reliability, operation speed and convenience, eliminate inefficient manual data processing, increase staff management efficiency by coordination of operations and data storage in a single database.

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