A Knowledge-Based Simulation Framework for Decision Support in Brazilian National Cancer Institute

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Abstract. Knowledge Management is decisive for clinical decision-making and for delivering better outcomes for patients care. The importance of medical knowledge has been emphasized in the researches to support evidence-based medicine. Currently, cancer is responsible for over 130,000 deaths every year in Brazil. Extensive waiting queues for diagnosis and treatments have become routine. One of the critical success factors in a cancer treatment is the early diagnosis. The reduction of waiting time to start cancer treatment is one of the main issues for improvement of patient's quality of life and possibilities of cure. This study presents a knowledge-based simulation framework developed at the Brazilian National Cancer Institute (INCA) to reduce patients' waiting time to start cancer treatment.

Keywords: Knowledge-based simulation · Decision support · Framework for decision support

1 Introduction

Nowadays, a great number of countries deal with grave problems and substantial expenditures in healthcare organizations, rising from the increase in the demand for healthcare services due to the growth in the number of elderly citizens with chronic diseases. The cancer treatment planning has become more complex with a huge demand for accessibility to hospital services with efficiency, equality, and customization of care [1].

Healthcare processes are characterized by knowledge-intensive tasks, and Information and Communication Technology (ICT) is largely used to support knowledge management in healthcare organizations. Knowledge is extremely important in healthcare organizations because low-quality information can lead to deficient clinical decisions and even endanger lives [2].

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In this circumstances, Knowledge Management is decisive for clinical decision-making and to offer better outcomes for patients. The importance of medical information has been emphasized in the researches to support evidence-based medicine. Gradually, healthcare staff depends on ICT tools to deal with the challenges to create, structure, share and apply knowledge [3, 4].

Taking into consideration the principal objective of Knowledge Management (KM) in clinical decision-making, it is fundamental to use ICT tools to support effective sharing of information among to the clinic staff. Accessibility to actualized and accurate information is crucial. The use of ICT supports the storage of a big volume of data, which can be processed by decision support systems in healthcare services [5].

Cancer is responsible for over 130,000 deaths per year in Brazil. Advances in life quality increased citizens' life expectations. However, because of limited resources, cancer in Brazil can be considered a severe public health problem. The management of cancer treatment is a long and complex process. The reduction of the patient's waiting time to start cancer treatment plays an increasingly important role in the treatment of this chronic illness [5, 6].

Healthcare simulation models generally require the implementation of systems with complex activities, involving stakeholders with a diversity of views and intentions [7]. It is thought that the active involvement of clinic staff throughout the study can decrease these problems, creating solid ownership of the model formulation and acceptance of charge for actions to be taken [8].

Organizations rely on data analytics to strategic decisions making. Descriptive analytics is commonly used to provide insight into past behavior. However, greater value can be achieved by predicting future behavior. Knowledge-based simulation represents an innovative area linking the fields of computer simulation and artificial intelligence. Simulation plays an important role in predictive analytics [9, 10].

The objective of this article is to describe the development of a knowledge-based simulation framework for decision support applied in the Brazilian National Cancer Institute (INCA) to reduce patients' waiting time to start cancer treatment. The adopted methodology was focused on the patient treatment flow and on the quick start of cancer treatment. The theory of constraints was used to identify bottlenecks in patient treatment flow and a discrete event simulation model was created to exploit the system's constraints and produce ongoing improvement efforts.

2 Methods

Knowledge Management is important for the clinical decision-making process and for delivering better outcomes for patients. The knowledge-based framework deployed at INCA includes four steps: creating, structuring, sharing and applying. The four stages support an integrated simulation environment for cancer treatment planning. Fig. 1 presents a list of activities and tools contained within each step. The graphics configuration of this simulation framework is presented in Fig. 1.

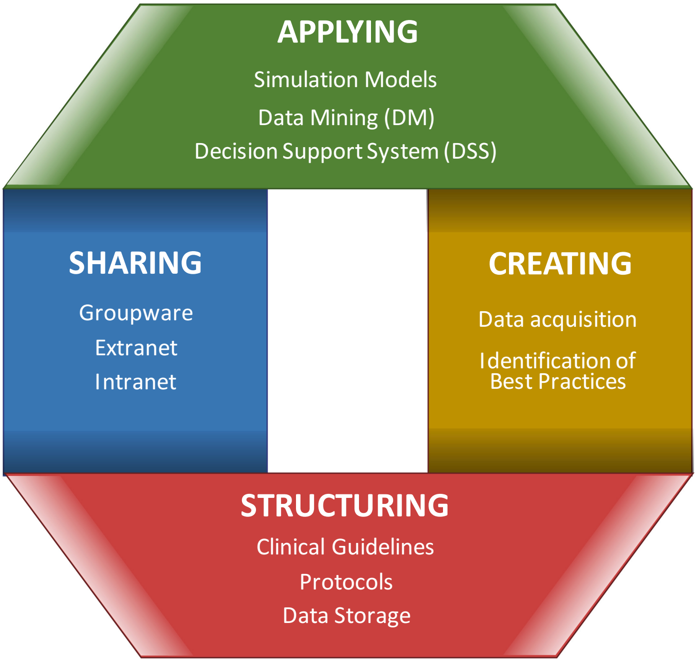

Fig. 1. INCA knowledge management process

The creating phase consists of data acquisition and identification of best practices. The process for data acquisition, from internal and external sources, is strongly interrelated with the clinical staff involved in cancer treatment.

The structuring phase consists of define, store, index and link clinical guidelines for cancer treatment. This phase involves classify and store protocols and clinical guidelines into data storages.

The sharing phase comprises the diffusion of best practices using extranets, intranet, groupware, communities of practice and multidisciplinary teams.

The last phase includes activities related to the clinical decision-making process and problem-solving using simulation models and Data Mining applications.

Computer simulation is an efficient tool to analyze complex systems and investigating different scenarios related to patient waiting-time reduction, resources allocation, staff scheduling, capacity planning, and on-going improvement.

A significant increase in the number of simulation models applied in healthcare services is evident. This growth is motivated by the ability of these simulation models in addressing complex problems that cannot be addressed by decision support systems. Much of its growth can be attributed to ICT development and the volume of real-time data available for analytics.

To support the physicians' activities, INCA's ICT technicians have developed data mining applications to find out the most effective treatments. These applications compare treatments patterns, symptoms and undesirable effects and then keep investigating which medical procedures will be most effective for a group of patients. This is also a way to identify the clinical best practices and protocols for cancer care.

Data mining have a high potential for cancer care institutions by allowing managers to consistently use data science and analytics tools to detect inefficiencies and apply good practices that increase outcomes and reduce costs. The INCA objective was to develop a framework to support the clinical decision-making process. Most of these tools are patient-centric as shown in the INCA Knowledge-based Simulation Framework presented in Fig. 2.

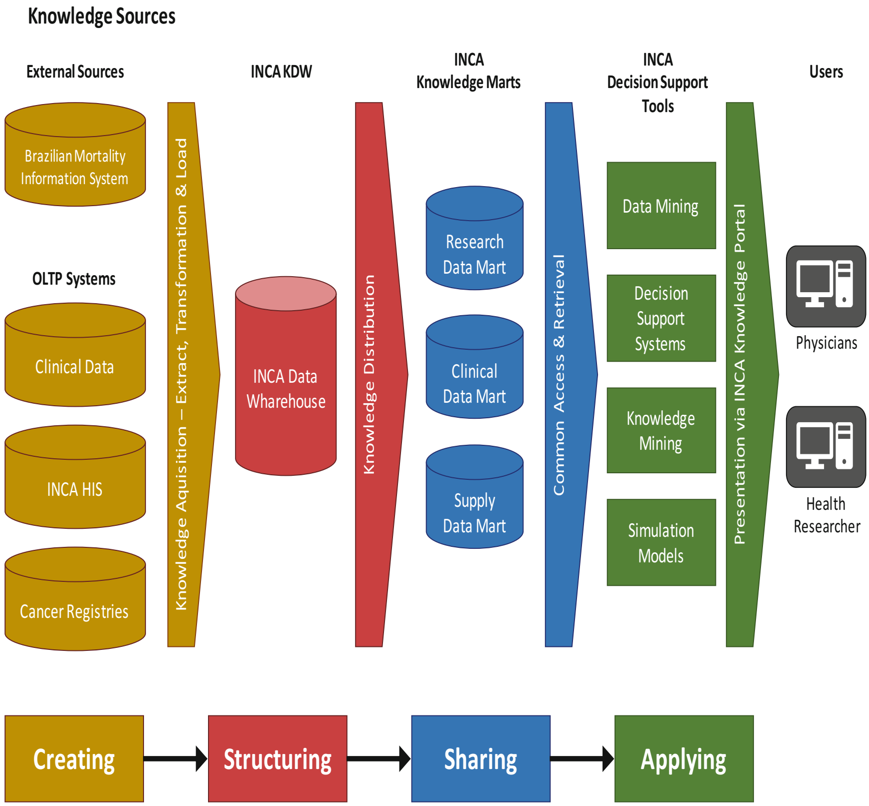

Fig. 2. INCA knowledge-based simulation framework

An innovative approach to analyzing issues of the healthcare services quality assessment is the creation of data-driven models. Such models allow considering the interests of all stakeholders to assess operations environment from the staff view and the effectiveness of work from the manager view. The critical success factor is to work with data from the hospital information system (HIS) and electronic health records (EHR).

This Knowledge-based simulation framework has developed using INCA's intranet network that provides safe access to key benefits of an e-health strategy that uses emerging information and communication technology to improve and facilitate health care. This solution has included enhanced collaboration between physicians and managers, simplifying the physician work, and empowering managers with sophisticated and cost-effective applications on the Web architecture. The legacy systems have fed the INCA data warehouse, which was the base to build the clinical data marts.

INCA data warehouse has processed information of 540,000 patients extracted from legacy systems. This repository was the hub of all data analysis. Several queries were created to validate data consistency. The development of a multidimensional database was to improve analytics applications and to examine the key performance indicators.

Over the last few years, the Brazilian National Cancer Institute (INCA) has been investing significantly in the implementation of an ICT architecture that integrates the organization's main processes and provides decision support systems which contain the following components.

3 INCA Knowledge-Based Simulation Framework

INCA has five specific hospital units with different stakeholders, but which share the same processes and technologies based on a common patient database and standardized information systems. To support the physicians' activities, several tools, such as tracking mechanisms for keeping the longitudinal patient history, online tools for gathering clinical information and the traditional medical record, are used. Most of these are patient-centric and make the hospital environment amenable to the kind of knowledge management system framework, such as presented in Fig. 3.

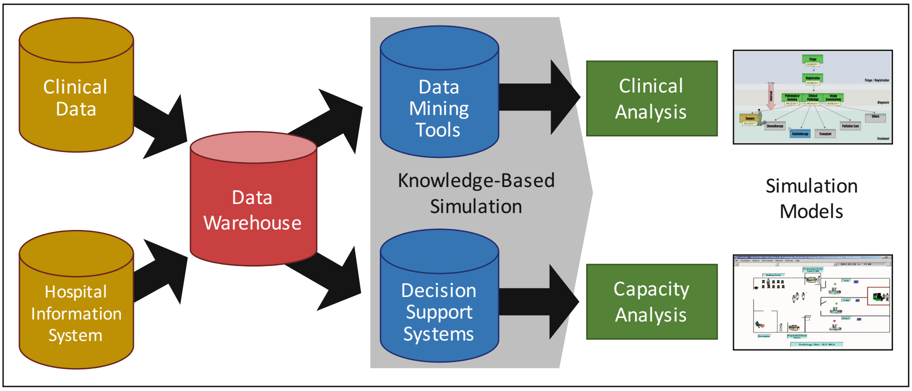

Fig. 3. INCA knowledge management system framework

The INCA knowledge-based simulation framework was developed using INCA's intranet network that provides a safe access to applications developed to improve healthcare. This solution includes a collaboration environment between physicians and managers, simplifying the physician work, and empowering managers involved in the decision-making processes. The legacy systems feed the clinical data repository, which is the basis to build the decision support systems.

3.1 Clinical Analysis (Patient Treatment Flow)

The proposed framework allows decision-makers to have a set of alternative scenarios in real-time. It consists of several models linked to the patient's treatment flow. The automated cancer treatment flow component is a new interesting feature. It offers the possibility to electronically generate the patient's treatment flow from the clinical data repository. Therefore, the users are able to examine, in a visual fashion, the evolution of the treatment. This component is a very useful tool to support decision-making with regards to the care provided. The doctors can blend, on one screen, the past, the present and the future events of the patient treatment history. The sequence of events, the dates and the duration of each event are very important to understand the structure of the treatment. Figure 4 shows an example of the flow of treatment for a particular patient.

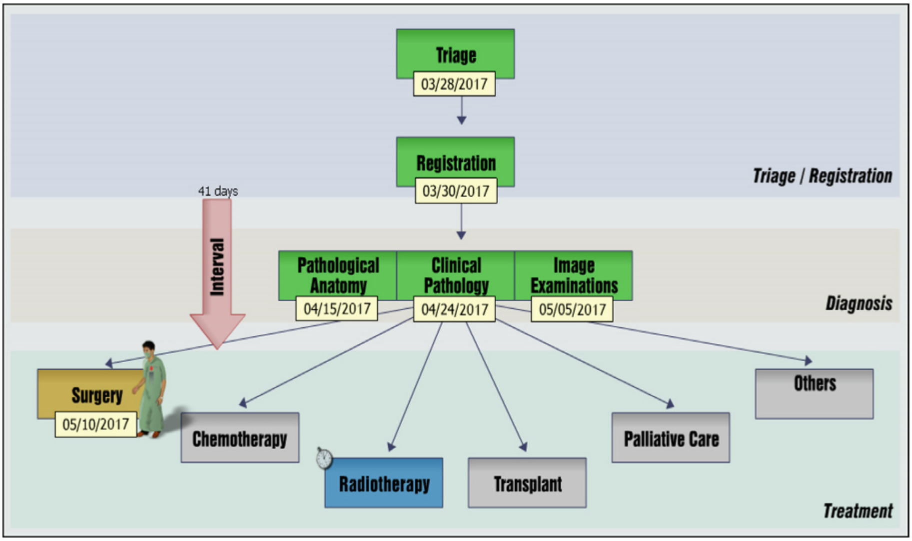

Fig. 4. Patient treatment flow

This component increases the traceability and is totally patient-oriented. It is possible to see, in an animated fashion, the details of the flow of a particular patient over the treatment process. The physician in charge of the case is able to follow a particular patient or a group of patients step by step in their cancer treatment. Based on the easily available information, one is able to detect and/or predict possible problem in the treatment flow.

Understanding the flow of the treatment, evaluating the constraints and managing the bottlenecks could be a possible way to improve quality. A constraint is anything that limits the system's performance. The identification of the constraints is a great opportunity to evaluate and improve the system concerned. There are five fundamental steps to follow: 1. Identify the system's constraint(s); 2. Decide how to exploit the system's constraint(s); 3. Subordinate/synchronize everything else to the above decisions; 4. Elevate the system's constraint(s); 5. If in the above steps the constraint has shifted, go back to step 1.

These concepts have already been explored for productivity improvements in the manufacturing area. The application of this approach to health services is suitable. A search in the literature provides an excellent and more detailed review of applying the theory of constraints (TOC) to healthcare services [11].

3.2 Capacity Analysis (Simulation Model)

Simulation modeling in healthcare is an efficient approach to analyze the interdependence between human resources and infrastructure variables in complex systems and to explore scenarios of decision-making from different stakeholders.

A discrete-event simulation is a valuable tool for studying system capacity and throughput. The use of simulation models with healthcare application includes emergency departments, hospitals, and outpatient clinics. Simulation models can help decision-makers to carry out a 'what if?' analysis to determine good policies for reducing the waiting times of patients, increasing system throughput and improving workflows.

A simulation experiment was developed at the radiology clinic of one of the hospital units of INCA. The objective of the model was to contribute to the reduction of the patient's waiting time to start cancer treatment. The patient's flow was analyzed, and the access alternatives focused. The preliminary steps were to identify bottlenecks and evaluate options for the allocation of resources. The model represents the flow of patients in the radiology department. The sector had three computed tomography scanners (CT). The annual production was about 15000 exams. The main activities evaluated included:

- Reception;
- Patient preparation;
- Medical examination;
- CT Scan;
- Film production.

The simulation model was used to examine alternative scenarios. The objective was the reduction of the waiting time between the computed tomography exam booking and its accomplishment. The target was to increase the capacity to make computed tomography (CT) exams. Figure 5 shows the model of the computed tomography exams' flow in the radiology clinic.

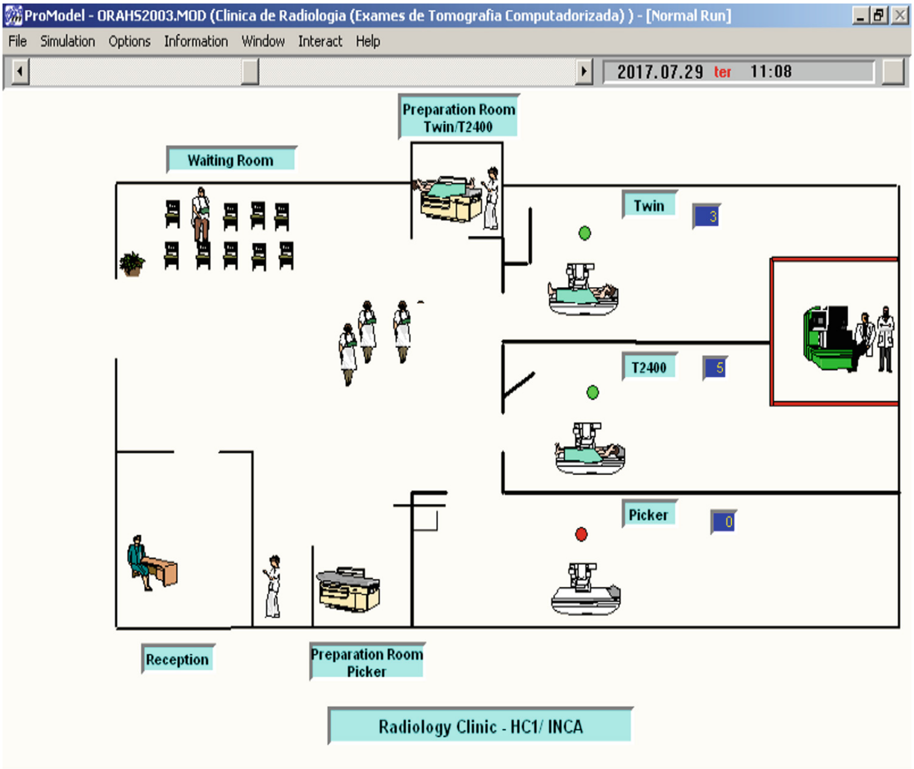

Fig. 5. Simulation model

This simulation model has supported decision makers through "what-if" scenarios for decision-making under conditions of high risks, uncertainty, and lack of information. Different scenarios were chosen for continually evaluating and improving upon key processes. They were characterized by different external environmental situations like a regular workload and an emergency workload at the radiology clinic. The first scenario was regular; it means that there were no unexpected additional patients in the radiology clinic. This scenario has provided management decisions about staff schedules and other resources like the numbers of computed tomography equipment. The emergency scenario has supported decision making in unpredictable circumstances in case of additional patients or equipment breakdown.

The method of conducting the experiment is the visual simulation that is proved to be a powerful tool. The proposed model examines individual patients as they arrive and pass through CT exams. Arrivals, priority rules and exam types provide the necessary detail to reproduce the real-life processes. Alternative scenarios can be compared and modified without high costs. The knowledge gained from the experiments allows one to take decisions without investing major resources.

4 Results

The Discrete Event Simulation model (DES) was used to investigate several "what- if" scenarios. The experiment showed that to reduce overall exam execution time was necessary to remove the phase of film production. The recommendation was to implement a Picture Archiving and Communication system (PACS). Figure 6 shows how the time of accomplishment of a group of examinations was reduced with the exclusion of the film production phase.

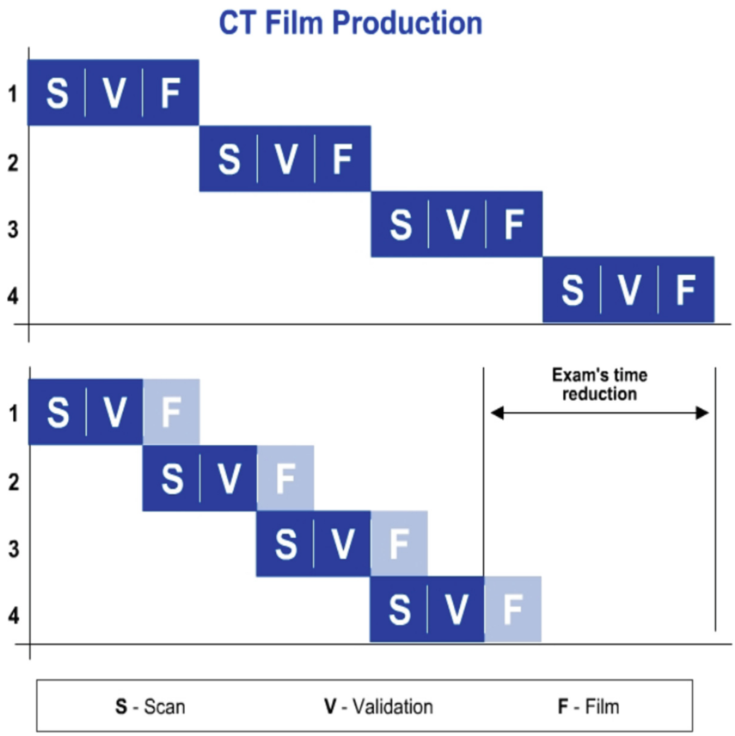

Fig. 6. Reduction of computed tomography (CT) exams time

All patients' data were aggregated in a clinical Data Mart to create the automated patient's treatment flow. This flow has joined electronic medical records and the sequence of events of a patient in only one screen. This approach was radically innovative allowing physicians to examine the clinical evolution of a patient quickly by using past events, current situation, and future procedures.

The dashboard has increased the traceability and was totally patient-oriented. It was possible to see, in an animated fashion, the details of the flow of a particular patient over the treatment process. The doctor in charge of the case was able to follow a specific patient or a group of patients step by step in their cancer treatment. Based on the easily available information, one was able to detect and/or predict possible bottlenecks in the treatment flow.

These analytics applications were developed to support clinicians' access robust data visualizations on their own, enabling them to *drill down* into and filter data based on their specific information needs.

The use of simulation model recommendations has made a significant impact in terms of reduction of the waiting time to obtain CT image diagnosis at INCA. A comparative study has evaluated this indicator before and after the implementation of the Picture Archiving and Communication system (PACS). Figure 7 shows that the interval was reduced from 30 to 22 days with a reduction of 25% of the average waiting time, proving the effectiveness of the process.

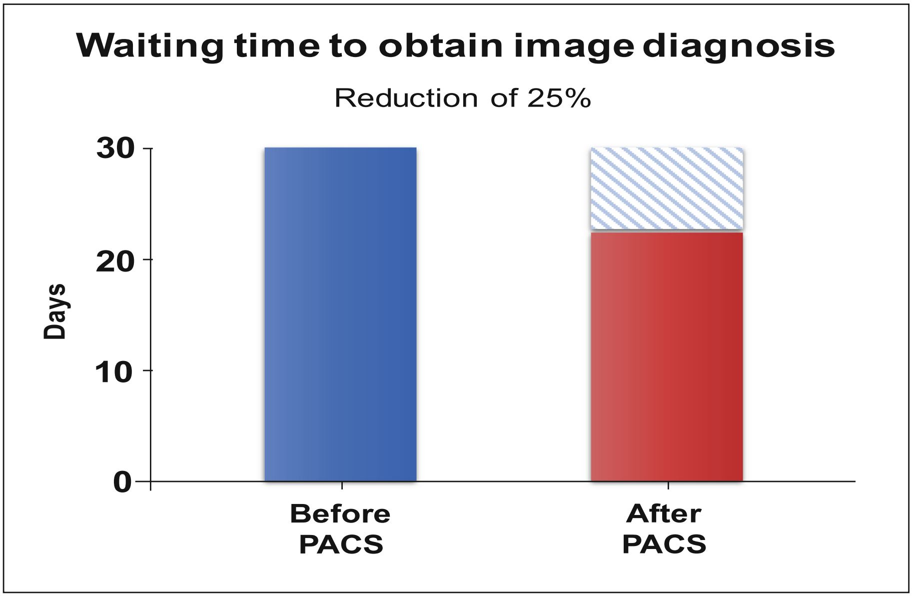

Fig. 7. INCA Patient's average waiting time to obtain CT image diagnosis.

5 Conclusions

Nowadays, healthcare organizations generate huge quantities of data, but regrettably, this asset is not yet entirely used for improving the management and delivery of healthcare services. The benefits gained from the implementation of this knowledge management framework are real-time knowledge access; knowledge share; costs reduction; cancer diagnosis agility and treatment quality.

The adoption of an integrated simulation environment can improve the efficiency of healthcare delivery allied with capturing and sharing patient data among different health professionals. The growth of simulation experiments over the last years has been encouraged by a great number of scientists and researchers conducting exploratory research with simulation models applied to diverse cases of healthcare services management.

This paper indicated how decision making in a cancer treatment center can be improved using a knowledge-based simulation framework. The use of this environment provided the necessary analytic support and insights into such operational decisions. The chosen approach was supported by the suite of applications which has retrieved information about the clinical history of patients, identified process bottlenecks and used discrete simulation technique to investigate alternative scenarios to reduce the patients' waiting time to realize CT's exams. The alternative which has indicated the PACS implementation has reduced patients' waiting time for cancer treatment. Its implementation showed, therefore, that good simulation experiments can make positive changes.

A clear understanding of the decision-making process by managers and clinical staff was essential. The reaction against new analytics tools on part of some physicians has been overcome by the development of user-friendly simulation interfaces. Another incentive has been the warm adhesion of young medical staff. A trend related to the use of graphics interfaces as a deployment critical success factor was observed.

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