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PERFORMANCE EVALUATION OF HEALTH INFORMATION SYSTEMS USING ARIS MODELING AND DISCRETE-EVENT SIMULATION

Vincent Augusto
Olfa Rejeb
Xiaolan Xie

UMR CNRS 6158 LIMOS
MINES Saint-Étienne
158 cours Fauriel
42023 Saint-Étienne cedex 2, France

Saber Aloui

Centre Hospitalier de Sens
1 Avenue Pierre de Coubertin
89100 Sens, France

Lionel Perrier
Pierre Biron
Thierry Durand

Centre Léon Berard
28 Promenade Léa et Napoléon Bullukian
69008 Lyon, France

ABSTRACT

Innovation and health-care funding reforms have contributed to the deployment of Information and Communication Technology (ICT) to improve patient care. Many health-care organizations considered the application of ICT as a crucial key to enhance health-care management. This paper aims at providing a global methodology to assess the organizational impact of high-level Health Information System (HIS) on patient pathway. We propose a performance evaluation for HIS using formal modeling with ARIS (Architecture of Integrated Information Systems) models and a Discrete Event Simulation approach. The methodology is applied to the consultation for cancer treatment process. Simulation scenarios are established to conclude about the impact of HIS on patient pathway. We demonstrated that although high level HIS lengthen the consultation, occupation rates of oncologists are lower and quality of care is higher (through number of available information accessed during the consultation). The methodology is flexible enough to be applied to other health-care systems.

1 INTRODUCTION

1.1 Context

In recent years, there have been substantial developments in information technology and there is now considerable international interest in exploiting the potential of information and communication solutions to enhance the quality and safety of health-care (Huckvale et al. 2010, Black et al. 2011). Indeed, the impact of Health Information Technologies (HIT) on the quality of health-care delivery is a topic of significant importance (Bardhan and Thouin 2013). However, Health Information Systems (HIS) are implemented, often at very considerable cost (Black et al. 2011).

To make HIT (or eHealth) more efficient, particularly for the quality and safety of care, the French Ministry of Health (DGOS) launched the national "Hôpital numérique 2012-2017" program, a strategic development plan for the modernization of health information technology (Ministre des Affaires sociales, de la Santé et des Droits des femmes 2011). The aim of this study was to assess the impact of the development of electronic health records (EHR) and new Information and Communication Technology (ICT) on the performance of French hospitals with quantified key performance indicators such as global costs for the hospital and for the community, impact on patient treatment and on physician activity. Note that hospitals in Europe rarely evaluate the impact of a new HIS on cost, activity, and/or efficiency.

In this context, the French project "Evaluation of Health Information System" intends to challenge this assessment by investigating the value creation through the use of HIS. Within this project the goal of our study is to provide a performance evaluation and cost analysis of information systems on patient care pathway (Ministre des Affaires sociales, de la Santé et des Droits des femmes 2014). The main purpose is to evaluate the impact of information and communication technologies on (i) the quality of care and (ii) on the costs. Oncology consultations are taken as a case study to assess the impact of HIS.

1.2 Literature review

Most of relevant literature advocates a relatively low number of articles examining the impact of information systems in economic terms and quality of care. A systematic review literature realized by (Bassi and Lau 2013) identified 42 papers that focused on evaluations of health information systems including an economic evaluation. 33 were deemed high quality providing relevant supportive information. These included 12 economic analyses, 5 input cost analyses, and 16 cost-related outcome analyses. A further review of the literature provides us with some common inclusions compliant with (Bassi and Lau 2013) study. This relative rarity is also highlighted in the publication of (O'Reilly et al. 2012) where the authors conduct a systematic review and synthesis of the evidence surrounding the cost-effectiveness of health information technology (HIT). Articles including an economic component were reviewed for further screening.

However, there is a growing focus in literature to asses impacts of HIT along multiple dimensions related to the cost, quality of care, efficiency, and financial performance of health-care providers (Bardhan and Thouin 2013). A recent study based on econometric methods assess the impact of using an advanced electronic health record (EHR) on hospital quality and patient satisfaction (Jarvis et al. 2013). This retrospective, cross-sectional analysis was conducted in 2012 shows an association between advanced EHR use and quality of care in the USA.

1.3 Scientific contribution

Given the current lack of evidence on quality improvements and on the cost-benefits associated with the introduction of ICT applications on health-care systems, it is important that health information systems should be evaluated against a comprehensive and rigorous set of methods. In order to effectively support decision makers of health-care systems, a formal modeling of the involved flows is therefore necessary to highlight the impact on the patient care pathway (Perrier et al. 2014). The flow models propose a simple interface between health care professionals and engineers, enabling communication and better understanding of modeled organizations. To do so, modeling tools such as ARIS (Architecture of Integrated Information Systems) are implemented rigorously to model the flow of patients, processes, information and material.

This paper tackles a scientific challenge which has not been treated yet in the literature to the best of our knowledge by proposing a comprehensive methodology for practitioners to evaluate the HIS of a hospital based on quantitative key performance indicators. To support that objective, the Health-care and Medico-social Support Agency (ANAP) proposed to disseminate that method among French hospital under the shape of a tutorial that can be applied by any practitioner. The methodology, the models and the tools described in this article are intended to be used in any structure to evaluate the performance of its HIS.

This paper is organized as follows: the general methodology is presented in Section 2. ARIS models are described in Section 3. DES (Discrete Event Simulation) models are presented along with data collection, performance indicators and numerical experiments to evaluate HIS strategies. Various scenarios are tested and results are presented in Section 4. Finally, conclusions and perspectives are presented in Section 5.

2 METHODOLOGY OF THE PROJECT

To assess the impact of using an advanced HIS on patient pathway care quality, the starting point for the study was to identify the wide range of activities, resources, information involved. A patient pathway (or care pathway) is a sequence of health and social care services a patient in receives after entering the system during a particular episode of care (in our case: the cancer consultation). is a succession of steps in the hospital. A process oriented approach to model patient pathway was conducted to design a generic model, i.e. the approach is focused on the sequence of tasks performed on/by the patient. The resulting generic model can be instantiated for a specific health-care system and be converted into an executable model for simulation. The highest levels of the models are identical for all the establishments, whereas the low levels models must be customized to fit the specific practices of practitioners and health professionals (for example, process of checking medical imaging during the consultation in our case study).

The global methodology is presented in Figure 1. Recall of information was assessed in a structured interview (1), questionnaires for both patient and information system characteristics and field-observations. One hundred and fifty consultations with patients affected with breast/lung cancer were observed in our case study. A detailed database was developed. In our case study, during these observations, two types of consultations were assessed: consultations of treatment prescription and consultation of follow-up/evaluation.

Based on information gathered during the observations, a formal modeling of oncology consultation process and the relevant information for the therapeutic decision-making is proposed (2). ARIS (Architecture of Integrated Information Systems) was chosen to model such processes and interactions between patient care pathway and information requirements. This step provides to health-care practitioners a comprehensive knowledge of the studied system's operations.

Our methodology includes also a cost analysis (3). The study aims to perform a cost analysis of consultations in oncology distinguishing ICT level. The perspective of the hospital was retained. Cost calculations were strictly based on a micro-costing approach. Therefore, only resources that entered the hospital production process were considered, including cost of staff (e.g. physician, medical secretary), costs related to the ICT, as well as overhead costs. Data on consumption of resources were prospectively collected from the consultation preparation until the transmission of the clinician report was done. Two strategies were studied: (i) consultations with a high level intensity in ICT (fully equipped with computers and software for medical examination consultation and prescription/report generation), and (ii) consultations with low-level intensity in ICT (no computer in the consultation office).

Finally, ARIS models and economic parameters serve as a basis for a simulation model implemented under Rockwell Arena. Relevant performance indicators used for the evaluation are economic costs from the hospital point of view (costs related to the consumption of resources, the cost of allocated resources). DES is a useful tool to compare different structures without bias and assess economic key indicators (Rodríguez-Verjan et al. 2013). *What-if?* scenarios can be proposed through a detailed process analysis of the system, depending on the needs of the practitioners.

All this methodology is intended to be used in a small amount of time with minimal guidance through rapid prototyping actions in the hospital to provide precise answers to health-care practitioners and hospital administrators. In this paper, the methodology is applied to the cancer consultation in oncology services as a case study. All subsequent models, data and numerical results are based on this concrete study. In addition, due to space limitations, we will not focus on step (3) in this paper.

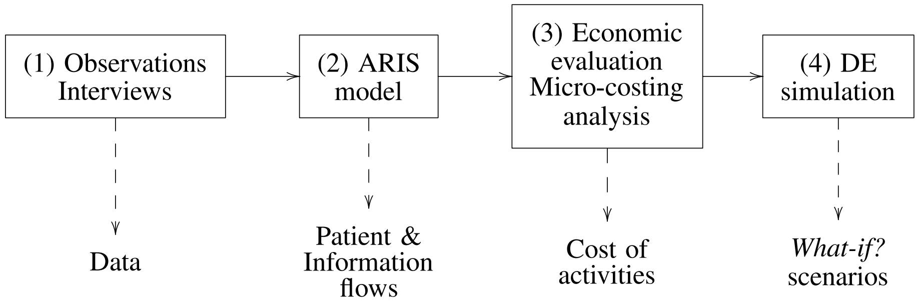


Figure 1: Global methodology

3 MODELING USING ARIS

To be able to analyze the processes, different views are required. We propose a two-layer architecture for system modeling: Business layer and application layer. ARIS models are organized into different views: organizational view, data view, and business process view. This organization is used to model each kind of entity in a separate view. Those models represent process related concepts, actors and their roles, resources and data flows. For these reasons ARIS software was selected to design and model existing processes, the exchanged data and the used resources.

1. Business layer, composed of three levels. Level 1: process map, where business processes are modeled on the macroscopic level. Level 2: CPE diagrams, where macro-processes are proposed with inputs, outputs, resources and required information. Level 3: CPE diagrams, where control flows are modeled using activities and events. Relations between activities and resources are proposed, as well as resource allocation and information usage.
2. Application layer, where the architecture of the HIS is proposed using ARIS application diagram.

A global view of the model's organization is proposed in Figure 2. At the highest level, the whole process is described. On the second level, a macroscopic model describes a specific activity as well as interacting elements. On the third level, generic CPE diagrams are proposed to detail the various activities (tasks, resources, information). Finally, on the lowest level, an operational description of the process is proposed. At this level, each model is dedicated to one specific hospital. For example, in Figure 2, activity "Preparation of the consultation" is made of several tasks existing in all hospitals such as "Mail preparation", "Daily organization", "Patient file preparation". Then, task "Daily organization" is composed on the lowest level of various models depending on the specific organization of each hospital.

Such strategy allows to reproduce the same modeling methodology in other hospitals: all level 1-3 models can be used as-is, whereas models of the lowest level (4 and subsequent) should be adjusted to stick with the new hospital organization. The ARIS modeling step is crucial to understand the patient pathway and the information flow in the studied hospital. The language is designed to focus on crucial steps involving the central entity (the patient), the information and the human resources involved. It also allows practitioners to formally model the operations before deciding on the analysis to perform.

The Event Process Chain (EPC) from ARIS can be used to model the system dynamics and translate the model to a discrete-event model. Activities and events are linked together to describe the process control flow. Further details on EPC and ARIS are proposed in (Scheer and Nuttgens 2000). To summarize, EPC diagrams are composed of columns (one for each actor in the process); in each column, activities are described as well as resources (information, documents, software...) and rules (AND, OR, XOR). Objects used for the EPC model are presented in Figure 3.

In this study, we focus on the consultation step where the main resources are the oncologist and the medical secretary. Figure 4 describes a part of the generic consultation process (level 3 in the architecture).

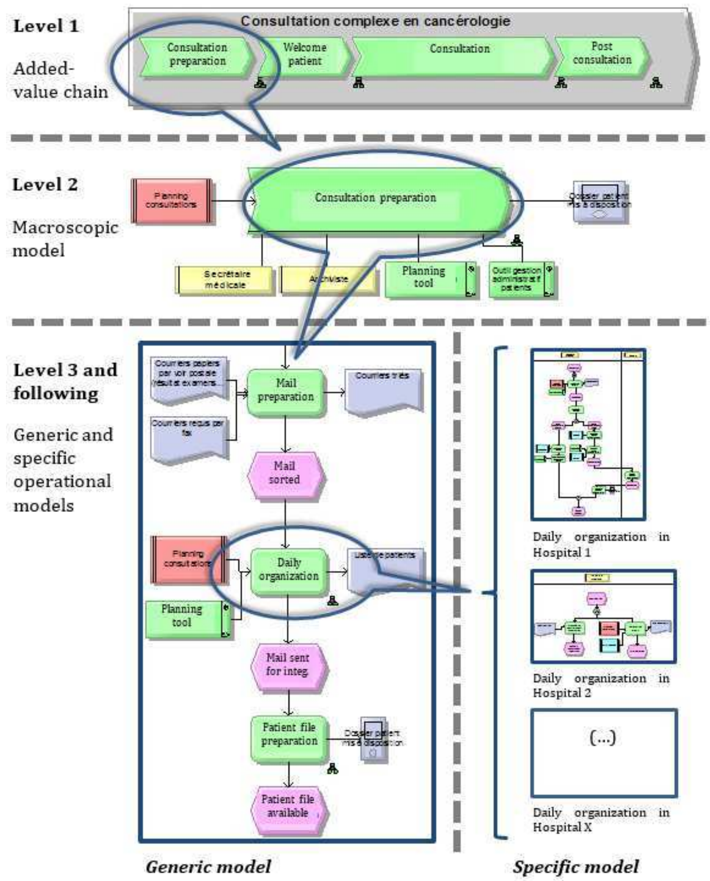


Figure 2: Global ARIS models organization

After the consultation preparation, the patient is welcomed by the secretary when he/she arrives. Then the patient enters the oncologist's office and his/her medical file is checked. After a discussion, the oncologist will check either one or all of the following examinations: medical imaging (CT scan, MRI), biology exams, histology exams, and other para-clinic exams. A clinical examination may also be performed on the patient. Then a diagnosis is performed by the oncologist. If necessary a prescription is made, allowing the patient to get additional exams, drugs, or other consultations. In this context, a prescription is a written order by a physician for the preparation and administration of a medicine or other treatment. Finally, after patient departure, a report is dictated by the oncologist, which will be typed and checked by the secretary during the post-consultation. Additional information are presented in the models, such as required information (red boxes), required tools (green square boxes), documents (gray boxes) and events (purple boxes).

For each activity (represented as a green block with rounded corners), information (red squares) and tools (green squares) are associated. For example, to check medical imaging exams, an imaging tool is required as well as the information under the shape of a physical or numerical document. Documents may also be outputs of activities, such as "Blood tests" for the "Prescription" activity.

If necessary, all activities may be detailed for specific case studies: for example, the activity "Check medical exams" is decomposed in two different processes for the hospitals partner: in H1, imaging exams are checked using negatives whereas in H2 a software is used to access MRI pictures in files.

Figure 3: EPC model objects

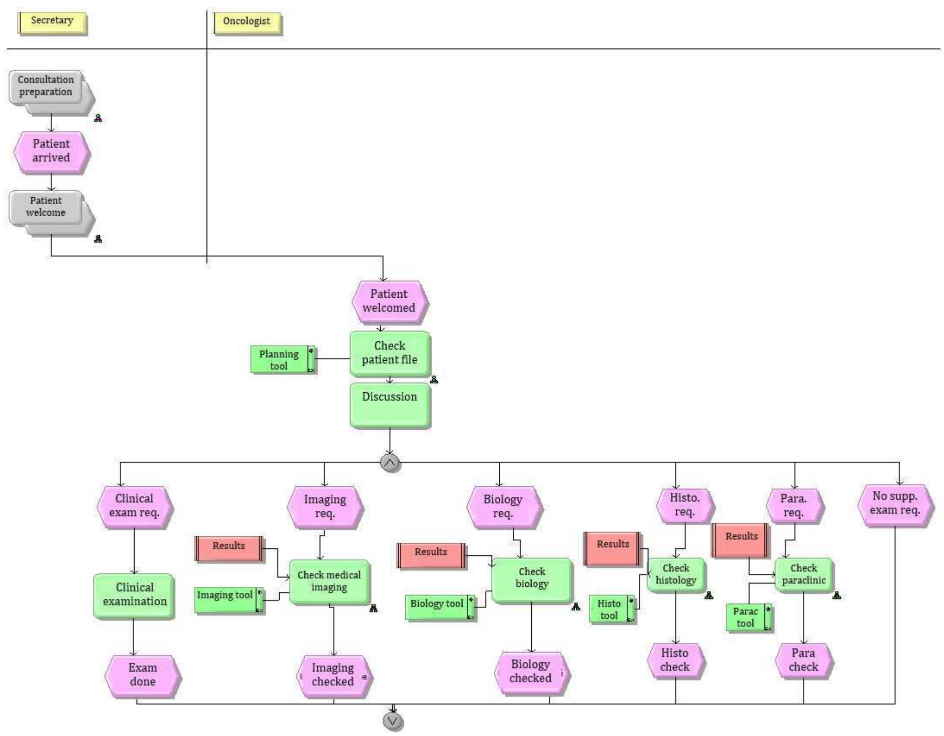


Figure 4: Generic consultation process: from patient arrival to medical examination consultation (level 3)

4 PERFORMANCE EVALUATION THROUGH DES

The performance evaluation of the HIS is performed using Discrete Event Simulation. The ARIS model has been implemented in ROCKWELL Arena 14.5 in order to be simulated. Then the simulation model has been validated using the data collected on the field. Finally, several simulation scenarios have been established in order to determine the added value of various level of HIS for the cancer consultation process.

4.1 Data collection

Data have been collected on the field for H1 and H2. In the end, 150 consultations were observed. For each consultation, a precise activity log has been built in order to enumerate all tasks observed during the process, and to extract time data for each task. The amount of observed consultations should be high enough to get a significant amount of values for each activity that may not appear for each patient. For each activity, two probability distributions are computed (for prescription and evaluation consultations respectively) using the set of durations collected on the field. Arena Input Analyzer was used to determine the best distribution.

4.2 Model conversion

The ARIS model is the starting point to implement the Arena model. Some conversion rules have been established in order to make that operation as simple as possible. Entities model patients in the system. Arrival of a patient in the system triggers a set of activities, and each of these activity is related with the HIS we want to evaluate. Each entity has a set of attributes. In the cancer consultation case study, the following attributes are recorded: internal id, type of consultation, type of cancer and set of probabilities related with patient pathway. Resources model tools and software used by the doctor, medical secretaries and other human resources having a role in the medical treatment of the patient. All items defined in the ARIS model are modeled as resources: exploitation resources (required tools for the consultation such as a phone, a dictation device...), documents, files, software. Human resources are also modeled as resources: doctors, medical secretaries, and so on. Finally, variables define the system under study: type of HIS used in the hospital, habits of doctors. Such variables are initialized at the beginning of the simulation.

CPE elements from ARIS are converted to Arena blocks: an ARIS Function using documents, files, software, tools is modeled as an Arena Process requiring various types of resources and having a random duration modeled using a probability distribution. A logical operator in ARIS is a Decision in Arena. An ARIS event is modeled using a link between two Arena blocks, and may also trigger a signal.

4.3 Model generecity

As described in Section 3, the simulation model has been implemented to be used in various situations. The patient pathway is modeled as seen in the case study (in our case, the cancer consultation), but the steps requiring various HIS elements are modeled as black boxes and may be replaced by an information consultation process model relevant to the studied system. Hence the model is generic because it is intended to be exported to other health-care structures for performance evaluation purposes.

For example, in the cancer consultation case study, the imaging examination consultation is performed in two different ways: (i) the doctor connects to a dedicated software, accesses the patient imaging history, select one or several MRI and formulates its diagnosis; or (ii) the doctor takes the physical images from the patient file, hang it on a negatoscope and formulates its diagnosis. Each process is related with a different level of HIS and associated through the micro-costing analysis to a different cost for the hospital: for a certain activity, two processes are defined with different resource usage, we deduce a cost from used resource in each process (in the previous example, the negatoscope has a certain cost whereas usage of the medical imaging software has also a certain cost). It also has an impact on patient medical treatment.

A predefined list of parameters are also implanted in the model: each patient is characterized by a list of attributes to determine his/her pathway, health state and cost for the hospital. Resources are also predefined as explained in the previous Section. Finally, costs retrieved from the micro-costing analysis are injected in the model. All external inputs are stored in MS Excel files.

4.4 Performance indicators

In order to evaluate the performance of the system by considering various types of HIS, a list of key performance indicators (KPI) has been established: (i) Time KPI: time to discharge of the patient in the system, total waiting time of the patient, activity duration for the patient, for the doctor, inactivity duration for the doctor, total time spent on HIS or non HIS tools and software; (ii) Resource usage KPI: human resource occupation rate and HIS related usage rate. Occupation rate is related to the time spent by a resource for the consultations in a day. Qualitative KPI are also proposed, related to the service quality for the patient, efficiency of the medical treatment. Such KPI are established by taking into account random probabilities in the model related to delays and lacking information during the process which may lead to incomplete diagnosis and patient appointment rescheduling.

4.5 Simulation scenarios

In this paper, we intend to provide a flexible tool to evaluate the performance of HIS and its impact on patient pathway and medical treatment. The simulation model can be used to achieve that objective by defining various scenarios allowing us to test the added value of one or all elements of modern HIS.

Simulation scenarios are summarized in Table 1. Scenarios S1 and S2 are validation scenarios, where the model mimics the hospitals where the data collection was performed. A comparison between the simulation output for S1 and S2 has been made with the collected data to validate the model and provided results close to reality (less than 10% error on selected KPI). Scenario S3 evaluates the impact of having a high level HIS with and without software integration. Scenarios S4-8 evaluate the added value of various element of HIS: imaging (MRI and CT scan images), biology (blood tests), histology (pathological examination of cell samples), para-clinic (all other documents needed to formulate a diagnosis), prescription (medicine prescription for the patient), report dictation. HIS components associated with medical examinations are software products allowing the consultation of numeric files (such as a scan of the letter containing the blood result to the patient) or the visualization of medical images (such as the slices resulting of a MRI exam). Finally, Scenario S9 evaluates the impact of having full electronic health records in the hospital.

Table 1: Simulation scenarios for HIS impact analysis in the cancer consultation example

Id	Label	Sim features		HIS features							
		Rep. count	Rep. length	Patient file	Imaging	Biology	Histology	Paraclinic	Prescription	Report dictation	Integration
S1	Validation scenario for H1	50	8h	0	0	0	0	0	0	0	0
S2	Validation scenario for H2 (full numeric and integrated)	50	8h	1	1	1	1	1	1	1	1
S3	Semi-integrated HIS	50	8h	0	1	1	1	1	1	1	0
S4	Medical image visualization software	50	8h	0	1	0	0	0	0	0	0
S5	Blood results numeric file	50	8h	0	0	1	0	0	0	0	0
S6	Cell sample analysis results numeric file	50	8h	0	0	0	1	0	0	0	0
S7	Other paraclinic exams	50	8h	0	0	0	0	1	0	0	0
S8	Editing software for prescriptions	50	8h	0	0	0	0	0	1	0	0
S9	Voice recognition report dictation and editing	50	8h	0	0	0	0	0	0	1	0
S10	Numeric patient file (no paper)	50	8h	1	0	0	0	0	0	0	0
S11-S20	Same as S1-S10 for long term simulation (5 years)	5	5y								
S21-S40	Same as S1-S20 for prescription consultations										

Scenarios S1-S10 simulation length is 8 hours (average length of a consultation day) and the number of replications has been adjusted to reach a 95% confidence interval. Scenarios S11-S20 parameters are identical to scenarios S1-S10 although they were simulated on a long period (5 years) in order to asses the long-term impact of HIS on hospitals and take into account fixed costs that will be amortized over a long period; for these scenarios, the amount of replications is lower (10 replications) because the high replication length contributes to a high confidence interval. Since we are studying a terminating simulation, each simulated day may be assimilated as a different replication for performance indicators that are not related to the long-term performance evaluation. No warm-up period is necessary.

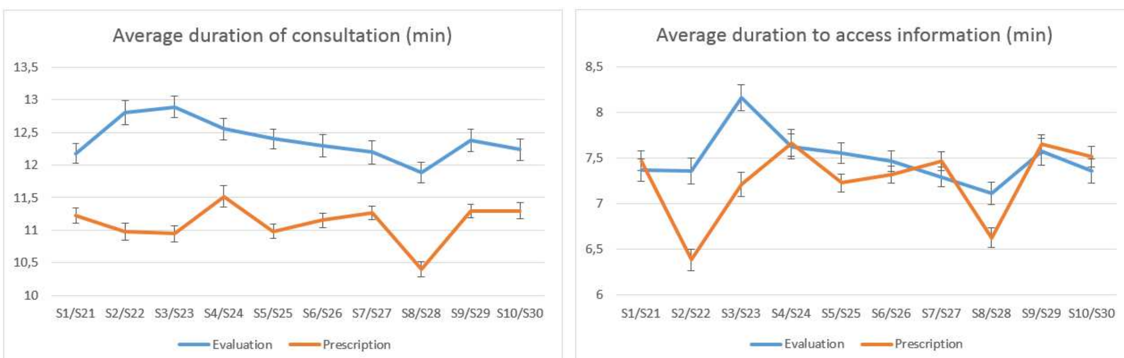
The following hypothesis are taken into account in the simulation model: (1) The added value of having an HIS for each step (Imaging, Biology...) is evaluated by calculating the time spent by the doctor on the related task. (2) Integration of HIS in the hospital is evaluated by taking into account the loading/logging times when switching between software products.

4.6 Results

Simulation results are presented in Figures 5, 6 and 7. Each scenario is simulated twice for prescription consultations and for evaluation consultations, resulting in a total of 40 scenarios to be evaluated for each set of KPI. Figure 5 presents the average time to discharge of patient in consultation and the average duration required to access information for short simulations (S1-S10 and S21-S30). For each scenario, the value of the KPI is indicated along with the resulting confidence interval as an error bar. Average LOS include discussion and clinical examination, which may introduce some bias in the results. However such indicators allow to validate the models for the as-is scenarios (S1/S21 and S2/S22) as the results are close to real values. KPI related to the average duration required to access information allow us to state that:

- Average duration increases when the HIS level is high (S2 and S3 vs S1). Implementation of dictation along with vocal recognition leads to the best decrease for that KPI.
- Average duration of prescription consultation is shorter when the HIS level is high (S22 vs S21 and S23): for such consultation, the required amount of information is lower.
- Integration has a high impact on required time to access information; hence a set of HIS resources unrelated may lead to a longer consultation because of loading times and software switching.

Taking into account the confidence intervals, it is difficult to conclude on time KPI related to the HIS status: implementation of imaging, biology, histology and paraclinic has a low influence on time KPI. Field observations corroborate such results.



(a) Time KPI for consultation duration

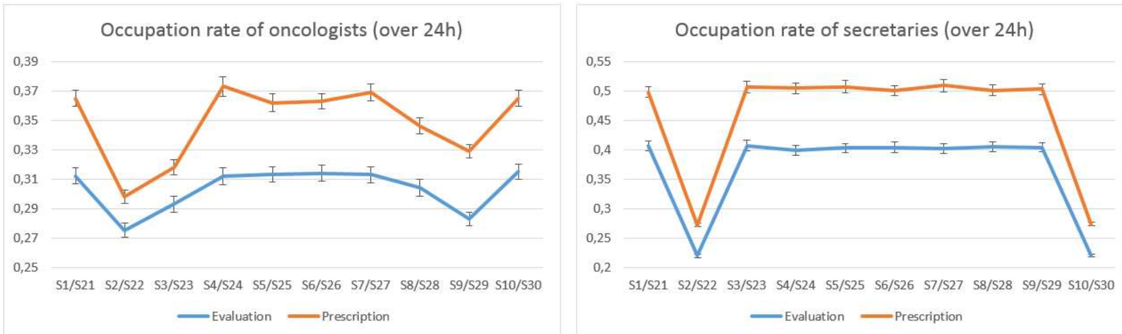
(b) Time KPI for information access

Figure 5: Time KPI

Figure 6 presents the occupation rates (over 24h) for oncologists and secretaries for all tasks taken into account for the consultation. For the oncologist, the following remarks can be formulated:

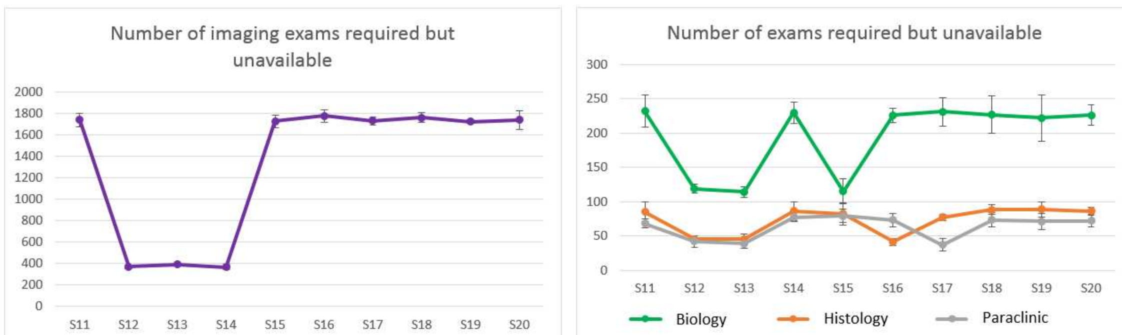
- Systems with high level HIS and integration (S2/S22) is the best scenario for that KPI, for both types of consultations.
- Systems with high level HIS without integration (S3/S23) has also a good performance and allow the oncologist to spend less time for the consultation, especially after the patient departure.
- Scenarios S8/S28 (computerized prescription) and S9/S29 (computerized dictation along with vocal recognition) are good alternatives to optimize the time of oncologists.
- For secretaries, the best improvement is obtained by using electronic health records for patient files; in that case, numerous tasks such as patient file transportation/preparation are no longer needed.

Figure 7 presents a quality indicator of HIS on patient care using the number of examinations required during the consultation but unavailable. In that case, having a computerized access to the information leads



(a) Occupation rate of oncologists (over 24h) (b) Occupation rate of secretaries (over 24h)

Figure 6: Resource KPI



(a) Quality of care regarding imaging exam access (b) Quality of care regarding other exams access

Figure 7: Quality KPI

to a great improvement in the system performance, especially for medical imaging examinations. Such results could only be achieve after observing the consultations, because such information is usually not recorded in the patient files.

5 CONCLUSIONS AND PERSPECTIVES

In this paper, we proposed a new methodology to evaluate the performance of HIS on the patient care process, with a direct application to the cancer consultation. We proposed a mixed generic and specific modeling framework applied to two hospitals; such method may be applied to other candidate hospitals with a low amount of work required by extending the proposed set of ARIS models. The DES model follows the same logic, and may be personalized depending on stakeholders. A design of experiment has been proposed to demonstrate the impact of HIS on consultation with various KPI related to resource utilization and quality of care. A high-level HIS does not shorten the consultation, but has an added value on quality of care through the amount of available information during the consultation. Cost effective actions are related to the implementation of medical imaging software and electronic report dictation.

We intend to integrate the economic analysis of the HIS on patient pathway to obtain cost KPI in forthcoming works. Indeed, we will propose additional *what-if?* scenarios to evaluate the economical impact of HIS on the hospital. Safety and likelihood of errors factors could be taken into account and are part of our perspectives. Dissemination of that work to practitioners will also be performed to allow other hospital managers to take advantage of that work.

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AUTHOR BIOGRAPHIES

VINCENT AUGUSTO received his Ph.D. in Industrial Engineering from the École Nationale Superieure des Mines de Saint-Étienne, France, in 2008. He was a visiting scholar at CIRRELT, Laval University, Quebec, Canada in 2009 and 2015. Currently, he is an assistant professor in the Department of Health care Engineering at the ENSM.SE. His research interests include modeling, simulation, optimization of health care systems and their supply chains. His e-mail address is augusto@emse.fr.

OLFA REJEB received her Ph.D in Industrial Engineering from the École des Mines d'Albi-Carmaux, France, in 2013. She did a postdoctoral in the Department of Health-care Engineering at the ENSM.SE.

Currently, she is a research engineer at OWI technologies. Her research interests include modeling, simulation and the study of business continuity issues. Her email address is rejeb.olfa@gmail.com.

XIAOLAN XIE received his Ph.D degree from the University of Nancy I, Nancy, France, in 1989, and the Habilitation à Diriger des Recherches degree from the University of Metz, France, in 1995. Currently, he is a distinguished professor of industrial engineering, the head of the department of Health-care Engineering and the head of IEOR team of CNRS UMR 6158 LIMOS, École Nationale Supérieure des Mines (ENSMSE), Saint Etienne, France. He is also a chair professor and director of the Center for health-care engineering at the Shanghai Jiao Tong University, China. Before Joining ENSMSE, he was a Research Director at the Institut National de Recherche en Informatique et en Automatique (INRIA) from 2002 to 2005, a Full Professor at École Nationale d'Ingénieurs de Metz from 1999 to 2002, and a Senior Research Scientist at INRIA from 1990 to 1999. His research interests include design, planning and scheduling, supply chain optimization, and performance evaluation, of health-care and manufacturing systems. He is author/coauthor of over 250 publications including over 90 journal articles and five books. He has rich industrial application experiences with European industries. He is PI for various national and international projects including ANR-TECSAN HOST on management of winter epidemics, NSF China key project on planning and optimization of health care resources, French Labex IMOBS3 project on home health cares, FP6-IST6 IWARD on swarm robots for health services. He has been an associate editor for IEEE Transactions on Automation Science & Engineering, IEEE Transaction on Automatic Control, IEEE Transactions on Robotics & Automation and International Journal of Production Research. He has been a Guest Editor of various special issues on health-care engineering and manufacturing systems. He is general chair of ORAHS'2007 and IPC chair of the IEEE WHCM'2010. His email address is xie@emse.fr.

SABER ALOUI has a Ph.D. in Risk Management (2007) from the École des Mines de Paris, Doctoral team called "Center for research on Risks and Crises". His research aims to develop and to formalize concepts and tools allowing to analyze the risk occurrence in large health care organizations. He is currently CIO of a French hospital. His email address is saloui@ch-sens.fr.

LIONEL PERRIER received from the University Lumière Lyon 2 his Ph.D. in economics in 2001 and the Habilitation Diriger des Recherches degree in 2010. Currently, he is responsible for the innovations and strategies unit in the Clinical Research and Innovation Direction of the Cancer Centre Léon Bérard. He is a member of the GATE Lyon Saint-Étienne (UMR CNRS 5824). He recently joined the Economic evaluation and public health Commission of the French National Authority for Health. His email address is lionel.perrier@lyon.unicancer.fr.

PIERRE BIRON is a doctor, specialist of medical oncology and hematology at Léon Berard cancerology center of Lyon. He has developed hematology in this hospital and was involved in intensive chemotherapy and autograft of hematopoietic stem cells in malignant neoplasms. From 1994 to 2004 he was director of medical affairs and is now counselor of the present director and in charge of hospital mediation. He is director of the regional cancerology network of Rhone-Alps. He is also the project manager of the electronic patient record and IS of Léon Berard and the medical referent for the regional health electronic platform and cancerology record in Rhone-Alps. His email address is pierre.biron@lyon.unicancer.fr.

THIERRY DURAND received his engineer degree in computer science from the INSA Lyon. Since 2001, he is the CIO of the Centre Léon Bérard (Lyon), paper-less hospital since 2002 and film-less since 2005. He is also the director and administrator of the GCS SISRA since 2006. SISRA is the regional eHealth platform for the Rhone-Alps region (6.5M people). His email address is thierry.durand@lyon.unicancer.fr.