FACULTY OF SCIENCE,
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School of Computer Science and Mathematics
Department of Computer Science

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Intelligent Cloud-Based Digital Imaging Medical System Solution

HAMDOUNI Hind

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Pr. Jamshid Dehmeshki

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This work or any part thereof has not previously been presented in any form to the University or to any other body whether for the purpose of assessment, publication or for any other purpose. I confirm that the intellectual content of the work is the result of my own efforts and of no other person

Signature: Hind Hamdouni

Date: 15/10/2019

To my dear parents, Ahmed and Raja, who have always been there for me; you have sacrificed everything for your children, sparing neither effort nor health. You gave me a beautiful model of hard work and perseverance. I am also grateful for an education which has helped me become what I am today.

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Abstract

This research started with a simple fact: The global needs in medical care, and in medical imaging specifically, are increasing. This is mainly due to a population that is getting older and hence more likely to be exposed to diseases; but this same population would wish to keep a high quality of life. Therefore, to cope with these challenges, many systems, innovations and programs have been created and developed. Among them is the Picture Archiving and Communication System or PACS. Although this filmless system has shown to have a great deal of advantages when onsite - such as the capability to access medical data at different locations - these benefits seem to be outbalanced by the high initial costs, potential risk of data loss and the complexity of data sharing.

Therefore, the aim of this research is to suggest a potential betterment of the onsite medical system, by introducing cloud and Computer Aided Diagnosis aspects to it. Lausanne Hospital has been used as a benchmark in order to evaluate the proposed solution, in terms of cost efficiency, diagnosis accuracy, users' productivity, medical data sharing opportunities, data accessibility, procedure when upgrading systems, reporting process, workflow performed for handling technical issues, and teleradiology benefits.

Investigating the potential impact of merging Cloud, PACS and CAD as one intelligent cloud-based digital imaging medical system solution has resulted with the following discovery: the proposed medical technology appears to be more profitable for its potential users than the current option. In point of fact, the proposed solution minimises initial costs, as a result of offsite hosting. Moreover, the suggested system eases offsite medical data viewing and sharing, which strengthens opportunities for

teleradiology and collaboration between medical experts. This system also allows its potential users to centre their focus on their core area of expertise, as the system provider becomes the sole manager responsible for the software. Regarding the integration of CAD, the analysis has shown that utilising this software presumably adds greater value to the cloud-based medical system, as CAD engenders higher efficiency and productivity during diagnosis and reporting processes.

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Abbreviations list

3D	Three Dimensional
AW	Advantage Workstation
CAD	Computer aided diagnosis
CHUV	Lausanne Hospital (Centre hospitalier universitaire Vaudois)
CT	Computed tomography
Dr.	Doctor
E.g.	Example
ER	Emergency room
GE	General Electric
GP	General practitioner
HIS	Hospital information system
IARC	International Agency for Research on Cancer
ICDIMS	Intelligent Cloud-Based Digital Imaging Medical System
ICU	Intensive care unit
IT	Information technology
MDTM	Multidisciplinary team meetings
Mm	Millimeter
MRI	Magnetic resonance imaging
MS	Millisecond
NAS	Network-attached storage
NHS	National Healthcare service

PACS	Picture Archiving and Communications System
RIS	Radiology information system
ROI	Region of interest
RP	RadioPACS
TN	True negative
TP	True positive
U.K	The United Kingdom
UML	Unified Modelling Language
Vs	Versus

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Chapter 1

Introduction

1.1. Context of the research project

The health conditions and treatments needed by the population will evolve; partially because of the ageing factor. The latest forecast stipulates that the proportion of people aged sixty years old and over will likely increase globally and reach over 1.4 billion in 2030, and 2.1 billion in 2050, compared to 901 million, in 2013 (United Nations, 2015). This increase in average lifespan will involve the generation aged over 80 years old as well. Indeed, the proportion of 80 years old and older should represent 434 million in 2050, a tripled number compared to 2015 (United Nations, 2015).

Thus, as the likelihood of facing cancer illnesses increases with age, cancer cases will evolve at a faster rate that matches the natural increase of the population. Indeed, a study led by the IARC (International Agency for Research on Cancer) reveals that cancer cases are estimated to increase by 68% by 2030, and are primarily expected to be comprised of colorectal cancers, cancers of the breast and prostate (Cancer Research UK, 2014).

In this context, focusing on early detection of diseases and illness prevention will no doubt be a core tool in avoiding higher healthcare expenditures. The progress made in research on various diseases, along with the new advances in medical imaging could lead to the prevention and early discovery of illnesses (Merle-lamoot and Pannetier, 2013). Indeed, with the enhancement of new technologies, it is possible to develop new systems which are more effective, less costly and more targeted at patients' health and wellbeing. This explains the appearance of the Picture Archiving and Communication System among other solutions.

Simply put, PACS is a computer system that centralises and manages the digital acquisition of all radiological examinations; consultations of radiological examinations in workstations; sending pictures in or out of service or hospital; and the exchange of administrative information through Radiological Information System (RIS) and Hospital Information System (HIS). PACS represents the evolution towards an environment where activities based on films are gradually replaced by their digital equivalent (Anderson and Flynn, 1997).

This filmless system, when onsite, has shown multiple advantages, such as ownership and control of data and the multi-location factor of the same medical information. The importance of PACS is highlighted in the ability to view images at the same time but in different places, along with the management of a huge amount of high-resolution data.

However, recent studies and articles tend to question the efficiency of such a system. In fact, high initial costs and a risk of data loss are mentioned as the main limitations. The next chapters will explore those arguments further.

Therefore, the challenge today is to strengthen the emergence of innovative solutions in medical imaging. For the healthcare systems, cloud computing and CAD services seem to represent a significant opportunity (Byung *et al*., 2011). Performing scans' analysis via CAD, and storing, archiving, sharing and accessing data in the cloud have been shown to allow health care professionals to manage the data efficiently and cost-effectively.

1.2. Aims and objectives

The aim of this study is to assess whether a cloud HIS, RIS and PACS, with Computer Aided Diagnosis software are more beneficial options for hospitals, specifically in terms of cost-effectiveness, time-saving, a higher diagnosis accuracy, a betterment in staff productivity, and a wider accessibility of medical data. The hypothesis was centred around the fact that a cloud-based digital imaging medical system which includes a computer aided diagnosis as a component is a more beneficial option than an onsite medical system which does not include CAD. In point of fact, the suggested solution would be cost effective (Section 4.3.2.5 and section 5.3) and time efficient (Section 4.3.1.2). Additionally, the proposed solution would increase diagnosis accuracy (Section 4.3.2.1) and staff productivity (Section 4.3.2.3) and would widen accessibility of medical data (Section 4.3.1.1).

In order to analyse whether a medical system that integrates CAD and cloud are advantageous for hospitals applying them, a set of specific objectives has been selected:

- Investigating the system PACS and its applications at hospitals, how this system has changed hospital management, along with the reasons that explains the predicament encountered by PACS to be spread to a wider number of hospital facilities (Section 2.2)
- Studying RIS and HIS and their high correlation to PACS (Section 2.4)
- Exploring the applications of PACS, RIS and HIS at Lausanne Hospital, via identifying the traceability of patient's data on these systems. This traceability begins from the making of appointment and ends when the report is performed and delivered (Section 3.3)
- Proposing a new patient's workflow (figure 14) operating an intelligent cloud-based digital imaging medical system, which includes CAD (Section 4.3)

- Comparing the performance of the proposed system against the existing system at Lausanne Hospital, and extrapolating the most advantageous option. (Section 4.3)
- Assessing the potential limits of using the suggested cloud medical system (section 4.4)

In order to achieve the aim of this project, the research was built applying the following methodology:

- First step: Literature review of each component of the proposed system: PACS, HIS, RIS, alongside CAD and cloud computing
- Second step: Determine the current workflow using PACS, RIS and HIS. Lausanne Hospital was used as a backdrop (Figure 3). The purpose of this is to later analyse whether the suggested system, can potentially improve efficiency and performance.

- Third step: Evaluating the current workflow (Figure 3) and delineate its main advantages and drawbacks
- Fourth step: Propose a workflow of the intelligent Cloud-Based Digital Imaging Medical System (Figure 14), based on Lausanne Hospital analysis results
- Fifth step: Evaluate the proposed system (Figure 14) and its potential limits compared to current conventional one (Figure 3)
- Sixth step: Extrapolate – From the results – the most advantageous solution

1.3. Significance of the study

It is generally acknowledged that one can create new products, services, ideas and procedures through transformation, by building on previous creations. The process of developing new concepts would be taking an idea or ideas, transform it or them, creating variations and new paradigms. Another way for creative leaps to occur is through the combination of ideas, connecting existing innovations and intertwining them to obtain a more interesting whole. This research is a result of the latter approach. Indeed, PACS, CAD, and cloud computing already exist and have engendered high performance results, however, these applications are usually applied separately. The main aim of this work is to consider how integrating these different components into a coherent totality would impact the hospital utilising this approach. (section 4.5). This impact would be measured at all main stages of the patient's workflow, from scans performance to the reporting stage, as well as when using back-ups to manage system's upgrades and maintenance. To achieve the above mentioned aim, the most renowned University Hospital in Switzerland was utilised as a backdrop: Lausanne Hospital. In fact, Lausanne Hospital already applies PACS as a tool for medical data management; nevertheless, neither CAD nor cloud computing have been considered by the hospital so far. Instead, Lausanne Hospital uses digital reporting to produce medical reports and RadioPACS, a cloud-based system, for partial sharing of data for medical expertise and follow-up purposes. Additionally, the university hospital relies on radiologists' expertise solely for diagnosis, and when overloaded, part of the diagnosis process is externalised via RadioPACS.

The following chapter will introduce each of these components, including PACS, RIS and HIS, cloud, CAD.

1.4. Structure of the thesis

The research will be built in five sections as follow:

- Literature review of each component of the proposed system: investigating PACS, HIS and RIS applications, alongside CAD and cloud
- Defining and evaluating a workflow using PACS, RIS and HIS (Figure 3). The purpose is to analyse how the suggested cloud-based system that includes CAD, can potentially improve efficiency and performance. Lausanne Hospital is used as a case study
- Suggesting a workflow of the intelligent Cloud-Based Digital Imaging Medical System, based on Lausanne Hospital analysis results (Figure 14)
- Evaluating the proposed system along with the potential limits compared to current conventional PAC system

Chapter 2

Literature Review:

An introduction to PACS, RIS, HIS and CAD and their applications in hospital management

The purpose of this chapter is to review the literature of PACS, RIS and HIS, as this research is centred on the hypothesis that implementing these systems on the cloud alongside CAD holds more benefits for their users than the onsite versions without CAD. Cloud and CAD's applications will be explored in this chapter as well. Prior to detailing these medical systems, it is necessary to introduce the main department in the hospital that would rely on this system the most, which is the radiology department. Afterwards, a review of PACS followed by the importance of such system in the healthcare field are explained.

2.1. Digital radiology

The first part aims to introduce in brief the department that is in the centre of medical data management. In addition to that, a summarised description of digital images will be included.

2.1.1. Radiology

Two areas of medicine are likely to be the ones which have known drastic adjustments over the past two decades: radiology and medical imaging (Paré *et al.*, 2005). Embryonic were the data collected from fluoroscopes, a medical tool used back then by previous generations. They had to suffer from large doses of X-rays behind a screen (Bradley, 2008).

Nowadays, medical images are obtained using different types of devices called modalities. These images contain information about the conditions of patients that is used to diagnose and facilitate treatments and surgeries. Thus, a radiology department is usually divided into several sectors including radiography, ultrasound, computed tomography, and magnetic resonance.

According to Bradley (2008), the first medical imaging application, with the use of X-rays, dates from 1895. It was the beginning of radiography. Since then, techniques have improved and diversified from the beginning of the twentieth century with the arrival of the scintigraphy scanner, ultrasound and Magnetic Resonance Imaging (MRI). These modalities permit the generation of medical digital images.

2.1.2. Digital images

Digital images are designated as any image that can be stored on a computer system. Once on a computer, images can be edited through software (e.g. change of image size, colours, and adding on, or removal of elements from images), or can be shared (e.g. image transmission via e-mail), or copied to the back-up system. Nevertheless, the possible list of editing options may differ depending on the device where images are stored. This is what differentiates them from the images on paper. There are a limited range of possibilities, as it cannot be stored on computer (Paré *et al*., 2005).

Digital imaging enables, beyond the clinical examination, to explore organs and cells (Merle-lamoot and Pannetier, 2013), not only to establish diagnosis but also to predict the course of a disease, as well as to plan the best treatment options. Furthermore, by extracting, compiling and classifying information, an increasing value is expected to predict futures events. To respond to the healthcare challenge of targeting better prevention, an earlier diagnosis and a personalised therapeutic monitoring, systems, innovations and programs have been created and developed. Among them, there was the Picture archiving and communication system or the PACS system.

2.2. Picture Archiving and Communication System (PACS)

The following section is about PACS diagnosis: Defining the system and its main functions.

2.2.1. Simplified Definition

As it was pointed out in the introduction to this paper, PACS is an information system – created in the the second half of the 1980s – that views, stores, and transmits digital medical images acquired by various modalities (Examples of modalities include the MRI, scanners and endoscopes) along with their processing and interpretation reports (Paré, et al., 2005; Coleman and Ralston, 2009). In this context, this medical imaging system is considered as an indispensable tool in various areas of medicine, not only by facilitating the establishment of the diagnosis but sometimes also in the treatment to follow and thus becomes an important structural element of these information system (Strickland, 2000; Smith, 2006).

2.2.2. PACS in the center of healthcare management

This medical imaging system occurs at all levels of the care process: screening, diagnosis, pretreatment assessment, decision support, planning and orientation of treatment as well as monitoring the effectiveness of certain treatments and prognosis (Carter and Veale, 2014). Thus, PACS is mainly becoming the apostle of imaging services and services where patients are hospitalised. It allows communication between health professionals concerned to provide high quality of healthcare. Specifically, PACS results ultimately by the disappearance of films to view medical images at a computer station.

PACS has favoured the evolution of medical practice to the growing use of processing techniques and image interpretation. Indeed, it currently seems difficult to imagine that one can optimise the use of a latest generation of scanners without allowing a PACS. The interpretation time is long enough due to the amount of images produced; it becomes advantageous to have a system for real-time interpretation, Furthermore, the evolution of medical demography, particularly radiologists' practitioners, encourages the implementation of the resources that allows telediagnosis (Societé Française de Radiologie, no date).

The digital medical imaging generates a considerable number of images and technological advances are such (including cuts increasingly thin, three-dimensional reconstruction) as radiology work becomes increasingly interventional. Its role goes well beyond the exploration and diagnosis. It is now seen as a modelling tool and aid for clinicians to better target the intervention area and guide the surgical or therapeutic procedure. Digital technology has opened up a field of possibilities as it does not seem conceivable for a radiologist to work nowadays without archiving images and without the use of modern access and sharing of information resources offered by IT (Information technology) networks (Societé Française de Radiologie, no date).

As stated earlier, one of PACS's role is to visualise scans in order to determine a diagnosis and a treatment to follow. A diagnosis can be established through the support of CAD. The next section will detail this tool.

2.3. Computer Aided Diagnosis (CAD)

CAD is a software used to assist radiologists to identify abnormalities on scans and make a decision about patients' outcome.

This software is used mainly to detect the following illnesses:

- Breast cancer
- Lung cancer
- Colorectal cancer
- Prostate cancer
- Coronary artery disease

The next part (Table 1) discusses each of above-mentioned illnesses, including statistics in the U.K and worldwide.

Table 1: Major application of CAD in radiology

	CAD main applications	Brief overview	Statistics in the U.K	Statistics worldwide
CAD	The medical examinations in mammography, to potentially detect breast cancers	Breast cancer is a malignant tumor of the mammary gland (Harvey, 2010).	Breast cancer is known as the most common type of cancer in the UK, with one in eight women diagnosed with breast cancer during their lifetime (NHS, 2016a).	Breast cancer is the first and second most occurring illness in women and overall respectively, with over two million new breast cancer cases in 2018 (World Cancer Research Fund International, 2018a)
	The diagnosis of lung cancer	Lung cancer is a malignant tumor of the lung (Harvey, 2010).	Lung cancer is the second most common cancer in the UK and over 44,000 people are diagnosed each year (NHS, 2019).	Lung cancer is the most common cancer in men and the third most common cancer in women. There were over two million new lung cancer cases discovered in 2018 (World Cancer Research Fund International, 2018b).

	Discovering colorectal cancer	Colorectal cancer develops from the colon or rectum, parts of the large intestine (Harvey, 2010).	Colorectal cancer is considered as the third most common cancer in the UK after breast and lung cancers, with approximately 40,000 new cases registered each year (NHS, 2016b).	Colorectal cancer is the third most spread cancer in the world, with 1.8 million new colorectal cancer cases in 2018 (World Cancer Research Fund International, 2018c).
	Detecting prostate cancer	Prostate cancer affects the prostate, a gland of men's reproductive system (Harvey, 2010).	Prostate cancer is the most common cancer in men in the UK, affecting one in eight in a lifetime (NHS, 2018).	With 1.3 million new cases of prostate cancer in 2018, it is the fourth most common cancer worldwide (World Cancer Research Fund International, 2018d).
	Determining coronary artery disease	Coronary artery disease is a disease of the arteries that vascularises the heart resulting in	Coronary artery disease is the most common cause of deaths in the UK. An estimated 1 in 5 men and 1 in 6	Cardiovascular disease is the leading global cause of death (Centers for Disease Control and Prevention 2017)

		myocardial ischemia, that is, insufficient blood supply to the heart muscle (Harvey, 2010).	women die from the disease each year (NHS, 2017).	

This software targets the most common illnesses worldwide (Figure 1), from breast cancer to colorectal cancer, passing by coronary artery disease and prostate cancer. This research’s aim is to detect whether such software could be of great use to support radiologists in the early detection and prevention from illnesses such as these commonly occurring ones.

In order to identify a diagnosis with the support of CAD, the software undergo four main steps. These are named pre-image processing, definition of Region Of Interests, feature extraction, and classification. The next part will elaborate on each of these steps respectively.

The first stage, the pre-image processing, involves the enhancement of the images’ quality via techniques of denoising and image contrast, among others. In brief, denoising suggests reduction of parasitic information that is naturally added to digital images, to improve sharpness in the details. As far as it concerns image contrast, it allows manipulating brightness for better distinction of the body part(s) scanned.

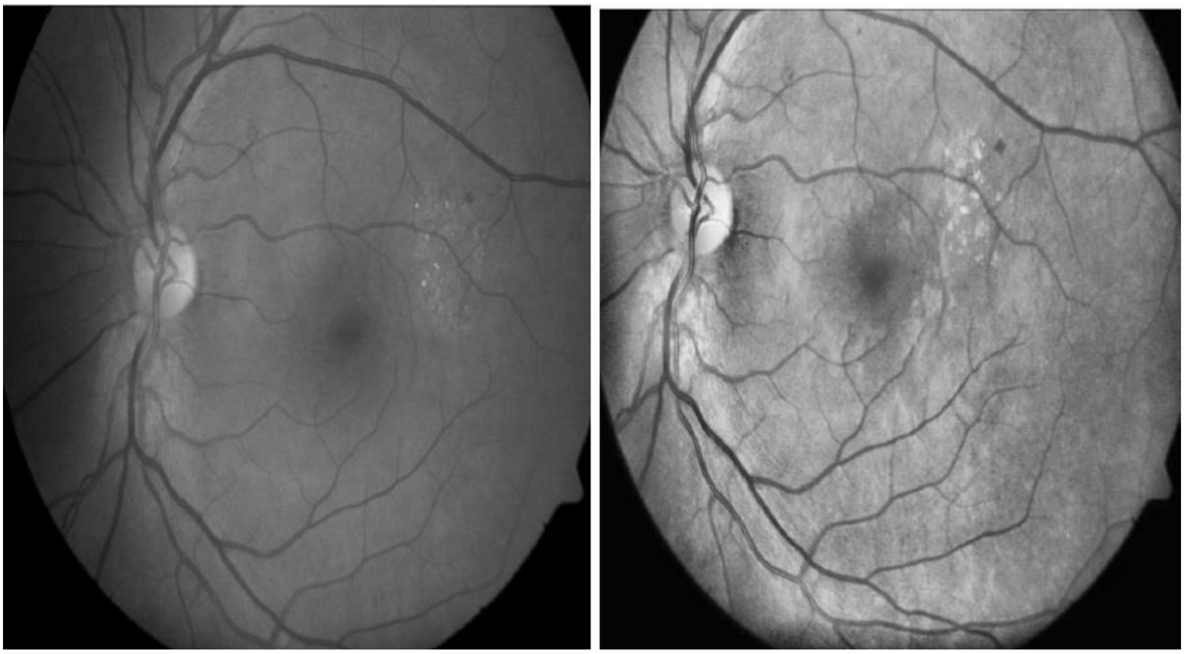


Figure 1: Scans of a retina

On the left (Figure 1), the original scan of retina. On the right, the same image following contrast enhancement (*Histogram Equalisation Sample Image*, 2011).

The second stage, definition of Regions Of Interests, consists of determining zones in the scan that could be considered as starting points for algorithms to extract features.

The third stage is feature extraction. Features in this case can be defined as quantitative measures that describe characteristics of a scan. Example of features can be shape (such as spiky or round) colour, size (including width and height). Feature selection considers only the necessary information in order to achieve a robust and accurate classification.

The last but not least stage in the process, the classification of each Region Of Interest discovered previously. Each ROI (Region Of Interest) undergo an individual evaluation with the features detected about it. The aim is to score the probability value for a true positive (TP) and a true negative (TN).

2.4. Radiology Information System (RIS) and Hospital Information System (HIS)

As indicated earlier, PACS is responsible for the visualisation, storage and transmission of medical images and their reports. At times, medical images are not sufficient to determine the nature of a symptom or concern. Therefore, complementary tests such as blood analysis are put in place. Additionally, prior to any sort of medical examination, hospitals should be aware of each patient’s characteristics in order to deliver the best service. Thus, a different system is usually implemented in order to store the complementary tests added to patients’ characteristics. This is what mainly justifies the existence and importance of RIS and HIS (Keayes and Grenier, 1997). The next section will focus on describing both systems.

The foregoing suggests that PACS is the indispensable complement of another important information system: RIS (Societé Française de Radiologie, no date; Strickland, 2009). RIS is used to manage the radiology department. The main functionalities of RIS include:

- Management of test prescriptions
- Management of appointments
- Management of reports: dictation, seizure typing and storage
- Publishing radiology reports
- Management of information specific to radiology: including injected products, contraindications, dose received, listing of patient' specific and necessary actions.

RIS contains or recovers from HIS the patients' demographic information necessary for the constitution of folders and to make the appointments. Without RIS, it is difficult to imagine the use of a PAC system. RIS is usually connected to the terms of the PACS to transmit the patient identification information onwards and to assist in the management production of medical examinations. The full integration of PACS into the HIS covers all the information flow from demand and planning of the medical examination to the drafting of the report passing by making available the images to care professionals in the different services (Hecht, 2015). For instance, when scans are acquired, they are then transmitted by the computer network of the hospital directly to the PACS, which will associate them with the appointment file it has received earlier from HIS. It is comparable to receiving envelopes from HIS with the name and details of the patient and following the performance of scans, the modality that acquired them will transfer those scans to the PACS, which will put the images on the correct virtual envelope.

Thus, all protagonists involved in the same case have access to the status of that particular file, for instance, patient' awaiting examinations, ongoing examinations, examinations to interpret, transcriptions to review and transcriptions to sign. In addition, the data exchange between the RIS and other systems helps reduce the workload for the principal users and lessen the risk of errors. Indeed, all data are acquired from a single entry, eliminating duplication of information, a common cause of errors. Finally, RIS includes useful features specific to different groups of employees of a radiology department, for radiologists, technicians (or manipulators in radiology) and secretaries and executives (Hecht, 2015).

On the other hand, the HIS is an information system designed to facilitate the management of all administrative and medical information from a hospital (Hecht, 2015). HIS and RIS retain identical data, however, HIS includes all hospital patients, whereas RIS includes solely patients who have medical images in their records (Haux *et al*., 2004).

The three medical systems, PACS, RIS and HIS, detailed previously alongside CAD software can be based inside hospital premises, or on a cloud. The next section will illustrate how data can be virtually saved in the cloud computing

2.5. Cloud Computing

Cloud computing is an access via a telecommunications network (usually Internet) to computer resources which are shared, configurable and self-service. In other words, there is no need to keep medical files at hospitals, everything is stored in data centres and users pay based on use.

In the early 2000s, Amazon faced an issue; outside of peak periods, vast computer servers were underused. The alternative that Amazon came up with was to rent the space to individuals. This is how the cloud was born. With cloud computing, information is no longer stored on devices, but rather sent to Internet on remote servers. Therefore, information can be retrieved from anywhere. Computer software is no longer needed to be bought, but the client rather rent a program, its options and the space required to store their data (Software Sherpa, 2018).

Cloud computing service has characteristics that distinguish it from other technologies, these include:

- In general, users of cloud computing do not own computing resources they use. They exploit servers that are hosted in data centres outside.
- A rapid elasticity: the proposed abilities can quickly increase or decrease as needed
- Services are provided on a pay-per-use model or subscription model.
- Resources and services provided to customers are often virtual and shared by multiple users.
- Services are provided using Internet connection, off site.

These features make cloud computing technology a new option that offers to its users the possibility of access to software and computing resources with desired flexibility and modularity.

2.6. Summary

The different individualised components of the technology which can be used in hospitals were described in this chapter.

In brief, PACS is a medical system whose principle role is to store scans acquired in order to be visualised usually for diagnosis purposes. RIS and HIS are complimentary systems to PACS. Both stores patients' data that complements their respective scans. This comprehend blood tests, reports and patients' demographic information. As for CAD, it is considered as a supporting tool for radiologists when performing diagnosis on scans. Regarding cloud computing, it grants its users to get detached from responsibilities of data management, as data is based offsite, handled by its provider.

This chapter introduced all these elements that will be in the centre of the analysis performed in the next chapters. Indeed, at Lausanne Hospital, the workflow of medical data requires the application of PACS, RIS and HIS. Additionally, the proposed digital imaging medical system would employ Cloud and CAD as added elements.

The next chapter reflects the results of the investigation made at Lausanne Hospital in order to look at the current status of the workflow at Lausanne Hospital and how integrating technology can increase performance and efficiency.

Chapter 3

Case study:

Medical data workflow at Lausanne Hospital

3.1. Introduction

In October 2016, a two weeks visit of the world renowned University Hospital of Vaud was completed. During that period, interviews and observations of the daily routine of hospital staff who work closely with PACS and/or RIS were put in place. Among the interviewees were a receptionist, a PACS manager, the head of radiology department, the reception manager and a radiology researcher. The main purpose for visiting Lausanne Hospital is to understand and evaluate their current process for managing medical data in order to determine how an intelligent cloud-based system can improve efficiency and performance. Such efficiency shall be measured using the following criteria:

- Cost comparison between the current medical system and the proposed one
- Dictation turnaround, contrast between CAD and digital reporting
- Juxtaposition of diagnosis performance using PACS with and without CAD
- Effects of CAD on radiologists' productivity
- Cost of CAD when PACS is onsite versus cloud-based
- Workflow contrast, when upgrading onsite medical system versus offsite one
- Workflow contrast, when handling technical issues with onsite medical system and offsite one
- Teleradiology benefits with cloud-based PAC system
- Opportunities of CAD enhancement through constant training
- Medical data sharing possibilities with onsite and offsite options
- Inter-observer reliability for radiographic assessments: contrast between current and suggested option

The upcoming patient’s workflow of Lausanne Hospital (Figure 5) adopts the onsite computerised management system for medical imaging PACS, HIS and RIS. It seems profitable to have an idea about the key historical elements of this hospital prior to detailing the workflow of the Swiss Hospital. All the information present on this chapter were collected during the visit to Lausanne Hospital, thanks to interviews conducted with a variety of staff members, including the PACS manager, the head of administration department, staff from the radiology department and PACS and IT management.

3.2. Overview of case study: Lausanne Hospital

Lausanne Hospital, which has been using PACS since 2001, has cordially approved the request for a short visit, with the aim to determinate the journey of the medical data, from patient entrance until completion of diagnosis report. A few of the hospital staff were co-operative in answering queries related to this topic,and enlightened some blurs. The majority of the information appearing on this section is the result of the data collected during the observation.

Lausanne Hospital (CHUV) is the main hospital in Lausanne, Switzerland. It is one of five Swiss university hospitals, along with Geneva, Bern, Basel and Zurich. With over 9,300 employees, Lausanne Hospital is the largest company in the canton of Vaud. It provides care in all areas of medicine: In somatic disorders or psychiatric diseases, in both medical and surgical disciplines. From ambulatory care to hospitalisation (CHUV, 2018).

Table 2: Lausanne Hospital general figures

	2010	2011	2012	2015	Average variation
Number of hospitalised patients	43,589	44,960	45,712	47,313	+2.68%
Number of treated emergencies	35,821	36,694	37,203	39,592	+ 3.25%
Number of employees	8,821	9,056	9,353		
Bed occupancy Rate	84.9%	83.2%	83.7%	-	-
Budget budget in round figures	-	-	1.4 billion CHF	1.6 billion CHF	+ 20%

CHUV remains, like the previous years, a saturated hospital. The occupancy rate has increased slightly. It reached 84% in 2012. Overall, the existing surfaces no longer allow the creation of additional capacities. The situation remains extremely tight in intensive care, with 92% bed occupancy in 2012, and the Department of Medicine, with 88% bed occupancy in 2012 (CEMCAV-CHUV, 2017).

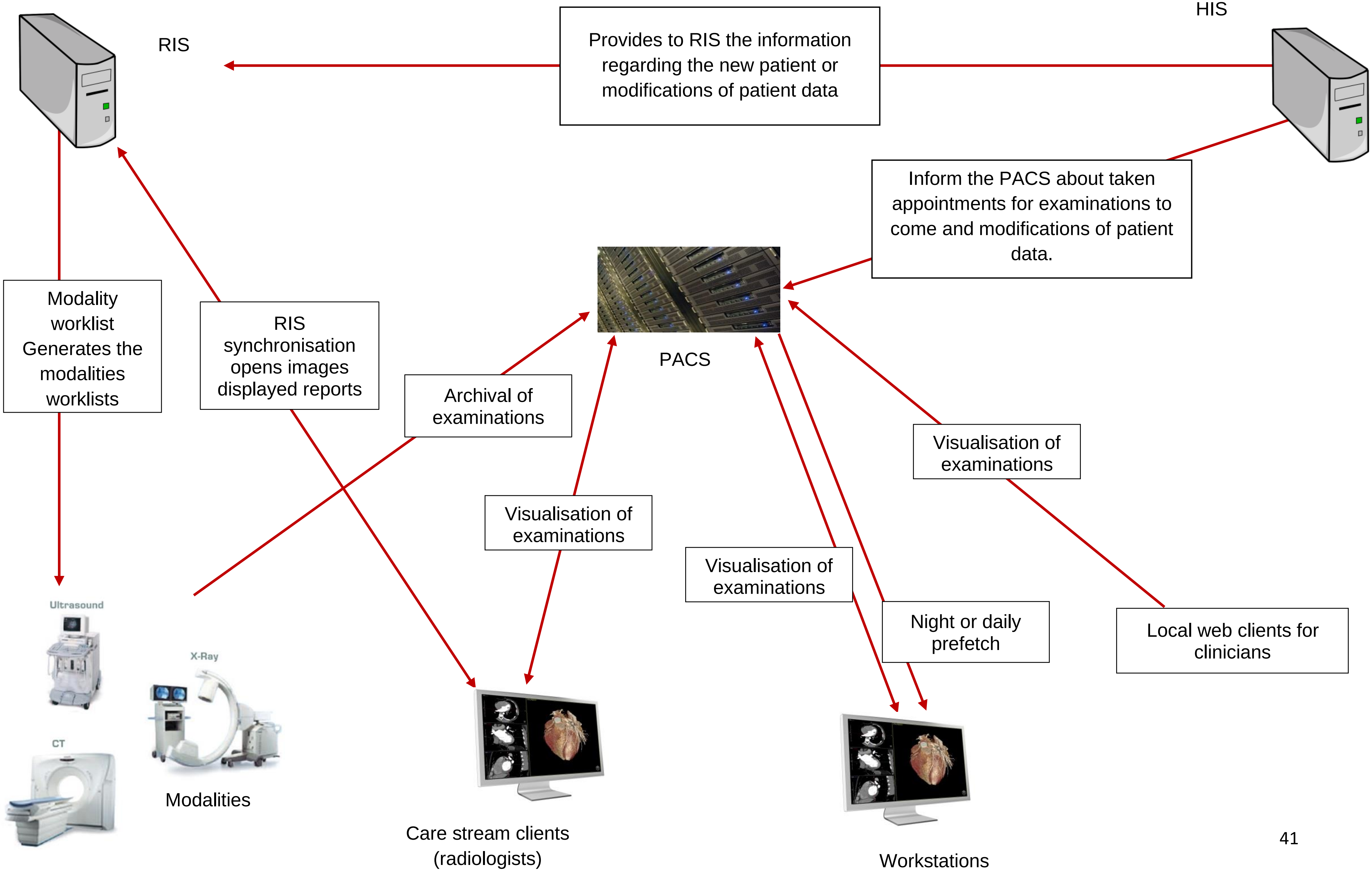
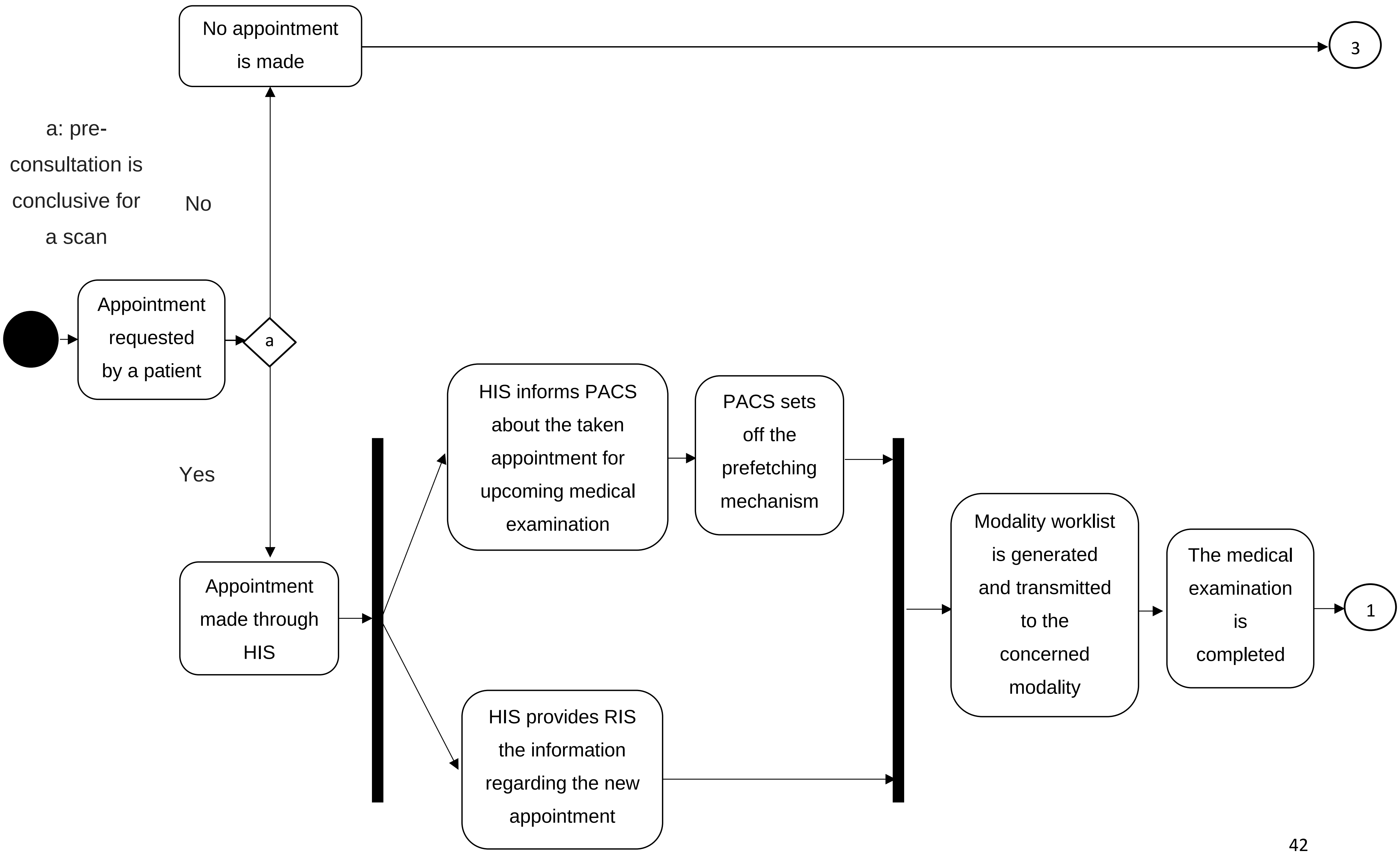
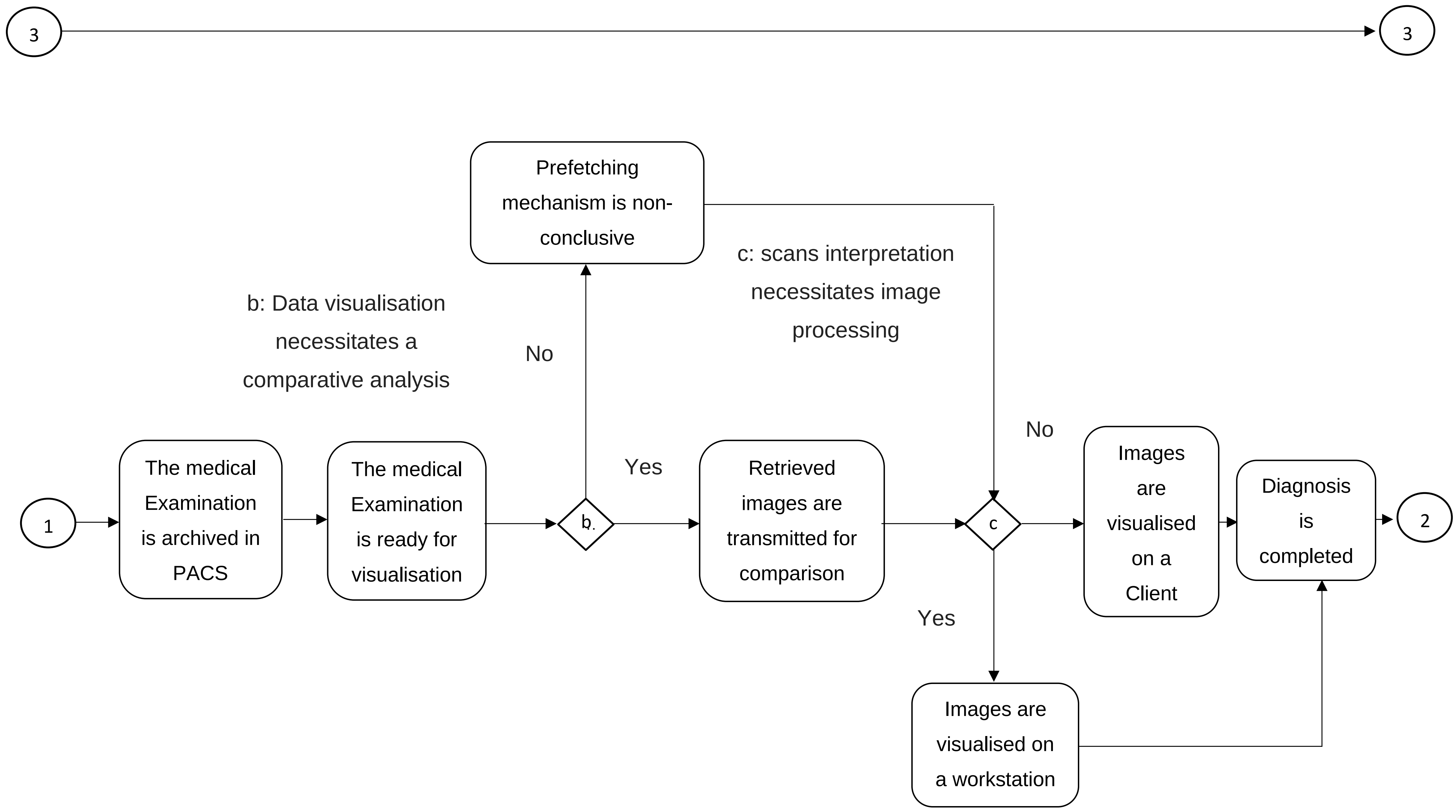


Figure 2: Flow of the administrative data of patients and examinations Lausanne Hospital


No appointment is made
3
a: pre-consultation is conclusive for a scan
No
Appointment requested by a patient
a
Yes
HIS informs PACS about the taken appointment for upcoming medical examination
PACS sets off the prefetching mechanism
Appointment made through HIS
Modality worklist is generated and transmitted to the concerned modality
The medical examination is completed
1
HIS provides RIS the information regarding the new appointment


3
3
Prefetching mechanism is non-conclusive
c: scans interpretation necessitates image processing
b: Data visualisation necessitates a comparative analysis
No
No
Yes
1
The medical Examination is archived in PACS
The medical Examination is ready for visualisation
b.
Retrieved images are transmitted for comparison
c
Images are visualised on a Client
Diagnosis is completed
2
Yes
Images are visualised on a workstation

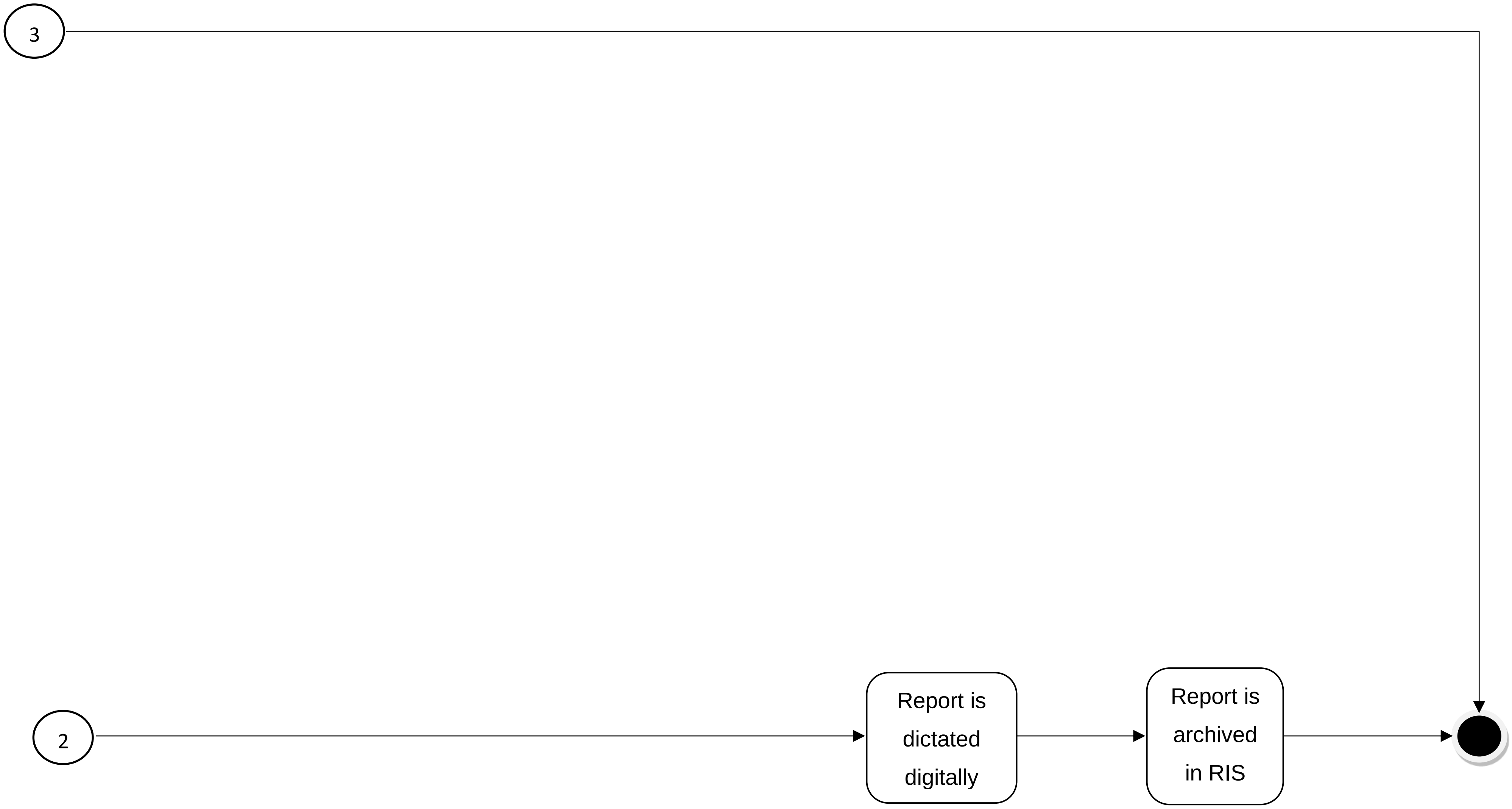


Figure 3: Flow of the administrative data of patients at Lausanne Hospital

Prior to describing the general workflow of administrative data at Lausanne Hospital (Figure 3), It needs to be clarified that medical scans are managed by PACS, while all other data such as blood test results are managed by both RIS and HIS. Nevertheless, there is a main difference between the two systems. HIS includes all data information for all patients, whereas RIS only includes the patients who have their medical images taken, or are scheduled to get medical images. This explains the virtual link on the graphic between modalities that are in charge of the acquirement of images, and the RIS. Whether for instance a patient requests a computerised tomography (CT) scan, an order with among other information the name of the patient and the date of the procedure is created through HIS who then transmits to RIS a message to add the CT appointment to the worklist. Each modality will afterwards receive a worklist of all procedures that necessitate to be completed by it. In case there is existence of multiple modalities that can perform CT scans, the worklist would be transmitted to one of those. According to an IT manager of Lausanne Hospital, transmitting image orders via the modality worklist help decrease the possibility of misconduct.

As it can be seen on the latest diagram (Figure 2), HIS has two main roles. The first one is to transmit to RIS all data information related to the patient who requires scans to be acquired. Moreover, HIS informs RIS about all updates or modification that occurred on patients' data. The second role is related to PACS. This imaging software is informed by HIS about future appointments for medical examinations along with any modifications regarding patients' data. Moreover, if a patient requires comparative analysis with previous scans, PACS is then charged to launch the prefetching mechanism. This mechanism allows the retrieval of previous images from the long term archive onto the short term server, prior to the acquisition and viewing of the current medical examination on that patient. It is sometimes completed at night, usually the night before the examination, to allow sufficient time and also to avoid disturbance of the daily medical activity.

Following the modality procedure (e.g. Head CT, Lung X-ray etc.), the examination is sent from the modality to PACS for archival. The modality archive images as well, however, those images are destroyed after a while. This storage is in fact temporary considering the fact that there is a purge after a certain amount of data. The duration for which pictures are kept depends on the modality itself. There are modalities that can keep a few days of data solely; due to the fact that they generate a large number of images for each patient. For instance, MRIs and CTs do not hold images more than four to five days. By contrast, other modalities such as mammography can store data up to one year, the reason is related to the low imaging production, along with the fact that these modalities have important storage ability.

Stored images would then be ready for visualisation by radiologists and clinicians through workstations, and the clients. The difference between the clients and workstations will be detailed further. The diagnosis results are then dictated digitally and stored in RIS.

The next figure illustrates the transfer of medical data, from one protagonist to another. Unlike the UML presented in the previous diagram (Figure 3), this focuses on the actors that connect those sequences of events.

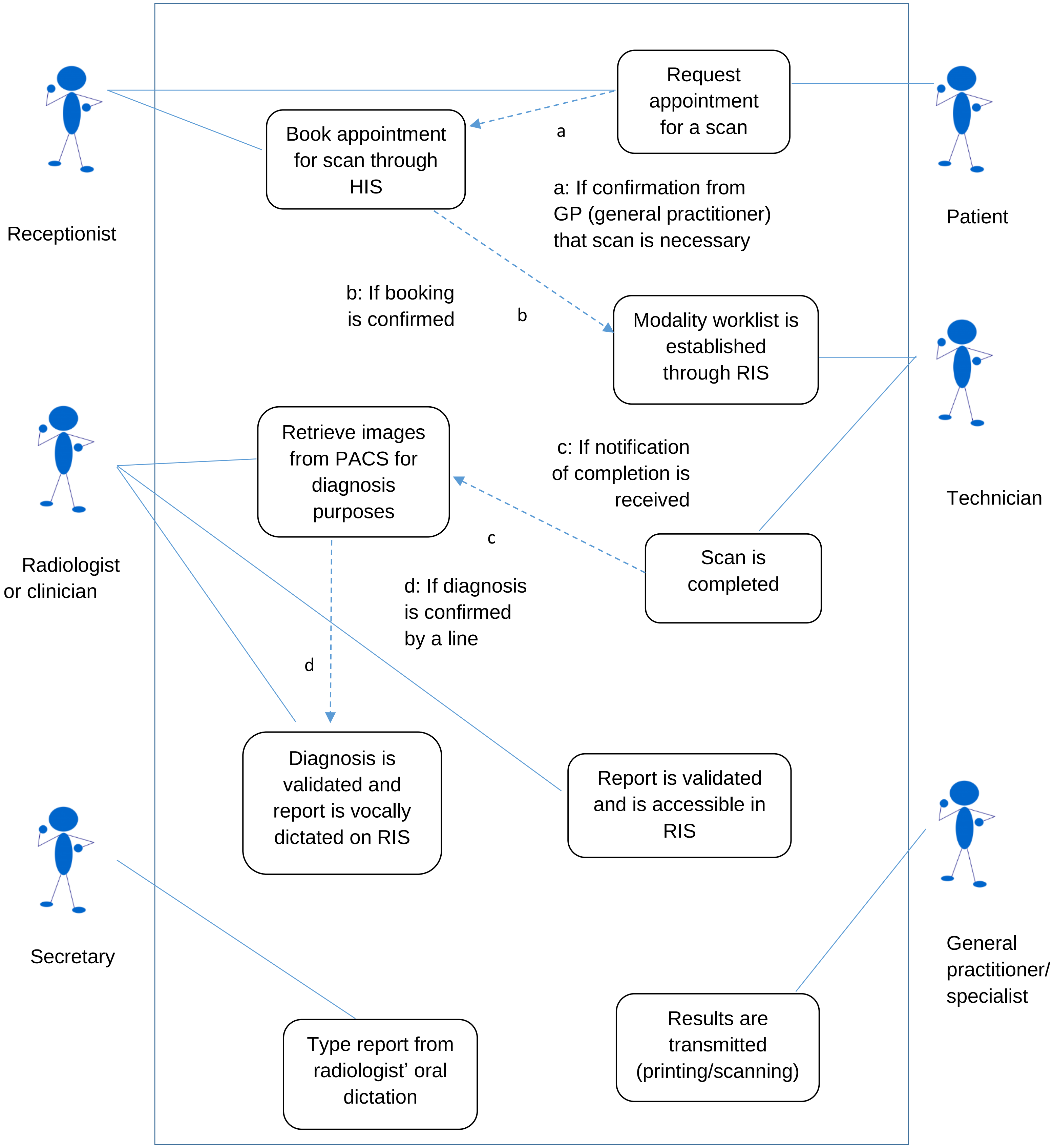


Figure 4: Administrative data flow of patients at Lausanne Hospital

The sequences delineated start with the requisition of a radiological appointment by the patient. The receptionist authorises a booking for a scan through HIS following an approval from a general practitioner of the necessity of a radiological examination. Thus, the technician generates a modality worklist through the RIS; moreover, he/she gets to be in charge of performing the scan on the decided appointment day. The radiologist or clinician will then have at his/her disposal the possibility to retrieve the acquired scans on a workstation or client usually for diagnosis purposes. The line supervisor would be in charge of confirming the diagnosis to then record the medical report vocally on RIS. The totality of the data linked to that case can now be transmitted to the initial general practitioner or specialist who solicited the scan.

3.3. Research methodology: Workflow for scans fragmented, Lausanne Hospital's approach

The upcoming section seeks to determine a traceability of patient's data on RIS, HIS and PACS. The traceability begins from the acquisition of scans until the scans' report is validated.

The workflow is separated into three principal stages:

- Data archival
- Data interpretation
- Data reporting

Each stage is outlined with a diagram that expresses the process that Lausanne Hospital follows during that stage.

In addition to that, the workflow occurring at Lausanne Hospital during systems' upgrade and maintenance is described on this chapter as well.

The totality of the information transcribed in the following paragraphs is a result of interviews with employees of CHUV.

3.3.1. Data storage

This section put an emphasis on the workflow structure subsequent to scans' acquisition, from data storage to scan retrieval for sharing or diagnosis purposes.

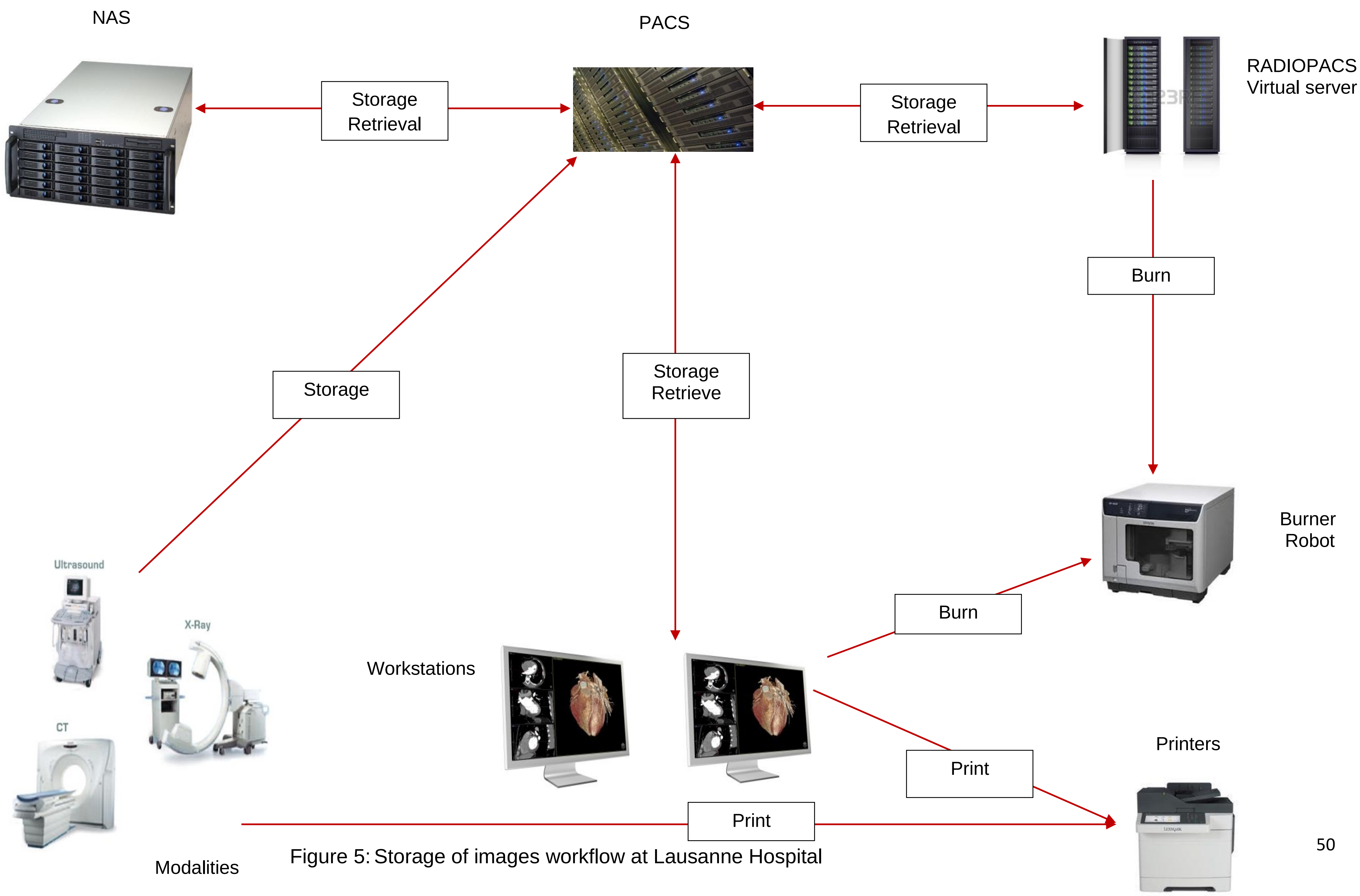


Figure 5: Storage of images workflow at Lausanne Hospital

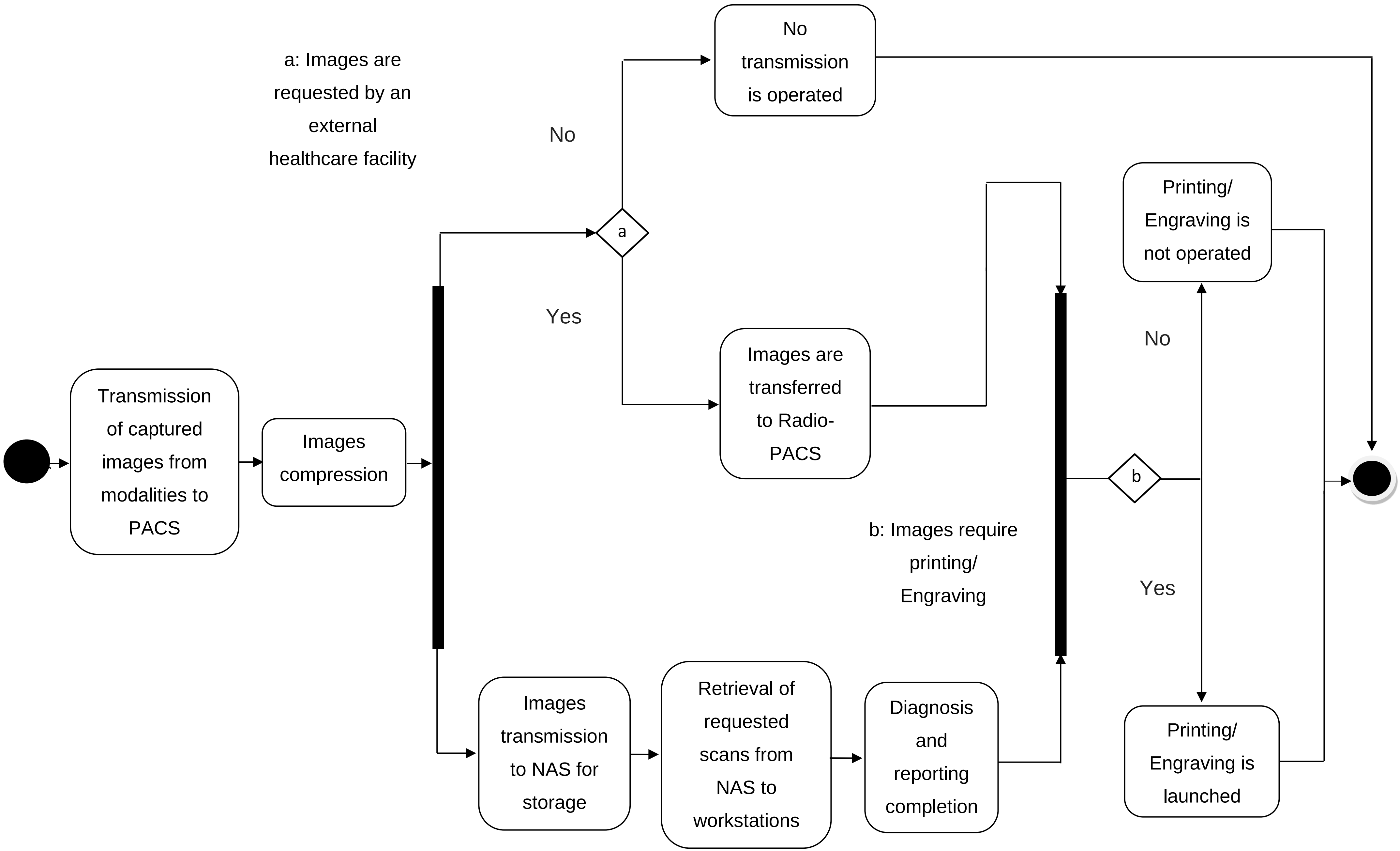


Figure 6: Storage of images workflow at Lausanne Hospital

The schematic representation of image storage at Lausanne Hospital (Figure 5) reveals that PACS holds three main functions:

- It receives scans from the modalities
- It sends scans to the workstations
- It transmits scans to the NAS (Network Attached Storage) and RadioPACS for storage

In other words, once PACS receives the images from the modalities, it sends all of them for storage to NAS and the requested ones for storage to what it is named by RadioPACS, shared by around 20 hospitals in the Swiss area of Vaud.

RadioPACS can broadly be defined as a cloud-based system used to send examinations outside of Lausanne Hospital, to other hospitals in the country which hold the same server type. Frederic Pedron compares RadioPACS to a letter box, accessible to all its key holders. The main aim of it includes enabling the sharing of medical data for expertise requests. Another reason that leads to the use of RadioPACS is when one hospital requires medical data of a current patient that are stored by another healthcare facility, usually for follow-up procedures. This virtual server is characterised by having fragmented machines which, as opposed to a complete servers, participates in reducing risks of a complete server failure. In fact, when a failure occurs on one server, this latter will not affect the others, as each machine is independent, and therefore not linked to its neighbours.

All archived data are usually preceded by image compression. Images are compressed automatically and without loss. This signifies that when an image is requested by a radiologist, it is transmitted to the workstation, and resumes its normal size and all the information it includes. PACS generally compresses the edges of the image that contain air to gain space. On average, compression enables 20 percent of gain in storage space.

As expressed earlier, PACS is an Intermediate between the NAS and workstations. PACS could hence be seen as serving as a halfway connecting the modalities to the NAS. When there is a need for retrieving certain images, radiologists rely on PACS to retrieve the relevant ones from the NAS and transfer them to the workstations. From there, images are analysed in order to perform a diagnosis. Those results could be sent out for printing – usually following patient's request – or for engraving. According to the aforementioned figure (Figure 5), the image printer can be used at two stages, either directly from the modalities, or following the image transmission to the workstations.

Images have been acquired and stored in NAS. They are at this stage ready to be read for diagnosis purpose. The next step will focus on the interpretation procedure.

3.3.2. Scans' interpretation

The next part (Figure 7) describes the procedure at Lausanne Hospital to perform scans' analysis and draw diagnosis and treatment conclusions.

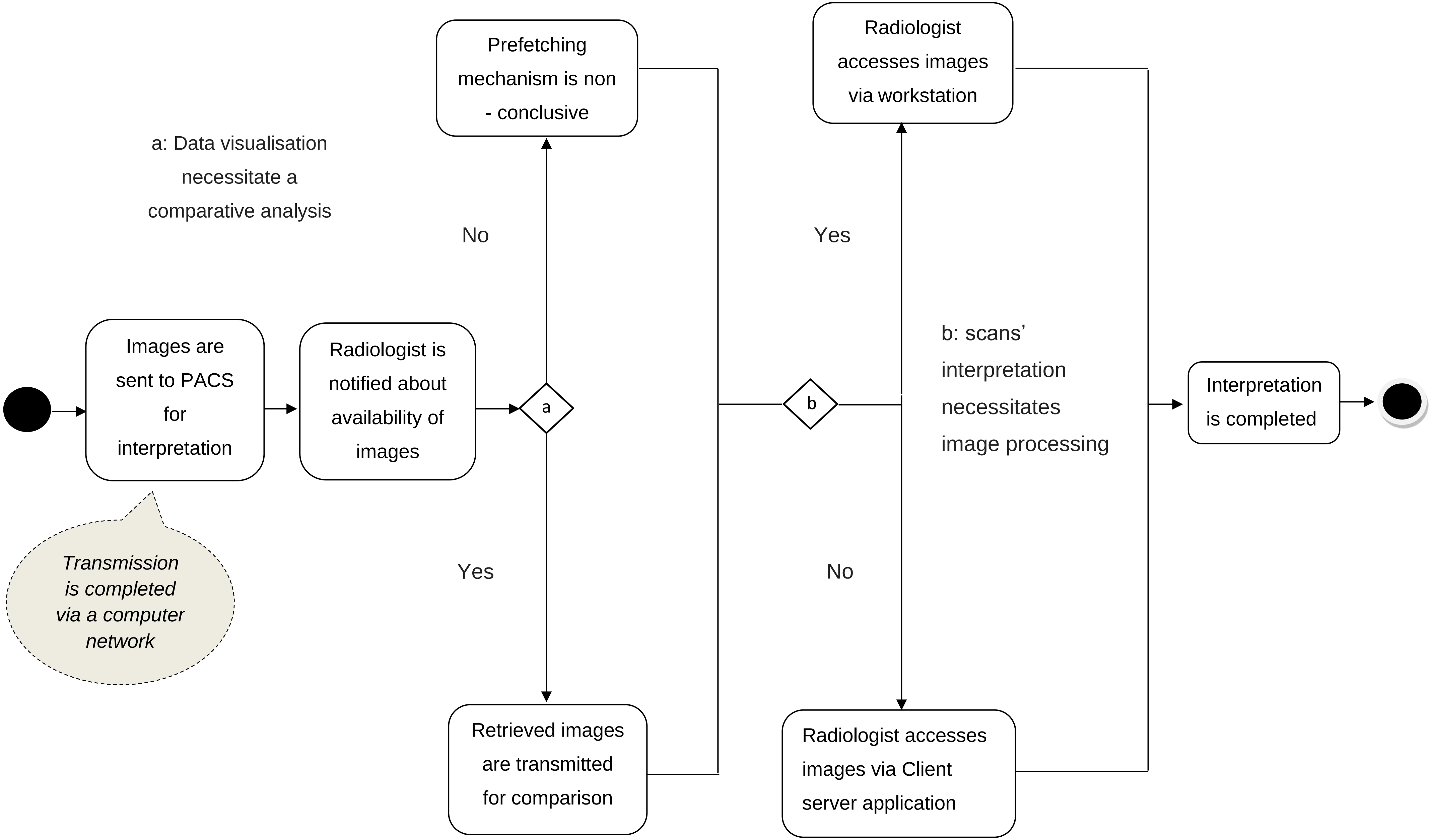


Figure 7: Scan interpretation's procedure at Lausanne Hospital

Subsequent to medical scan performance, the radiologist is notified about the availability of the needed data on PACS. There are two possible means to do so, the client server application, and workstations.

The client server application is directly linked to PACS. If, to give an instance, the radiologist is working on a CT, he/she will be able to click on a tab called CT examinations of the day, and will be able to perceive all the CTs of the day that has been completed. As they are achieved, they will be attached to the list for visualisation. The radiologist would then be able to scrutinise images without having to transfer them locally. It is as if using binoculars, with which what happens in the PACS can be seen.

As of workstations, they are completely autonomous. They make it possible to obtain an examination from PACS and to make a copy in the machine, to permit reprocessing it and to create other images including cuts, zoom and three dimensional (3D) reconstructions. Connected to the PACS via a network, the examination is virtually brought back into the machine, in the sense that, if PACS happens to be extinguished, the machine would keep its examination, as opposed to the server client.

A proportion of medical cases necessitates a comparative analysis between current and previous images captured for the same patient, hence the launch of the prefetching mechanism for those cases.

Following the possible retrieving of previous data, the radiologist is now able to read all images. The interpretation of a radiological examination may take some time; especially if the radiologist may need to compare the current examination with those previously made, and if there is a need to search for multiple pathologies. Furthermore, it should be emphasised that the length of time to interpret scans without CAD varies according to the type of scan. According to Frederic Pedron, a thorax x-ray can be read in less than 30 seconds. A bone x-ray, with no known cancer, can be read in less than two minutes. A CT or MRI picture can be scrutinised on average in 10-15 minutes. Finally, a full body scan can take up to 30 min to read.

During the interpretation of an examination, the physician user may need to have at the workstation, for comparative purposes, some or all of the images of the patient's history. These examinations may have been made a few hours earlier or months before. The prefetching mechanism involves sending to a targeted station, the previous images needed in advance, to limit the occupation of server and network when they are stressed by current production. It is therefore usually performed at night, from the list of examinations scheduled for the next day.

The total duration of this loading is usually based on the number of images to be transferred: indeed, the more images one would need them to be prefetched, the longer it would take for the process to be completed.

Subsequent to the completion of scans analysis, a report of the diagnosis and treatment is proceeded. The last step of the workflow detail the latest fact.

3.3.3. Scan reporting

The next part centres attention on the reporting process at CHUV, via digital reporting.

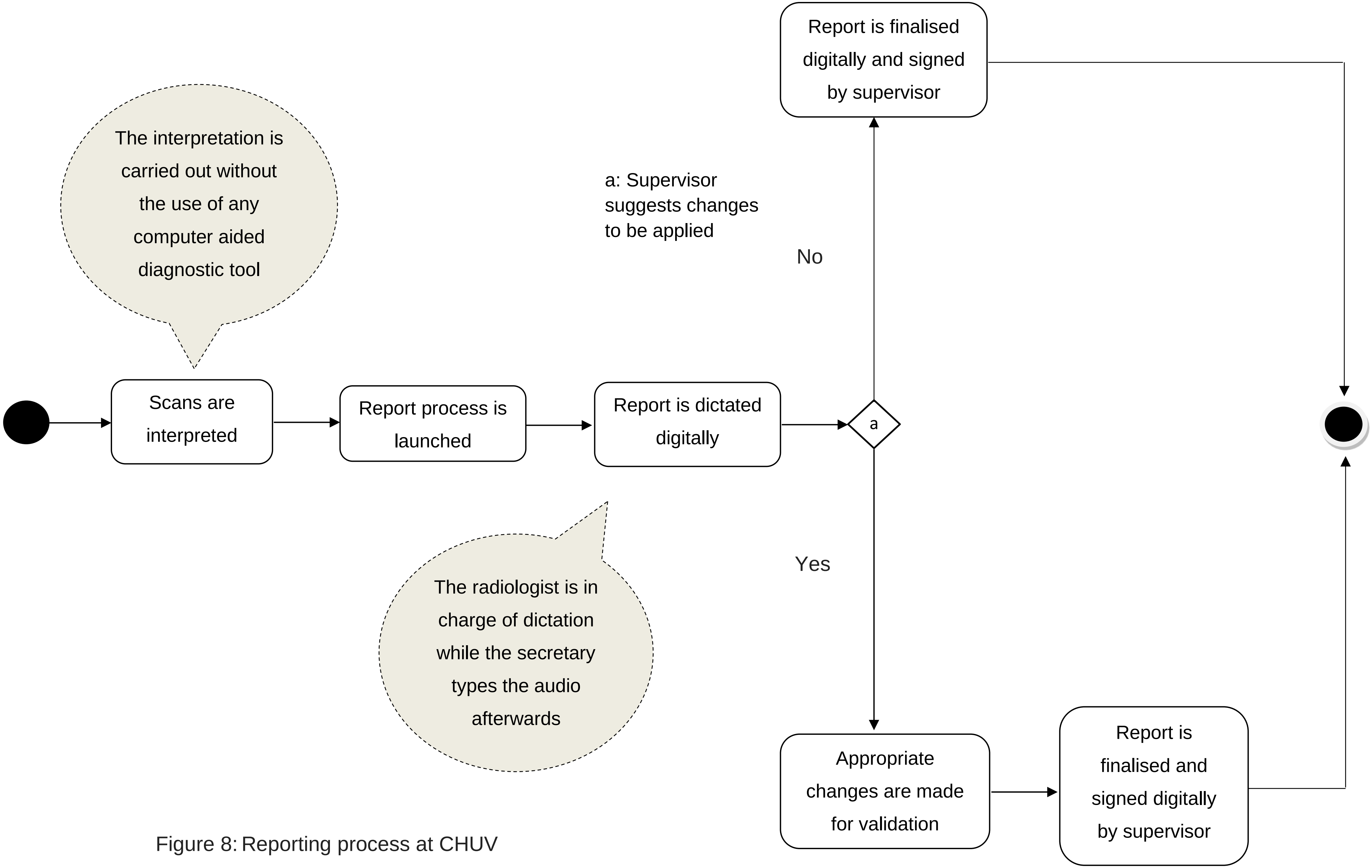


Figure 8: Reporting process at CHUV

Once the reading is completed, images are transferred to the RIS, as this application mainly manages patients who come to radiology along with their reports. With this tool, a radiologist will be able to dictate and record his/her report. The approach applied by Lausanne Hospital for report dictation is the digital one. The radiologist opens an image of a patient and then uses it to establish the report on that patient's name. Using a microphone, he/she will dictate the report. This audio report will afterwards be listened to by the secretaries through the same tool to type the audio report into a written version via a word processor. The digital version of the report will be addressed to a radiologist, who will make corrections if necessary and approve it with a signature.

3.3.4. Back-up option: system upgrade and maintenance

Lausanne Hospital is the owner of two back-ups, one based onsite, and the other one is based in the city of Lausanne. A back-up server is not used unless one of the two main scenarios is put in action:

- Upgrade of the existing system
- Temporary transfer of data, during occurrence of technical issues

The next section will illustrate the procedure for each of the scenarios stated above

3.3.4.1. Upgrade of the existing system

The next part describes the process applied by Lausanne Hospital during system’s upgrade

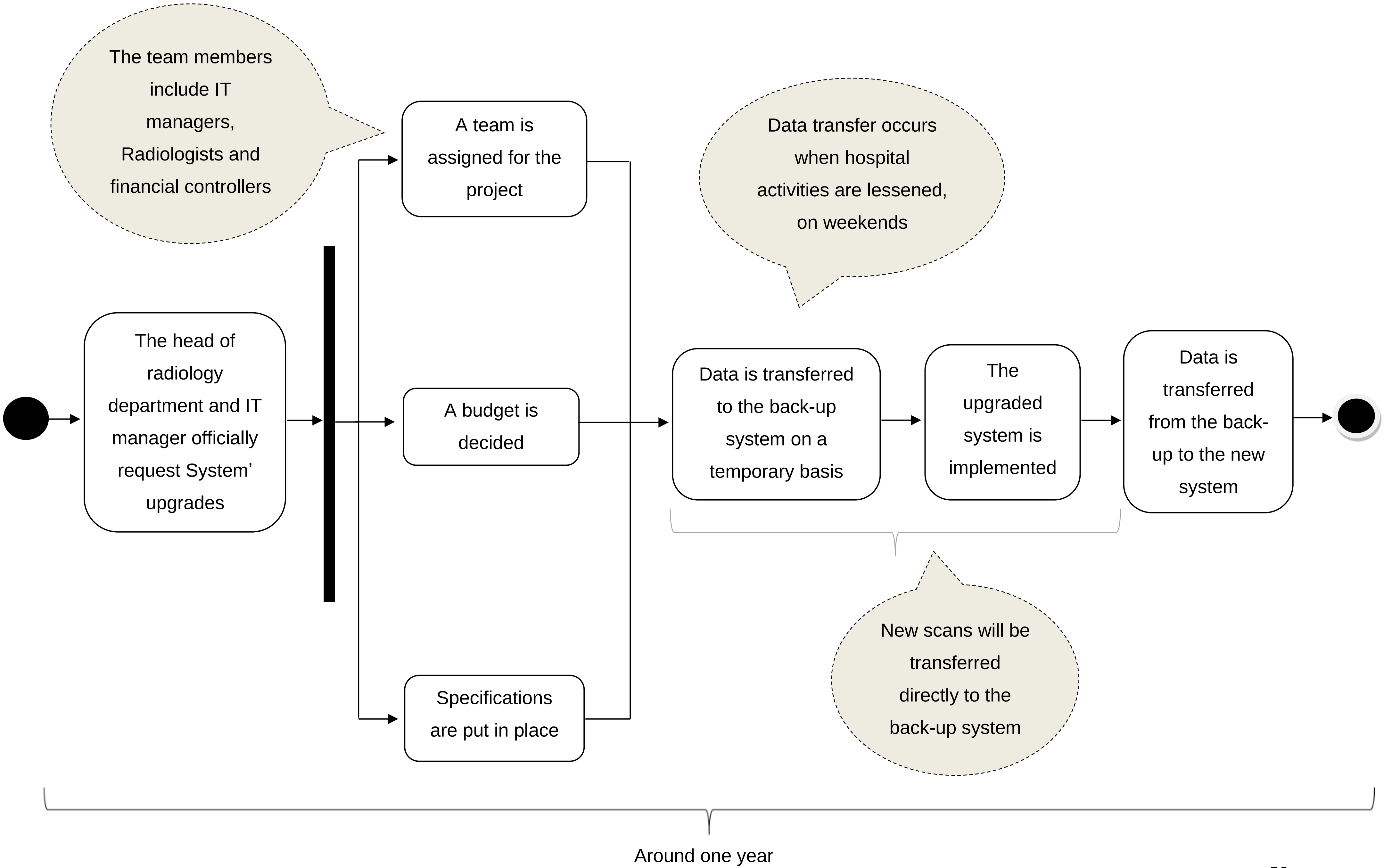


Figure 9: Current system's upgrade workflow

In order to launch the process of upgrading of the existing system at Lausanne Hospital, the head of the radiology department along with an IT manager of the imaging system of Lausanne Hospital are selected as the main protagonists to decide on the necessity to upgrade the current medical system. In order to upgrade the system's current version, the totality of the data is required to be transferred to the back-up systems on a temporary basis. It takes a few hours to make the transfer happen; moreover, the transmission is set in place during weekends, as hospital activity is mostly less intense outside weekdays. As stated by Mr. Pedron, from the initial version, acquired in 2001 until October 2016, eight updated versions of PACS were purchased. Among those eight updates, two comprised an alteration of servers, while the remaining six were set for the PACS software solely. The updating process involves setting specifications, a budget, and an assigned team for the project. It has been confirmed by Mr. Pedron that around a year passes from the moment of decision to update versions up to the effective change of the system. Thus, in 15 years, half of the time was spent in system updates.

3.3.4.2. Temporary transfer of data, when technical issues occur

The following UML schematises Lausanne Hospital's process during system's maintenance

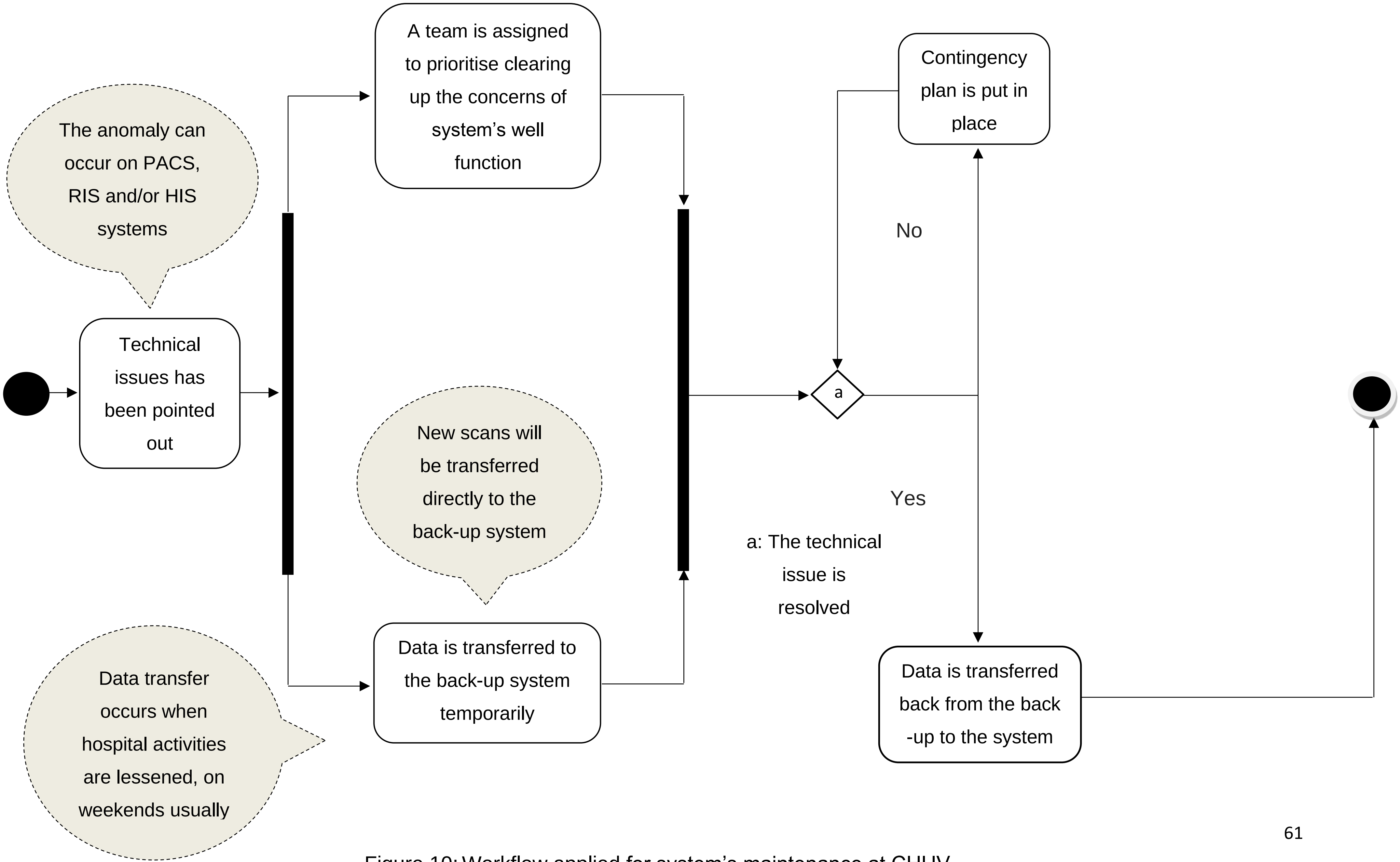


Figure 10: Workflow applied for system's maintenance at CHUV

As presented above (Figure 10), back-ups could be utilised to receive medical data, from the main hardware (NAS), at the occurrence of a bottleneck, generated from a technical issue. Pedron mentioned that the data transfer to the back-up is established on weekends, when hospital activity is lessened. During the visit, there was an inability to obtain answers regarding the methodology to process and access medical data on a manual basis until then. For instance, when the technical issue takes place earlier in the week. Around the same time of data transfer, a team is chosen, to seek as a priority, the elimination of all concerns that obstruct the system's ability to function properly.

Philippe Pedron confirmed the occurrence of past minor IT difficulties in the PACS, RIS and HIS workflow. This has led to a temporary dysfunction of those IT services, which has caused Lausanne Hospital to apply the abovementioned workflow and opt for the back-up as a main option to access medical data. Unfortunately, it was impossible to disclose further information such as the financial consequences of those technical difficulties.

3.4. Advantages and limitations of onsite medical system

Over the years, onsite medical PAC system have shown a great number of advantages, such as the control and ownership of data and the multi-location viewing factor. However, on the other hand, it has been discovered that this same system has its limitations, as the main ones, the risk of a system failure, limited data accessibility offsite, as well as high initial costs (Figure 11).

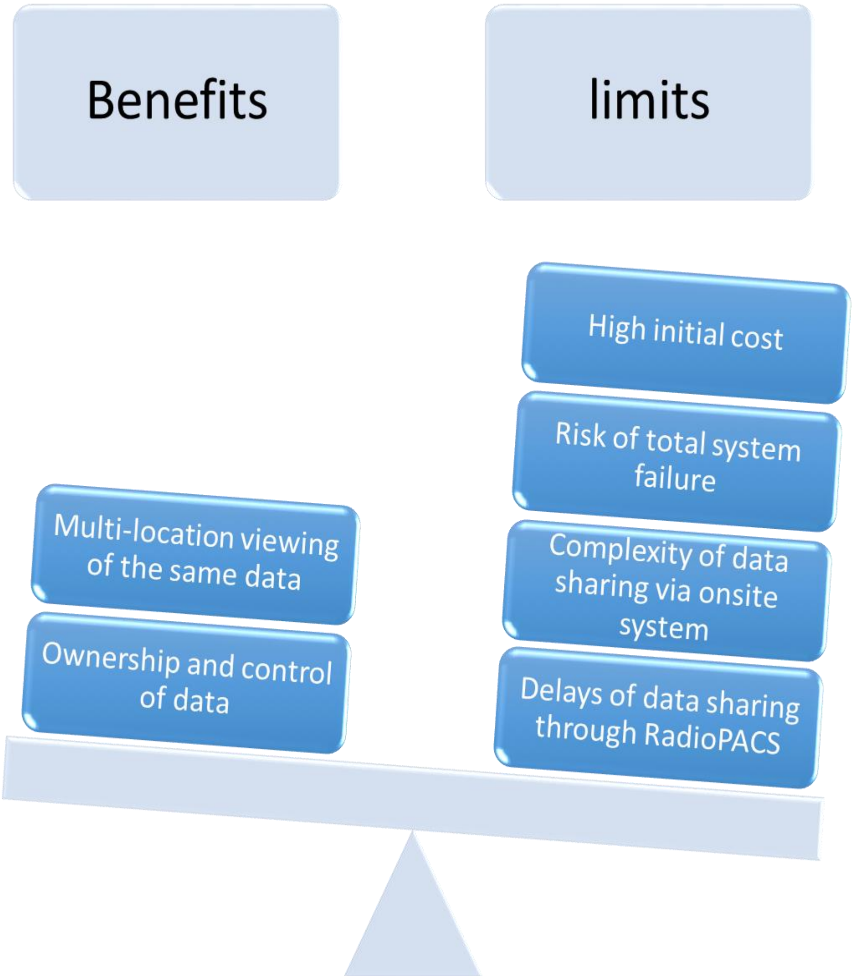


Figure 11: Main benefits and limits of current medical system at Lausanne Hospital

The analysis of the main benefits and limitations of an onsite PACS (Figure 11) involves a medical system that is installed inside a hospital, and does not integrate CAD. The multi-location viewing of medical data and the control of ownership of data are highlighted as the major advantages. Nevertheless, these benefits are outbalanced by PACS' drawbacks. A risk of total system failure, high initial costs, are considered as the main limitations. The next part will detail each advantage and disadvantage stated on the diagram.

3.4.1. Advantages of using onsite medical system

As mentioned on the last balance shaped diagram, two key points have been pointed out as the main benefits of Lausanne Hospital's onsite medical system:

- Multi-location viewing of the same data
- Ownership and control of data

It seems significant to highlight that onsite PACS signifies that system's servers are based inside hospital premises. Additionally, the PACS user is solely in charge of managing software, servers as well as system's back-ups.

The next part will emphasise each advantage, starting with the ability to view medical data at multiple locations, followed by the control and ownership of data.

3.4.1.1. Multi-location viewing of the same medical data

The many PACS terminals throughout a hospital allow simultaneous viewing of the same medical images. These terminals are either workstations or clients, connected to PACS software. The choice of which terminal – workstation or client – is selected for images viewing is conditional on the purpose of the data analysis. Section 3.3.2 provides a clarification to this.

The simultaneous multi-location viewing of images enables collaboration among radiologists. Indeed, radiologists at the same hospital or with peer hospitals can seek each other's opinions by viewing the cases at the same instant and discussing them to potentially build common conclusions.

The next section lifts the curtain on the medical data ownership and control aspect.

3.4.1.2. Ownership and control of data

Adopting an onsite system signifies that the user is the system's sole owner. Some hospitals consider that having physical possession and ownership of the data is an advantage. Fact of the matter is, owning and controlling data signify that the reliability and proper functioning of the system are solely dependent on the human resources and equipment the hospital have at hand, without having to rely on a third party.

3.4.2. Limitations: Issues in the transition to filmless radiology

It is true that PAC system, when onsite, has shown a great number of advantages, but this same system has shown its limitations as well. The next section will detail some of the major limitations:

- The risk of a system failure
- High initial cost
- Complexity of data sharing

The next part will draw attention to the limitations above-stated, beginning with the likelihood of a system failure.

3.4.2.1. The risk of a system failure

The first and major risk that can result from using onsite PACS is mainly that of system failure. Indeed, radiology departments are becoming more dependent on

PACS, which increases vulnerability to interrupt the smooth handling of the department (McBiles, 2000). Digital data are fragile and can easily be lost or corrupted. It would hence be devastating for any medical facility to function if such a central tool keeps shutting down (Strickland, 2000). The consequences would be disastrous for clinical care as no hospital can function without an imaging service. And even a minimal delay in resolving the problem, whether through the maintenance of the onsite system or by moving to the back-up system, is unacceptable. Hospitals are not always fully equipped to handle major technical issues. Besides, computer engineering is not the core area of expertise for the majority of staff (McBiles, 2000).

3.4.2.2. High initial costs

PAC system, when onsite, tends to be very expensive. Typically, on average, PACS costs about millions of pounds (Strickland, 2000). In the early 2000s, an institution that only deployed the basic functions might have to pay about £150,000 while a full PACS in a large hospital could cost around £4,000,000 (Pare, 2005). That often explains why it is only used by relatively few hospitals.

In 2000, after 20 years of existence, there were fewer than 20 hospitals that could be considered as truly filmless. Consequently, the deployment of PACS is currently hampered by the lack of financial means of many small and medium-sized structures that might not have the opportunity to invest in the equipment needed for its implementation, and resources to make it work (Hecht, 2015). The high cost of the system has also led to the development of small-scale systems (partial PACS). These tend to be confined to the radiology department connected to only a few services such as intensive care (Hecht, 2015).

On the authority of the imaging technology news source published in May 2012, approximately 7,000 hospitals are using the PACS worldwide (see comparison chart below). When one considers that in China alone, there are approximately 70,000 hospitals, one can conclude that the number of PACS users around the world is relatively few. This is despite the fact that the PACS market has achieved a stage of maturity as it has existed since the 1980's (Kuhl, 2012).

With the exponential increase of medical imaging archive volumes, many healthcare organisations are wondering how they will manage to pay for potentially huge amounts of data storage.

Table 3: Comparison chart of number of PACS users

Organisation	Fujifilm Medical Systems	Integrated Modular Systems	Infinitt North America	McKesson	Med web	Merge Healthcare	Novarad Corp	PACS plus
Number of years offering PACS	10	4	6	19	20	11	12	13
Number of clients as of 2011 (approximate numbers)	3000	10	420	2500	1100	300	620	200

Organisation	Philips Healthcare	Ramsoftinc.	Sclamage	Sectra	Siemens healthcare	Visage imaging	Viztek	Voyage imaging
Number of years offering PACS	11	15	13	18	3	2	7	15
Number of clients as of 2011 (approximate numbers)	38	35	300	1100	100	dozens	350	32

Kuhl (2012) assembled 16 different main providers to compare the numbers of their PACS users (Table 3). These figures appears to be the most recent statistics published. As one can perceive from the above diagram, on the one hand, Fujifilm medical system has the highest number of clients, with around 3,000 buyers, knowing that this company has ten years of existence. On the other hand, with two years of existence, Visage imaging has provided dozens of healthcare facilities with a PACS system. The sixteen major medical system providers have allowed around 7,000 in total to use PACS (Kuhl, 2012).

3.4.2.3. Complexity of data sharing through RadioPACS and/or onsite PACS

3.4.2.3.1. Complexity of data sharing through RadioPACS

Lausanne Hospital, with 20 other hospitals of the canton of Vaud, are merging their medical data on a partial basis through a cloud-based software named RadioPACS. When one is in need of a specific medical information held by another, RadioPACS is deployed as a medium to enable transmission of this information.

The diagram hereinafter (Figure 12) portrays data exchange between two healthcare facilities, applying onsite PACSs, as well as holding a common cloud-based PACS, such as RadioPACS.

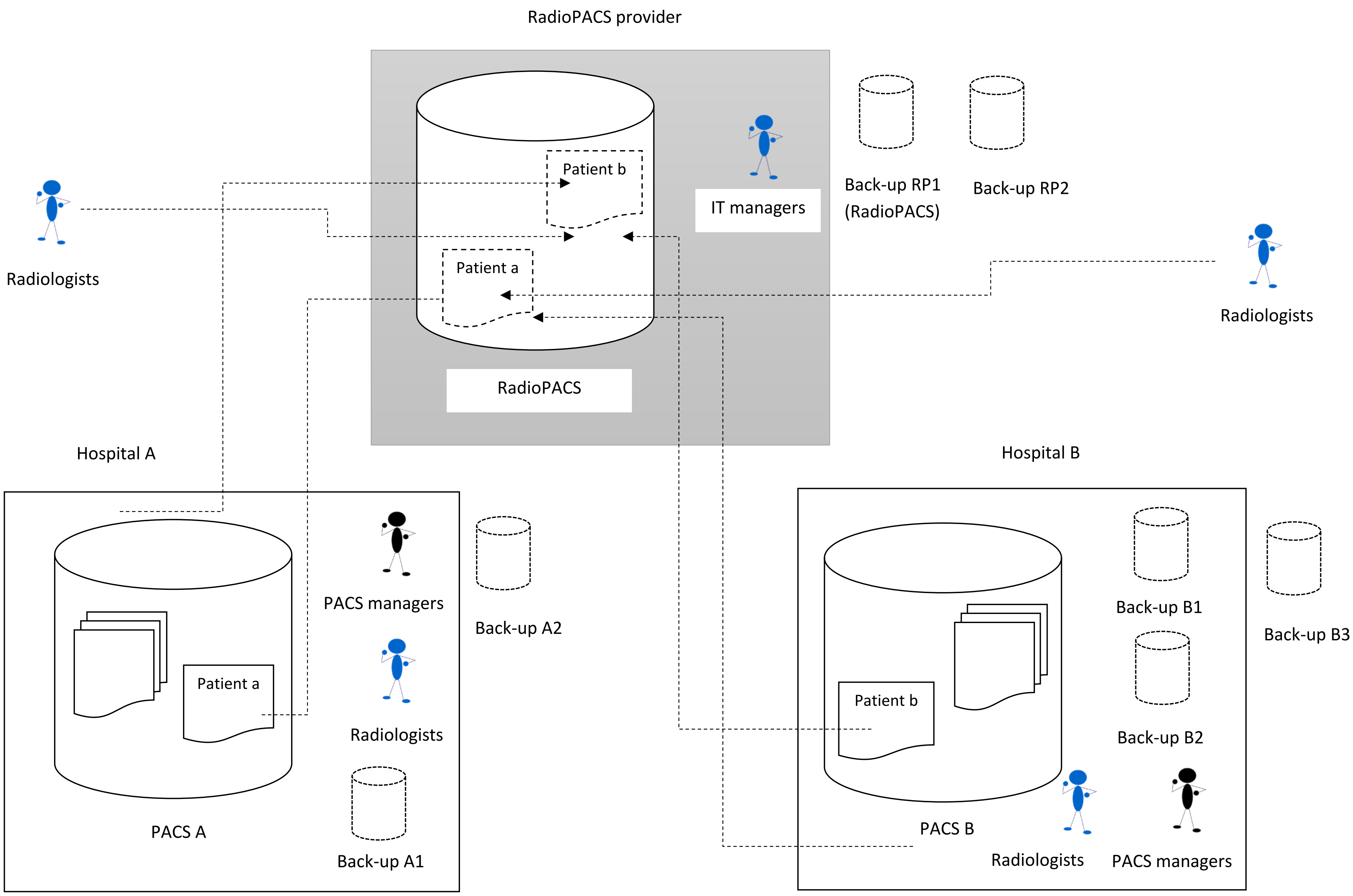


Figure 12 : Data sharing with external healthcare facilities via RadioPACS

One of the medium applied by Lausanne Hospital to permit accessibility of medical data by external healthcare facilities is via a cloud-based PACS server. In fact, Lausanne Hospital along with 20 hospitals in the Swiss canton of Vaud possess a cloud PACS, which allow them to transmit data via RadioPACS when needed. This solution however has been criticised by Lausanne Hospital's PACS manager. As believed by Frederic Pedron, even though RadioPACS grants availability of medical data held by a peer hospital, the length of time necessary to actually access those data can be a hindrance to further radiologist's analysis. This section will develop this statement further

In this instance – as a way of illustration to comprehend the process of data exchange between the Swiss hospitals adopting RadioPACS – hospital A detains medical information that hospital B would wish accessibility to, and vice versa. Thus, each of these hospitals transfer that specific data to the common RadioPACS. Following hospitals' data transmission, RadioPACS can at this stage proceed on enabling data exchange. In other words, RadioPACS will authorise hospital A to visualise patient b's data, while hospital B has been given the ability to read patient a's data through the software (Figure 12).

Frederic Pedron affirmed the usefulness of this tool for data sharing when necessary, especially when it concerns one hospital in need of retrieving previous scans and results of patients held by another medical facility. Nevertheless, Lausanne Hospital's PACS manager mentioned one principal drawback related to the use of RadioPACS as a tool to share medical data between its users. It has a link with the necessary time to transfer data from onsite PACS to the common RadioPACS.

As maintained by Frederic Pedron, transferring data from onsite PACS to RadioPACS takes on average 20 additional minutes than the requisite time to transmit scans from the modality – in charge of the scanning – to PACS. This might delay processing the transferred medical data by the hospital that requested them, especially if the medical case is classified as an emergency. A second drawback from selecting RadioPACS as a data sharing tool can be highlighted as well. It is the hindering responsibility for hospitals to fully manage their respective onsite PACS, in addition to managing partial medical data sharing through their common cloud PACS. The responsibility is potentially hindering for its users as bearing the maintenance of such system engenders a shift from hospital's core area of expertise.

3.4.2.3.2. Complexity of data sharing through onsite PACSs

The schematic representation (Figure 13) illustrates an example of three hospitals Including Lausanne Hospital, alongside two peer hospitals, named for this instance hospital A and B. this lifts the veil on a possible mean to access scans stored by other healthcare facilities. Each hospital in this case are in charge of managing of their personal onsite PACS and back-ups.

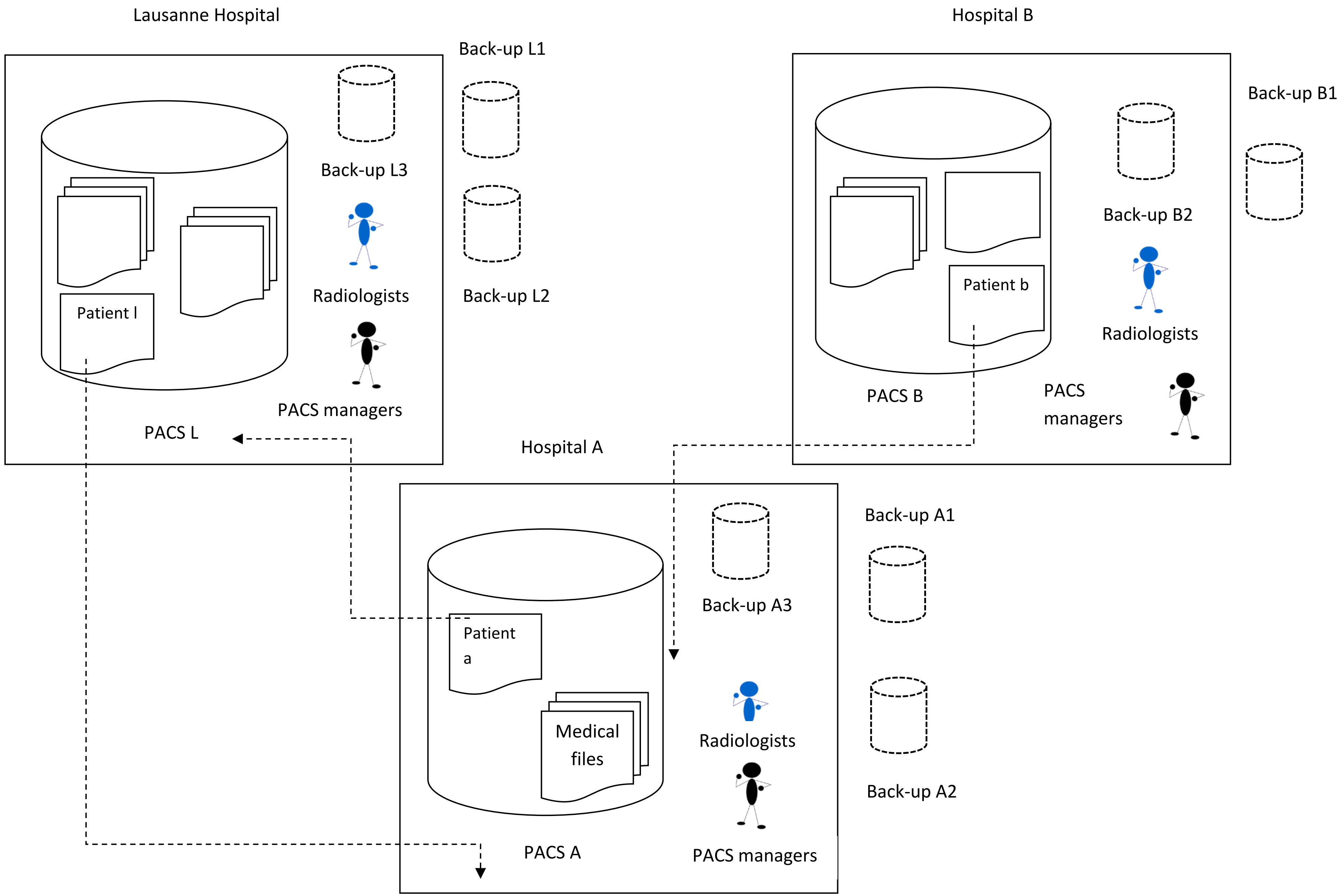


Figure 13: Data sharing process with external healthcare facilities with onsite PACSs

On this instance, Lausanne Hospital wishes to access scans about one patient – patient “a”– from hospital A, while hospital A is hoping to view images about patient “l”, held by Lausanne Hospital. In this case, one approach to enable data exchange between two onsite PACSs (Lausanne’s and A) is through a mutual agreement to exchange electronically one patient’s data with another (patient “l” and “a”). It is noteworthy to hint at the fact that information regarding patient “l” and “a” might be issued from the same department, or from different ones. For illustrative purposes, data of patient “a” can be a lung CT and patient b scan can be a head CT, or both scans might be lung CTs. furthermore, the motive behind hospital A to view specific information held by Lausanne Hospital’s PACS may be dissimilar, or identical. To cite an instance, hospital A requires patient “l” antecedent scans to juxtapose them with the latest ones, while Lausanne Hospital’s aim behind requesting for patient a’s images is for research support. From the same figure, one can perceive that Lausanne Hospital requested accessing medical data – patient b – detained by hospital B. An electronic connection can be put in place, granting Lausanne Hospital that access. The two hospitals – hospital B and Lausanne Hospital – decide at that stage on the conditions of the agreement. Overall, electronic connections between hospitals permit to exchange medical data, however, difficulties arise for the concerned hospitals to agree on the same terms, which might lead to delays in obtaining accessibility of one’s medical information. Additionally, data protection is seen as another limit that delays the transmission of data to peer hospitals.

3.5. Summary

This chapter outlines the process that Lausanne Hospital follows when a patient requests a scan. The workflow has been fragmented into three distinctive steps:

Step 1: Data storage. Lausanne Hospital detains two types of data storage. NAS and RadioPACS. The first one stores all hospital's medical data, while the latter only detains data requested by other medical facilities. Reasons for that include expertise requests to determine the appropriate diagnosis.

Step 2: Data interpretation. Radiologist reads the acquired scans to establish the appropriate diagnosis. At times, the reader is in need of previous scans for follow-up purposes, which can lead to the launch of the prefetching mechanism that allows easy retrieval of data. The data analysis can be completed either on a client server application, or on a workstation. The latter is utilised when scan processing is required to progress in the diagnosis establishment.

Step 3: Data reporting, through digital reporting. A transcription of the diagnosis is completed and validated.

It has been concluded from the analysis that the advantages of the onsite medical system is outbalanced by its drawbacks.

Therefore, this raises obvious questions about the possible approaches to restore the balance between the benefits and limits of the existing system. The other query that can be pointed out is related to the tool which could be used to minimise the drawbacks and maximise the benefits of the existing PACS.

The following chapters will address these queries, with a service that does not seem familiar in the healthcare sector, which is cloud computing, through a cloud-based digital imaging diagnosis system. Moreover, a Computer Aided Diagnosis software will be added to this system.

Chapter 4

Intelligent Cloud-Based Digital Imaging Medical System Solution

4.1. Introduction

The healthcare sector is a growing field of activity that plays a major role in the world in general, and in the European economy in particular. In Europe, employment in the healthcare field increases at a higher rate compared with the European economy as a whole. At the same time, the labour force is growing at a slower rate than the elderly population. The shortage of personnel in the European labour market will therefore continue and force human resources to strengthen their measures to attract the right profiles, while retaining and developing talent (University Hospital of Vaud, 2013).

For the case of Lausanne Hospital, a high turnover is added to the shortage of medical staff in the healthcare field. Indeed, every year, from 2008 until 2012, approximately 12% of the staff members decided to let go of their respective positions at Lausanne Hospital. Approximately half of departures, in each of the years mentioned previously, were linked with a process of resignation. Additionally, the second reason for leaving was due to the expiration of their contracts. The annual report does not highlight whether the renewal of the contract was rejected by the concerned staff member or by the hospital. A minority of the departed staff members were either dismissed, faced retirement, or had to go through other triggers (e.g. disability) (CEMCAV-CHUV, 2014)

To respond to the shortage of health professionals, Lausanne Hospital have announced on their annual report that they will have to strive on three levels:

Firstly, Lausanne Hospital wants to invest in training programs. The aim here is to ensure the excellence and know-how of its employees, to encourage innovation, efficiency and quality of patient services

Secondly, the Swiss healthcare facility wishes to Improve and optimise the management of its human resources to enhance existing skills, and attract and retain the best talent.

Lastly, Lausanne Hospital aims to provide a framework and high-quality work tools to enable each employee to achieve his or her work, find satisfaction, recognition, pride and prospects for development (CEMCAV-CHUV, 2013).

The next chapter could be seen as a direct response to these goals, which are common to most hospitals. Indeed, the next part is centered on a potential high-quality work tool. This instrument, the intelligent cloud-based medical system might have the potential to ease hospitals' workflow from patient's entrance to patient's leave and increase overall performance. Indeed, this system would fulfill three major requirements:

First, this system would strengthen one of the main advantages of the current PACS, which is the ability to view medical data anytime and anywhere. The enhancement would occur with the introduction of cloud.

Secondly, this system would address some of the limitations of the onsite medical system in the following ways:

- It would be cheaper through the elimination of major initial costs
- It would be less risky as the system is not handled onsite
- External sharing of data would be simplified and quicker through cloud computing

Last but not least, this system would be a valuable asset to the computer aided diagnosis, by including an intelligent computerised image processing that facilitates the diagnosis and thereby the treatment that follows. The intelligence is based on the fact that at any time, the computer aided detection system can train the data set, and for any new patient, it can be re-trained and improved to become more intelligent. The intelligence allows the software to make a decision on behalf of the radiologist.

The proposed cloud-based solution is the result of a collaborative work with Lausanne Hospital, with professor Salah Dine Qanadli, the head of radiology department, as main point of contact.

It is worth mentioning that this proposed system can be applied to any hospital facility. In fact, the impact of the new system could be greater in most other hospitals than the Swiss hospital. Lausanne Hospital is considered as one of the most technologically advanced hospitals in Europe, at a cutting edge in medicine and radiology. Therefore, integrating the Intelligent Cloud-Based Digital Imaging Medical System to Lausanne Hospital's workflow would have a smaller impact than hospitals that are less advanced in medicine comparatively.

4.2. The intelligent cloud-based medical Imaging system: Overall patient's workflow

Prior to introducing the proposed workflow, the following part introduces the technology involved in this solution.

This section is intended for all protagonists involved in a cloud PACS, RIS and HIS implementation project and likely to participate (for example, radiologists, Administration, IT managers, GPs). This list is provided to focus the reader's attention towards the transversal character of an implementation project of a medical imaging system. Indeed, it is important that one measures the impact of such project and does not limit it to the central actors that are the clerical of the medical imaging service.

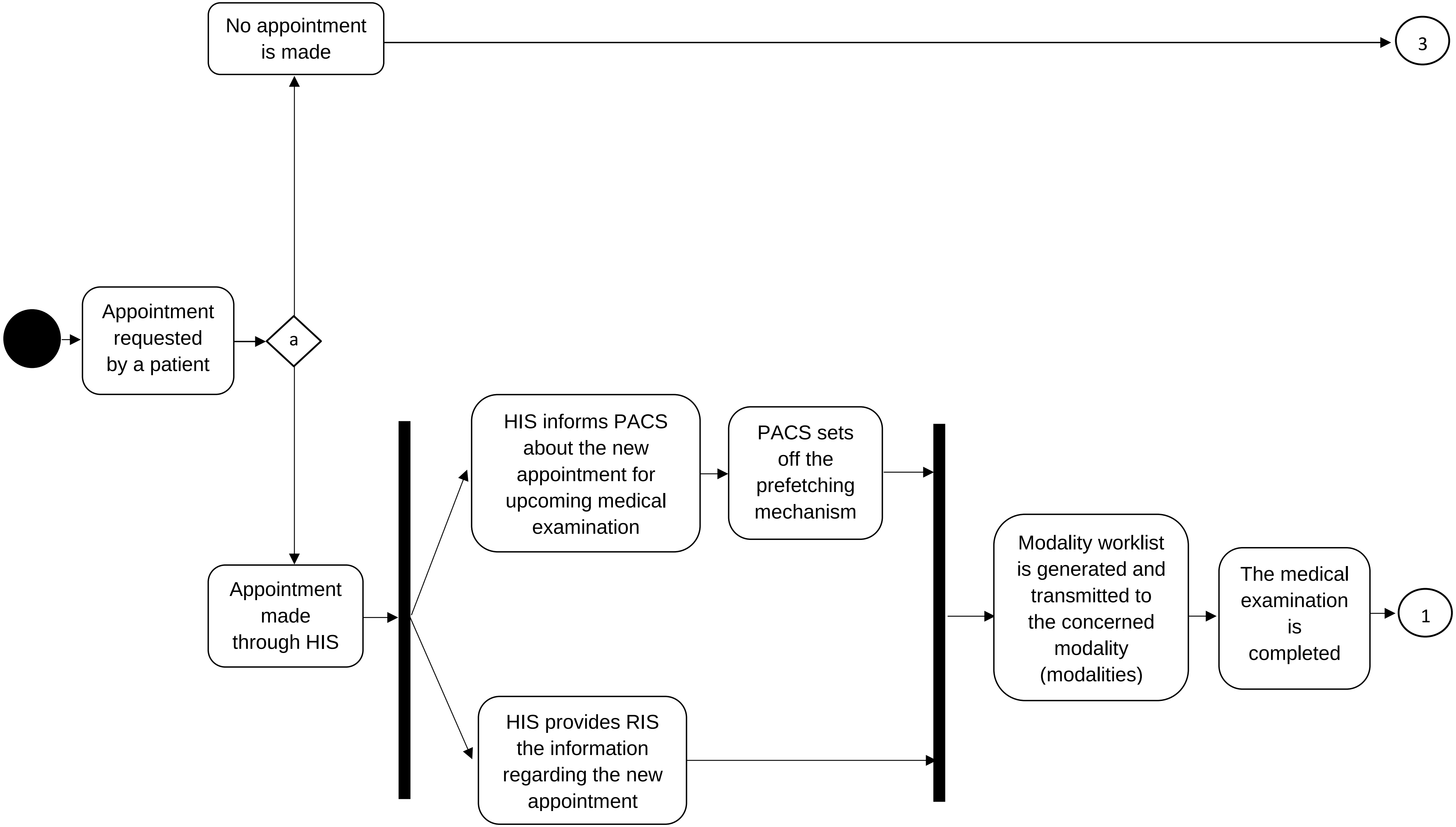
An imaging system consists of several functional and physical entities, to take over all the tasks that contribute to the efficiency of an imaging service.

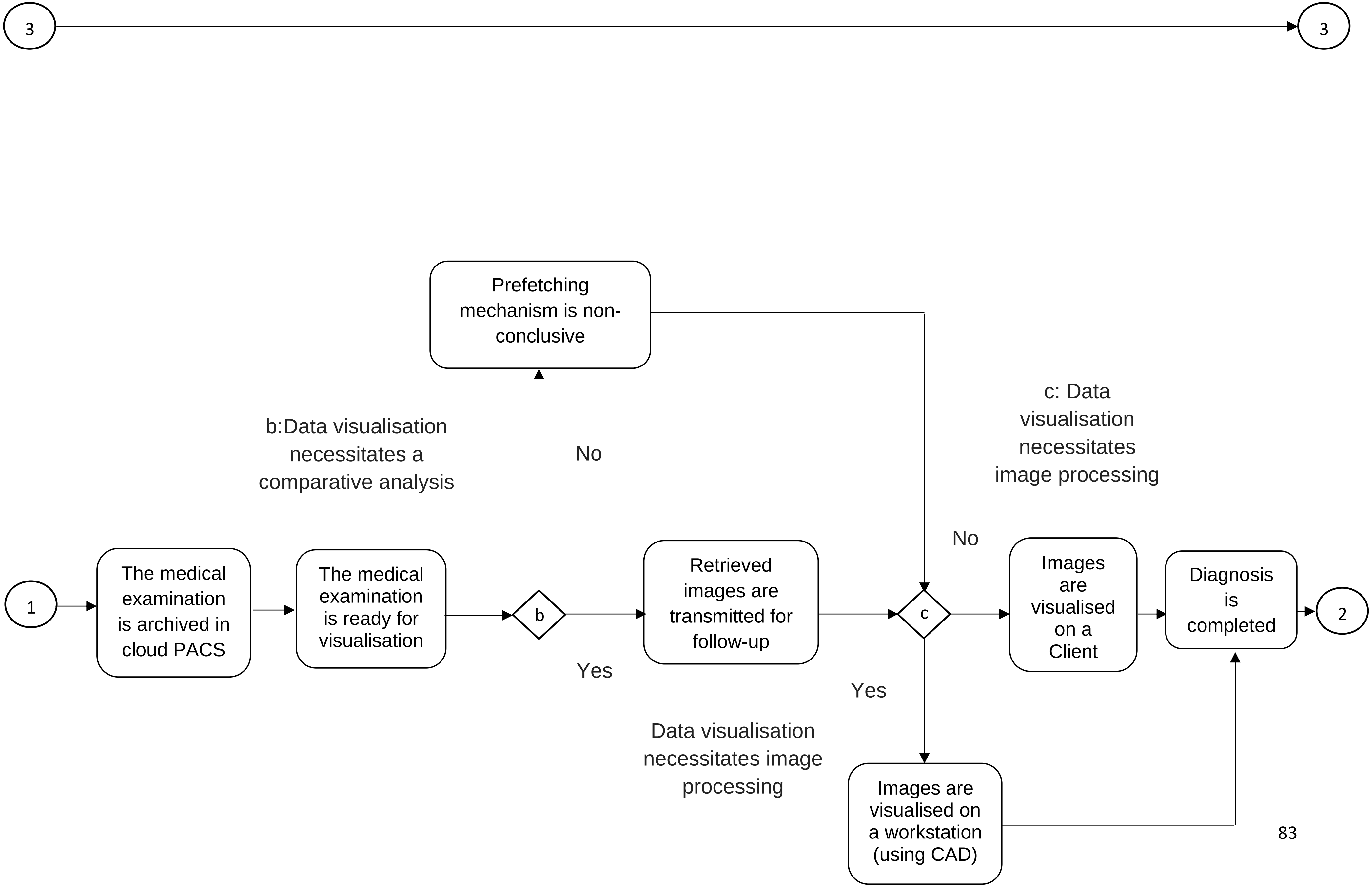
The breakdown between the various components is often the following:

- HIS: Hospital Information System: Software that tracks patient's workflow within all departments
- RIS: Radiology Information System: Software that tracks patient's workflow within the radiology department
- PACS: Picture Archiving and Communication System: System where images are viewed, stored and transmitted for diagnosis and treatment purposes
- Workstations: Support that visualise the data generated
- Cloud-based archival: Support where the data will be retained
- Modalities: Support that captures images (e.g. CT scan, MRI)
- Computer Aided Diagnosis: Image interpretation system

UMLs (Figures 3 and 14) illustrate two workflows that detail the movement of data from one department to another and from one system to another. The first one (Figure 3) is the flow of medical data at Lausanne Hospital, a healthcare facility that is adopting three medical systems integrated with each other, HIS, RIS and PACS. These systems are all onsite, Moreover, PACS does not include CAD as a component. The second UML uses Lausanne Hospital as a backdrop to suggest a new workflow that uses the same systems. However, there are two main differences to point out. One is the use of the cloud as a repository to store and retrieve data. The other is the incorporation of the Computer Aided Diagnosis software alongside cloud-based PACS. This chapter will draw a comparative analysis between the new system and the current one. The analysis will lead to conclusions that would confirm or contradict the initial hypothesis stating that an intelligent cloud-based option has greater benefits than the current system. The analysis will be mainly centred on medical performance, benefits for patients and cost-efficiency for hospitals.

At first glance, one can perceive that up to the completion of the medical examination for a patient, there is no apparent contrast between the two UMLs. Nevertheless, following scans' completion, one can notice three principle disparities, when archiving data, the diagnosis establishment stage, and when performing reports. The next sections will bring to the fore each of these differences.


No appointment is made
3
Appointment requested by a patient
a
Appointment made through HIS
HIS informs PACS about the new appointment for upcoming medical examination
PACS sets off the prefetching mechanism
HIS provides RIS the information regarding the new appointment
Modality worklist is generated and transmitted to the concerned modality (modalities)
The medical examination is completed
1


3
3
Prefetching mechanism is non-conclusive
b:Data visualisation necessitates a comparative analysis
No
c: Data visualisation necessitates image processing
No
1
The medical examination is archived in cloud PACS
The medical examination is ready for visualisation
b
Retrieved images are transmitted for follow-up
c
Images are visualised on a Client
Diagnosis is completed
2
Yes
Yes
Data visualisation necessitates image processing
Images are visualised on a workstation (using CAD)

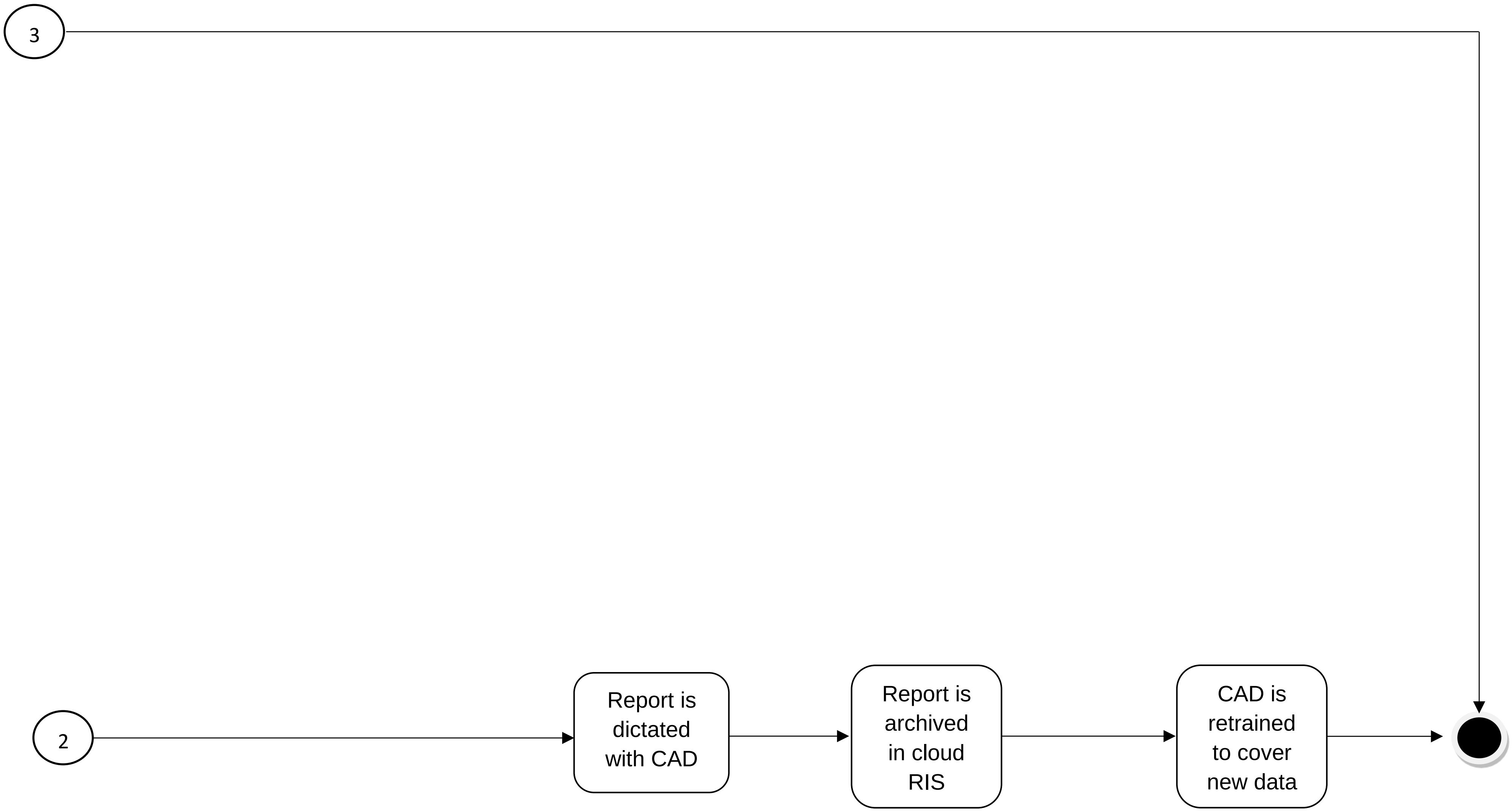


Figure 14: Flow of the administrative data of patients at a hospital using the proposed intelligent cloud medical system

4.3. Medical data workflow fractioned: Understanding differences between intelligent cloud-based and current onsite option

This section divides the overall cloud-based medical data workflow into the same fractioned three steps from scans acquisition to data reporting, as expressed in the previous chapter with Lausanne Hospital, which are the following:

- Medical data storage on the cloud
- Scans' reading and interpretation, with the application of CAD
- Data reporting, with the integration of CAD

In addition to that, the workflows of the ICDIMS (Intelligent Cloud-Based Digital Imaging Medical System) during systems' upgrade and maintenance are described in this chapter as well.

4.3.1. Storage of medical data – Cloud-based option

On the day of the medical examination - following the confirmation of appointment, engendering a modality worklist - scans are captured by the appointed modality and transmitted to cloud PACS for storage. The next part emphasises on how data is stored and retrieved with the proposed system.

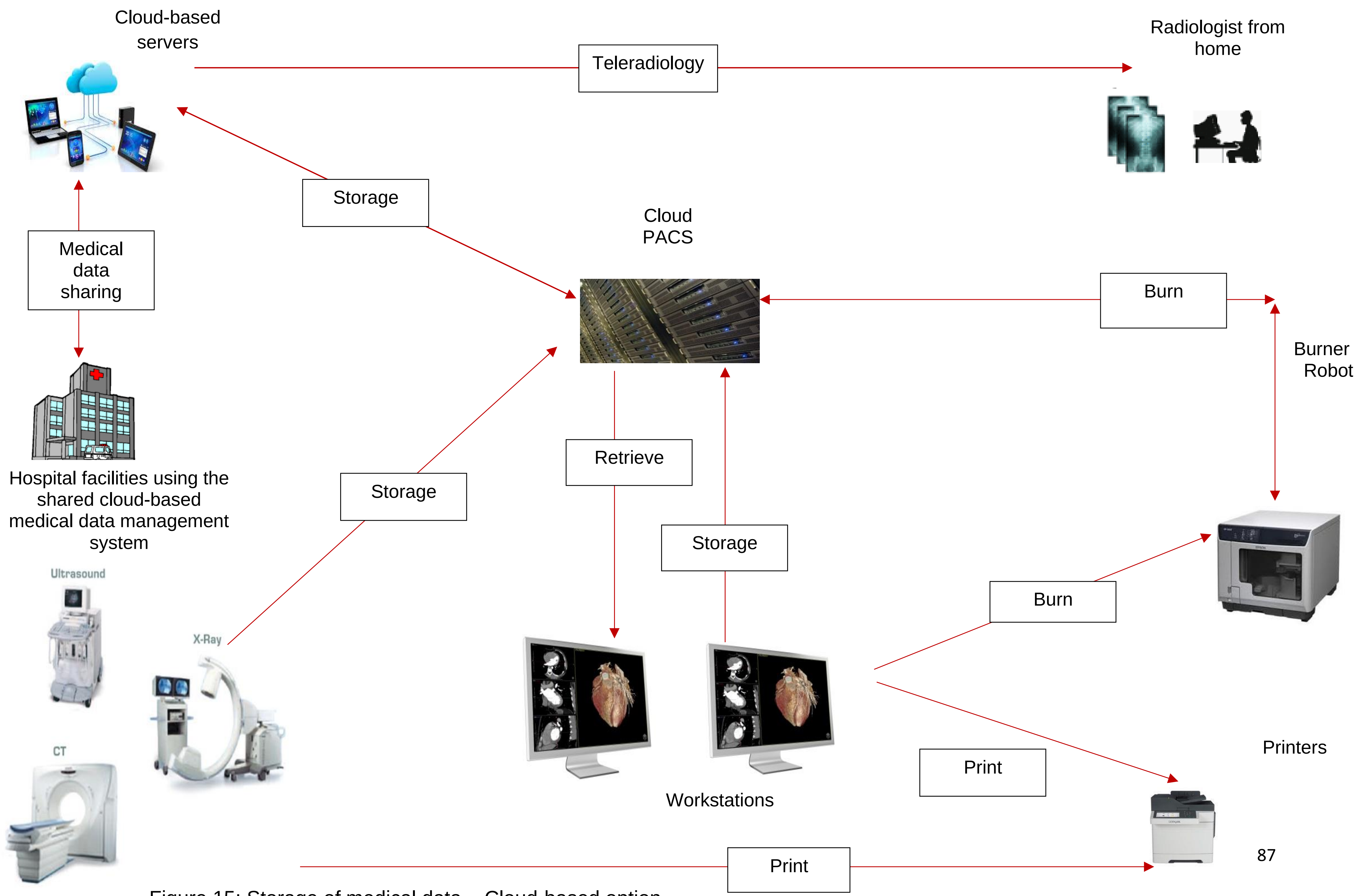


Figure 15: Storage of medical data – Cloud-based option

Prior to completion of the medical scans, the concerned modality receives a worklist from RIS, detailing the upcoming scans to be taken. This worklist detains the necessary information for the technician to acquire scans accordingly. The captured images are then transmitted via PACS to the external storage at the company that manages hospital's data in the cloud (Figure 15).

The stored data in the ICDIMS can be retrieved for four different main purposes. The first one involves reading medical data at hospital's workstations for reasons including diagnosis, follow-up, research and teaching purposes. The second one is to burn data, which signifies making a CD (compact disk) out of collected data. The third one is to print out the scans. It should be emphasised that printing and/or burning can as well be effectuated from the modality itself. The reason behind that is related to the ability of the modality to temporarily store data. Details about this last statement were illustrated in chapter 3, section 3.2. The last but not least of importance implicates the possibility of accessing data outside of hospital premises. Indeed, medical specialists can now visualise medical information anywhere through the cloud host option. The reachability of medical information on other sites, or even from home opens opportunities for teleradiology.

4.3.1.1. Teleradiology benefits

Applying this proposed system strengthen remote consultations and interpretation of radiological images. This makes it possible to analyse the most complex files, and to have the opinion of experts specialised in their area of expertise.

By providing access to images, examination results and reports, onsite and offsite hospitals' premises, the suggested cloud PACS allows access to care for remote areas as well as for patients with difficulties to relocate themselves outside of their usual place of residence, such as for people who are frail or suffering from chronic diseases.

4.3.1.2. Instant access of data

As it has been stated in the Royal College of radiologists report (2016), radiologists seem to be facing difficulties getting access to medical data of patients registered in different hospitals that apply onsite medical systems. Hospitals have often dissimilar medical systems and thus dissimilar workflows. This may lead to diagnosis delays, and thus treatment delays. To put numbers into the latest statement, the report included a survey of a total of 782 medical staff. The surveyed persons handed in their responses between February and March 2016.

The main purpose of the questionnaire was to determine the familiarity of clinicians with PACS and RIS systems. The familiarity is especially linked to the transmission and accessibility of medical information. The transmission and reception of images and reports can be carried out from a hospital to another outer facility or vice versa. The questionnaire incorporated close ended questions along with qualitative observations. The report divulged that the outcome of the survey was crucial as the main hospital IT systems' users are indeed the clinicians, considered as the main actors in delivering a diagnosis and a suitable therapy.

At first glance, the comments accentuate the idea of complications faced by clinicians when managing data sharing (The royal college of radiologist, 2017).

Table 4: the difficulty experienced by radiologists in the U.K to access external radiology images and reports for the purposes of radiotherapy planning, attending MDTMs (multidisciplinary team meetings) and producing follow-up image reports

	Never	Occasionally	Almost every time or every time	total
Clinical oncologists	13 (8%)	134 (79%)	22 (13%)	169 (100%)
Clinical radiologists	14 (39%)	15 (42%)	7 (19%)	36 (100%)
All respondents	27 (13%)	149 (73%)	29 (14%)	205 (100%)
Multidisciplinary team meetings				
Clinical oncologists	6 (4%)	130 (77%)	32 (19%)	168 (100%)
Clinical radiologists	21 (4%)	390 (67%)	166 (29%)	577 (100%)
All respondents	27 (4%)	520 (70%)	198 (26%)	745 (100%)
Follow-up image reporting				
Clinical oncologists	11 (9%)	98 (77%)	18 (14%)	127 (100%)
Clinical radiologists	25 (4%)	432 (72%)	140 (24%)	597 (100%)
All respondents	36 (5%)	530 (73%)	158 (22%)	724 (100%)

The majority of the respondents have agreed on the fact that accessing external radiology images and reports can on occasions be arduous. The struggle is faced by both Clinical oncologists and clinical radiologists. Additionally, on average, between 69% to 73% of the surveyed oncologists and radiologists respectively mentioned occasional issues when accessing data for the purpose of radiotherapy planning, multidisciplinary team meetings and follow-up image reporting (The royal college of radiologist, 2017).

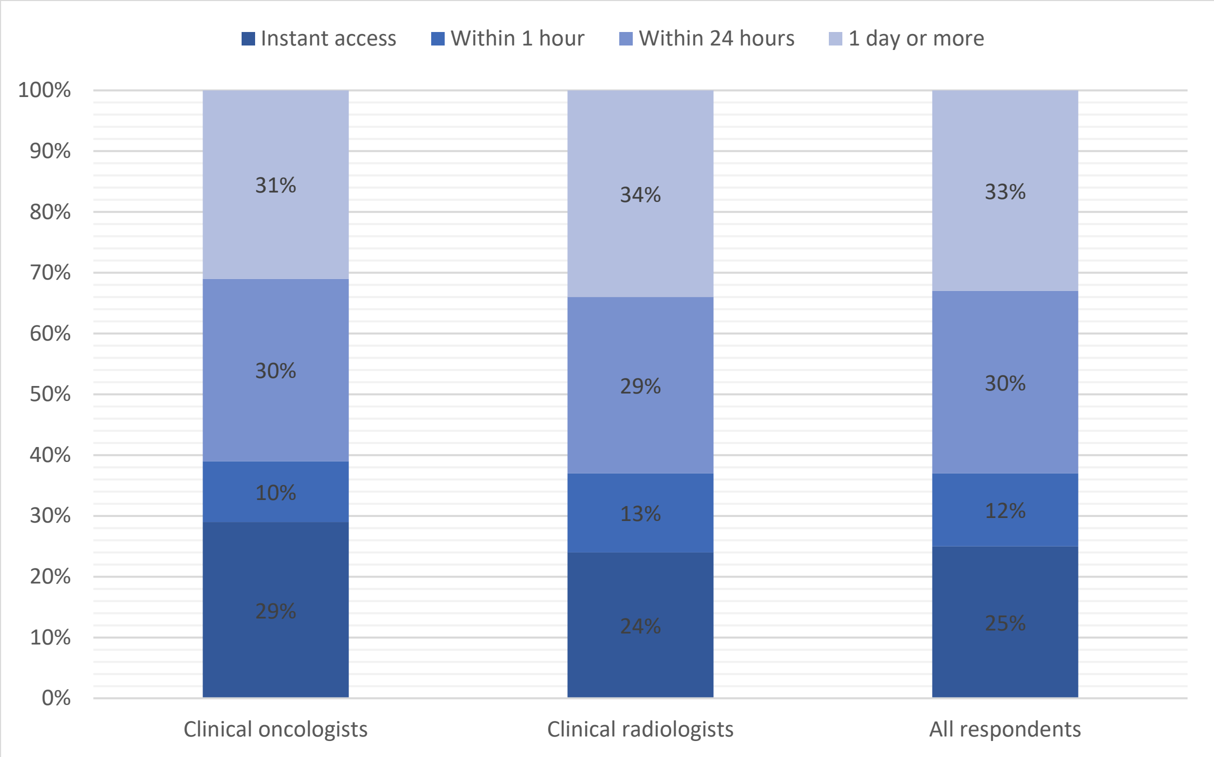


Figure 16: Length of time taken by respondents to access external radiology images

Another study confirms the challenge experienced by hospitals' staff in accessing external medical data (Figure 16). Indeed, a third of the respondents, whether clinical oncologists or radiologists, affirmed to wait at least a full day prior to the reception of medical data from an external facility. In addition to that, only around a third of the radiologists and oncologists (24 and 29% respectively) expressed that their access to external medical data occurred on an instant basis. One might believe that oncologists have a slightly higher percentage as they are dealing with more serious cases. From few hour to few days is the length of time the majority of the respondents have to halt before viewing their requested medical data (The royal college of radiologist, 2017).

Applying a cloud-based PACS could counter the challenges faced by hospital professionals to access external data with onsite medical systems. As a matter of fact, cloud-based PAC system grants instant accessibility of data, whether users are onsite or offsite hospital premises. Via cloud, there is no more necessity of transmission of data via sharing agreements or RadioPACS as applied by Lausanne Hospital. This opportunity presumably facilitates diagnosis and strengthens collaborative work between medical experts based at different hospitals, thanks to the rapidity in accessing images and reports.

The upcoming figure illustrates data accessibility and sharing through the suggested cloud-based solution. On this instance, the system is shared between two users (hospital A and hospital B) and the system provider detains three back-ups.

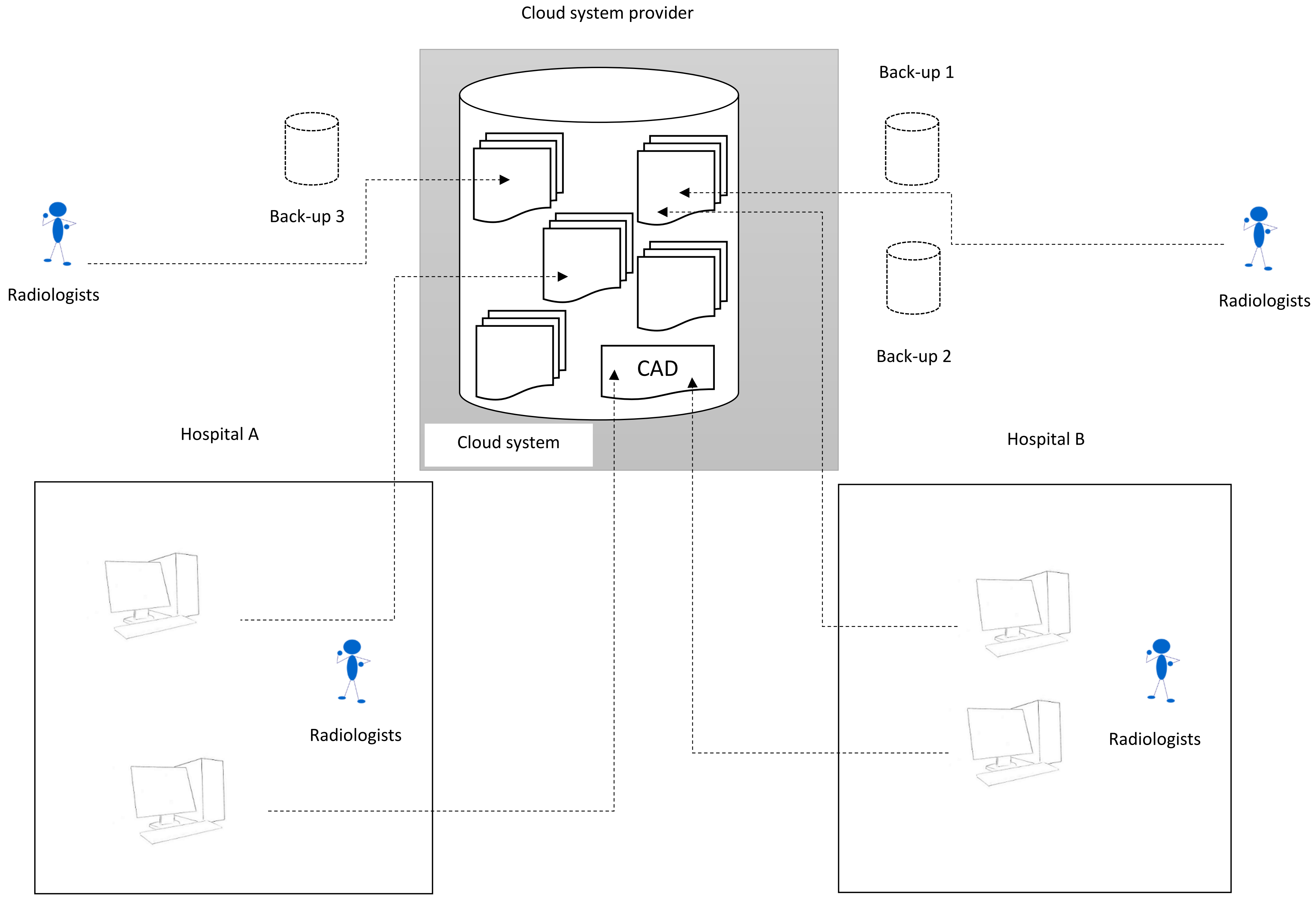


Figure 17: Data accessibility and sharing through cloud medical system

In this case, Hospital A and B are granted instant access of data saved on the cloud-based system, whether its users are onsite or offsite, provided that they have internet connection.

4.3.1.3. Summary

For the case of Lausanne Hospital, a full ownership of a local PACS added to a shared ownership of cloud PACS (RadioPACS) suggests complete responsibility to operate and maintain the local medical system. This signifies that the Swiss hospital is held accountable for recovering system's failures alongside processing system's updates. Furthermore, due to fluctuation of hospitals activities generally, Lausanne Hospital needs to ensure that sufficient servers are put in place when number of medical files rises. Whereas, when integrating one medical system, offsite, the user is detached from any responsibility to maintain a smooth running of the system. Thus, the cost of the local PACS in addition to the cost of the team that would have been employed for its management can be saved.

As referred to previously in section 3.4.2.3.1, transferring scans from NAS to RadioPACS does not take place instantaneously. Consequently, medical practitioners who made requests to read specific scans through the shared RadioPAC system will have to tolerate delays for the transfers to be completed. As for integrating one PAC system, whose location is offsite – based in the cloud – the assumption is that data access would be provided on an instant basis. This opportunity is assumed to enhance collaboration between medical experts based at different locations. Moreover, rapidity of access to data could quicken the diagnosis process.

Hence the suggestion that adopting one PAC system, on the cloud, seem to endorse more advantages for the user in terms of efficiency and performance. A cloud-based PACS would as well allow hospitals' attention to be converged towards their primary domain of competence.

4.3.2. Diagnosis completion

At this point in the patient's workflow, the pre-consultation has been conclusive for a scan. The patient attended his/her scan appointment, which led the appointed modality or modalities to obtain the requested scans and transferred them to PAC system for storage. The forthcoming stage, following scans' completion and storage is the diagnosis establishment. The next part (Figure 18) implies the use of CAD to support radiologists perform scans analysis rather than relying solely on their observations.

The four steps of CAD data analysis highlighted on the next diagram have been described in section 2.3.

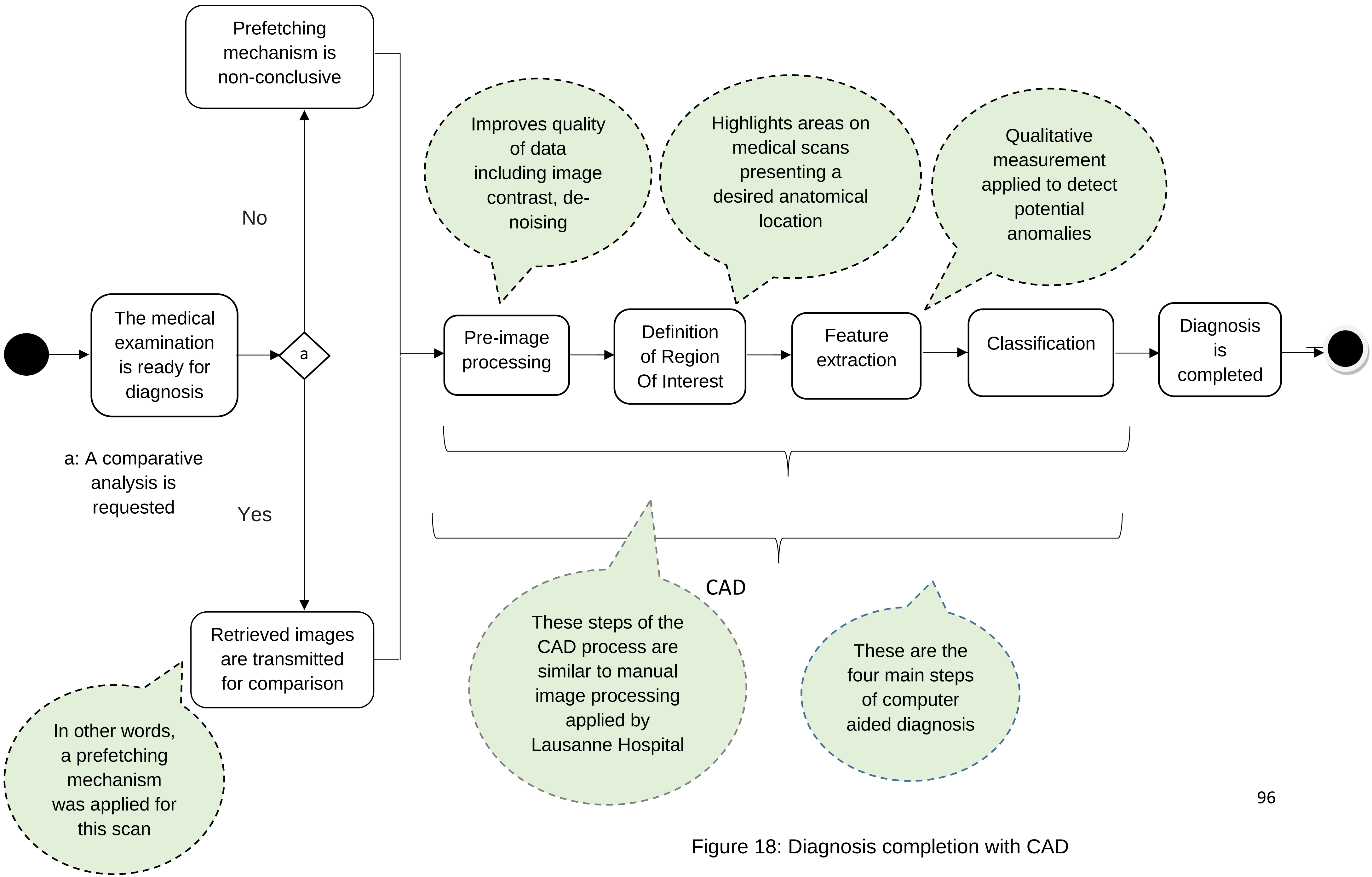


Figure 18: Diagnosis completion with CAD

One might query the potential gains from employing a computerised scan processing, the CAD, as an alternative to manual processing. Both options are included in the diagnosis process, but the first one appears to be more beneficial than the second. The main benefits of cloud-based CAD include:

- Diagnosis accuracy increase
- Inter-observer variability betterment
- Productivity enhancement, when applying CAD in the diagnosis process
- General productivity increase, through the Hawthorne effect
- Opportunity of CAD enhancement, when CAD is based in the cloud
- Cost dilution

4.3.2.1. Diagnosis accuracy increase

There are various research papers that have confirmed CAD's potential to increase diagnosis accuracy, and thus decrease misdiagnosis rates. This section will detail few of those publications.

One of the main research studies in this field has put suppression of inattentional blindness in correlation to accuracy of diagnosis among the potential benefits of CAD for its users. The next section will further elaborate on this fact.

4.3.2.1.1. Inattentional blindness factor, the gorilla experiment

The appearance of an unanticipated event can easily be detected by anyone, one tends to assume, yet, when the focus is on a distinct assignment, one is prone to miss out on those uncommon occurrences. This is referred to as "inattentional blindness" (Trafton, Vo, Wolfe, 2013). Indeed, a study directed by Simons and Chabris (1999) confirmed this fact. A considerable amount of the candidates on this experiment did not acknowledge a person wearing a gorilla outfit, walking throughout a game where people are exchanging a ball between themselves. Anyone can visualise this video and participate in this challenge (http://www.theinvisiblegorilla.com/videos.html).

However, one leans towards the idea that this situation could rarely occur to those whose careers are centered on the location of small scaled anomalies, pathologies, aneurysm, or tumors, such as radiologists. Nevertheless, a study led by Trafton, Vo and Wolfe (2013) has proven the contrary. In fact, 24 radiologists and 25 non experts were requested to carry out an acquainted lung nodule detection exercise. 83% of Radiologists did not spot the gorilla hiding in the scan, considering that the size of the gorilla on those CT scans was 48 times bigger than the average lung nodule, which is about 5 millimeters.

The three researchers divided the study into three distinct experiments:

The first part of the study involved 24 radiologists. The age range of these radiologists was between 28 and 70 years old. Knowing that 10 was the average nodules number on every CT, The study's participants had a maximum of three minutes to observe 5 lung CT's, aiming to detect nodules in each of them. It needs to be added that the norm for a CT scan generates 100 to 500 slices. For this research, there were 239 slices, with 5 that included the gorilla (Figure 19).

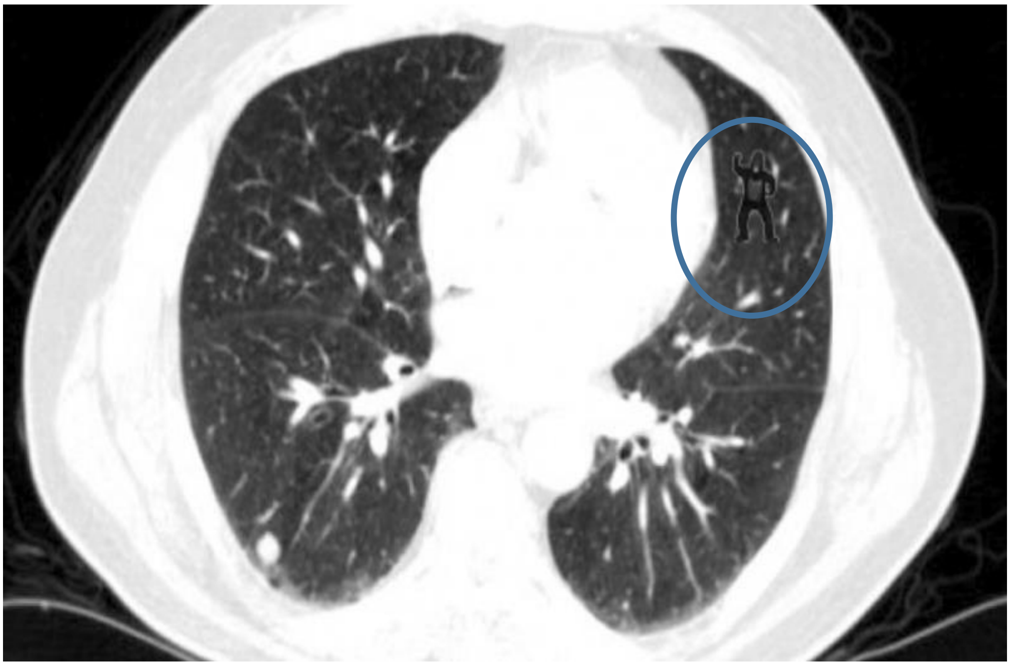


Figure 19: Chest CT scan with gorilla (up right side)

The CT scan above is one of the slices where a gorilla is present in it, on the top right of the picture. The size of it was 29 mm in width and 50mm in height. In those 5 images with the gorilla, its size was surpassing 48 times the size of the average lung nodule. The experiment observers verified that the gorilla was centered in a way that all lung nodules are clearly visible with the naked eye (C*hest CT scan with gorilla*, 2013).

In order to avoid the common reader commenting about the possible difficulties to find out the animal among the stack of images, the three research observers added a third experiment, a control one. It consisted of the displacement of the series of the same CT scan images on a video, requesting from the candidates to detect the presence or absence of the gorilla among the 239 images. Those candidates had less time to observe each image than those who completed experiment one and experiment two. The results were conclusive as the majority (88%) could accurately answer whether the image had a standing gorilla or not.

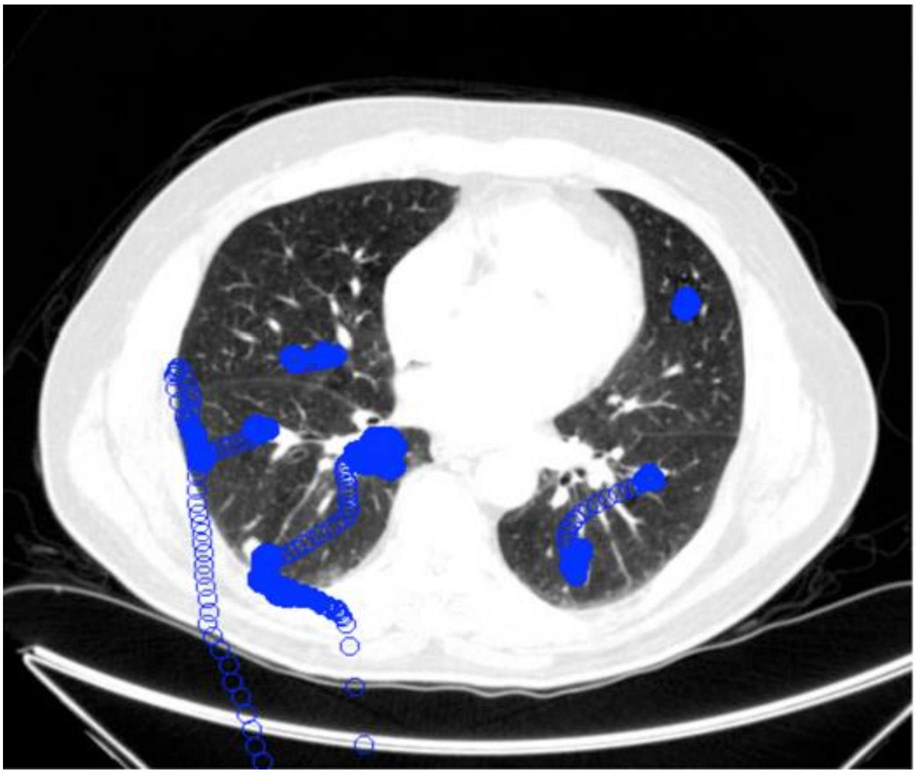


Figure 20: Chest CT scan with eye tracking

The latest image shows where one of the 24 radiologists looked at when they were seeing one of the 5 images that contained the gorilla. Each blue circle is equivalent to eye-position of 1 Ms (millisecond). One could notice that this person had looked at the area where the gorilla was without being able to discover its existence (*Chest CT scan with eye tracking*, 2013).

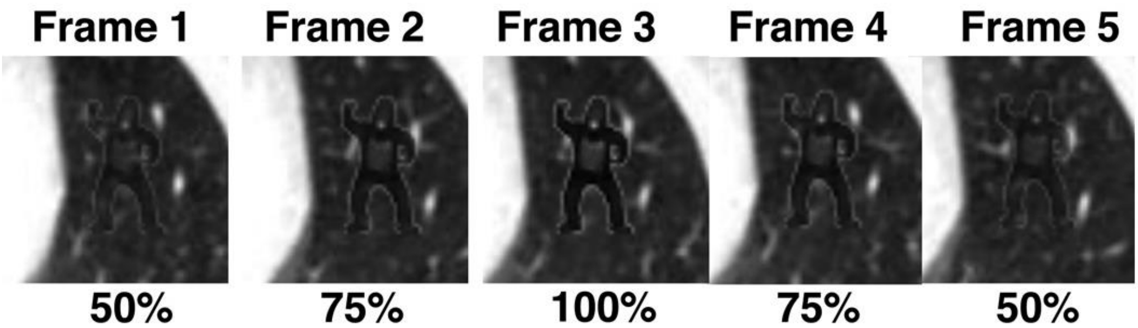


Figure 21: Gorilla's opacity

Gorilla's darkness expanded from 50 to 100%, to then back down to 50% over the course of five pictures of the CT scan (*Gorilla opacity*, 2013).

The second part of this study involved 25 people who did not have a background in the medical field. They were assigned the same exercise as the experts. Nevertheless, in order to make their experience legitimate, they received a short training regarding lung nodules detection. Additionally, their experiment did not begin until they managed to discover at least one nodule (Trafton, Vo, Wolfe, 2013). None of the observers had managed to successfully detect the gorilla picture on the CT scans (Figure 22).

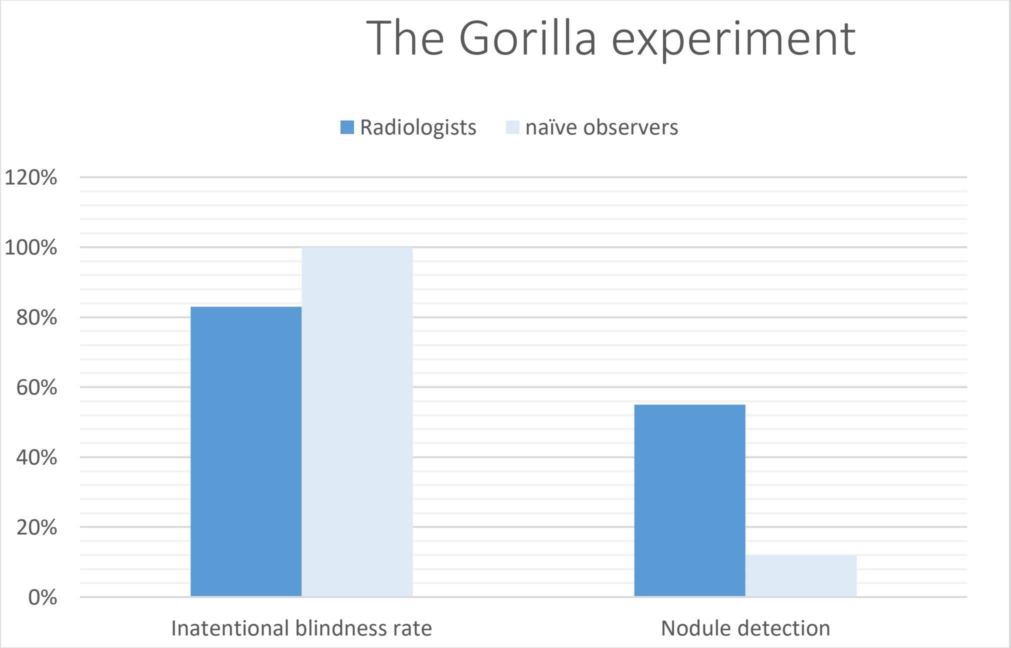


Figure 22: Results of experiment 1 and 2

As a sum up of both experiment one and two, naïve observers were all incapable of discovering the gorilla present on the CT scans slices. Hence, they were all facing inattentional blindness. As for the experts, the majority, with 83%, or 20 out of 24, did not get to point out the presence of an uncommon picture in a CT scan, the gorilla. Only 55% of the radiologists were able to detect nodules on the CT scan case, while a minority of 12% of non-medical experts succeeded on the nodule detection task.

It was mentioned on the research paper that 12 out of 20 radiologists who missed the detection of the gorilla looked directly at it (Figure 20 is an example of one of those radiologists whose eyes were tracked to prove that, that person looked at the location of the gorilla, however, they were not able to discover the existence of the animal) (Trafton, Vo, Wolfe, 2013).

4.3.2.1.2. Other research inputs

Schalekamp et al. (2014) constructed a study to determine whether CAD is capable of detecting what the naked eye failed to point out. The results of this research were conclusive (Table 5). Indeed, 8 radiologists had to conduct an analysis on 300 chest radiographs, 189 were nodule cleared while 111 had a solitary pulmonary nodule (the average nodule diameter scan was 16.2 mm). Out of 239 missed nodules, CAD managed to detect the majority of them, even those whose size is smaller than 10 mm.

Table 5: Nodule detection by readers and CAD

Diameter of nodule (mm)	Number of nodules missed by all readers	Number of nodules missed by all readers but detected by CAD
>25	11/56 (20%)	11/11 (100%)
20-25	26/128 (20%)	18/26 (69%)
15-20	77/256 (30%)	29/77 (38%)
10-15	102/376 (27%)	56/102 (55%)
<10	23/72 (32%)	13/23 (57%)
Overall	239/888 (27%)	127/239 (53%)

Another study led by White (2009) allowed the discovery of 89 cases of lung cancers, overlooked by observations made by two readers. The tumor was overlooked on one radiograph in 72 patients, two radiographs in 10 patients, three radiographs in six patients, and four radiographs in one patient. This allowed the launch of close follow-up and treatment for all 89 initially misdiagnosed patients.

When it concerns pointing at nodules in pulmonary scans – nodules are referred as abnormal balls that are formed inside the lungs – research has proven the efficacy of CAD to support radiologists in discerning small sized pulmonary nodules. Indeed, the analysis of 54 CT scans with the application of CAD has resulted with a success rate of 95 nodules detected out of 104. Moreover, out of the nodule detected, 33 out of 38 measured less than 5 mm (millimeters). This Study have also demonstrated a better performance in terms of measures of these nodules using CAD. The software holds its importance in determining the characteristics of the detected lung nodules as well as increasing the ability to distinguish any changes in those nodules in follow-up scans stage (Ye, 2009).

Another study - performed by 10 researchers including Professor Dehmeshki - involved 10 readers and 60 patients with polyps was concluded with an overall increase of polyp detection. In fact, 9 out of 10 readers were able to detect 12 more polyps on average with the support of CAD. This study has also demonstrated an overall decrease in interpretation time by 2 minutes on average when adopting CAD as a supporting tool for polyps' diagnosis (Halligan e*t al*. 2006).

4.3.2.1.3. Summary

In a nutshell, Attention is a powerful tool of our brain. An essential ability that allows one to focus, to make sense of the world around and to classify all information that comes in. Nonetheless, one's attention has flaws. Indeed, the brain can lose track of certain details when observing a scan for instance, and may become "blind" to pinpoint an abnormality. When a radiologist observes a sequence of images, passing from one image to another, the brain develops a memory to be able to notice a change, to identify an anomaly, but this memory will only exist for the details in which the radiologist has his/her attention on. Therefore, our attention is focused on something specific that our brain disregards everything else. Thus, attention cannot be everywhere, similar to a blanket too small. When you are cold, you pull the blanket upwards, but you end up cold on your feet, and then reciprocally when you cover your feet with the same blanket. This creates the phenomenon of inattentional blindness (*Le pouvoir extraordinaire de notre cerveau,* 2018).

Drew's study has confirmed the existence of this phenomenon, even when it comes to experts in the field of anomalies detections. The totality of naïve observers and the majority of radiologists failed in detecting the gorilla image present in the lungs CT scans. Additionally, the majority of radiology experts did not validate the discovery of all nodules present in the scans (Trafton, Vo, Wolfe, 2013).

As a consequence, it appears plausible that having CAD to support one's scan observations and analysis to detect nodules or other anomalies will challenge inattentional blindness. In point of fact, intelligent cloud-based CAD is holding a large amount of up to date data that makes it able to detect what the human eye might misinterpret or even miss out. The system is in fact considered intelligent as based on the training of the data set, CAD can support radiologists in the diagnosis process. In the case of nodule detection, CAD will be absorbed with information such as sizes, diameters and shapes for nodules detection. These features might however not allow the software to identify the gorilla image in Drew's experiment. The reason behind it is that the gorilla's size does not fit the norms of average sizes of nodules. Nevertheless, the software is presumed to increase nodule detection in comparison to this experiment, where only 12% achieved a full success on nodule detection. One of the main determinants of CAD's non-recognition of nodules will be whether the missed out nodules does not fit the features held by the software. It is a question of a new nodule features discovery. In this case, CAD will have this new information added to its database for subsequent CT lung scans. Furthermore, with cloud computing, CAD's database can easily be shared between its users. As a consequence, any added nodule discovery in one hospital is potentially available to the others. Minimising inattentional blindness and spreading medical knowledge through intelligent cloud-based medical system are means to the advancement of medicine to support early identification of diseases.

4.3.2.2. Inter-observer variability betterment

Inter-observer variability is the fact that the same scan analysis performed by several observers does not lead to the same result. A study held by the National Lung Screening Trial about lung nodules detection concluded with CAD being considered as a positive supporting tool for radiologists who disagree on cases. The trial worked closely with 7 radiologists on 134 cases. The results involved a 7 points improvement of agreement between readers on the positivity of screening results (from 77% to 84%), and an 8 points enhancement of agreement regarding follow-up and recommendations (from 72% to 80%) (Jeon et al. 2013).

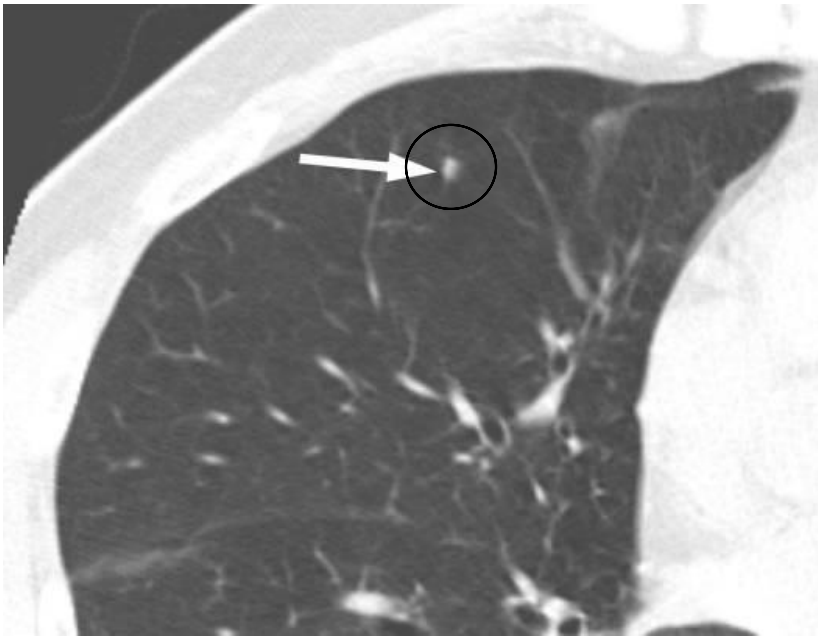


Figure 23: CT scan for nodule detection

“A nodule in the right middle lobe (arrow) was classified as positive by three readers and negative by four readers at the initial assessment (CT scan for nodule detection, 2017). Three readers recommended a low-level follow-up, while four readers recommended no follow-up. After the review of CAD results, all readers classified this nodule as negative and recommended no follow-up “(Jeon et al. 2013).

Thus, CAD detains the capability to reduce the percentage of disagreement between scan readers on a medical case.

4.3.2.3. Productivity increase

Radiology is a victim of its own success. As a matter of fact, in the U.K, a rise of the amount of medical scans went in parallel with the almost stagnation of radiologists available to perform analysis on medical examinations, and draw a diagnosis verdict (The royal college of radiologist, 2017). Radiologists are therefore confronted with higher workload. (Van Ginneken, et al., 2011). As a consequence, implementing CAD with PACS can trigger this problematic. Indeed, various research have supported the idea that CAD positively impacts diagnosis accuracy, and thus reduces the risk of misdiagnosis, and having to call back patients for further scans. Other studies agreed on the fact that CAD can as well, accelerate the diagnosis procedure and reduce variability between radiologists in the interpretation of scans (Section 4.3.2.2.).

Therefore, utilising a software that studies have supported as a tool that not only eases and quickens diagnosis procedure (Schalekamp et al. 2014, White, 2009), but also decreases diagnosis disagreements between radiologists (Jeon et al. 2013) could engender to a productivity increase in the departments applying CAD. Moreover, a general productivity enhancement could potentially be sensed even in departments that have not CAD implemented in their workflow. This can be explained by the Hawthorne effect.

In brief, in psychology, the Hawthorne effect describes the situation in which the results of an experiment are not due to experimental factors but to the fact that subjects are aware of participating in an experiment in which they are tested, which usually results in greater motivation. Observation of the Hawthorne effect comes from a series of studies conducted at the Chicago-based Western Electric Company, when the company's management instructed a group of engineers to measure the effect of a variation in lighting intensity on workers' performance. They conducted the experiment on a part of the factory. This experiment not only resulted in a productivity increase for the workers who were part of the working conditions change, but also, and unexpectedly, with the workers who were witnesses of the experiment, whose working conditions had not perceived any betterment. Applying Hawthorne effect in a hospital setting signifies that if CAD is only applied at a hospital to detect certain pathologies (for instance lung and breast cancer), radiologists' productivity should generally increase, no matter what medical case they are working on. According to Hawthorne effect theory, the general performance enhancement is the result of the feeling of being taken care of by the management, to ease radiologists' workload by introducing a diagnosis supporting tool.

4.3.2.4. Opportunity of CAD enhancement

A stand-alone CAD system that some of the PAC system providers or medical device manufacturers (such as Toshiba or Phillips) offer is being trained based solely on the fixed data. In this case, CAD is trained based on the selected data and then integrated to their PAC system. This signifies that there is no possibility of retraining CAD where the new data is being scanned.

Whereas an intelligent CAD software detains the possibility of constant training; its data grows larger every day. The fact remains that at the occurrence of a medicine discovery by one of CAD's users – for instance, a new nodule has been detected by one particular hospital that uses the common cloud-based CAD – this can be added to CAD's database and shared between its users. Moreover, when this intelligent software is based in the cloud, it empowers its users to potentially have access to a larger up to date medical database, which can contribute to enhance the software's performance further.

Thus, hospitals accessing this growing medical data will be distinguished from the mass by their accessibility of huge amount of data.

4.3.2.5. Cost dilution

One can believe that even though CAD holds multiple benefits, stated in the previous paragraphs, having to bear the cost of the aided diagnosis software could hinder hospitals from adopting such a tool. Nevertheless, this cost can be diluted between its users through cloud computing. Indeed, whether CAD is onsite, each user will have to bear the cost of the software alongside hardware and maintenance costs. Whereas when CAD is based in the cloud, its price will be fragmented between all its users. Additionally, cloud will suppress costs of hardware and maintenance, as the first is located with the IT provider while the latter is handled by the host. Another positive aspect is the possibility to adopt a pay per click option.

4.3.2.6. Summary

Whether one either relies on their scans' observations and analysis to pinpoint a diagnosis or trust CAD as a supporting tool to validate or contradict their medical conclusions, both retain a similar end goal. Indeed, the intent for either choice is to provide an accurate diagnosis, and potentially an early illness discovery, to thus adopt appropriate treatments that targets the threats. The current section aims to enlighten about whether a cloud-based computer aided diagnosis software, when integrated to PAC system could benefit its users or paradoxically, create confusion in their diagnosis process.

An increase in the diagnosis accuracy – and thus a decrease in misdiagnosis rates – appears to be the main benefit of CAD's application in radiology. Research has demonstrated a correlation between inattentional blindness and diagnosis accuracy. Studies have indeed shown that naked eye can omit to detect information that can be crucial for accurate diagnosis. In fact, when one focuses their attention on a specificity in a scan for instance, it acts as a projector. The neurons that process the elements of our attention are active, to the detriment of those who analyse the rest of the visual field. The more one focuses on a specific element, the more shadows appear around their observation, making the person inattentionally "blind" to the rest.

However, CAD can be trained to avoid this scenario. Indeed, provided that the database is complete enough and updated on a regular basis, CAD could suppress inattentional blindness and revolutionise medicine, especially when associated with cloud computing.

Studies have also framed CAD as a supporting tool for radiology's increased workload. CAD in fact eases and quickens accessibility to external data, as well as shortens the diagnosis process. Consequently, CAD's application in a radiology department could enhance staff's productivity in the department that will integrate CAD in their workflow, and perhaps even when radiology do not utilise it. As an illustration, CAD is implemented in a hospital specifically for lungs nodules detection. In case radiologists are confronted with different anomalies in their scans, and therefore have to process the analysis manually – for instance, potential tumors in mammary glands

- their productivity might still increase generally rather than specifically when it concerns detecting lung nodules. The reason could be correlated with the Hawthorne effect explained in section 4.3.2.3.

The proposed cloud-based CAD can also be retrained on a daily basis by having access to new data. This signifies that cloud-based CAD can become extremely intelligent as the number of data to be trained is much more than each individual hospital. The more users it has, the more rapidly evolving it would become.

As a whole, the suggested CAD is a software that seems to hold the ability to revolutionise medicine. It is seen as a tool that enables a betterment in diagnosis accuracy by challenging human errors. These errors are mainly due to presence of inattentional blindness aspect alongside a general overwhelm by an increased workload and a stagnating workforce (Mohammad et al. 2017). Nevertheless, this is conditioned to the completeness of the database. Indeed, completeness of the answers will not be possible without a completeness of the database.

4.3.3. Medical scan results reporting

Subsequent to scan analysis and diagnosis performance, a report of the diagnosis and treatment is proceeded. The workflow (Figure 24) is similar to the current system, nevertheless, the difference is sustained in the mean to complete the report. The current system at Lausanne Hospital adopts digital diagnosis where a medical professional dictates the report for the secretary to put in writing. As for the new option, reports are automatically generated by CAD. This tool is shown to counter the general shortage of medical staff alongside the general increase of medical examinations performed. The next section zooms in on the latest fact.

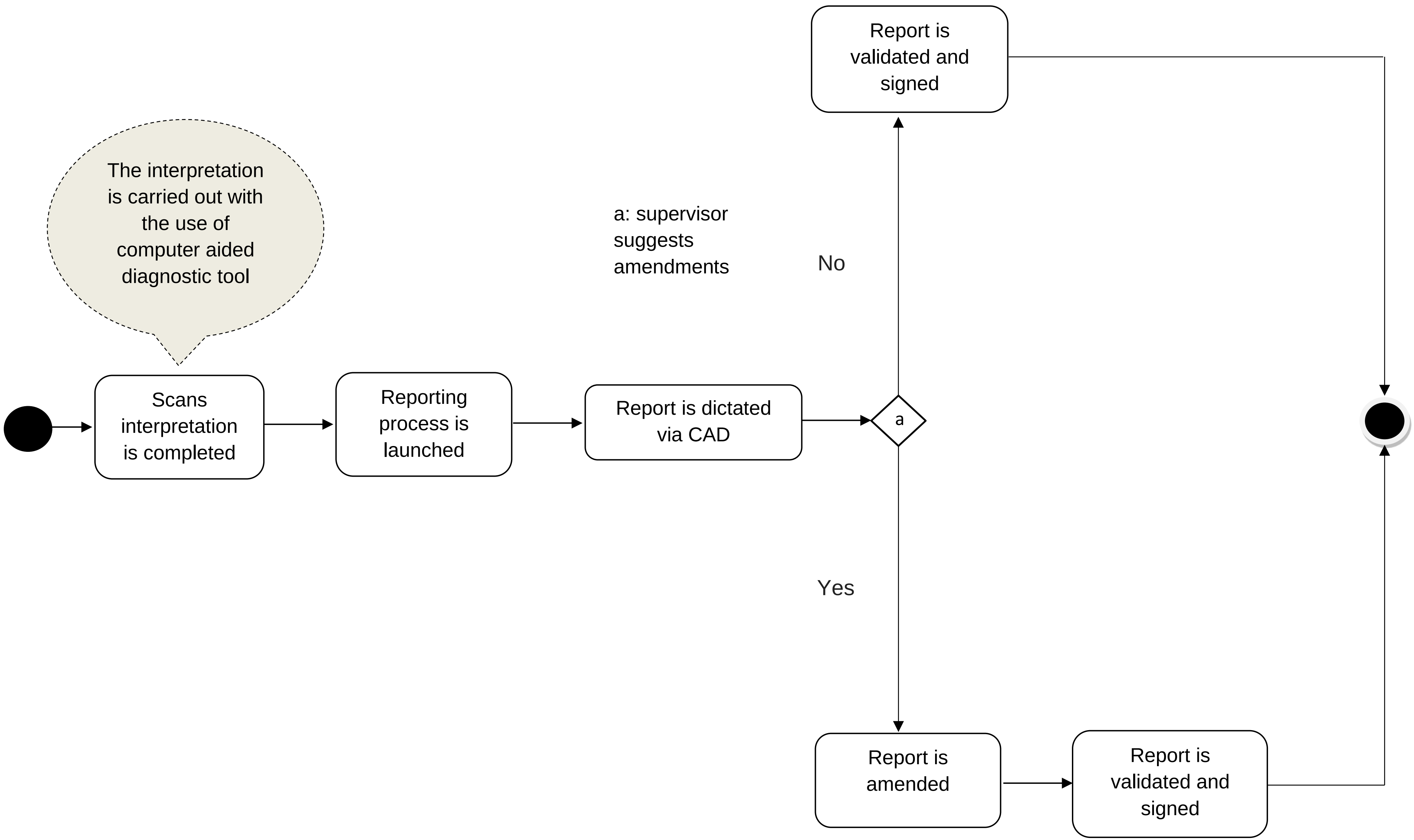


Figure 24: Reporting via CAD

4.3.3.1. CAD's input on reporting process

Imaging has become a determining factor in medical practice. Almost all of the surgical hospital stays and the vast majority of medical stays result in the completeness of imaging acts. Nevertheless, the growing need for imaging raises organisational problems as more and more hospitals are under-staffed by radiologists.

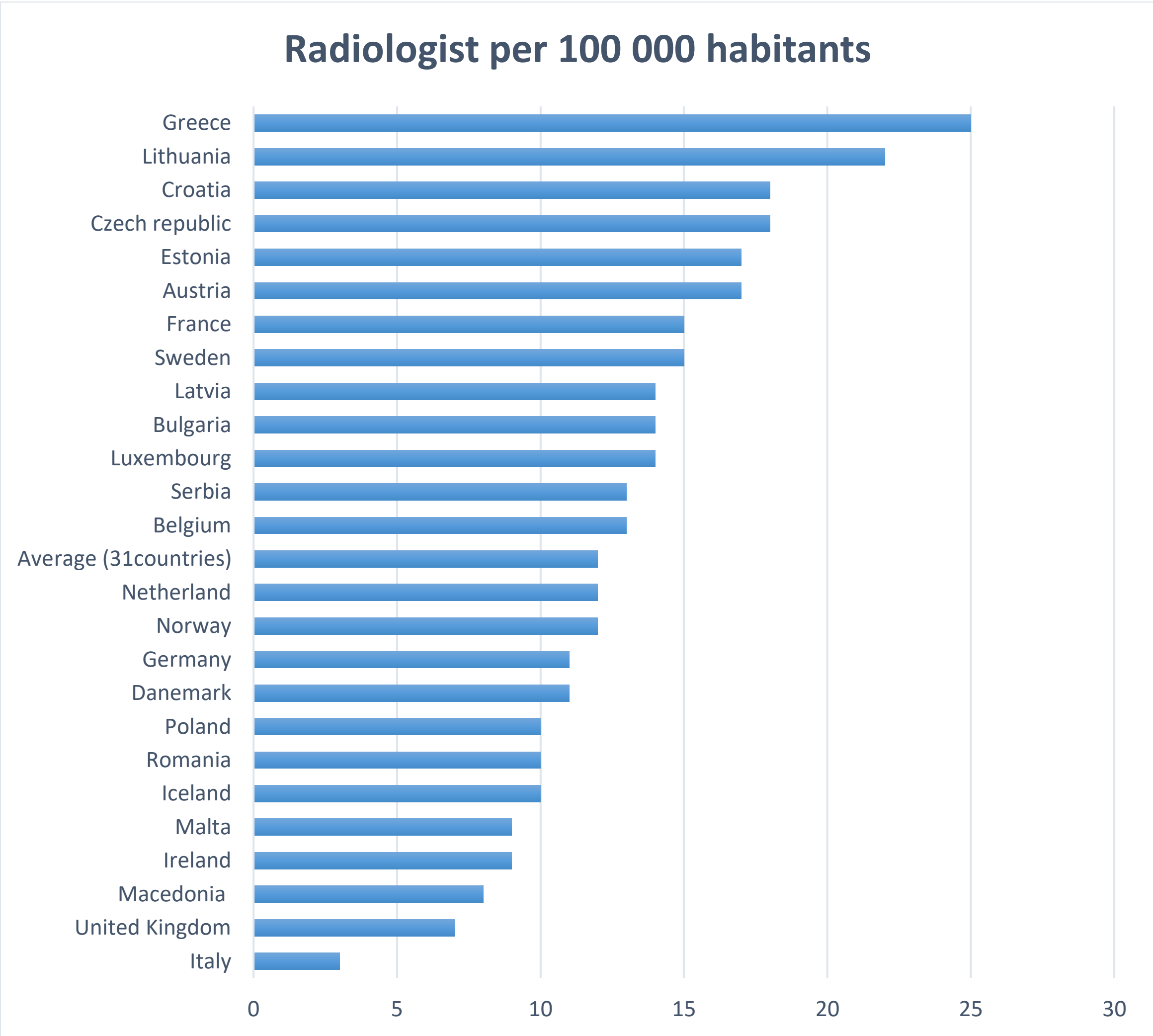


Figure 25: Average number of radiologists per 100,000 habitants

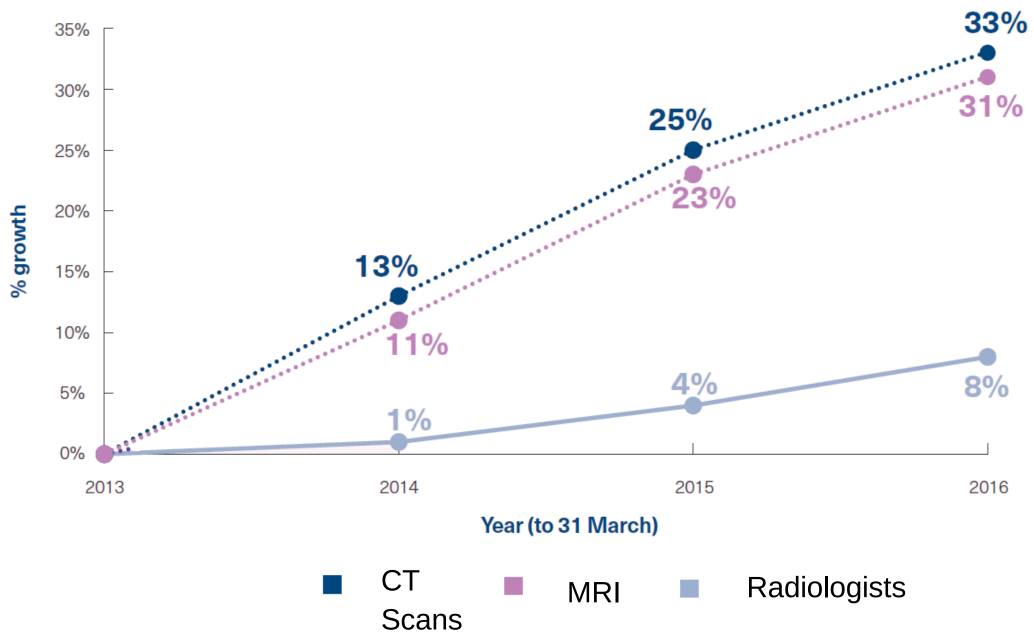
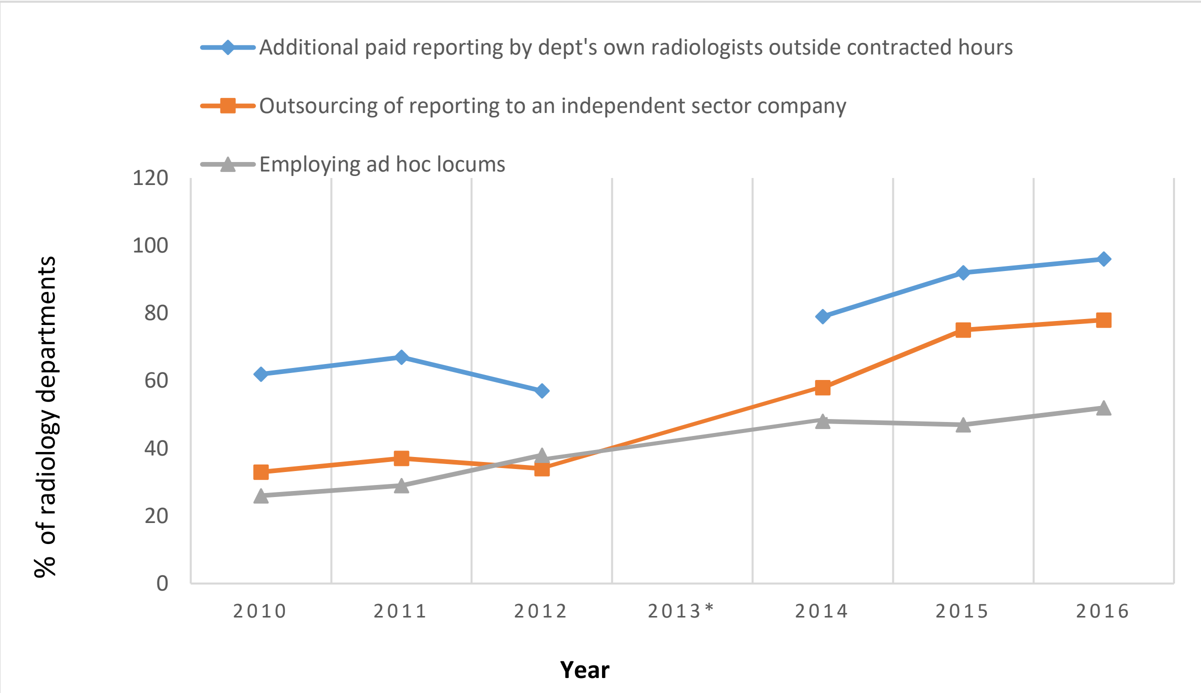


Figure 26: Growth of CT scans examinations, MRI examinations, and number of radiologists in the U.K between 2014 and 2016.

Some indicators illustrate the evolution of medical imaging acts in contrast with the evolution of number of radiologists. In the United Kingdom (U.K), the number of radiologists has grown by an average rate of 3 points each year from 2014 to 2016 (The royal college of radiologists, 2016). Nevertheless, this increase did not go in line with the evolution of clinical demand occurring in the radiology department. Indeed, on the one hand, from 2014 to 2016, there has been a 20 points increase in the number of CT and MRI scans performed respectively. On the other hand, in that same period, the full time consultant radiology workforce has seen a growth of merely 7 points (Figure 26). Furthermore, the royal college of radiologists study (2016) has shown that in 2015, The U.K has one of the lowest number of radiologists (including trainees) per 100,000 habitants. Indeed, the number of radiologists per 100,000 persons is as little as 7 (Figure 25). Thus, this number remains poor compared to the high demand for radiology examinations (The royal college of radiologists, 2016).

Thus, these professionals are confronted with major challenges in their profession. The imperative in this situation is mainly to save time. For 49% of respondents of a survey launched by the royal college of radiologists (2016), time spent on reporting is the first difficulty they encounter when issuing examination results. Indeed, in a radiology department, one of the bottlenecks is at the level of transcription of the reports (The royal college of radiologists, 2016). The next section illustrates the latest fact.



*Information for 2013 is not provided due to the timing of the RCR (Royal College of Radiologists) census being altered from calendar to financial year

Figure 27: Percentage of radiology department in the UK employing stated methods (at costs) in meeting shortfalls in reporting requirements

In six years, the three options - additional paid reporting by dept's own radiologists outside contracted hours, outsourcing of reporting to an independent sector company, and employing ad hoc locums or creating posts to specifically and on a temporary basis fill the duty of data reporting - have known a steady rise. In 2016, 96% of radiology departments in the UK have allocated radiologists a supplement to work outside working hours on reporting. Moreover, the majority of radiology departments have used outsourcing of reporting to an independent sector company, or has employed ad hoc locums, with 78% and 52% respectively. The results indicate the problem of managing the amount of reporting with the available medical staff employed as radiologists.

To help solve this rising issue, one of the possibilities could be reporting via CAD. This procedure allows the automatic reporting of CAD’s results. Indeed, several studies show that the integration of CAD with PACS system increases rapidity in the production of examination reports (Hecht, 2015). One of the studies Carried out by Nuance Healthcare in 2012 suggests that CAD has a positive impact on efficiency and autonomy.

Regarding the impact of CAD on efficiency, a large majority of the 175 radiologists surveyed as part of the Nuance Healthcare study says motivated by the possibility of reducing production time for reporting. Applying CAD engendered reports to become available in less than one hour to three-quarters of surveyed radiologists, and even less than half an hour for 50% of them. Radiologists found improved working comfort and serenity from the fact that their reports prove to be more complete, less susceptible to errors, and reliably associated with images (The royal college of radiologists, 2016).

As far as the benefits of CAD on the radiologist’s autonomy is concerned, the adoption of such technology helps to give secretaries more time to welcome the patient and improve the physician-secretary relationships. Radiologists are also granted autonomy when they have to take the examinations at night, in the absence of the secretariat.

4.3.3.2. Summary

Overall, CAD is a software that presumably grants its users with a reduced length of time to obtain reports, and a strengthened autonomy for radiologists. In fact, CAD is able to automatically produce reports, which lessens the duration from diagnosis completion to report validation. Additionally, radiologists are no longer relying on secretaries to type reports, as it is the case at Lausanne Hospital.

4.3.4. Back-up storage

The upcoming sections introduce a comparative analysis. On the one side, the procedure applied by Lausanne Hospital to deal with systems' upgrading or technical issues. On the other side, the workflow that would be applied by hospitals integrating the suggested cloud-based system. In other words, how hospitals will respond to systems' upgrade or technical problems when integrating the intelligent cloud-based system.

4.3.4.1. Upgrade of current systems

The next section outlines the differences pointed out between a hospital using an onsite system, and a hospital adopting the proposed solution, when the medical system necessitates an upgrading procedure.

At Lausanne Hospital, when an update of the current medical system becomes inexorable according to head of radiology and an IT manager, a specific process is implemented (Figure 9). Mr. Pedron, current PACS manager at The Swiss hospital, acknowledged the information illustrated.

When it concerns implementing an up to date system, the decision has to come from the head of the radiology department of the hospital along with the IT manager. Following the system's update request, a team is assigned to manoeuvre the project. Generally, manoeuvring a project necessitates a budget allocated specifically for it. In addition to that, specifications are put in place as a guidance for the assigned team to guide the project to its end line. Subsequent to the three mandatory steps to upgrade a medical system (project team, budget and specifications), all medical data present in the outdated system are transmitted to a back-up on a temporary basis. It should be emphasised that, as the transmission takes from hours to over a day, it is advised, according to Mr. Pedron, for hospitals to allow the transfer to happen during the weekend, when the medical workload is less significant. Following a successful transmission of the data to the back-up, the updated system is implemented by the hospital. The end line of the process includes the transfer of the data from the back-up system to the new updated system.

Frederic Pedron voiced that around one year is necessary from the requisition of an updated software version to the successful installation of it. PACS was updated eight times at Lausanne Hospital. This signifies that eight years were spent by a team of eight – including 2 radiologists, a head of radiology department, 3 IT managers and 2 financial controllers – in the processing of the upgrade. The following two tables (Tables 6 and 7) details estimations of the amount spent on upgrading the medical systems, in terms of salary of the assigned team. For the case of Lausanne Hospital, Frederic Pedron estimated that 20% of the assigned team's time was intended for the upgrading project. The calculation of 20% of their yearly salaries multiplied by the eight years equivalent to the eight upgrades gives a result of over £800,000 required to manoeuver the upgrade projects (Table 7). An equivalent amount would have been spent whether the hospital was based in the UK (Table 6). Thus, applying a cloud-based system will allow the radiologist team to redirect their focus on their core area of expertise, and support the understaffing (section 4.3.3). Additionally, when it comes to the financial controllers, a cloud-based option will permit them to centre their attention on providing financial guidance for hospitals, to ensure that they reach the vision and goals set at the beginning of every year (PayScale, 2019)

Table 6: Average salary in the UK of the team assigned to conduct the upgrade of systems' project (rounded numbers)

Profession	Average salary (yearly)	20% of the average salary	8 years (8 upgrades)
2 Radiologists (at least 10 years of experience)	£77,000 each £154,000	£15,400 each £30,800	£123,200 each £246,400
Head of radiology department	£103,500	£20,700	£165,600
3 IT managers	£40,000 each £120,000	£8,000 £24,000	£64,000 £192,000
2 Financial controllers	£48,000 each £96,000	£9,600 £19,200	£76,800 £153,600
	Total	£94,700	£757,600

Table 7: Average salary in Switzerland of the team assigned to conduct the systems' upgrade project (rounded numbers)

Profession	Average salary (yearly)	20% of the average salary	8 years (8 upgrades at Lausanne Hospital)
2 Radiologists(at least 10 years of experience)	CHF105,000 each CHF 210,000	CHF21,000 each CHF 42,000	CHF168,000 each CHF 276,000
Head of radiology department	CHF154,000	CHF30,800	CHF246,400
3 IT managers	CHF112,500 each CHF 225,000	CHF22,500 each CHF 45,000	CHF180,000 each CHF 360,000
2 Financial controllers	CHF106,000 each CHF 212,000	CHF21,200 CHF 42,400	CHF169,600 CHF 270,200
	Total	CHF130,200 £ 99,800	CHF1,152,600 £883,280

Another benefit from implementing a cloud-based medical system is time saving. As a matter of fact, when launching an upgrade project, hospitals are required to function with the back-up until successful implementation of the upgraded version. Thus, new medical scans are submitted directly to the back-up system until then. Frederic Pedron confirmed the existence of delays to transfer new medical images to the back-up, as it takes on average 20 additional minutes to send every new examination (Table 8).

Table 8: Duration for image transfer, comparison between transfer to NAS and to back-up

Type of Scan	Duration to transfer images from the modality to NAS	Duration to transfer images from the modality to back-up (hospital based systems)
Thorax X ray (plain radiography)	Few seconds	20 minutes
Bone X ray (plain radiography)	Few seconds	20 minutes
Spine X ray	Few seconds	20 minutes
Head CT (cross-Sectional images) (≃ 100 images)	Around 7 seconds	20-21 minutes
Abdomen CT (Cross Sectional images) (≃200 images)	Around 14 seconds	20-21 minutes
Head MRI (≃100 images)	Around 7 seconds	20-21 minutes
Abdomen MRI (≃200 images)	Around 14 seconds	20-21 minutes
Full body scan (≃1000 Images)	Approximately 1 minute	21 minutes

According to Frederic Pedron, on average, Lausanne Hospital adds approximately 500 medical examinations to its database daily. Knowing that each examination holds between 1 and 6,000 images, 15,000 images are created on average, every day. Whether each examination takes around 20 minutes to be transferred, delays might be sensed to access images, diagnose the patient and draw proper treatments.

As a whole, when it concerns the cloud-based option, hospitals do not apply any process of upgrading system, assigning a team, or building specifications among others. Indeed, users will rely on the cloud providers to manage system’s upgrade on their behalf.

4.3.4.2. Temporary transfer of data during software maintenance

Back-up servers can either be put into service to support system's upgrade or, when a maintenance procedure is applied to resolve technical abnormalities. The next section addresses this statement.

The manifestation of a technical issue tends to hinder the smooth functioning of a PAC system. The effects of the issue on the end user vary according to the scale of dreadfulness, along with how effectively hospitals are approaching the abnormality. As far as Lausanne Hospital is concerned - an onsite medical system user - the appearance of a technical issue on their system leads to the kick-off of a definite workflow (Figure 10). The aim of implementing a workflow is to point out the location of the bottleneck to then resolve the issue. This will permit the system affected by the anomaly to return to their normal function.

The foremost stage is illustrated by the data transfer to the back-up system, on a temporary basis. As detailed on a previous occasion, this act is achieved when hospitals' activity is less intense, usually on a weekend. In parallel, a team involving IT specialists and medical system managers is put in place in order to detect the anomaly and set up a strategy for clearing it. The end of the tunnel from the work developed by the team can be one of the two upcoming scenes. The first one, where the bottleneck is cleared and the affected system can run smoothly. This means that the proposed plan set up by the assigned team has led to success. The second one, where the system still holds a red flag, and the anomaly has not been resolved. In this case, a contingency plan has to be put in place to either permit to suppress the abnormality or otherwise, to generate the development of other strategies until eventually, resolving the technical issue. This will then result in a transfer of the medical data back from the back-up to the system that was affected by the abnormality.

One of the main distinctions between an onsite PACS and a cloud-based PACS lies on the location of the servers, where medical data is stored. As a matter of fact, one has servers detained inside hospital's premises while the other relies on the software provider to hold the servers. The location of the servers does not seem to be correlated with neither the probability of a technical issue to appear, nor the intensity of it. Nevertheless, the venue of the servers goes in pair with the designated responsible to resolve the technical problem, and bear the cost of it, hence the absence of a workflow to manage software's bottlenecks for a cloud-based medical system end user. Indeed, hospitals adopting the cloud based option are advantaged from bearing no cost during maintenance process. In this case, cost of maintenance includes any IT purchases when necessary along with the salary of the team allocated in this instance. Additionally, entitling the software provider to take charge of the management of software's abnormalities empower the beneficiary to dedicate their focus in their core area of expertise.

Lastly, while the source of the technical issue has not yet been identified, the medical system user allocates new medical data inputs to the back-up servers. Similarly to when the PAC system requires an update, the shift to back-ups beget delays in processing new scans. This is due to the fact that transferring data to back-ups entail more time than the transmission to systems' servers.

4.3.4.3. Summary

When it concerns the recommended option, potential users are detached from any procedure to upgrade the system or resolve technical issues. Indeed, the cloud system provider is solely responsible to keep the system updated and free from bottlenecks.

4.4. Sunk cost effect, main challenge of cloud PAC system

When money, time and efforts are all devoted to a project, companies have the tendency to pursue the project even knowing that the end of the tunnel is everything but bright. That is called the sunk cost effect (Dilts and pence, 2006).

In brief, sunk costs are fixed costs that have already been spent and therefore cannot be recovered. The costs are related to certain activities that require specialised assets that cannot easily be allocated to other uses. As examples of sunk cost, the investment in equipment enabling the manufacture of one specific product, the development of products for specific customers, the advertisement expenditures and research and development. The upcoming sections, explained through Arkes and Blumer scenario, evoke the potential implications of sunk cost on cloud-based medical system projects.

4.4.1. Arkes and Blumer scenario

The fallacious idea that one must absolutely make profit on past expenditures not to squander any investment made is explained by Arkes and Blumer with the following two scenarios: the first one involves picturing one as the head of an aeronautics company. This company wishes to invest in an aircraft that conventional radars cannot detect. The project would cost 10 million US dollars. The company already spent 9 out of 10 millions, and the project is at 90% of its achievement. The issue emanating is that there is a competitor who previously developed a more efficient aircraft, while investing less. The dilemma in this case would be to make a choice between investing the remaining 1 million to complete the project, or to completely abandon the project. In this study, 85% of the interviewees agreed to complete the project while the remaining 15% rejected the idea to do so. The second scenario is quite similar, but in this case, the investment cost only 1 million US dollar, and the project has not started yet. In this case, 83% of the interviewee refused to start the project with all facts in hand (Dilts and pence, 2006).

Eventually, the interrogation remains the same, which is correlated to the worthiness of investing a million US Dollars on a project that will likely fail. Thus, the answer should not differ in both scenarios. The fallacious reasoning related to unrecoverable costs tends to create situations where one continues to spend further on to make past investments more profitable.

4.4.2. Sunk cost effect on cloud PAC System

The following section aims enabling the perception of the purchase of a cloud-based medical system from a different paradigm.

The scenario of Arkes and Blumer, when applied to the case of hospitals and PACS, draws two principal case scenarios involving:

- Hospitals that are in the early stages of implementing onsite PACS
- Hospitals that have completed major instalments of their onsite medical system

If one applies Arkes and Blumer scenario to this case, hospitals that barely started the implementation process are likely to trust a shift to a cloud-based medical system. However, for the case of healthcare facilities that are in the last stages of their onsite PACS project, they might not be eager to transition to a cloud-based option. Indeed, applying Arkes and Blumer theory in this case means that these hospitals would rather maintain their attention on the return of the already made investments, including servers, software, and staff training. Additionally, time and efforts to set a team and allocate a budget have been put in place. This has led to the emergence of sunk cost effect. Consequently, in order to enhance the likelihood of hospitals dropping out the onsite PACS project for a cloud-based one, certain main factors are to be considered.

One of main aspects to consider involves the fact that onsite PACS holds a higher risk of data loss (section 3.4.2). Indeed, the majority of employees in a hospital are personnel with a medical knowledge, which bears no correlation with IT. To ensure that this mass of information is generally secure, it requires the recruitment of a team dedicated specifically for the daily management of the system, as well as the management of system's complications and upgrades. This engender efforts, time and expenses whereas delegating this task to an entity whose core business is to ensure the security of the information appears to be a more efficient and lower priced solution. Discern the number and salaries of employees in charge of the management of the system is suggested for hesitant hospitals to evaluate cost saving possibilities.

Another main factor is correlated to recurring costs. Expenditures tend to not end at the late stage of implementation of the onsite PAC system. In fact, in addition to the one-time costs or charges invoiced throughout the execution of the project, there are other additional expenses called the recurring costs, which include but are limited to:

- Investments on hardware and software's upgrades alongside their implementations costs to enable PACS's users remain on the edge with IT trends. These are called as conversion costs. According to Howell (2014), the average lifespan of a PACS does not surpass the decade, which means that the obsolescence of the hardware and software would possibly lead to these recurrent expenses. As for Lausanne Hospital, in 15 years, 8 PAC software upgrades and 2 hardware upgrade were put in place

- Additional investments when hospitals require supplementary servers to cover the increase of their database. Generally, hospitals have fluctuant patients' admissions. As a result, hospital facilities may need to purchase additional servers to accommodate data on peak periods, but these additional servers would not be used on periods with fewer patients. By shifting to cloud PACS, the cost for purchasing and maintaining these additional elements will be saved as the cloud system is tailored on a pay per use model.

Moreover, the implementation of a cloud PACS could lead to other savings, among them:

- The space or area used to host hardware, back-ups and heating ventilation and air conditioning systems (HVAC) can be seen as an indirect cost to the hospital. Given that this square footage could benefit to accommodate more patients, by setting up additional beds, desks or even radiology rooms. The more hardware, back-ups and HVAC you have, the larger the space you need and the wider the benefits would be sensed from eliminating this voluminous tool. A comparison in percentage of the yardage of the hospital with the yardage of the space used to host Hardware could reveal the possibilities of savings
- In case the current system is not implemented with a computer aided diagnosis option, the risk of higher misdiagnosis rates could be a financial and non-financial issue. On the one hand, it is likely that hospitals would have to support readmission charges for misdiagnosed patients. On the other hand, the

reputation of this institution can be at sake if cases of misdiagnosis occur frequently

- Reading hundreds of medical images and data to obtain a close to accurate diagnosis can be nerve racking. Indeed, radiologists must be precise and mindful in each analysis they set. When CAD is included with PACS, studies have shown that it is highly likely that the analysis will require less efforts. Additionally, having more motivated radiologists is indicated to be in line with a better productivity, less turnover and misdiagnosis cases (Section 4.3.2)
- Resale possibilities to developing countries. Indeed, those countries have limited resources, and sometimes poor healthcare facilities. Therefore, a will to acquire a second-hand medical system that manages their data is highly likely to occur
- Last in order but not least of importance is the instant accessibility to substantial amount of medical data from all hospitals sharing the use of the cloud PACS and CAD. This would eliminate delays when transferring data from one hospital to another (Section 3.4.2) and is subject to the fact that both hospitals are using the shared cloud PACS. Additionally, this advantage ease opportunities for second diagnosis input from other colleagues working in different medical facilities. Finally, the new cloud-based CAD is filled with up to date medical discoveries, thus, having access to such cutting edge technology empower its users to be a step ahead in comparison to other hospitals.

4.4.3. Summary

Generally, when a decision has to be made, rationality tend not to be the path chosen. Indeed, not only feelings interferes with one’s decision, but in addition, automanipulation hinders the process as well. The latter being generated by the sunk cost effect.

Sunk cost effect is thus a phenomenon that everyone faces regularly. It appears when one decides to continue a strategy or behaviour for which they have already spent resources. Thus, they remain in a line of conduct in which they have invested enough to no longer want to leave it, even if another strategy is available and would lead to a more profitable comfort. One can lose 400 pounds to gain 200, or wait longer for the bus than he/she would have needed to return home by foot.

In order to avoid being self-manipulated by the potential wasted expenditure, it appears essential to consider what is on the opposite side of the spectrum. In other words, the outbalancing gains from adopting a different strategy than the one initially opted for. For the case of a cloud-based versus onsite system, a pay-as-you-grow concept, lower risk of data loss, decentralising upgrading and maintenance procedures due to absence of infrastructure are perceived as the main benefits of shifting to cloud PAC system.

4.5. Overall summary

To recapitulate, the suggestion of a cloud system that integrate CAD appears to outbalance Lausanne Hospital's onsite option in terms of advantages and limits that each have. As a matter of fact, the suggested cloud-based option benefits mainly from reduced expenses by eliminating local storage costs and a more efficient exchange of health information. Furthermore, conditioned on the presence of internet connection, image accessibility can be explored anywhere and anytime, which enhances opportunities of teleradiology. Other gains from opting for the proposed medical system include adaptability of resources according to hospital's activity, elimination of procedures for software's upgrade or maintenance. Additionally, integrating CAD adds a greater value to cloud PACS as CAD detains multiple benefits such as elimination of inattentional blindness, software enhancement due to daily training, productivity increase and betterment of inter observer variability. Finally, research has demonstrated efficiency enhancement when utilising CAD as a reporting tool. Moreover, adopting CAD empowers radiologists with more autonomy during reporting process, especially when examinations occur outside of facilities working hours.

Sunk cost effect has been mentioned as a potential limit to the new proposed system. Nevertheless, the analysis has revealed that the stated limit can be eliminated through considering the outnumbered advantages correlated with the cloud-based option to proceed with a rational decision making process.

The next part gives an ending to this research project, as it summarises the main points discussed throughout the previous chapters. Additionally, the following chapter evokes this study's limitations as well as potential areas for further research on this topic.

Chapter 5

Summary and conclusions

5.1. Summary

In medicine, new technologies enable an improvement in the quality of care and a better flow of information available to patients. These new medical related creations involved medical imaging dematerialisation, such as PACS. It is an IT creation that aimed to support the ageing population that wishes to better their quality of life, and become a key tool for the care of patients and the coherence of care.

PACS, an electronic medical image management system with archiving, storage and rapid communication functions, is the essential complement to the network management system for the activities of an imaging service and a hospital center for management of images. The first generation of image archiving and communication systems dates back to the second half of the 1980s. Their logic was dominated by the desire to replicate the circuit of the film without it. Today, the context of setting up the network has evolved. Indeed, PAC systems are now open to technological innovations. For instance, rather than remaining onsite, PACS can also be based in the cloud. Moreover, this system can include a new technology, CAD, which aims to support its users to detect abnormalities. Both options - onsite and offsite - hold benefits alongside limits. The third chapter analysed the onsite option using Lausanne Hospital as a backdrop, while the fourth chapter scrutinised the proposed cloud-based system. This raised a query as to which option outbalances the other.

Therefore, the aim of this study has been to assess whether a cloud HIS, RIS and PACS, with a Computer Aided Diagnosis component are more beneficial options for hospitals than the current one applied by Lausanne Hospital, specifically in terms of cost-effectiveness, time saving, a higher diagnosis accuracy, and a wider accessibility to medical data. This research has considered how integrating different components - PACS, cloud computing and CAD - into a coherent totality would impact hospitals adopting this system. To achieve the above-mentioned aim, one of the most renowned University Hospital in Switzerland, Lausanne Hospital, has been utilised as a backdrop. For two weeks, Interviews and observations of the daily routines of hospital staff who work closely with PACS, RIS or both were put in place. The aim was to comprehend and operate an analysis of Lausanne Hospital's current process to manage medical data in order to determine how an intelligent cloud-based system can improve efficiency and performance.

The next section juxtaposes the two options discussed on the previous chapters. The one adopted by Lausanne Hospital, an onsite PAC system, and the proposed cloud-based medical system option. The comparative analysis results are summarised into different fragments (Table 9), including method of function, storage opportunities, cost and procedures adopted in disaster recovery or upgrading.

Table 9: Key differences between traditional – onsite medical systems at Lausanne Hospital versus the proposed intelligent cloud-based digital imaging medical systems

	Traditional onsite medical system Lausanne Hospital	Intelligent Cloud-Based Digital Imaging Medical System
Method of function	The traditional medical system uses local storage solutions to store patient digital images. In the local storage model, the server connects directly to an array of hard drives that provide quick access to patient files. These files are saved directly to the server as they are created.	A cloud-based storage solution uses an offsite, online method to store patients' digital images. Patients' files are automatically streamed into the cloud as they are being created. Authorised users can access the data anytime, anywhere, on the condition of having an Internet connection.
Storage	Lausanne Hospital houses the servers along with all related hardware and software onsite.	The cloud model uses virtual storage to house data.

	The user has complete control and ownership over the infrastructure. This signifies that this Swiss healthcare facility is the sole responsible of operating and maintaining the PACS. Additionally, the system's user needs to take into account the fluctuation of number of files, and ensure that the server has sufficient capacity when these numbers expand	The cloud provider manages both hardware and software, on behalf of the user, at an offsite location. Users gain access to the cloud-stored data through internet. Cloud storage can be easily scalable, through pay-as-you-grow concept.
Medical records accessibility	Physicians, technicians, and administrators access PACS by logging into the server.	Radiologists, technicians, and administration responsible access a cloud-based PAC system by logging into a PAC system application online.

	To visualise data on the PAC system, access to server along with presence of PACS software on the computer or workstation is necessary. When patients' records are held at a different hospital than Lausanne Hospital, agreements need to be put in place to permit electronically sharing of data Data sharing is also allowed through an external cloud PACS named RadioPACS	With access rights, one can have access to PACS data from any location with an Internet connection. This permits medical staff to work on a remote basis. Hospitals sharing data at one location are rewarded with instant access of shared patients' records. Thus searching for scans held by a different healthcare facility is less of a scavenger hunt and more a straightforward path.
Disaster Recovery and upgrade process	Back-ups are managed by the system's owner and user, Lausanne Hospital.	The hosted cloud system provider is held responsible if the system crashes or needs an upgrade.

	The hospital has developed a back-up strategy to ensure a sense of security. This requires significant management and expenses. Indeed, a process is applied when the system is upgraded or facing anomaly. This requires a team, time and money. Moreover, IT is not a hospital's core area of expertise.	As experts in the IT management field, the host is able to restore systems, databases, and applications on a quicker basis, which leads to faster recovery time after a system's failure. The end user holds no responsibility on that level
Cost	Traditional PAC systems tend to have higher initial costs. The hospital or facility have to bear the initial hardware and software costs	Cloud PAC system providers offer the possibility of payment on a pay-as-you-go procedure

	Cost to maintain, repair and upgrade the system is endured by the user, which is outside a hospitals' core area of expertise	Maintenance and repair costs are lower. This is because hardware and software are managed by the vendor, whose core area of expertise is IT management
Main benefits	Multi-access of data is possible, but limited Ownership and control of data (Section 3.4.1)	Data sharing between users contributes to medicine advancement Access is endless, as long as Internet connection is present Management of the system is centred with the providers, experts in IT management Productivity increase Rapid elasticity (Section 4.3)

Main challenges	Higher risk of system's failure High initial cost Complexity of data sharing with external facilities (Section 3.4.2)	Sunk cost effect (Section 4.4)
Scan interpretation	Lausanne Hospital is currently not in possession of any computer-aided diagnosis system. Therefore scans are interpreted with the sole support of medical staff's expertise	Medical experts perform diagnoses with the support of CAD Cost of CAD is spread between its online users, as a difference to onsite CAD, where users are the sole owners of CAD and therefore have to bear the full cost of it.

		CAD is constantly being trained with new inputs by all its users. The more users it has, the more rapidly evolving it would become
Reporting	Reporting is performed digitally. Radiologist orally dictates the report for the secretary to type. The typed report is then amended when applicable and validated	Reporting is performed via CAD who automatically generates the reports. These reports are then amended when applicable and validated.

5.2. Conclusion

Of all the areas of healthcare affected by technological advances, medical imaging is probably the one that sees the most dazzling technological developments (Coste and Simon, 2010). But these developments tend to create new needs, correlating with the increase in image production, which requires an easier archiving and circulation of data, as well as reading and analysis of scans. That is where the intelligent cloud-based medical system makes its appearance.

The juxtaposition of the results of Lausanne hospital workflow analysis with the suggested option, where cloud and CAD aspects were introduced to it, led to the conclusion that the proposed medical system carries significant benefits for its potential users. The analysis results – stated below - were based on the criteria outlined in section 3.1.

Hosted remotely, the suggested cloud medical system minimises initial costs. Moreover, through cloud, access to images is possible at multiple locations, onsite and offsite, which enhances possibilities for teleradiology. This strengthens the collaborative work between radiologists and clinicians for medical expertise and diagnosis establishment. As far as it concerns CAD, practitioners can exploit the daily updated digital data to highlight the relevant information, with higher accuracy and efficiency. Indeed, CAD allows suppression of inattentional blindness, a naturally occurring flaw with the human brain. Moreover, this intelligent CAD software detains the possibility of self enhancement, due to constant addition of new data by its users. As of the cost of CAD, it is spread between its online users, in contrast to onsite CAD, where users are the sole owners of CAD and therefore have to bear the full cost of it. The productivity of CAD users is strengthened, not only due to the fact that the diagnosis procedure is eased and quickened, but also because the diagnosis disagreements between radiologists is decreased. Productivity could also be impacted by departments that have not CAD implemented in their workflow, thanks to the Hawthorne effect, a situation in which the results from applying CAD to detect a specific anomaly (e.g. nodules) can lead to a general motivation from radiologists, whether they apply CAD in their medical cases or not. CAD finally detains the ability to decrease the percentage of disagreement between scan readers on a medical case. Additionally, the proposed intelligent medical system engenders complete elimination of workflow when upgrading system or at the occurrence of technical issues. In fact, cloud providers are the sole system's managers and therefore hold entire responsibility to implement system's upgrades or to apply procedures to resolve technical abnormalities. Finally, reporting the diagnosis results via CAD has shown to hold higher efficiency and productivity from it users. It also reduces reliability of radiologists with secretaries who would usually perform part of the reporting procedure.

As of the limit of the proposed solution, sunk cost effect has been mentioned as the main one. Indeed, some hospitals could refrain themselves from adopting the proposed system and remain faithful with their current system until obtaining a return on their respective investments. Nevertheless, the analysis has revealed that sunk cost effect can be eliminated through taking into account the outnumbered benefits correlated with the cloud-based option. This would lead to a more rational decision-making process.

The development of intelligent cloud based PACS and the online distribution of images throughout hospitals and probably private practitioners, is about to become a basic need; not only in large institutions that may have the human and financial resources necessary to design and implement it, but also in smaller structures; as these technical elements are a prerequisite to reach the cutting edge of medicine and telemedicine.

The proposed system has been approved by Lausanne Hospital, who is considering implementing it with two peer hospitals in the near future. Additionally, it seems important to highlight that this proposed system can not only be applied at Lausanne Hospital, but also in any other hospital facility. In fact, the impact of the new system could be greater in most other hospitals than the Swiss hospital. Lausanne Hospital is considered as one of the most technologically advanced hospitals in Europe, at a cutting edge in medicine and radiology. Therefore, integrating the Intelligent Cloud-Based Digital Imaging Medical System to hospitals that are less advanced in medicine comparatively to Lausanne Hospital's workflow would have a greater impact on efficiency and performance.

5.3. Study's limitations

One of the main challenges encountered during this research project was the difficulty obtaining general figures of costs of both onsite and offsite medical system. It is difficult to determine an estimation of the cost of the medical system mentioned on this research project, whether it is based on cloud or onsite. This is due to the existence of multiple factors that influence the fluctuation of the price estimation. These factors include the characteristics present on each system (PACS, RIS and HIS), hospital's size and the number of system users. Another reason involves the fact that vendors are not willing to make their pricing information public.

The sole data obtained in terms of costs regarding the onsite option is the fact that these costs are separated in two categories:

- Capital costs: the upfront investment, one-time costs. It mainly includes hardware (the hardware in this case is the server itself where data is hosted), software, back-up, implementation, and training
- Operating costs: these costs are paid on a yearly basis and are usually divided per user. It is comprised of hardware and software maintenance and replacement, software license, and IT staff hired on-place for daily maintenance

As far as it concerns the cloud based option, the costs is usually dispatched as follow:

- Capital costs: the upfront investment will only include software, and training
- Operating costs: the ongoing costs only come from the initial software license. Indeed, as the system is based with the operator, there won't be any onsite software maintenance or replacement or IT staff hired for the same purpose. However, the yearly software license price will be higher than for the hospital based one, as the operator will remotely manage servers, secure data with back-ups, and upgrade the software when new versions are on the market (Gerra, 2010)

Studies have concluded however, that overall, Cloud-based systems cost generally less than onsite counterparts (solutions dots systems, 2018).

5.4. Areas for future research: Security of medical data concerns

This topic has been investigated through a business and management paradigm. Thus, it appears beneficial to complement these research results with a more Information Technology oriented investigation of the same topic. Consequently, the next section focuses on an important aspect to consider when shifting to a cloud based model: security of medical data.

Medical data can be archived in the form of writing. This is true of both medical certificates and prescriptions. Thus, the term medical data encompasses all that refers to a method of conserving a patient's state of health. The question of confidentiality and integrity of this same data when hosted on cloud, with the rules of ethics and respect for privacy relating to it, is perceived as an additional limitation to the sunk cost effect that can prevent hospitals from adopting cloud PAC systems. The hosting of hospitals' data is in fact outside medical premises, in a service available to hospitals by their providers. Therefore, the risk of data ending up in a situation of theft or misuse remains a possibility (Bank of France, 2013).

Confidentiality can be defined as the reserved nature of information, or treatment of information to which access is limited to those persons or entities admitted to know it for official purposes. The integrity of data or process is the property ensuring that information has not been stolen, altered or destroyed in an unauthorised manner. It should be noted that the confidentiality and integrity of data, whether concerning health sector or other, is an important criterion in the evaluation of the implementation of any service in the cloud.

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