

Information Infrastructure in Use

An empirical study at a radiology department

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Abstract

This paper illustrates how radiological information infrastructures emerge in a larger medical network. This is done by focusing on how artifacts are linked together into long chains and how these chains are linked together with the working practices of the personnel at the department. The replacement of medical records and radiological films has shown to be problematic. This study analyzes how an infrastructure perspective can support designers replacing existing parts of an infrastructure, as medical records or films, by a computer based sub-infrastructure. In this process we use the notion of gateways, as an interface between different networks, to achieve compatibility between the new electronic network and the larger old actor network.

Keywords: Artifacts, Information Infrastructure, Gateways, Work Practice, Health Care

BRT Keywords:

Introduction

Increasingly is PACS¹ (picture archive and communication systems) being introduced in the medical field at considerable costs. For instance, 60 % of the radiology departments in Sweden are in the process of or planning to introduce PACS by year 2002 (Laurin, 1998) to improve the information access within the department as well as throughout the hospital. However, several studies have identified problems in the use of PACS together with other already established artifacts and computer systems: electronic records and administrative systems (Styrling et al., 1998, Peissl, Tellioglu & Wild, 1996). The problems related to the intertwined use of systems have hampered the ability to realize the possibilities of the technology e.g., developing new ways of working and new services within health care.

"... A hospital consist of a variegated workshops - places where different kinds of work are going on, where different resources (space, skill, ratios of labor force, equipment, drugs, supplies, and the like) are required to carry out that work, where the

¹ PACS supports the electronic storage, retrieval, distribution, communication, display, and processing of x-ray image data.

divisions of labor are amazingly different, though all of this is in the direct or indirect service of managing patients' illnesses" (Strauss et al., 1985, p.6). Medical practice requires complex collaborative activities involving multiple actors from different specialties and professions who are usually not face to face.

This paper is based on the hypothesis that the high rate of failures among projects aiming at introduction of PACS systems into radiology departments, just like electronic medical record system, is due to the variety, richness and complexity of work practices inside hospitals and the interdependencies between all artifacts and technologies supporting them.

We want to regard infrastructures as heterogeneous socio-technical networks, including many networks in which both technical and social actors take part. We will emphasize how the local PACS system is part of a large and open infrastructure for the whole hospital, and even a shared infrastructure for communication between all health care units. Impeding that the design of PACS may be considered as the design of an infrastructure.

We describe how the radiological information infrastructure at a hospital in Sweden emerge as medical records, films, meetings, secretaries, transporters, computer systems, shelves, tables, telephones etc. are linked together into long chains. And how these chains are linked together with the working practices of those medical units using the infrastructure in their work, like the radiologists and the clinicians. Furthermore, we will explore challenges for design of PACS and electronic reports in health care from an infrastructure perspective.

The PACS system implemented at the radiology department observed must be considered as a success. In our view, this success is primarily due to the way the design takes the existing network as its starting point and how the PACS system is well integrated with the technology supporting the other networks, using a fairly clean and simple interface to other networks. The interfaces have primarily been taken care of in terms of gateways e.g., plug-ins to the intranet, secretaries, transporters etc. Gateways allow the information flow between different elements and humans.

The aim of this study is to analyze and illustrate how the information infrastructure emerges in the radiological actor network. This is done by focusing on how artifacts are linked together into long chains and how these long chains are linked together with the working practices of the personnel at the department. The aim is also to analyze how an infrastructure perspective can support designers of large actor networks. This is done by focusing on how one part of the existing infrastructure may be replaced by a computer based sub-infrastructure. In this process we use the notion of 'gateways' (Hanseth & Monteiro, 1998) as interfaces to the already existing network, in order to achieve compatibility with the larger network.

The study can be characterized as "Quick-and-dirty Ethnography" (Hughes et al, 1994). This research method has lately become widely recognized within the IS field (Suchman, 1991; Bellotti and Bly, 1996; Button and Shorrock, 1997; Button and Harper, 1996; Bowers et al, 1995;). Its research approach is to investigate and understand the actual work practice in context. The empirical fieldwork was initiated in October 1996, at one radiology department using PACS. Several different qualitative research methods were used: workplace video studies; interviews articulated by the illustration of video documentation; unstructured interviews; observations and an integration of discussions-interviews and observations of diagnostic practice and social interaction. More than 40 hours of video documentation were conducted, more than 45 hours of observations and 22 interviews were conducted, each about an hour and a half in length, with some

participants being interviewed more than once over the period of study.

The remainder of the paper is organized as follows. In the next section we present our theoretical framework, based on infrastructures and concept from actor network-theory. It is chosen for its ability to describe how things are linked together in a heterogeneous network. The third section describes radiological work. In the fourth section the radiological infrastructure is presented. The fifth section analyses the convergence between the information artifacts and clinical practice. Challenges for design of information infrastructures are discussed in the sixth section, while in the seventh section is the PACS experience presented. The eighth section presents three different design alternatives for the design of information infrastructures at radiology departments, and finally concluding remarks are given.

Related Research

Laurin (1998) carried out a survey of PACS implementations in Sweden in 1997. Questionnaires were distributed and collected between spring and summer 1997, asking respondents to provide information about IT use in 1996. All radiology departments in Sweden responded. It is illustrated by this study that the majority of radiology departments have a Radiology Information System (RIS), that includes functions for managing patient scheduling and producing reports used for accounting. However, most of these systems are old and can not directly be integrated with PACS. Another aspect relating to Hospital networks was investigated in the questionnaire. It was illustrated that 51% of the Hospitals had already installed Hospital networks. Only, 5 of the 132 radiology departments used a PACS system for image production, storage and distribution, 1996. Although, another ten departments planned to introduce it by 1997-98. In addition, it is interesting to note that 60% of all radiology departments planned to install PACS by year 2001. This illustrates a considerable interest from the shift from conventional film based technology to operations using PACS. Another study was made in 1991 by the Health Economics Research Group at Brunel University. They undertook an independent study of the PACS installed at Hammersmith Hospital in London, UK (Stirling et al, 1998). The study reported that the complexity of the PACS hardware and software were significantly underestimated by the suppliers and their subcontractors, resulting in a delay of the project time-scale by three years. They also found that the PACS system was built as a stand-alone technology that rapidly was beginning to look old-fashioned and inflexible, and that this was not likely to meet the cooperative needs between Hammersmith and primary care sites or trusts. The study was not primarily focusing on user experience from the implementation of PACS. However, the evaluation found evidence of user benefits, for instance, the incidence of unavailable images was lower, the reject rate of images was lower and the image availability was improved. Lessons learned from this study were that end-users should have been involved from the start of the project and that project management should be realistic rather than optimistic about project time scales.

Telliouglu and Wagner (1996) carried out a different study by focusing on the interdependence between space/place and work practice, in the Radiology Department at City Hospital, Vienna. They point out that the spatial arrangements shape work practices, just as it reflects the hierarchy of knowledge. In addition they say that PACS systems replicate traditional boundaries and hierarchies of knowledge instead of challenging them. While a recent paper by Lundberg and Sandahl (1999) illustrates how artifacts are

active elements in the relationships of people and between people and their environments in a radiology department in Sweden and in a news agency in Norway. They found that artifacts were not only active in the sense that they were necessary, but also, active in a way that coordinate, and even trigger or initiate, work. This illustrates that the use of artifacts may over time become manifold and not necessarily just serving their initial purpose. Based on the artifacts' property various conventions grow around them and become resources that a community of practice relies on.

Strauss et al. Analyze a different kind of interdependence, namely the interdependence between technology, illness and medical work. This is a significant contribution to the understanding of medical work and technology. The authors provide us with a sociological understanding of the diversity of medical work, given from a medical staff perspective. In this study different aspects of medical work are analyzed, for instance, medical work as machine work, safety work, comfort work, sentimental work, the work of patients and articulation work. These different aspects of work has contributed with the increased understanding of medical tasks, the interactions of staff members and with patients linked to the overall patient treatment and response.

Luff et al (1992) in their study of a Hospital and an architecture organization analyzed the interdependence between documents, work practice and technology to highlight how documents' properties support collaborative work. They illustrate the possibility to tailoring written documents', for instance, doctors can underline or mark text in medical records to aware medical colleges of essential medical findings. They also emphasize the document's 'ecological flexibility'. This refers to the potential of a radiologist to 'scan' the clinical information in the examination order at hand while simultaneously diagnosing the images presented on the screens in front of him.

In this study we emphasize on the interdependence between artifacts, work practice and technology. In order to highlight how infrastructures become embedded in work and furthermore to inform designers of infrastructures in larger actor networks.

Information infrastructures as actor networks

In order to improve our understanding of how the artifacts and technologies are linked together and how technologies and work practices are interdependent, we will look at collections of artifacts as (information) infrastructures (see e.g., Hanseth, 1996; Monteiro & Hanseth, 1995; Star & Ruhleder, 1996;). Further, we do not see an infrastructure as some kind of purified technology, by rather in a perspective where the technology cannot be separated from social and other non-technological element, i.e. as an actor-network (see e.g., Callon, 1986; Latour, 1987; Akrich, 1992 and Law, 1992).

When approaching information infrastructures we focus on three aspects: they are *shared recourses* for a community; the different components of the infrastructure are integrated through standard interfaces; they are *open* in the sense that there in no strict limit for who can use it and for which purpose or function; *and* they are *heterogeneous*, consisting of different kinds of components – human as well as technological.

An infrastructure emerges as a shared resource between heterogeneous groups of actors. This is opposed to artifacts of which each user has its own private copy, which each user can use independently. This distinction can be illustrated by the difference between word processors and the e-mail sub-infrastructure of the Internet. Each user using a word processor has its copy and their use is independent. The e-mail infrastructure of the Internet, however, is one resource shared by all its users. All e-mails

are transferred through the same network (although not exactly the same nodes). And how one user uses the infrastructure affect other users. If one user sends an incredible amount of information, this might jam the network and cause problems for all users.

The different parts of an infrastructure are often acquired by individual and independent actors. To make the overall infrastructure work, they must fit together. Accordingly, standard interfaces between components are crucial for making infrastructures.

Infrastructures are open in the sense where there are no limits to how many users, interests, computer systems, other technical components etc. that can be linked to it. Infrastructures are heterogeneous socio-technical networks, including many networks in which both technical and social actors take part. The Internet, for instance, is composed of several sub-infrastructures: The global TCP/IP network, and e-mail, news, and Web infrastructures. These networks can partly be seen as separate and individual infrastructures. However, lots of new infrastructures, for instance infrastructures supporting electronic commerce, are built on top of and integrating these infrastructures. This makes infrastructures heterogeneous as they are built of different kinds of components and sub-infrastructures. But they are also heterogeneous in the sense that they include non-technological elements. For instance, a running Internet includes the work of large numbers of support personnel. We see infrastructures as socio-technical webs, as actor-networks.

When we are making a larger infrastructure by connecting two smaller existing ones, an important strategy for linking them is by setting up a gateway. This makes gateways an important tool for building larger infrastructures and for transforming one version of an infrastructure into a new and improved one (Hanseth, 1996; Hanseth, Monteiro, and Hatling 1996, Hanseth and Monteiro 1998, Monteiro 1998).

Radiological work

We will in this section describe the work practices at the thoracic section, which is one of three sections, at the Radiology department at Sahlgrenska Hospital in Gothenburg, Sweden. We will describe the services delivered to and communication and interaction with its "customers," as well as the activities (including IS design and introduction) going on inside the section.

The interaction between the radiology department and its "customers"

The radiology department is a service unit for clinical departments inside the hospital, other hospitals, and primary care units (general practitioners). The service delivered is radiological examinations and reports. Such reports are based on X-ray and other types of radiological images. They are important "tools" for patient treatment and intervention.

The different types of radiological examinations offered by the radiology department are categorized as skeleton, chest, mammography, ultrasound, odontological, gastrointestinal, examinations performed at intensive care units, urinary tract, vascular examinations, CT and MR. The services defined by the name of a part of the body (chest, skeleton) implicitly means X-ray imaging.

To order an examination the "customers" (clinical wards, outpatient clinics, primary care units, etc.) send a paper request - or order - form to the radiology department. The order specifies the examination required, the ordering customer (ward,

physician), relevant medical information about the patient, and her demographic data.

When the examination is completed, a report is sent to the ordering unit. The report is just the original physical paper order with additional information specified by the radiology department. This includes date and time for the examination, radiographic details, and the diagnostic answer.

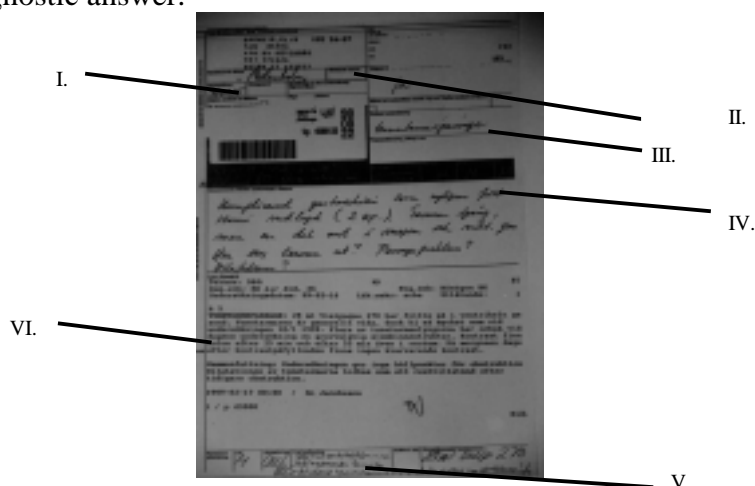


Figure 1. A clinical examination request/report.

The following information is indicated in the paper request (figure 2.): the scheduled date and time of examination (I), confirmation of scheduling with referring hospital ward (II), confirmation that the patient has a catheter in the stomach that can be used for contrast medium administration (III), consultant radiologist's recommendation about choice of procedure (IV), multiple notations by the radiographer involved in the examination: radiology room used, signature of radiographer, contrast medium given - type and volume (V) and preliminary evaluation by the radiologist who did this examination (VI). Seven individuals (beside the typist) have written on this order. Usually the requisition of this type of examination also has a priority rating given by a consultant radiologist. The heterogeneous use of the paper order is illustrated in figure 2.

In about 10% of the cases the ordering units specifies that the (relevant) images taken should be sent together with the report. Occasionally clinicians request the images after having received the report.

Often clinicians need more information and help from radiologists than what can be specified in the report. To deal with such cases formal meetings where radiologists meet a group of clinicians from or more specialties take place on a regular basis. There are about 9 daily interdisciplinary meetings, called 'ward-rounds,' and three by-weekly ones.

Radiologists often receive phone calls from clinicians that want to discuss a patient's diagnosis while patient treatment is in progress. Because, there is no straightforward way to treat patients, a clinician may approach a radiologist at any time either in person or by phone to discuss a particular patient's diagnosis and condition.

In most acute cases a number of ad-hoc groups of radiologists and other specialists (surgeons, internists, cardiologists, anesthesiologists, etc.) are established. These collaborative and temporarily teams are constituted to fit the needs of the patient and are dissolved when patients have been diagnosed and treated.

PACS

The work inside the thoracic section of the radiology department is based on a PACS and on a RIS² (radiological information system). A gateway is developed enabling the clinician to get access to images in the PACS archive through the hospital intranet. The team designing the tailored PACS in use at Sahlgrenska consisted of a senior radiologist as the IT manager and three computer technicians. In addition has students from the Department of Informatics and computer science been working in the project from half a year to one year each, focusing on the design of PACS and connected gateways. Since, the senior radiologist is in charge of the project there has been a strong focus on existing work practice within the radiology department. There has throughout the project been a strong awareness of what keeps the radiological chain of actions together. The image production applications have been purchased from different retailers. The computer technicians have done the modeling and programming of the gateways between various image production applications and PACS working close together with the IT manager. The graphical interfaces was determined by the IT manager on the basis of discussions with the computer technicians, taking cautious consideration to the heterogeneous work practices in the radiology department. The differences in work practice were highly recognized and the implementation and design of the tailored PACS has been a success.

Medical practice – the case

In the normal (i.e. non-acute) cases each radiological report is distributed to the requesting clinic by transporters. The transporters place the reports on a table in the administrative area. Occasionally, in complicated cases, the patients themselves, parents to the patients or the ordinary postal service is used to transport the documents from clinical wards, private clinicians, primary care units and other hospitals. The activities in the radiology department related to an examination start when an examination order is received. The examination is booked and scheduled by assigning a room and a radiographer or a radiologist to the examination. The receptionist use the RIS to check whether the patients have been examined at the department previously, and he checks the details of the patient data, e.g., name, address, date of birth and telephone number. If there are any prior examinations that seems relevant, he requests the images from these examinations from the archive.

The order form is put into a binder notebook. All requests for examinations are stored in binder notebooks until the day the examination is taking place. The binders are stored in shelves in the administrative area. They are organized according to examination type and date. A glance at the shelves gives an overview of the scheduled workload for the present week.

The radiographers go to the shelves to find out whether there are any patients for examination and to collect the request forms and x-ray envelopes. The patient registers herself in the reception area when arriving at the examination day. She is thereafter shown to an undressing room and/or a laboratory.

² RIS is mainly used for administrative purposes, includes functions for communicating and managing patient data, managing patient registration, scheduling radiological examinations as well as creating statistics used for accounting.

Before the examination starts the receptionist has placed prior film (i.e. non-digital) images, in case there are any, in a trolley in the diagnostic area – available for the radiologists when interpreting the new images.

The radiographer takes the images, verify that they are of acceptable quality. The images are stored in PACS when they are found to have acceptable quality. Administrative personnel bring the order form to the diagnostic area.

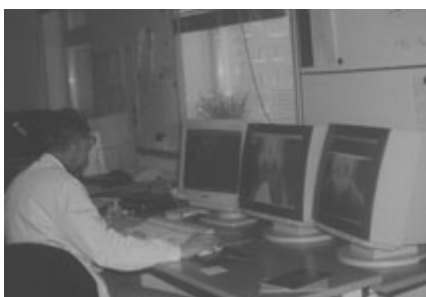


Figure 2. A radiologist diagnosing PACS images on workstations.

At the thoracic section, there are usually five to six radiologists being assigned to interpreting the images every day. However, this is only one of several tasks they are doing (others include regular meetings, answering on ad-hoc requests from clinicians, participating in multidisciplinary teams in acute cases, etc). Radiological work – like the work of clinical doctors – is not office work. They work in meeting rooms (like the especially designed rooms for ‘ward rounds’) in the image interpretation area, in the imaging labs, etc. A very large part of the work is, in fact, done by moving around in the corridors and other shared open spaces between the different rooms having specific functions. While walking up and down the corridor outside the image interpretation area, the radiologists can see how big the pile of orders on the table is. When it has reached a certain size – which depends of the degree of urgency of other tasks – the radiologist fetches the paper orders from the table and sits down at one of the computer screens being connected to the PACS system. With paper at hand she checks whether there are any relevant film images from an earlier examination. If so, these need to be compared with the images in the PACS. She will then fetch the films from the trolley and position them in a row at the light board being located next to the computer screen. Sometimes the radiologist uses the telephone to request additional images from the archive. She returns to the workstation and scans the barcode to get an overview of the patient’s previous radiological examinations. The PACS and RIS are integrated into one interface. Information of a number of previous examinations as well as their examination dates is communicated by RIS, while PACS communicate images (5x5cm) on two rows below the RIS information. The images just taken and possibly images from earlier examinations stored in the PACS system are presented on two computer screens. The radiologist reads and compares the images to complete the diagnosis.

Radiologist's reports, when short, are entered directly into the RIS by the radiologists themselves. The radiologist thereafter prints the report on a laser printer and puts it into a plastic folder together with the paper order to thereafter place it on an ‘out-shelf’ for the requesting unit. In case of long diagnostic answers the radiologists dictate their reports to typists to be entered into the RIS, and printed on paper to be placed in the radiologist’s personal shelf. The order form is checked and signed off by the radiologist and placed in an ‘out-shelf.’

If the ordering unit has specified on the order that they want copies of the images,

analogue film images are produced from the PACS system and put into a folder together with the report.

In the normal cases the reports are picked up in the out-shelves by transporters and brought to the ordering departments. The transporters place the reports on a table in the administrative area. The secretaries in the administrative area sorts and places the radiological reports in shelves linked to a particular clinician. The clinician collects the radiological report from the shelf when passing by and reads it. She writes a summary of the radiological report into the medical record. The clinician places the medical record accompanied with the radiological report on a table in the administrative area. The secretary brings the medical record to a table in the archive, archive clerks sort and places it in a particular shelf, according to patient demographic data. In emergency and complicated cases, the clinician calls the patient and forwards the patient diagnosis and future treatment. In the non-complicated cases the diagnostic results are sent to the patient via mail.



Figure 3. An interdisciplinary meeting at the radiology department.

At the daily meetings the order forms are placed in a pile on a table and film images are placed on light boards. If needed a trolley with additional films are placed on the floor. All this has been prepared in advance by a secretary. Additional film images may also be retrieved from the archive during the meeting if needed. After the meeting the film images are demounted by secretaries and placed in folders accompanying the orders, the folders are placed in a trolley to be moved to the administrative area. These meetings give specialties from different wards a chance to jointly discuss the progress of the patient's condition as well as patient treatment and diagnosis.

During the ad hoc conversations (and calls) between radiologists and clinicians, clerical staff brings film images from the archive and secretaries are helping to arrange the material. Secretaries call the archive and request the images. In addition they collect the films from the archive and fetch an order from a shelf in the reception area, and personally handing all documents over to the radiologists. In complex conditions where there is no straightforward way to treat patients, are ad hoc discussions of further investigations and interventions necessary before patient treatment can proceed and a diagnosis can be made.

In the acute cases, radiological staff usually receives a preparatory phone call from the emergency department or another hospital ward prior to the patient's arrival at the department. The order form is in these cases either faxed or sent with the patient. An ad-hoc group of radiologists and other specialists (surgeons, internists, cardiologists, anesthesiologists, etc.) is established and collaborating closely together. How these groups are operating depends on the patient condition and the overall workload at the hospital. They often need rapidly to develop complex strategies, they have to make a number of innovations, which in turn provoke unexpected rearrangements of work context and

content.

Radiological Infrastructure

The infrastructure supporting the collaboration between the radiology department and its "customers"

The infrastructure, the foundation, supporting the cooperation between the radiologists and their customers includes, first of all, the physical order and the report forms (which the orders are transformed into during the examinations) and the images. We also include in the infrastructure the institutionalized communication forms used: the request/response communication, the images, the daily meetings, and the ad-hoc conversations. This infrastructure is supported by a more general and basic one consisting of transporters, trolleys, shelves, tables, personal callers, phones and fax machines, secretaries, and other support staff (medical assistants), etc.

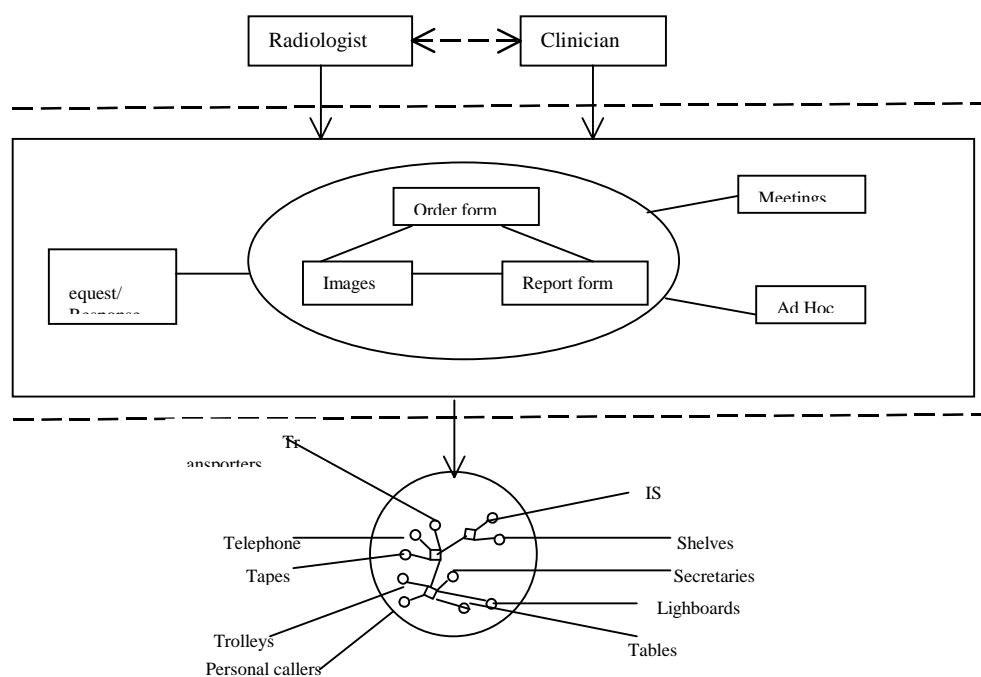


Figure 4. The radiological information infrastructure

Seeing orders, reports, images, meetings and ad-hoc conversation as infrastructure is in conflict with a narrow, and rather conventional, understanding of infrastructure as just material structures in terms of roads, cables (for telephone or electric power transmission), water pipes, etc. But we want to look at the orders and reports as well as the immaterial phenomena such as meetings and conversations as infrastructure because:

They constitute together the foundation upon which the collaboration and division of work between radiologists and clinicians rests,

the different elements are linked together in the sense that each of them is based upon the existence of the others, and the role of each is defined in terms of how this role

fits together with and links with the other elements' roles.

This infrastructure is linked to and a part of the infrastructure for collaboration between all departments in a hospital. It is also to a large extent part of a shared infrastructure, foundation, upon which collaboration between all hospitals and other health care organizations are based.

For these reasons, the orders, reports, images, meetings and ad-hoc conversations have all the characteristics of an infrastructure, and we accordingly prefer to use this term. It is a shared resource, or foundation, underlying the collaboration inside the hospital just as the Internet is a resource shared by and supporting the cooperation between university students, managers, teenagers, stores, stockmarkets, banking, associations, medical staff etc.

The "top level" infrastructure described above only works as such when there is another layer of infrastructure supporting it. This underlying, supporting, infrastructure is highly heterogeneous, consisting of physical artifacts, more advanced technologies as well as humans. For the requisitions and reports to work as a shared information infrastructure, the paper forms must be transmitted between the radiology department and the clinics. Transporters are bringing the forms from the out-shelf in one department to an in-shelf in the other. In other words, the transfer is taken care of by an infrastructure constituted by the combination of transporters and shelves.

In the cases where the patients themselves, parents to the patients or ordinary postal service are used when communicating with private clinicians, primary care units and other hospitals are these actors parts of the infrastructure. In the clinical wards in the hospital the bed, telephone, secretary, mail, table, archive, archive clerks and shelves are included in the supporting infrastructure.

At the daily interdisciplinary meetings images are retrieved and processed on workstations, order forms are placed in a pile on a table and film images are placed on light boards. If needed a trolley with additional films are placed on the floor. All this has been prepared in advance by a secretary. This means that the meetings are taking place based on a supporting infrastructure composed of a table, light boards, trolleys, and secretaries.

During the ad hoc conversations (and calls) between radiologists and clinicians, in which secretaries collected films from the archive and fetched an order from a shelf in the reception area, made phone calls etc. In this case, secretaries, clerical staff, the archive, shelves and phones are included in the supporting infrastructure.

The transporters, secretaries, clerical staff, telephones, shelves, tables and trolleys constitute a shared infrastructure supporting the collaboration around patients between radiologists and clinicians. The components of the supporting infrastructure are not obvious recourses within health care, although lying as they do beyond the core infrastructure, they must be seen as resources that the medical staff relies on to keep medical practice together. In the process of understanding work practice it is important to understand the supporting infrastructure.

Just like the infrastructure consisting of orders, reports, meetings, and ad-hoc conversations is also the underlying one open in the sense that it is supporting a wider range of collaborative activities inside the hospital (partly by being a part of a larger infrastructures of equal components).

The order form – a part of the infrastructure

The order form plays a crucial role as a shared infrastructure for the personnel working

inside the radiology department. It helps coordinating and keeping track of all main activities. All groups in the department use the order form in various ways to carry out their work. For instance, radiologists use it when diagnosing patients, radiographers use it when taking the images, receptionists use it when booking an examination, secretaries use it when transcribing the radiologists' reports, etc. The order is a shared resource used by all these groups. But it also coordinates the different activities they are carrying out. This coordination partly takes place by using the order as a medium for representing and storing information. One person writes information on it, later in the process others use this information when determining what to do and how. For each step in the radiological examination process, information is recorded on the order. This means that the order during the examination process also becomes a documentation of what has actually been done. This documentation can after the examination is finished, be used for lots of different purposes: quality control, statistics, proving what happened if the patient sues the hospital for mistreatment, etc.

The order form also coordinates the activities at the department not only as a medium representing information, but also by means of its physical features (for an analysis of these features, see Lundberg and Sandahl 1999). In particular, the simple fact that the order is one single physical object plays a crucial role. The chain of steps are coordinated as the person carrying out one step puts the order on a predetermined location when the task is finished. The one, which shall carry out the next step in the process, will then find the order in this position and then do her task. Locations where the orders are placed include binders put into shelves, tables, and mailboxes. For instance, after the images are taken the administrative staff at the radiology department places the examination order on a special pile on a table in the diagnostic area, visible to the radiologist. After a glance at the table when walking down the corridor, the radiologist has an overview of the image interpretation work to be done. The visibility of the paper pile at the table triggers the radiologist to take action. This example also illustrates how coordination is based on the interplay between different artifacts – the order and the table. And similarly, shelves, tables and mailboxes are more than storage's of documents. They also inform receivers about progress and status in various production processes.

The collaboration within the radiology department is based on an underlying supporting infrastructure. For instance, in order to "communicate" the order form between the reception area, image production area, diagnostic area and administrative area, secretaries, tables, shelves, trolleys etc. are used as a supporting infrastructure. Similarly, during the diagnosis of patients, radiologists fetch documents from tables and films from trolleys, they position films on light boards, use the telephone to request additional films from the archive, use barcodes to scan patient demographic data. Accordingly, shelves, tables, trolleys, light boards, phones, archive staff and the archive are included in the supporting infrastructure.

Links and interdependencies

The artifacts mentioned above that are involved in the coordination of radiological work are highly interdependent. They are not just individual tools, they are partly a shared infrastructure in itself, but first of all they are linked to others which together constitute the infrastructure all radiological work depends upon.

The shelves, binders, folders, tables, mailboxes are all designed to fit the paper order. In the same way are light boards, trolleys, and archiving shelves designed to fit the radiological images. The order is designed to fit the needs of all departments concerning

communication routines. The tasks of secretaries and other administrative staff at the radiology and clinical departments are all designed to fit the communication needs. But they are also shaped by the fact that this communication is based upon the paper order. The other artifacts used in the communication also shape the tasks: folders, tables, and mailboxes. The same is true for the transporters.

The components constructing the radiological information infrastructure described in this paper are not unique for or isolated to radiological communication. The radiological infrastructure is also a part of a large and open infrastructure for the whole hospital, and even a shared infrastructure for communication between all health care units.

Inside the hospital there are several service departments in addition to the radiology department. This includes clinical-chemical and other (microbiology, laboratories, pathology department, blood bank, etc.) Services from all these departments are ordered in the same way. Similarly, hospitals send patients between and order services from each other. Accordingly, the way these services are ordered need to be standardized and the infrastructure used need to be shared.

Convergence between information artifacts and clinical practice

Above we have described how infrastructures emerge as artifacts are linked together into long chains. To work properly, the artifacts in the chain must interact. Further, the chain of artifacts is linked together with the working practices of the personnel at the departments. The artifacts are linked together with the working practices of those using the infrastructure in their work, like the radiologists and the clinicians. The chain of artifacts is also linked together with the working practices of the support personnel being a part of the clinicians and radiologists infrastructure, i.e. the secretaries and administrative staff and the transporters. Their tasks is to bring the orders from one temporary "storage" (tables, folders, mailboxes) to another. Further, the structure of the order and the rules for what kinds of information that should be documented in it, shapes how the specific tasks which the registration of the information is a part of are carried out (Latour 1987 and Berg 1997 and Bowker 1997).

Just like the artifacts are linked together into chains, so are also the work practices. The different tasks being a part of the chain of activities related through the diagnostics and treatment of one patient are linked together and adapted to each other to make the overall process smooth and efficient. Similarly, the work practices are linked more indirectly because clinical departments need to communicate and collaborate with all service departments according to the same procedures to operate smooth and efficient, and each service department wants to communicate and collaborate with all clinical departments being their customers in the same way. Together this means that the work practices at hospitals are linked together in large networks. In total, artifacts and humans are linked together into a socio-technical web, an actor-network constituting an infrastructure. And infrastructures and working practices are further linked into larger networks. For the hospital to work smoothly and efficiently all elements must be aligned with each other, all networks of networks must be aligned and convergent. Both infrastructures and practices are standardized and institutionalized (Hanseth and Monteiro 1998).

Infrastructures change over time. But due to their size and complexity, the whole infrastructure cannot be changed instantly. It changes as some of its parts changes so that the new still is aligned with the overall infrastructure. The same is the case for working practices. This means that infrastructures and working practices co-evolve slowly over long time. This is an evolutionary process through a series of small steps. This pattern is the standard change process for infrastructures. Over time, it results in a "deep ecological penetration" (Joerges 1988, p 29-30) i.e. the infrastructure are deeply embedded into practices. The infrastructure is strongly adapted to the practices at the same time as the practices themselves are shaped in a way making them heavily dependent on the infrastructures and artifacts.

Larger changes are invisible as they are not planned as such. That means that all links and interdependencies between separate artifacts and between individual as well as collections of artifacts (i.e. infrastructures) are "hidden" and so are links and interdependencies between practices (Star and Ruhleder 1996).

Challenges for Design of Information Infrastructures

Based on the analysis of the radiological infrastructure and work practices above, we will now turn towards design of new infrastructures. We will first discuss what we see as the major challenges in infrastructure design.

Standards

For large networks, and large networks of networks, to operate smoothly, they must be convergent and aligned. In technical terms this means standardized. The communication must take place according to shared, standardized protocols. Work must follow standardized practices.

Conventions such as the paper order must be placed on a particular table, in order to communicate to the radiologist that there is a patient to be diagnosed. In this case, the placement of paper orders connects one activity with another activity. Just as the placement of paper order in other predefined shelves connect the radiological network with networks outside the radiology department. A requirement of an infrastructure is that everyone follows the same standard. In the standardized radiological network actors rely in their actions on other actors following the same standards. In this case, an example is the paper order that is heterogeneously used by many medical actors with different needs and interests; secretaries use paper orders to book examinations, radiographers to carry out examinations, radiologists to diagnose examinations, archive staff to archive documents, clinicians to order radiological examinations and to carry out patient intervention and treatment.

This implies that designing infrastructures means defining standards. This means technical standards in terms of communication protocols and coordination artifacts (Schmidt and Simone, 1996), and standard work practices – i.e. designing a large actor-network with standardized interfaces.

Designing such networks is, however, no easy task. One difficulty is related to the fact that infrastructures are open networks, i.e. they are indefinite. The other problem relates to the design of organizational and human components in the networks. Organizations (in terms of acting agents, not formal organizational structures) and humans' activities cannot just be designed. We will here discuss the first issue, which

deals specifically with infrastructures.

Irreversibility

The larger number of actors communicating, or the larger number of components linked, the more important standards are. On the other hand, the larger network implementing a standard, the harder it becomes to change the network. This is so for the following reasons: Changing the network means changing the shared standard. The larger a network becomes, the harder it will be to coordinate all actors' actions. For a large network, it will become, in practice, impossible to make all agents switch from one standard to another one at the same time. The large networks communicating using the same standard paper orders and film images cannot be changed instantly. Another example which all of us are in touch with is the ongoing transition of the Internet to a new version of the IP protocol. This has been going on for some years already and it is supposed to take many years still.

Changing a network from one standard to another over a longer period means that different parts of the network are incompatible during that period. Incompatibility means that the network is not aligned – it does not work. However, the degree of compatibility plays an important role. To make a major change will cause a major incompatibility between the existing network and the new. Such an incompatibility causes problems and the intended change will not take place. To succeed establishing a new network a new practice must be established, the new must match the old during the transition period. This implies that the existing structure constrain how the new can be designed.

The more resources linked to the infrastructure the greater the probability of successful resistance to translations. In health care numerous of artifacts have over a long time been linked to the infrastructure. Just consider all the artifacts already surrounding the paper order in our case; typewriters, cupboards, shelves, tables, printers, pens, dictaphones, computers, archives, telephones etc. and the different ways work practice has been shaped according to all these artifacts, as well as the spaces arranged around these artifacts. Other resources have also been invested in: knowledge and skills surrounding the paper documents, and the introduction of staff managing the documents: archive staff, administrative staff, medical assistance etc. The standard in the paper order supports communication and coordination within and between the heterogeneous socio-technical networks and is therefore most important in these socio-technical networks.

To replace the paper order with an electronic version is facing such irreversibility problems. As the paper order links together, in fact, all health care institutions in a country, the transition must take time. During this change there will be incompatibilities and breakdowns because the paper-based network/protocol does not interoperate with the ones based on computers. A successful transition will then require links and some kind of interoperability across these inconsistencies.

Installed base cultivation and gateways

An approach to changing large networks must take the existing network, the installed base, as its starting point. The whole network can only be changed in a process where smaller parts, sub-networks, are replaced by new ones while at the same time the new sub-network works together with the larger network. The success of such an approach depends on the identification of sub-networks which are, first, small enough to be changed in a coordinated process, second, the sub-networks have so simple interfaces to the larger network that these interfaces between the new and the old can be manageable.

The interfaces between two networks will primarily be taken care of in terms of gateways translating between them, or by users being linked to both networks. How this happens in the introduction and use of PACS at Sahlgrenska will be described in the next section.

The PACS experience

We will now look a bit closer at the introduction and use of the PACS system at the thoracic section. This system was developed in an improvisation (Ciborra 1996, Orlikowski, 1996) like process, i.e. through a series of versions where each version has been in use for a period, and the next one is developed based on the use experiences. Through such a process, a system well adapted to users' needs has been developed. An important characteristic of this version, an important explanation of its success we believe, is the smooth integration between the PACS system and the "system" based on film images.

The digital system is the primary one internally at the thoracic section. The instruments generating the images are all based on digital technology. This means that when the radiographers are taking the images, they are directly stored in the PACS system's database. And the radiologists are also using digital equipment when interpreting the images. They are however, using the order on paper form to retrieve the images to be interpreted. This is done by using an electronic bar code reader to read the bar code on the order which is generated by the RIS system. Although the digital images are the primary 'tool' for radiologist's diagnoses of a patient, old analogue images are still being used during the comparison of new and old findings. In addition, analogue images must be printed when requested by in-house clinicians, or when the patient is admitted to the radiology department from other hospitals or primary care units. The digital images are then printed from the PACS system onto film via laser printers. The new digital and the old film based infrastructure are integrated through the co-location of light boards and computer screens in the radiologists' image interpretation area, and the printers for printing images.

The systems are also integrated to support the ad hoc discussions between radiologists and clinicians. The analogue images are usually fetched by secretaries from trolleys and mounted on a light board beside a computer screen. Often during these discussions, the clinicians want to have the opinion from the radiologist about how a phenomenon (like a cancer tumor) has changed over time. In such a discussion, comparing images taken over a long time is crucial.

The rooms used in the ward rounds are also equipped to enable the comparison of film and digital images.

After the PACS system has been in use for a while, both clinicians and radiologists wanted to extend the system with functions enabling the clinicians to access the images from PC's at the clinical departments. As the PACS system was running on Unix work stations, the software could not just be installed on the PC's. Instead a gateway was developed converting the images to a format readable by Web browsers (or more precisely, by plug-ins to web browsers). This was a simple solution developed by a master student within a three-month time span. The gateway enables the clinicians to access the images via the hospital's Intranet.

The PACS system implemented at Sahlgrenska must be considered as a success. In our view, this success is primarily due to the way its design supports a network of activities that has a fairly clean and simple interface to other such networks and how the

PACS system is well integrated with the technology supporting the other networks.

Designing Information Infrastructure

We will now discuss how the approach outlined above can be applied to the design of an infrastructure for electronic orders at Sahlgrenska. Such an infrastructure will have several important advantages as it will speed up the transmission of orders and reports, the secretaries do not have to register the order in the RIS, the orders and reports will be more easily accessible when needed, etc.

The first important issue, then, is to identify the subnetwork to be changed. We can identify four alternatives. The first subnetwork is the radiology department. Then we can extend this by including the secretaries at the clinical departments. This network can be further extended by also including the clinicians, and finally the external units sending patients to the radiology department for examination.

Which alternative to choose depends on the complexity and costs of changing the subnetwork and the complexity and costs of the links to the surrounding networks. We will here briefly discuss the three first alternatives. The first one is of course the simplest one, but also the one giving least benefits. The interface to surrounding networks will be very simple (based on paper orders). It can be seen as a gateway converting the order/report between paper and digital forms. When the order arrives at the radiology department, a secretary at the reception will register its information. When the examination is finished, a paper report will be written and put in the mailbox to be picked up by a transporter. The gateway in this case is then a human registering the information and printing the report. This solution also needs to provide functions supporting the coordination of the activities inside the radiology department. An alternative solution would be to register the information, but to keep the paper order for the coordination purposes.

One critical issue with this solution is the registration of the order. This has to be error-free. The order is handwritten by a clinician using medical terminology not (always) known by the secretaries. This problem can possibly be solved by also scanning the part of the requisition where the clinician has specified the examination and other relevant medical information about the patient. If the paper order is used for coordination purposes it will also be available so the radiologists can read the clinicians' handwritings.

In the second alternative, the orders will be filled in electronically at the clinical department, either by a doctor or by a secretary based on a doctor's dictated specifications. In this case, the problems related to registration of the secretaries at the radiology department will not appear. If the radiology department wants to, it may still print out the order and use the physical paper as a coordinator. The report will electronically be available (for instance sent by e-mail) to the secretary at the clinical department when the examination and diagnostics work at the radiology department is finished. The secretary will then print the report and put it into the receiving clinician's mailbox just as today when the report is brought to her by the transporter. In this case, the gateway between the two networks, the electronic and the paper based, is the secretary at the clinical department.

The third alternative extends the second by sending the report straight to the receiving clinician. In this case, there will not be a gateway between the networks based on paper and computers respectively. On the other hand, paper based and electronic networks will indirectly be connected as the clinician will use (be connected to) two

separate networks – an electronic one when communicating with the radiology department and a paper based one when communicating with the other service departments.

In case some of the other service departments already have introduced a system sending their reports to the clinical departments. If so, the radiology department should adapt their system to the existing one so that the clinician receives the electronic reports from both departments in the same way. This may happen by building a gateway between the requisition system and the existing one so that the clinician receives also the radiological reports in the system they are already using.

The order plays basically two roles – a medium representing information, and a physical artifact used to coordinate multiple activities. The first role can most easily be played by an electronic order. The coordination role it plays due to its physical aspects is harder to take over by a computer. Although some cases are not so hard. Radiographers working all day taking images may, for instance be informed about which patient is the next by a sorted ‘to-do’ list of patients to be examined. But it is harder to design functions informing radiologists about the number of patients’ images waiting to be interpreted and clinicians about the fact that a report has arrived. One could imagine that they could be informed by sending them e-mail. But hospital doctors are not ordinary office workers sitting at their desk using their PC’s. They are working in different rooms and locations, which are not their personal working locations. Such spaces are rooms for examination, meetings, patients, the reception area, discussing with other doctors in the corridors, etc. They are everywhere - except in their offices. And the computers they are using are public rather than personal, located in public spaces like the image interpretation and the reception area in the radiology department. This implies that conventional models, metaphors, and tools for computer based communication do not apply.

If the reports should be sent directly to the clinicians and the paper order should not be used to inform the radiologists about the number of images waiting to be interpreted, an electronic system informing the doctors about this while they are walking (running) up and down the corridors would be crucial. Such a system could be a large screen mimicking the table and the pile of orders in the image interpretation area in the radiology department, and a similarly large screen mimicking the mailboxes (and the reports inside them) at the clinical departments. In addition, the system should be linked to the rest of the infrastructure at the clinical department to inform the clinician about the reception of an urgent report. For instance, a message could be sent to the secretary who then would inform the clinician, or a message could automatically be sent to her personal caller.

Conclusion

The objective of this paper has been to illustrate how radiological information infrastructures emerge as artifacts in use are linked together into chains. The chains of artifacts are also linking together different practices inside the hospital. Individual activities are also linked together into chains. Further, these chains of artifacts and activities are linked to working practices of personnel using infrastructures in their work. The different chains of activities each constitute a subnetwork. These sub-networks representing different working practices are also linked. Together this means that the working practices at hospitals are linked together in large networks. To succeed with the

implementation of PACS systems, they must be designed in a way supporting all aspects of the artifacts they will replace that existing work practice is based on. Further, it must be designed and implemented so that it interoperates smoothly with other systems.

Current practices in hospitals are heavily depending on paper. Accordingly, understanding all roles played by paper documents as well as designing computer systems that fits together with paper based practices are important success criteria. We believe the concept of infrastructure as it is defined and used here is useful to understand the interdependencies of existing artifacts and technologies, how these through a process of "deep ecological penetration" typical for all infrastructures have become embedded into the practices, and how one part of the existing infrastructure may be replaced by a computer based sub-infrastructure.

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