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Designing Work Oriented Infrastructures

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Abstract. Healthcare is making huge investments in information systems like Picture Archiving and Communication Systems (PACS) and Radiological Information Systems (RIS). Implementing such systems in the hospitals has been problematic, the number of systems in regular use is low, and where the systems are in use the benefits gained are far below what has been expected. This paper analyzes and identifies a number of challenges one will be confronted with when implementing PACS and RIS. To deal with these problems it is suggested to consider them as "*work oriented infrastructures*". This term is supposed to draw our attention to the fact that these systems have the same general characteristics as traditional infrastructures at the same time as they are developed to support specific work tasks. These are, and should be, designed and implemented primarily by their users based on their actual use of the technology. Standards are equally important for both work oriented and other kinds of infrastructures. But in the first case, the standardization process is more of a "cleaning up" type which follows a period where the infrastructures have been changed in different ways in different regions or communities.

Key words: artefacts, gateways, healthcare, information infrastructure, work practice

1. Introduction

The introduction of IT into (large) hospitals has been slow and problematic. Electronic Patient Records (EPRs) have been in development since the sixties but are still not well represented – at least in large hospitals (Berg, 1999). The state of affairs among general practitioners, however, is the opposite. In Norway, for instance, close to 100% of them are using EPRs. The idea of Picture Archiving and Communication Systems (PACS) is also fairly old. The role of these systems is to store and give access to different kinds of patient related medical images like X-ray, MRI, CT, ultrasound, etc. And just as in the EPR case, implementing such systems in the hospitals has been problematic. The number of systems in regular use is still rather low, and where the systems are in use the benefits gained are far below what has been expected (Bryan et al., 1998; Peissl et al., 1996; Lundberg, 1999). The aim of this article is to get a better understanding of the challenges of implementing PACS and RIS systems and how to deal with them. We also believe that our insights are valid for larger groups of complex information systems and infrastructures. The paper is based on the hypothesis that the high rate of failures among projects aiming at the introduction of PACS into radiology departments (just like EPRs) is due to the variety, richness, and complexity of work practices inside hospitals, and the interdependencies between the artifacts and technologies supporting the work practices. The complexity of and interdependencies between medical practices and technologies are increasing as medical knowledge increases, new medical technologies are introduced, new illnesses emerge (ranging from AIDS to Internet addiction), and the role of chronic diseases is growing. The high rate of failures among projects aiming at the introduction of PACS into radiology departments (just like EPRs) is also due to the fact that the systems to be introduced as well as existing technologies are seen as separate and independent rather than as parts of complex overlapping infrastructures.

Considering the information systems as well as other technologies in use as integrated infrastructures gives us new tools and strategies for implementing new technical solutions. First of all, we might learn from the implementation of other infrastructures like railroad, power, and telecommunication networks. But we want, in this paper, to move beyond the characteristics of such "classic" infrastructures. A careful analysis of the infrastructures used within hospitals will teach us, we believe, lessons which will be useful in the development and deployment of such IT solutions. We also believe that these lessons will be helpful in the development of a larger class of infrastructures. We call this class *work oriented infrastructures*. This term draws our attention to the fact that such infrastructures are developed to support specific work tasks and practices as opposed to the simple and universal services provided by traditional infrastructures like those mentioned above (i.e. electric power at a certain voltage, access to telephone networks, water in a pipe, etc.)

The study is based on ethnographic methods (Hughes et al., 1994), which has lately become widely recognized within the IS and CSCW fields (Suchman, 1991; Bellotti and Bly, 1996; Button and Sherrock, 1997; Button and Harper, 1996; Bowers et al., 1995). When using this research approach the focus is on investigations and understandings of actual work practice in their particular contexts. The empirical fieldwork was initiated in October 1996 at one radiology department using PACS. Several different qualitative research methods were used for data collection, including 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, 45 hours of observations, and 22 interviews of 1 1/2 hour each were conducted. Some participants were interviewed several times.

2. Information infrastructures

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

When approaching information infrastructures we focus on four aspects. Infrastructures are *shared resources* for a community; the different components of an infrastructure are integrated through *standardized* interfaces; they are *open* in the sense that there is no strict limit between what is included in the infrastructure and what is not, and 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 users. This is opposed to artifacts of which each user has its own private copy, which each user can use independently e.g. Microsoft Word, Excel, etc. This distinction can be illustrated by the difference between word processors and the Internet's e-mail infrastructure. Each user using a word processor has its own copy and one user's use of her system does not interfere with others'. 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 necessarily exactly the same nodes). And how one user uses the infrastructure may affect others. If one user sends an incredible amount of information, this might jam the network and cause problems for all.

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

Infrastructures are *open* in the sense that there are no limits for how many users, computer systems or 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, the 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 different sub-infrastructures of the Internet, making them heterogeneous. But they are also heterogeneous in the sense that they include non-technological elements. For instance, Internet includes the work of large numbers of support personnel. Without them the Internet would not work. Accordingly we see infrastructures as socio-technical webs, as actor-networks.

3. Radiological work practices and infrastructures

We will in this section describe the work practices within the radiology and the clinical departments and their collaboration. We also describe the technologies used – physical artifacts as well as computer systems – and how they are linked together into infrastructures.

3.1. WORK PRACTICES

The work practices described are observed at the thoracic section at the Radiology department at Sahlgrenska Hospital in Gothenburg, Sweden. We describe the services delivered to and the communication and interaction with its "customers" and other activities going on inside the section.

3.1.1. *The interaction between the radiology department and its "customers"*

The radiology department is a service unit for clinical departments inside the hospital, for other hospitals, and for primary care units (general practitioners). The services delivered are radiological examinations and reports based on X-ray and other types of radiological images. Radiological services are important "tools" for patient diagnosis, 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, etc.) implicitly means X-ray imaging. To order an examination the "customers" send a paper form, a request (or order), to the radiology department. The order identifies the patient and 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 including (Figure 1): (I) the patient name, address and other demographic data, (II) confirmation of the scheduling with the referral hospital, (III) patient history – clinical information given by referring physician, (IV) referring physician's request of choice of procedure, (V) multiple notations of the radiographers involved in the examination: examination room used, signature of radiographer and contrast medium given, (VI) preliminary evaluation by the radiologist who did the examination, (VII) priority as decided and signed by radiologists, and (VIII) final report signed by radiologist.

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

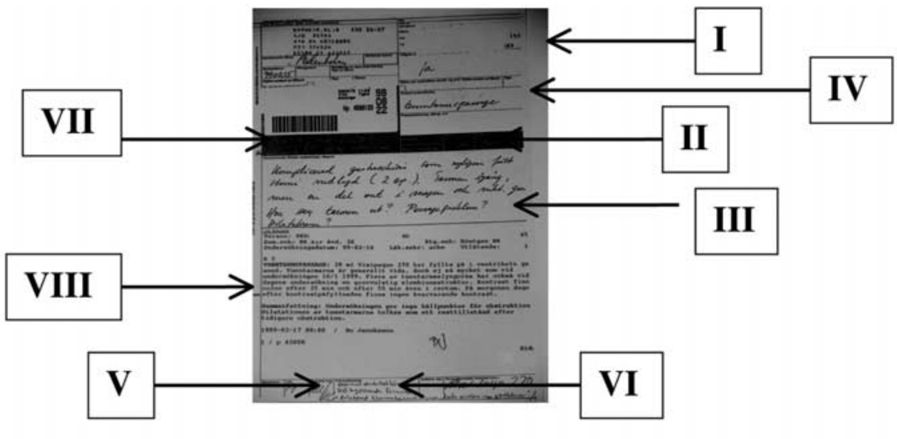

Figure 1. A radiological examination request/report.

Clinicians often need more information and help from radiologists than what can be specified in the report, for which they have regular formal meetings with each other. At the section we studied there are about nine daily interdisciplinary meetings, called 'ward-rounds,' and three bi-weekly ones. In addition, clinicians often call radiologists to discuss a patient diagnosis or to get advice while patient treatment is in progress. Sometimes clinicians also approach radiologists in person to discuss a particular patient's diagnosis and condition.

In most acute cases ad-hoc groups of radiologists and other specialists (surgeons, internists, cardiologists, anesthesiologists, etc.) are established. These temporary teams are composed of members of specific medical specialties according to the needs of the patient, and are dissolved after patients' diagnosis and treatment.

3.1.2. *Inside the radiology department*

The work inside the thoracic section of the radiology department is based on both PACS and RIS[1] (radiological information systems). A gateway is developed enabling the clinician to get access to images in the PACS archive through the hospital intranet.

The team designing the PACS consisted of a senior radiologist as project leader and three computer technicians. In addition, students from the departments of informatics and computer science have worked on the project for periods ranging from half a year to one year, focusing on the design of the PACS and various gateways linking the system to its environment.

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 the PACS in close collaboration with the project leader. The graphical interfaces were specified by the project leader on the basis of discussions with the computer technicians, taking cautious consideration of the heterogeneous work practices in the radiology department.

In the normal (i.e. non-acute) cases the radiological reports are brought to the requesting clinical departments by transporters. The primary task of transporters is to bring bed-bound patients from one department to another. When moving between departments they also bring with them other goods like orders and reports, medical records, etc. The transporters put the reports on a table in the administrative area within the clinical departments. Occasionally the patients themselves, their parents, or the ordinary postal service are used to bring 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 a radiological request form is received. The examination is booked and scheduled by assigning a room and a radiographer or a radiologist. The receptionist uses the RIS to check whether the patient has been examined at the department previously, and the details of the patient's demographic data, e.g. name, address, date of birth, and telephone number. If any prior examinations are relevant, he requests the films from these examinations from the file-room.

The order form is put into a binder notebook. All requests for examinations are stored in such 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 walk to the shelves to find out whether there are any patients to be examined and to collect the order forms and x-ray envelopes. The patient registers herself in the reception area when arriving at the examination day. She is thereafter directed to a dressing room and/or a laboratory.

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 which is easily available for the radiologists when interpreting the new images.

The radiographer takes the images and verifies that they are of acceptable quality. The images are then stored in the PACS and administrative personnel bring the order form to the diagnostic area. The request form is put on a table located in the area between the corridor and the image interpretation area.

At the thoracic section, there are usually five to six radiologists assigned daily to the interpretation of the images. This is, however, only one of several tasks they are doing (others include regular meetings, answering ad-hoc requests from clinicians, participating in multidisciplinary teams in acute cases, etc). Radiological work – like the work of clinicians – is not office work. They work in meeting rooms (like those especially designed for 'ward rounds'), in the image interpretation area, in the imaging labs, etc. A large part of the work is, in fact, done while moving around in the corridors and other shared open spaces between different rooms having specific functions. While walking up and down the corridor outside

Figure 2. A radiologist diagnosing PACS images on workstations.

the image interpretation area, the radiologists can see how big the pile of orders on the table is. The radiologist fetches the paper orders from the table and sits down at one of the computer screens being connected to the PACS. With the paper order at hand she checks whether there are any relevant film images from earlier examinations. 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 on the order to get an overview of the patient's previous radiological examinations. The PACS and RIS are integrated into one shared user interface. Information about previous examinations as well as their examination dates is found in the RIS system while images are found in the PACS. The images are presented in two rows below the RIS information (5×5 cm per image). The images just taken, and images from earlier examinations stored in the PACS, are presented on two computer screens for detailed examinations. The radiologist reads and compares the images to complete the diagnosis.

The radiologist enters the reports, when short, directly into the RIS, and thereafter prints the report on a laser printer and puts it into a paper envelope together with the paper order and thereafter on an 'out-shelf' for the requesting unit. In case of long diagnostic reports the radiologists dictate their reports to typists who later on register the information in the RIS system. The typists then print the written report on paper and puts it into the radiologists' personal shelves. The reports are checked and signed off by the radiologists and placed in an 'out-shelf.'

If the ordering unit has specified on the order that they want copies of the images, analog film images are produced from the PACS on a laser printer and put into a folder together with the report.

In normal cases the reports are picked up from the out-shelves in the radiology department by transporters and delivered to the ordering departments. The transporters put the reports on a table in the administrative area at the clinical departments. The secretaries sort and place the reports in the shelves of individual clinicians. The clinicians collect the reports from their shelves when passing by and read them. They write a summary of each report into the medical record. The

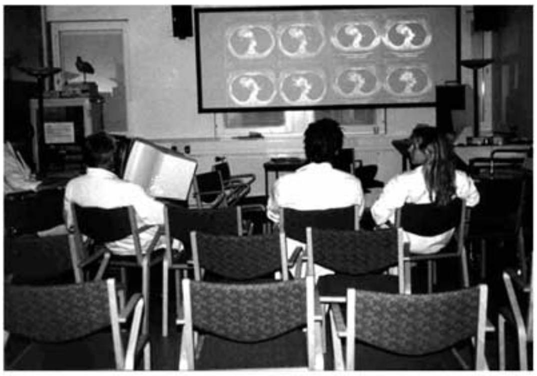

Figure 3. An interdisciplinary meeting at the radiology department.

clinicians put 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 file room (archive). Archive clerks sort and place the medical records in their proper locations in the shelves (determined by the patients' demographic data). In emergency cases (and complex ones) the clinicians call the patients and inform them about their diagnosis and future treatment. In the non-complicated cases (i.e. out-patients) the diagnostic results may be sent to the patients via mail.

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. A secretary has prepared all this in advance. Additional film images may also be retrieved from the file-room during the meeting if needed. After the meeting, secretaries demount the film images and put them in folders accompanying the orders and place the folders in a trolley to be moved to the administrative area. These meetings give medical specialists from different wards a chance to jointly discuss patient diagnosis and treatment.

During ad hoc conversations (and calls) between radiologists and clinicians, secretaries call the archive and request the images. Archive staff bring film images to the radiology department, and secretaries help the radiologists to arrange the material. In addition, secretaries, sometimes, bring the material to a table in the administrative area. Archive staff fetches, sort and place the material in their proper places in shelves.

In complex cases, ad hoc discussions about further investigations and interventions are required before a diagnosis can be made and patient treatment can proceed.

In acute cases, radiological staff may receive an alert 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. How such groups operate depends on the patient condition and the overall workload at the hospital. They often need to develop complex strategies rapidly, and they have to make a number of "innovations". For instance, in a car accident with abdominal trauma the medical staff need to discuss the workup; what diagnostic examination to do; what tests to take; what life support systems are needed etc. The staff also needs to make examination rooms available, which in turn may provoke unexpected rearrangements of work context and content. Changes in the patient's condition may at any time change the handling.

3.2. RADIOLOGICAL INFRASTRUCTURE

We now turn to the infrastructure supporting the work practices just presented.

3.2.1. *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 orders and reports (which the order forms 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 daily meetings, and the ad-hoc conversations. This infrastructure is supported by a more general one consisting of transporters, trolleys, shelves, tables, personal callers, phones and fax machines, secretaries, other support staff (medical assistants), PACS, RIS and their computer and network infrastructure (together referred to as IS on Figure 4), etc.

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 like 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 labour between radiologists and clinicians rest,
- 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 Healthcare 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. They are shared resources, or foundations, underlying the collaboration inside the hospital just as the Internet is a resource shared by and supporting

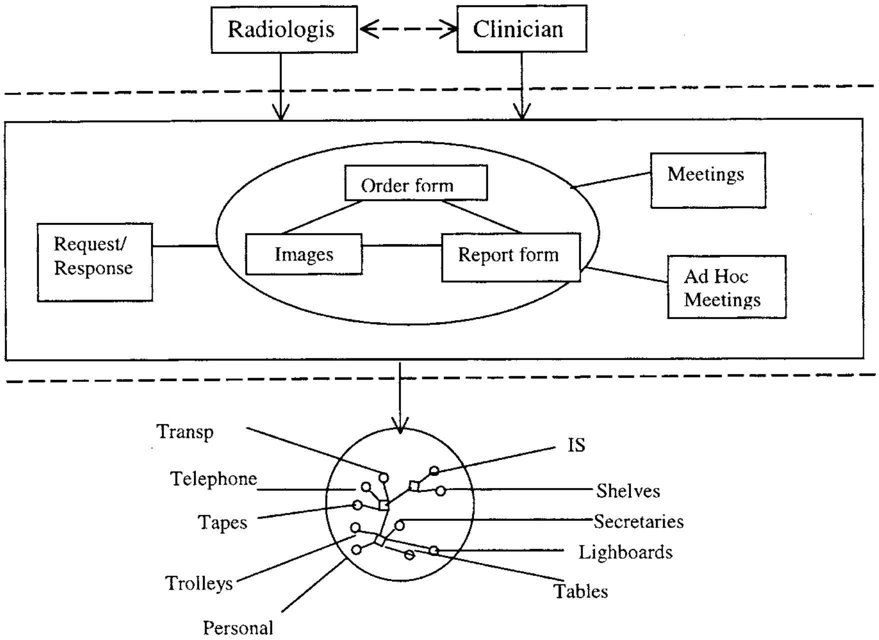

Figure 4. The radiological information infrastructure.

the cooperation between university students, managers, teenagers, stores, stock markets, banking, associations, medical staff, etc.

The "top level" infrastructure described above (i.e. the one composed of orders, reports, images, etc.) only works as such when there is another layer of infrastructure supporting it. This underlying, supporting, infrastructure is highly heterogeneous. It consists of physical artifacts, more advanced technologies as well as humans. For the orders and reports to work as a shared information infrastructure 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 a supporting infrastructure constituted by the combination of transporters and shelves.

In the cases where the patients themselves, parents to the patients or the ordinary postal service are used when communicating with private clinicians, primary care units, and other hospitals these actors are also parts of the infrastructure. In the clinical wards beds, telephones, secretaries, mail services, tables, archives, 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 is 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 between radiologists and clinicians radiologists often call secretaries or other clerical staff and ask them to collect films from the archive. In such cases secretaries, clerical staff, the archive, phones, etc. are included in the supporting infrastructure. In total the transporters, secretaries, clerical staff, telephones, shelves, tables, and trolleys constitute a shared infrastructure supporting the collaboration around patients between radiologists and clinicians. Just like the infrastructure consisting of orders, reports, meetings, and ad-hoc conversations, this one is also open in the sense that it is supporting a wider range of collaborative activities inside the hospital (partly by being a part of larger infrastructures of equal components).

3.2.2. *The infrastructure inside the radiology department*

The request 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 in their work. For instance, radiologists use it when diagnosing patients, radiographers use it when performing the examination, 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 form. This means that the order form 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 a more detailed analysis of these features, see (Lundberg and Sandahl, 1999). Closely related analyses are found in Berg's (1999) discusion of the role played by the lab order as an independent actor in the ordering process and Mackay's (2000) discussion of the role of paper strips in air traffic control.) In particular, the simple fact that the order form 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 carrying 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 examination has been performed the administrative staff at the radiology department places the examination order on a table in the diagnostic area visible to the radiologist. Usually there will be a pile of orders on the table, and the new ones are put on the top. When the radiologists are walking down the corridor, just a short glance at the table will give him 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 storages of documents. They also inform receivers about progress and status in various production processes.

3.2.3. *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 so that they together constitute the infrastructure that all radiological work depends upon.

The shelves, binders, folders, tables, mailboxes are all designed to fit the paper order form. In the same way light boards, trolleys, and archiving shelves are 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 Healthcare 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.) labs. 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 needs to be shared.

3.3. 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 are to bring the orders from one temporary "storage" (tables, folders, mailboxes) to another. Further, the structure of the order and the rules for what kind of information that should be documented in it shapes how the specific tasks are carried out (Latour, 1987; Berg and Bowker, 1997).

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 smoothly and efficiently, in the same way as all service departments want to follow the same procedures in their communication and collaboration with all clinical departments being their customers. Together this means that the work practices at hospitals are linked together into huge (socio-technical) networks. In total, artifacts and humans are linked together into a socio-technical web, an actor-network. 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 (For extensive discussions of this kind of convergence, see Bowker, 1994; Bowker and Star, 1999; Star et al., in press). Both infrastructures and practices are standardized and institutionalized (Hanseth and Monteiro, 1996).

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, but constrained by the fact that the overall infrastructure needs to be aligned. The same is the case for working practices. This means that infrastructures and working practices co-evolve slowly over long time, an evolutionary process through a series of small steps. This pattern is the standard change process for infrastructures. Over time, work practices and infrastructures are deeply adapted to and embedded into each other (a process Bernhard Joerges (1988, pp. 29–30) calls "deep ecological penetration").

Larger changes take place as the aggregation of numbers of small ones. They are invisible, as they are not planned as such. That means that links and interdependencies between separate artifacts and between individual as well as collections of artifacts (i.e. infrastructures) are often "hidden" and so are links and interdependencies between practices (Star and Ruhleder, 1996).

4. Designing infrastructures

Based on the analysis of the radiological infrastructures and work practices described above, we now turn towards design of new infrastructures. We will first discuss what we see as the major challenges in infrastructure design in general. Later on we will address how we can deal with these challenges in the design and organizational implementation of electronic infrastructures supporting radiological work.

4.1. CHALLENGES FOR DESIGN OF INFORMATION INFRASTRUCTURES

4.1.1. *Standards*

If large networks, and large networks of networks, are going to operate smoothly, they must be convergent and aligned. In technical terms this means standardized. Communication must take place according to shared, standardized protocols. Work must follow standardized practices. Conventions and rules, such as the fact that the paper order form must be placed on a particular table in order to communicate to the radiologist that there is a patient to be diagnosed, are examples of such standardized protocols. In this case, the placement of paper orders connects one activity with another activity just as the placement of paper orders 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 standards. An example of this is the rules for how different actors should use the orders. Secretaries use the orders to book examinations, radiographers to carry out examinations, radiologists to diagnose patients, archive staff to archive documents, clinicians to order radiological examinations and to carry out patient intervention and treatment, etc.

This implies that designing infrastructures means defining standards. This includes 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 now discuss the first issue, which deals specifically with infrastructures.

4.1.2. *Momentum and irreversibility*

The larger number of actors communicating, or the larger number of components linked together, the more important standards are. On the other hand, the larger a network implementing a standard is, 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 is 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 (Monteiro, 1998).

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 often 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 resistance to translations. In Healthcare numerous 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, shelves, tables, printers, pens, dictaphones, computers, archives, telephones etc., and the different ways work practices have been shaped according to all these artifacts, as well as the spaces arranged around them. Other recourses 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 for 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 Healthcare 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.

4.1.3. *Installed base cultivation and gateways*

An approach to the management of the change of large networks must take the existing network, the installed base, as its starting point (Hanseth, 1996). 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 the Sahlgrenska University Hospital will be described in the next section.

4.2. THE PACS EXPERIENCE

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

The digital system is the primary one internally at the thoracic radiology section. The instruments generating the images are all based on digital technology. This means that when the radiographers are "shooting" the images, they are directly stored in the PACS's database. 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, generated by the RIS on the order form. Although the digital images are the primary 'tool' for the radiologist's diagnoses of a patient, old analog images are still being used during the comparison of new and old findings. In addition, analog 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 that do not have PACS. The digital images are then printed from the PACS onto film via laser printers. The new digital and the old film based infrastructure are integrated through the 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 analog 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 radiological rounds are also equipped to enable the comparison of film and digital images.

After the PACS technology 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 PCs at the clinical departments. As the PACS technology was running on Unix work stations, the software could not just be installed on the PCs. 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.

It is our judgement that the PACS implemented at Sahlgrenska University Hospital has been rather successful. 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 technology is well integrated with the technology supporting the other networks.

4.3. EXTENDING THE PACS/RIS INFRASTRUCTURE

We will now discuss how the approach outlined above can be applied to the design of an infrastructure for electronic orders at Sahlgrenska University Hospital. 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 (i.e. other hospitals and primary care centers) 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 network is of course simplest, 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 composed of a human registering the information and a printer printing the report. This solution also needs to provide functions supporting the coordination of the activities inside the radiology department. One solution could be to register the information in the RIS, 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 by 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 and the printer 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 labs and service departments.

In some cases, 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 system receiving the radiological report 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 (Berg, 1999). 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. Some cases, however, are not so hard. Radiographers working all day obtaining 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 whose images are waiting to be interpreted and inform 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 PCs. They are working in different rooms and locations, which are not their personal working locations. This includes rooms for examinations, meetings, patients, reception areas, discussing with other doctors in the corridors, etc. They are everywhere – except in their offices. The computers they are using are public rather than personal, and they are 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 electronic 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. This functionality might be achieved by using PDAs or other forms of mobile computers or computer terminals. But such a system could also be implemented by using 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.

5. Beyond universal service: work oriented infrastructures

Having argued that the design of information systems for hospitals has a lot to learn from the development of "classical" infrastructures, we will now move one step further trying to identify features of the paper based radiological infrastructure which go beyond those of "classical" infrastructures – features whose "design" can teach us some lessons about the design of electronic radiological infrastructures as well as others. Taking this step is of crucial importance because implementations of PACS systems so far seem to contribute to the reproduction of existing practices rather then changing them (Bryan at al., 1998; Tellioglu and Wagner, 1996). This was also what happened in the case we studied, and that will largely be the result of the three design proposals presented in section 4.3. In all these examples, some local changes and benefits may be achieved, but the overall structure stays unchanged. And, in fact, it may be even harder to change because the practice is now (i.e. after the implementation of PACS/RIS systems) embedded into larger and more complex material structures and the socio-technical network that needs to be changed to improve the practice has become even more irreversible.

We will argue that the radiological infrastructure described in this article has some features which it has been attributed in order to support specific communities of practice in their work. In this case we are talking about highly complex and specialized practices whose properties are largely hidden for those who are not members of these communities (and which also the members are unconscious about). We call such infrastructures *work oriented infrastructure*s while the "classical" infrastructures can be called "universal service infrastructures" because they are providing universal services to all citizens. The services provided by the latter kind of infrastructures are fairly simple in terms of user interfaces and functionality, used by everybody, and equal for all. Power infrastructures deliver 220 (110) voltage current, telecommunication infrastructures give us telephone services so we can call our friends, roads enable us to drive our cars, etc. And the "user needs" are fairly well known to everybody and they have hardly changed for hundred years. (This picture is changing as far as telecommunication is concerned due to all new services which new digital telecommunication technology opens up for and which the operators want to sell.)

We believe that these differences account for the fact that the different kinds of infrastructures have been designed in different ways and also that the design of new infrastructures of these two kinds requires different design strategies. Classical infrastructures are, and should be designed, primarily by engineers while work oriented infrastructures are, and should be, designed and implemented primarily by their users (and in use). The radiological infrastructure described above is based on (i.e. implements) standards. But the infrastructure is not built by implementing a set of standards, which are defined by standardization bodies. The infrastructure is built in a piecemeal (bit-by-bit) fashion over a long period – new elements are added to the existing infrastructures and parts are improved or replaced by improved ones. The changes are carried out by the user communities. There are no engineers telling the radiographers and radiologists, for instance, that the images should be stacked on a table and that its height should be used as a medium for communication and coordination. This specific "communication technology" is "designed" by radiographers and radiologists over time as they discover the fact that the paper orders and films they are transferring have features that can be utilized in this way. The aim is to improve technology use through the introduction of new ways of working and new services. Following Brown and Dugid's (1994) we can describe this as a process where a community of practice assigns meaning to peripheral aspects of the physical artifacts (paper and film). The central attributes of the paper and the films are their role as media for representation of information in forms of written text and images. Peripheral issues, like some physical aspects of the paper and films, are attached shared meanings and turned into borderline issues. Infrastructures are constructed by linking artifacts together and thereby making them interdependent. This happens partly by linking their central issues together, for instance, by assigning orders and films unique identifiers and using them to specify which sets of orders and films that belongs to the same examination. But infrastructures may to an even larger extent be constructed by linking artifacts together by means of their borderline issues. For instance, the coordination and communication between radiographers and radiologists are using both the order (and the films) and a table on which the orders are put. This coordination is utilizing the table not only as a storage paper, but as a storage of paper which can be located "anywhere", including the border area between the corridor and the area where the radiologists are interpreting the images. A large-scale infrastructure emerges as artifacts are linked together and the work of large communities of practice share their meanings. Transporters' primary task, for instance, is to bring patients in bed from one department (or room) to another. Their traffic between departments was later seen as a possible resource to be utilized for other means, and accordingly the transmission of paper documents all over the hospital is “piggy-backing” upon the main service they are delivering.

The radiological infrastructure is designed by its community of practice. We will argue that this is not just an historical accident – it could not have been otherwise. This is so because of the complexity of the working practices involved. To discover, or even understand, the need for improved technological support, one needs close relationship to existing practices, so close that one has to be involved in the practice oneself. However, practitioners can tell engineers about limits of existing technology and their ideas about what improved solutions may look like. Engineers can then design new solutions, which the medical personnel again can adopt. This is the traditional understanding of software (technology) development. This approach works pretty well in many cases, but work oriented infrastructure design is beyond its limits. The reason for this is that to design such an infrastructure, the engineers cannot develop solutions for a closed group of users but for more or less the whole Healthcare community. Engineers can design solutions, which can support existing practices in a better way, but only to a limited extent. For complex and highly specialized areas like radiology, only those knowing the area can discover potential improvements. Improved solutions will be discovered in work. Some improvements will take place as reinterpretation of meanings of existing technologies (i.e. using it in different ways, for instance additional information could be included in the orders and reports), some as reinterpretation of existing borderline issues or by constructing new ones, and, finally, some improvements will require changes in the technology itself. Work oriented infrastructures will be developed through bricolage (Ciborra, 1996) or improvisation (Ciborra, 1996; Orlikowski, 1996) like improvement processes. The difference between improvisation in the design, or improvement, of “traditional” (or rather standalone) systems like design of the Lotus Notes application that Orlikowskti (1996) describes, is related to the open character of infrastructures. Contrary to the Notes application, they are not used by a closed user group, but rather a large (indefinite) number of connected and overlapping communities of practice. In the collaboration within and between these communities of practice different but overlapping groups of services provided by, or parts of, the infrastructure are utilized. One group of functions or services, or part of the infrastructure, can only be changed in a way that maintains its compatibility with the other groups of functions it overlaps and is connected to.

The fact that large numbers of users are sharing the same piece of technology is usually assumed to imply that this technology should follow one shared universal standard. This argument has certainly some validity. The fact that all computers linked to the Internet is running the TCP/IP protocol demonstrates the power of such an approach. However, defining shared standards supporting the exchange of medical information is a strategy for building work oriented infrastructures that has proved to be very problematic (Hanseth and Monteiro, 1997). For more than fifteen years one has tried to work out standards for exchange of chunks of information like lab orders and reports (including radiological orders and reports). The proposals that have been worked out have been extremely complex and accordingly very expensive to implement and use and very hard to change. Existing practices are inscribed into the standards, and their lack of flexibility implies that they make it harder to improve existing practice rather than enabling this (ibid.). These problems seem to be present to very strong degree in the definition and implementation of EDIFACT messages in general (Graham et al., 1996).

Changes in the infrastructure in terms of changing its meaning or borderline resources, i.e. without changing the technological solutions in itself, can, of course, be carried out by the users without involvement of any kinds of experts concerning the technology used. Concerning the radiological infrastructure described above, which is based on artifacts and technologies like paper forms, tables, shelves, etc., the technology is very simple. The users have the required knowledge and capabilities to change it the way they want. We believe this fact to be an important explanation for of the successful development of this infrastructure. Heath and Luff (1992) and Nygren and Henrikson (1992), for instance, document how important the flexibility of paper documents is in the work of medical personnel. Paper documents can, for instance, be moved around and showed to patients whatever positions they are in, physicians can browse through the paper based medical record extremely fast in the search for relevant information, important information can be derived from the thickness of the record and what kind of forms it contains, etc. Further, paper documents are flexible in the sense that whenever needed, physicians can, when it is relevant, put text into the document beyond what the document template specifies. This is important in complex cases. But it is also important because it enables the users to improvise and improve the technology when new needs appear or opportunities are discovered.

We believe this user control of technology is important for the design of work oriented infrastructures in general. Computer technology, however, is far more complex than paper, tables, shelves, etc. However, some computer systems are more flexible and give more space for the users to find new ways of using the technology to improve their work. The Internet technology introduced at Sahlgrenska University Hospital to give clinicians access to images in the PACS demonstrates this. Other hospitals and Healthcare regions are using Internet technology (Web technology and e-mail) more extensively. Their experience clearly shows the potential of this kind of technology concerning innovative and user driven development of improved infrastructures and working practices.

Standardization has, however, played an important role in the development of the paper based radiological infrastructure. The order form, for instance, is in most countries settled as a standard by national standardization bodies. These standards specify the layout of the paper form and what kind of information they should contain. It is important to note, however, that these standards are defined after paper orders have been used extensively. The standardization process is more of a "cleaning up" type which follows a period where the orders have been changed in different ways in different regions or communities. When a new standard for the paper order is defined, it contains the information and structures required in current practices, at the same time as it has the flexibility required by the users. They can change the standard when new needs appear and new possibilities for improving practices are discovered.

Standards will certainly be important in electronic radiological infrastructures and work oriented infrastructures in general – just like any infrastructure. We believe, however, that they must, to be successful, be developed in ways similar to those of the paper based infrastructure. They will have the same "cleaning up" function. The standards will primarily provide benefits in terms of "cleaning up" the technology in use and making its future maintenance cheaper and easier. Work practices will not be changed although some benefits might be obtained because standardization may enable the scaling up and distribution of successful practices developed locally.

Gateways are key elements in the evolution of work oriented infrastructures. They make it possible for users to explore improved versions of large installed infrastructures at the same as they are using the existing ones. Gateways also enable smooth upgrading processes where one standard is replaced by another.

6. 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 subnetworks, representing different working practices, are also linked. Together this means that the working practices at hospitals are linked together into huge networks of networks. To succeed with the implementation of PACS and RIS systems, the systems must be designed in a way supporting all aspects of the artifacts they will replace that exiting work practice is based on. Further, they must be designed and implemented so that they interoperate 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 that 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 *vice versa*, and how one part of the existing infrastructure may be replaced by a computer based sub-infrastructure.

We suggest that the design of PACS and RIS could be improved by considering these systems as *work oriented infrastructures*. This term is supposed to draw our attention to the fact that these systems are developed to support specific and highly complex work tasks. We conclude that such infrastructures are, and should be, designed and implemented primarily by their users based on their actual use of the technology.

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Note

1. 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.

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