Medical Imaging Workstation: CAF Views

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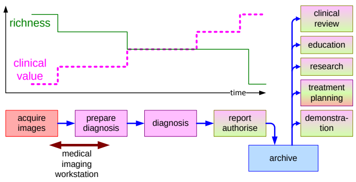

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Abstract

The Customer objectives, Application and Functional views are described. The radiology department and the radiologist are the main customer. The clinical and the financial context of the radiology department is shown. The medical imaging workstation is positioned in the field of IT products and in the clinical workflow. The market segmentation is shown. The typical URF examination is explained. Key drivers are linked to application drivers and to product requirements. The functionality development over time is shown and the role of the information model for interoperability is discussed.

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1 Introduction

This chapter discusses the *Customer Objectives*, *Application* and *Functional* views of the Medical Imaging Workstation. Section 2 describes the radiology context. Section 3 describes the typical application of the system. Section 4 shows the key driver graph, from customer key drivers to system requirements, of the Medical Imaging Workstation. Section 5 shows the development of functionality of the family of medical imaging workstations in time. Section 6 discusses the need for standardization of information to enable interoperability of systems within the department and the broader scope of the hospital. The conclusion is formulated in section 7.

2 Radiology Context

The medical imaging workstation is used in the radiology department as an add-on to URF X-ray systems. The main objective of the radiologist is to provide diagnostic information, based on imaging, to the referring physician. In case of gastrointestinal problems X-ray images are used, where the contrast is increased by digestion of barium meal.

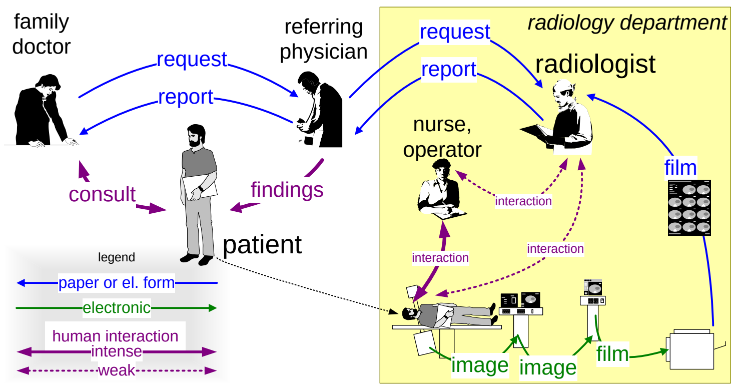

Figure 1: The clinical context of the radiology department, with its main stakeholders

The work of the radiologist fits in an overall clinical flow, see Figure 1. The starting point is the patient visiting the family doctor. The family doctor can refer to a consultant; for gastrointestinal problems the consultant is an internist. The family doctor writes a request to this consultant. In the end the family doctor receives a report from the consultant.

Next the patient makes an appointment with the consultant. The consultant will do his own examination of the patient. Some of the examinations are not done by the consultant. Imaging, for example, is done by radiologist. From the viewpoint of the radiologist the consultant is the referring physician. The referring physician uses a request form to indicate the examination that is needed.

The patient makes an appointment via the administration of the radiology department. The administration will schedule the examination. The examination is done by hospital personnel (nurses, operator) under supervision of the radiologist. Most contact is between nurse and patient; contact between radiologist and patient is minimal.

The outcome of the imaging session in the examination room is a set of films with all the images that have been made. The radiologist will view these films later that day. He will dictate his findings, which are captured in written format and sent to the referring physician. The referring physician performs the overall diagnosis and discusses the diagnosis and, if applicable, the treatment with the patient.

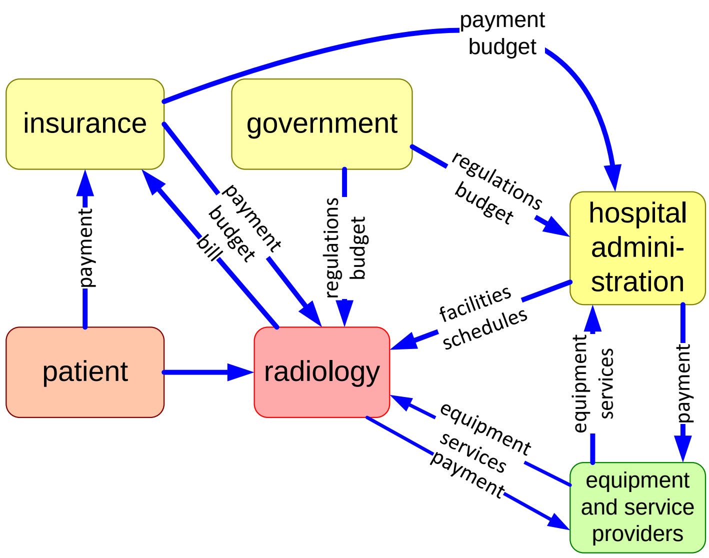

Figure 2: The financial context of the radiology department

The radiology department fits in a complex financial context, see Figure 2. The patient is the main subject from a clinical point of view, but plays a rather limited role in the financial flow. The patient is paying for insurance, which decouples him from the rest of the financial context.

The insurance company and the government have a strong interest in cost control[1]. They try to implement this by means of regulations and budgets. Note that these regulations vary widely over the different countries. France, for instance,

[1] sometimes it even appears that that is the main interest, quality of health care appears than to be of secondary importance

has stimulated digitalization of X-ray imaging by higher reimbursements for digital images. The United States regulation is much less concerned with cost control, here the insurance companies participate actively in the health care chain to control the cost.

The hospital provides facilities and services for the radiology department. The financial decomposition between radiology department and hospital is not always entirely clear. They are mutually dependent.

The financial context is modeled in Figure 2 in a way that looks like the Calculating with Concepts technique, described by Dijkman et al in [2]. The diagram as it is used here, however, is much less rigorous as the approach of Dijkman. In this type of development the main purpose of these diagrams is building insight in the broader context. The rigorous understanding, as proposed by Dijkman, requires more time and is not needed for the purpose here. Most elements in the diagram will not even have a formal interface with the product to be created. Note also that the diagram is a simplification of the reality: the exact roles and relations depend on the country, the culture and the type of department. For example a university hospital in France is different from a commercial imaging center in the USA. Whenever entities at this level are to be interfaced with the medical imaging workstation then an analysis is needed of the greatest common denominator to be able to define a rigorous interface.

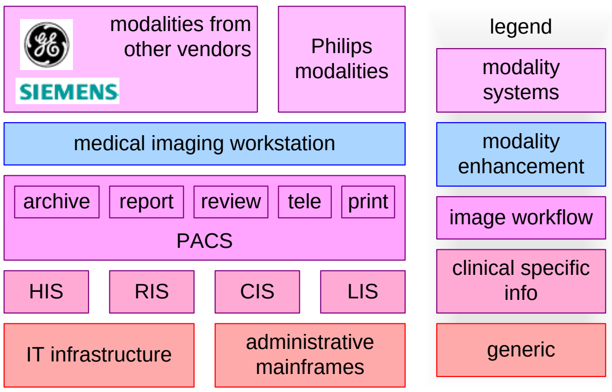

Figure 3: Application layering of IT systems

The medical imaging workstation is playing a role in the information flow in the hospital, it is part of the large collection of IT systems. Figure 3 shows a layered model of IT systems in the hospital, to position this product in the IT context. It is a layered model, where the lower layers provide the more generic functionality and the higher layers provide the more specific clinical imaging functionality.

In the hospital a normal generic IT infrastructure is present, consisting of networks, servers, PC's and mainframes. More specialized systems provide clinical information handling functions for different hospital departments (LIS for laboratory, CIS for cardio and RIS for radiology) and for the entire hospital (HIS Hospital Information System).

The generic imaging infrastructure is provided by the PACS (Picture Archiving and Communication System). This is a networked system, with more specialized nodes for specific functions, such as reporting, reviewing, demonstration, teaching and remote access.

The medical imaging workstation is positioned as a modality enhancer: an add-on to the modality product to enhance productivity and quality of the examination equipment. The output of the modality enhancer is an improved set of viewable images for the PACS.

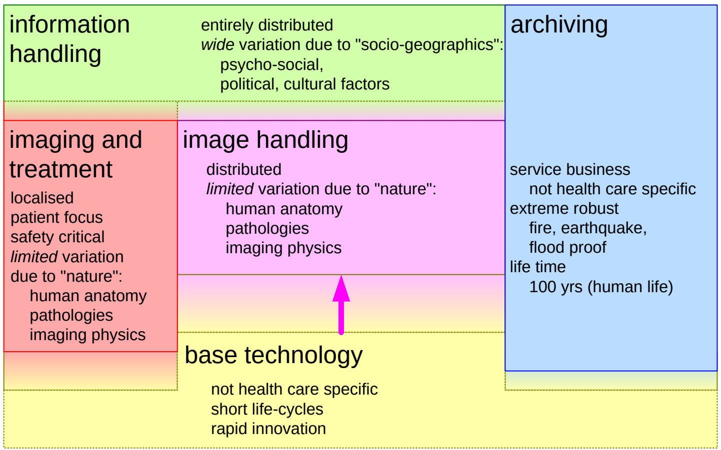

Figure 4: Reference model for health care automation

Figure 4 shows a reworked copy of the reference model for image handling functions from the “PACS Assessment Final Report”, September 1996 [1]. This reference model is classifying application areas on the basis of those characteristics that have a great impact on design decisions, such as the degree of distribution, the degree and the cause of variation and life-cycle.

Imaging and treatment functions are provided of modality systems with the focus on the patient. Safety plays an important role, in view of all kinds of hazards such as radiation, RF power, mechanical movements et cetera. The variation between systems is mostly determined by:

- the acquisition technology and its underlying physics principles.
- the anatomy to be imaged
- the pathology to be imaged

The complexity of these systems is mostly in the combination of many technologies at state-of-the-art level.

Image handling functions (where the medical imaging workstation belongs) are distributed over the hospital, with work-spots where needed. The safety related hazards are much more indirect (identification, left-right exchange). The variation is more or less the same as the modality systems: acquisition physics, anatomy and pathology.

The *information handling* systems are entirely distributed, information needs to be accessible from everywhere. A wide variation in functionality is caused by "social-geographic" factors:

- psycho-social factors
- political factors
- cultural factors
- language factors

These factors influence what information must be stored (liability), or must not be stored (privacy), how information is to be presented and exchanged, who may access that information, et cetera.

The *archiving* of images and information in a robust and reliable way is a highly specialized activity. The storage of information in such a way that it survives fires, floods, and earthquakes is not trivial[2]. Specialized service providers offer this kind of storage, where the service is location-independent thanks to the high-bandwidth networks.

All of these application functions build on top of readily available IT components: the *base technology*. These IT components are innovated rapidly, resulting in short component life-cycles. Economic pressure from other domains stimulate the rapid innovation of these technologies. The amount of domain-specific technology that has to be developed is decreasing, and is replaced by base technology.

Figure 5 comes from the same report [1] showing the information flow within this reference model. During this flow the clinical value is increasing: annotations, comments, and anamnesis can be added during and right after the acquisition. The preparation for the diagnosis adds analysis results, optimizes layout and presentation settings, and pre-selects images. Finally the diagnosis is the required added value, to be delivered to the referring physician.

At the same time the richness of the image is decreasing. The richness of the image is how much can be done with the pixels in the image. The images after acquisition are very rich, all manipulation is still possible. When leaving the acquisition system the image is exported as a system independent image, where a certain

[2]Today terrorist attacks need to be included in this list full of disasters, and secure needs to be added to the required qualities.

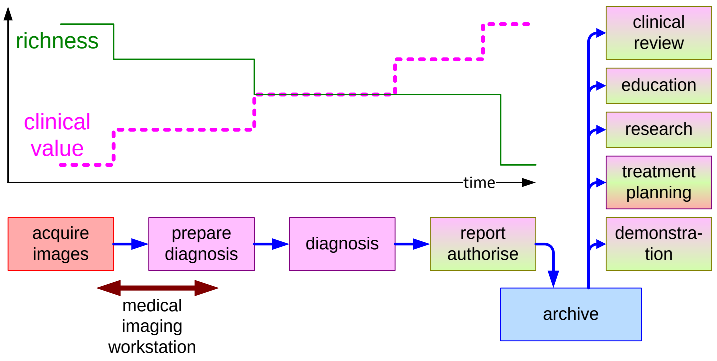

Figure 5: Clinical information flow

trade-off between size, performance, image quality, and manipulation flexibility is made. This is an irreversible step in which some information is inherently lost. The results of the preparation for diagnosis are often frozen, so that no accidental changes can be made afterwards. Because this is the image used to diagnose, it is also archived to ensure liability. The archived result is similar to an electronic photo, only a limited set of manipulations can still be performed on it.

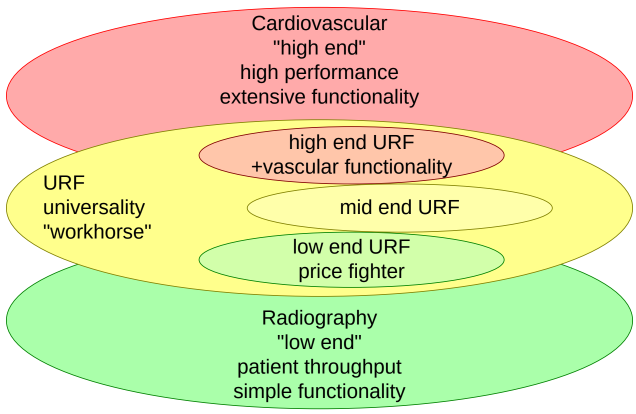

Figure 6: URF market segmentation

The first releases of the medical imaging workstation, as described in this case, are used in conjunction with URF (Universal Radiography Fluoroscopy) systems. This family of systems is a mid-end type of X-ray system, see Figure 6. At the high end cardiovascular systems are used, with high clinical added value and a corresponding price tag. At the low end "radiography" systems offer straight forward imaging functionality, oriented at patient throughput. Approximately 70% of all

X-ray examinations are radiographic exposures.

The URF systems overlap with cardiovascular and radiography market segments: high end URF systems also offer vascular functionality. Low end URF systems must fit in radiography constraints. The key driver of URF systems is the universality, providing logistic flexibility in the hospital.

3 Typical Case

The specification and design of the medical imaging workstation was based on "typical" cases. Figure 7 shows the typical case for URF examinations. Three examination rooms are sharing one medical imaging workstation. Every examination room has an average throughput of 4 patients per hour (patient examinations are interleaved, as explained below for Figure 8).

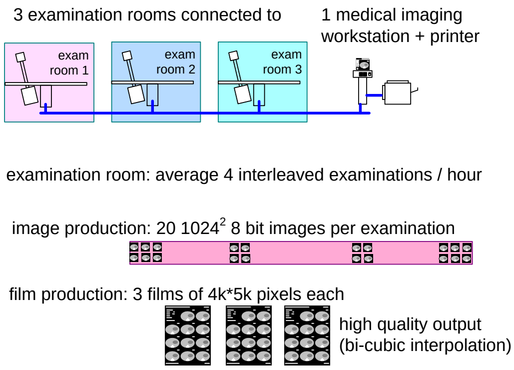

Figure 7: Typical case URF examination

The average image production per examination is 20 images, each of 1024^2 pixels of 8 bits. The images are printed on large film sheets with a size of approximately $24 * 30cm^2$. One film sheet consists of 4k by 5k pixels. The images must be sufficiently large to be easily viewed on the lightbox. These images are typically printed on 3 film sheets. Image quality of the film sheets is crucial, which translates into the use of bi-cubic interpolation.

Figure 8 shows how patient examinations are interleaved. The patient is examined over a period of about one hour. This time is needed because the barium meal progresses through the intestines during this period. A few exposures are made during the passage of clinical relevant positions. The interleaving of patients in a single examination room optimizes the use of expensive resources. At the level of the medical imaging workstation the examinations of the different examination rooms are imported concurrently. The workstation must be capable of serving all three acquisition rooms with the specified typical load. The latency between the

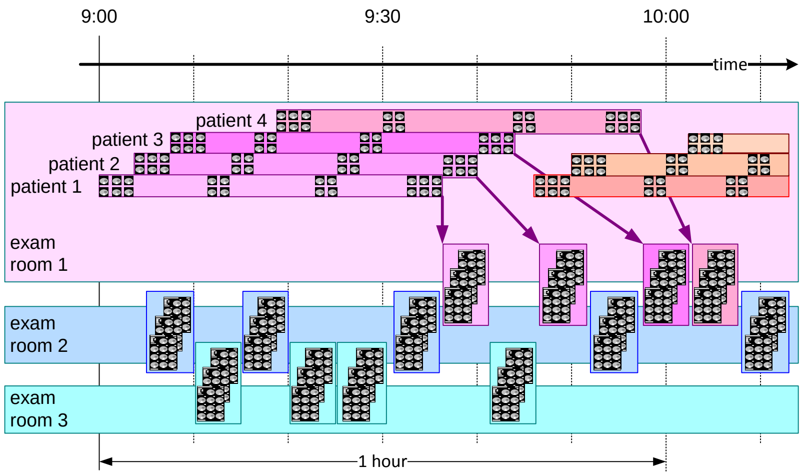

Figure 8: Timing of typical URF examination rooms

end of the examination and the availability of processed film sheets is not very critical.

4 Key Driver Graph

Figure 9 shows the key drivers from the radiologist point of view, with the derived application drivers and the related requirements, as described in Section **??**. The graph is only visualized for the key drivers and the derived application drivers. The graph from application drivers to requirements is a many-to-many relationship, that becomes too complex to show in a single graph.

The key drivers are discussed in Subsections 4.1 to 4.5.

4.1 Report Quality

The report quality determines the satisfaction of the referring physician, who is the customer of the radiologist. The layout, accessibility, and all these kind of factors determine the overall report quality. The radiologist achieves the report quality by:

selection of relevant material The selection of the material to be reported to the referring physician determines to a large degree the report quality.

use of standards The use of standard conventions, for instance pathology classification, improves the report quality.

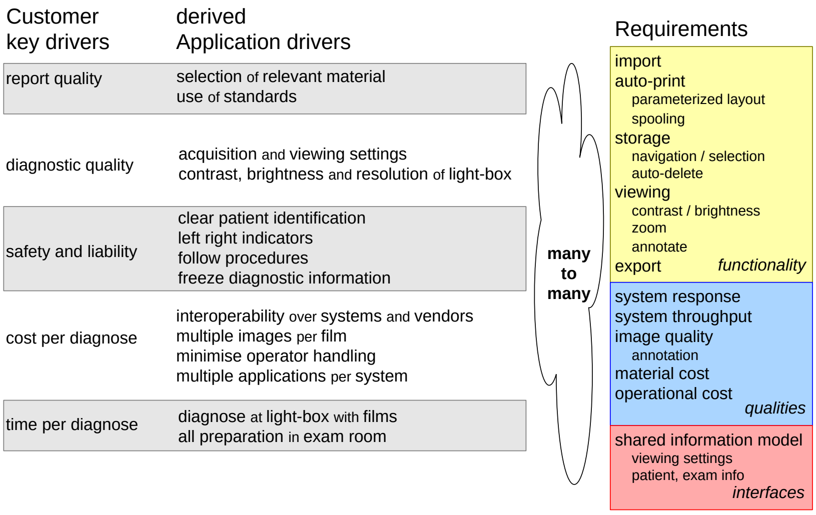

Figure 9: Key drivers, application drivers and requirements

4.2 Diagnostic Quality

The diagnostic quality is the core of the radiologist's work. The diagnostic quality is achieved by:

acquisition and viewing settings The actual acquisition settings and the related viewing settings have a great impact on the visibility of the pathology and anatomy.

contrast, brightness and resolution of lightbox The lightbox has a very good diagnostic image quality: high brightness, high resolution, and many images can be shown simultaneously.

4.3 Safety and Liability

Erroneous diagnoses are dangerous for the patient; the radiologist might be sued for mistakes. Also mistakes in the related annotations (wrong patient name, wrong position) are a safety risk for the patient and hence a liability risk for the radiologist. The derived application drivers for safety and liability are:

clear patient identification Erroneous patient identification is a safety risk.

left right indicators Erroneous positioning information is a safety risk. Left-right exchanges are notoriously dangerous.

follow procedures Clinical procedures reduce the chance of human errors. Following these procedures lowers the liability for the radiologist.

freeze diagnostic information Changing image information after the diagnosis is a liability risk: different interpretations are possible, based on the changes.

4.4 Cost per Diagnosis

Insurance and government generate a lot of cost pressure. Cost efficiency can be expressed in cost per diagnosis. The cost per diagnosis is reduced in the following ways:

interoperability over systems and vendors Mix and match of systems, not constrained by vendor or system lock-ins, allow the radiology department to optimize the mix of acquisition systems to the local needs.

multiple images per film Film is a costly resource (based on silver). Efficiency of film real estate is immediately cost efficient. A positive side effect is that film efficiency is also beneficial for viewing on the lightbox, because the images are then put closer together.

minimize operator handling Automation of repeated actions will reduce the amount of personnel needed, which again is a cost reduction. An example is the use of predefined and propagated settings that streamline the flow of information. This is a cost reduction, but most of all it improves the convenience for the users.

multiple applications per system Universality of acquisition system and workstation provides logistics flexibility in the radiology department. This will in the end result in lower cost.

4.5 Time per Diagnosis

Time efficiency is partially a cost factor, see 4.4, but it is also a personal satisfaction issue for the radiologist. The time per diagnosis is reduced by the following means:

diagnose at lightbox with films This allows a very fast interaction: zooming is done by a single head movement, and the next patient is reached by one button, that exchanges the films mechanically in a single move.

all preparation in exam room The personnel operating the examination room also does the preparation for the diagnosis. This work is done on the fly, interleaved with the examination work.

4.6 Functional Requirements

The functionality that is needed for to realize the derived application drivers is:

import The capability to import data into the workstation data store in a meaningful way.

autoprint The capability to print the image set without operator intervention:

- **parametrized layout** Film layout under control of the remote acquisition system.
- **spooling** Support for concurrent import streams, which have to be printed by a single printer.

storage The capability to store about one day of examinations at the workstation, both as a buffer and to enable later review:

- **navigation/selection** The capability to find and select the patient, examination and images.
- **autodelete** The capability to delete images when they are printed and no longer needed. This function allows the workstation to be used in an operator free server. The import, print and auto-delete run continuously as a standard sequence.

viewing All functions to show and manipulate images, the most frequently used subset:

- **contrast/brightness** Very commonly used grey-level user interface.
- **zoom** Enlarge part of the image.
- **annotate** Add textual or graphic annotations to the image.

export Transfer of images to other systems.

Note that the *import*, *storage* and *autoprint* functionality are core to satisfy the key drivers, while the viewing and export functionality is only *nice to have*.

4.7 Quality Requirements

The following qualities need to be specified quantitatively:

system response Determines the speed and satisfaction of preparing the diagnosis by means of the workstation.

system throughput As defined by the typical case.

image quality Required for preparation of the diagnosis on screen and for diagnosis from film. Specific quality requirements exists for the relation between image and annotation:

annotation The relation between annotation and image is clinically relevant and must be reproducible.

material cost The cost price of the system must fit in the cost target.

operational cost The operational cost (cost of consumables, energy, et cetera) must fit in the operational target.

4.8 Interface Requirements

Key part of the external interfaces is the shared information model that facilitates interoperability between different systems. The cooperating systems must adhere to a shared information model. Elements of such an information model are:

viewing settings Sharing the same presentation model to guarantee the same displayed image at both systems.

patient, exam info Sharing the same meta information for navigation and identification.

5 Functionality

Figure 10 shows a retrospective overview of the development of functionality over time. The case described here focuses on the period 1992, and 1993. However the vision of the product group was to design a platform that could serve many applications and modalities. The relevance of this retrospective overview is to show the expected (and realized!) increase of functionality.

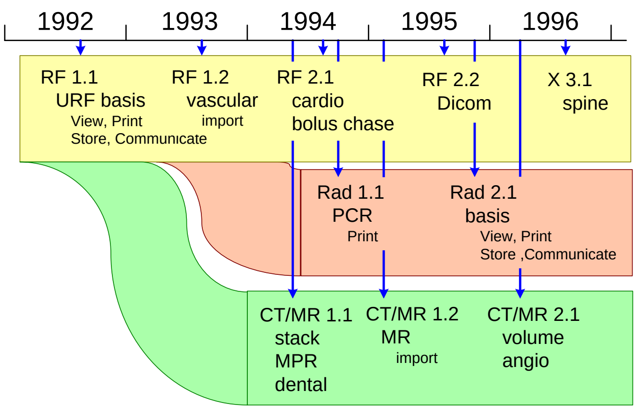

Figure 10: Retrospective functionality roadmap

The first release of the product served the URF market and provided the so-called view-print-store-communicate functionality. We already saw in figure 9 that a lot of functionality is hidden in this simple quartet.

Release 1.2 added import from vascular systems to the functionality. Cardio import and functionality and bolus chase reconstruction were added in release 2.1. Cardio functionality in this release consisted mostly of analysis functions, such as cardiac volume and wall motion analysis. The bolus chase reconstruction takes a series of exposures as input an fuses them together into a single large overview, typically used to follow the bolus chase through the legs.

Release 2.2 introduced DICOM as the next generation of information model standard. The first releases were based on the ACR/NEMA standard, DICOM succeeded this standard. Note that the installed base required prolongation of ACR/NEMA-based image exchange. Release 3.1 added spine reconstruction and analysis. The spine reconstruction is analogous to the bolus chase reconstruction, however spine specific analysis was also added.

On the basis of the URF-oriented R1.1 workstation a CT/MR workstation was developed, which was released in 1994. CT/MR images are slice-based (instead of projection-based as in URF), which prompted the development of a stack view application (fast scrolling through a stack of images). Reconstruction of oblique and curved slices is supported by means of MPR (Multi Planar Reformatting). A highly specialized application was built on top of these applications. This was a dental package, allowing viewing of the jaws, with the molars, and with the required cross sections.

Release 2.1 of the CT/MR workstation added a much more powerful volume viewing application and a more specialized angio package, with viewing and analysis capability.

Also derived from the RF workstation a radiography workstation was built. R1.1 of this system was mostly a print server, while R2.1 supported the full view-print-store-communicate functionality.

The *commercial*, *service* and *goods flow* decompositions were present as part of the formalized documentation (TPD).

6 Interoperability via Information Model

The health care industry is striving for interoperability by working on standard exchange formats and protocols. The driving force behind this standardization is the ACR/NEMA, in which equipment manufacturers participate in the standardization process.

Standardization and innovation are often opposing forces. The solution is often found in defining an extendable format. and in standardization of the mature functionality. Figure 11 shows the approach as followed by the medical imaging

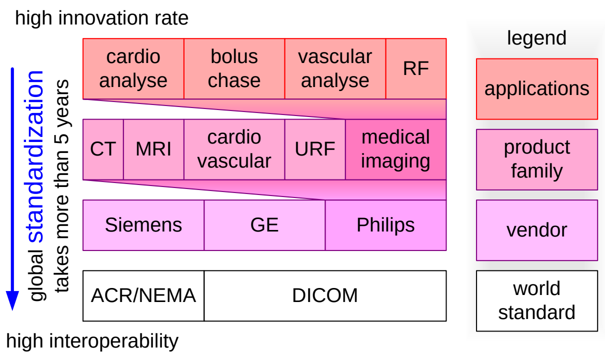

Figure 11: Information model, standardization for interoperability

product group. The communication infrastructure and the mature application information is standardized in DICOM. The new autoprint functionality was standardized at vendor level. Further standardization of autoprint is pushed via participation in DICOM work groups.

A good strategy is to use the standard data formats as much as possible, and to build vendor specific extensions as long as the required functionality is not yet standardized. The tension between standardization and innovation is also present at many levels: between vendors, but also between product groups in the same company and also between applications within the same product. At all levels the same strategy is deployed. Product family specific extensions are made as long as no standard vendor solution is available.

This strategy serves both needs: interoperability for mature, well defined functionality and room for innovative exploration.

The information model used for import, export and storage on removable media is one of the most important interfaces of these systems. The functionality and the behavior of the system depend completely on the availability and correctness of this information. The specification of the information model and the level of adherence and the deviations is a significant part of the specification and the specification effort. A full time architect created and maintained this part of the specification.

7 Conclusion

The context of the system in the radiology department has been shown by means of multiple models and diagrams: clinical context with stakeholders, financial context, application layers in IT systems, a reference model for health care automation, clinical information flow, and URF market segmentation. Figure 12 shows the coverage in actual documentation of the submethods discussed in part II. The actual documentation of the *Customer Objectives* and *Application* views was quite poor, as indicated in Figure 12. Most of the models and diagrams shown here were not present in the documentation of 1992. The application of the system has been shown as typical case. The typical case was documented explicitly in 1992. The key driver graph, discussed in Section 4, is also a reconstruction in retrospect. The limited attention for the *Customer Objectives* and *Application* views is one of the main causes of the late introduction of printing functionality.

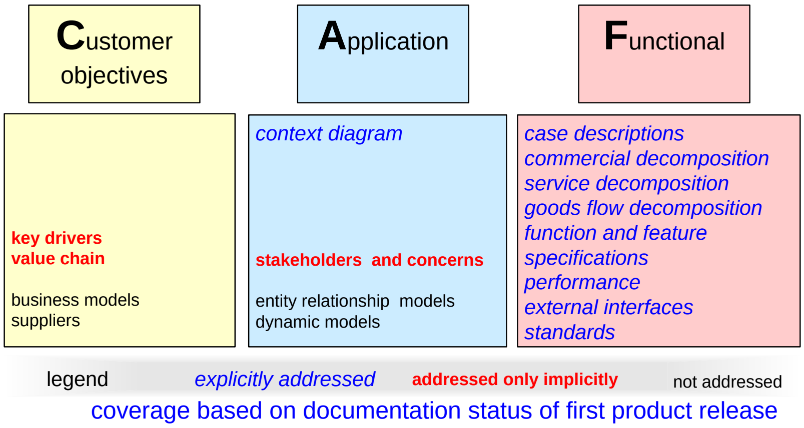

Figure 12: Coverage of submethods of the CAF views

The functional view was well documented in 1992. The functions and features have been discussed briefly in Section 5. The functions and features were well documented in so-called *Functional Requirement Specifications*. Interoperability, discussed briefly in Section 6, was also documented extensively. Figure 12 shows that the coverage of the *Functional* view is high.

8 Acknowledgements

Some of the figures are based on material of the PACS assessment team, with Gerardo Daalderop, Ann Ouvry, Luc Koch, Peter Jaspers, Jürgen Müller and myself.

References

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[2] Remco M. Dijkman, Luï¿½s Ferreira Pires, and Stef M.M. Joosten. Calculating with concepts: a technique for the development of business process support. In A. Evans, R. France, A. Moreira, and B. Rumpe, editors, *Lecture Notes in Informatics*, volume 7, pages 87–98. GI-edition, 2001. http://www.google.com/url?sa=U&start=3&q=http://www.ub.utwente.nl/webdocs/ctit/1/00000068.pdf&e=7764 Proceedings of the UML 2001 Workshop on Practical UML-Based Rigorous Development Methods.

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History

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- small textual changes
- moved text about decompositions from the conclusion to the section Functionality.
- changed status to finished

Version: 1.3, date: March 1, 2004 changed by: Gerrit Muller

- added reference to Calculating with Concepts and a discussion paragraph.

Version: 1.2, date: February 27, 2004 changed by: Gerrit Muller

- added sections “Introduction” and “Conclusion”
- changed status to concept

Version: 1.1, date: November 6, 2003 changed by: Gerrit Muller

- many small text improvements in Section ”Key Driver Graph”

Version: 1.0, date: November 4, 2003 changed by: Gerrit Muller

- more structure and text in Section ”Key Drivers”
- changed name of Section ”Key Drivers” in ”Key driver Graph”
- many small text improvements
- changed status in draft

Version: 0.1, date: November 3, 2003 changed by: Gerrit Muller

- many small text improvements
- changed status in preliminary draft

Version: 0, date: February 11, 2003 changed by: Gerrit Muller

- Created, no changelog yet