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# System Evolution Barriers and How to Overcome Them!

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## Abstract

Creating complex systems from scratch is time consuming and costly, therefore a strategy often chosen by companies is to evolve existing systems. Yet evolving a system is also complicated. Complex systems are usually the result of multidisciplinary teams, therefore it is essential to understand barriers those teams face when evolving a system.

From the research carried at Philips Healthcare MRI, we have identified that main evolution barriers employees face are; managing system **complexity**,**communication** across disciplines and departments, finding the necessary **system information**, lack of **system overview**, and ineffective **knowledge sharing**. Those barriers were identified as the root cause of many development problems and bad decisions.

To overcome those barriers, and therefore enhance the evolution process, effective reuse of knowledge is essential. This knowledge must be presented in a fashion that can be understood by a broad set of stakeholders. In this paper system evolution barriers and a method to effectively deal with them, based on the creation of **A3 Architecture Overviews**, is presented.

## Introduction

System requirements change over time; consequently, companies need to develop new products to cope with those changes. Since developing a system from scratch is time consuming and costly, new systems are often created by evolving an existing system (Borches and Bonnema 2009). However, the effort and resources required to adapt complex systems to changing requirements can be significant. Products have increased complexity over the years, as well as the organizations that develops them. This complexity causes non-trivial dependencies across system and organizational boundaries. As a result, a change may have unexpected consequences due to dependencies, unknown or hidden, in the system.

Methods and tools do not evolve systems, humans do (Axelsson 2002). Unlike tools, humans can only handle a limited amount of information. In addition, people may perceive the same information in many different ways; different stakeholders have different mental models of the system and problem at hand. Many people have difficulties sharing knowledge across organizational boundaries, and sometimes even with persons in the same office but different backgrounds. There are organizational measures to reduce communication barriers like allocation, project meetings, etc, yet those measures do not eliminate different jargons and do not create a synergetic way or working.

To provide guidance to architect new generations or variations of the system reuse of knowledge is needed. By helping the different disciplines and departments to reuse the knowledge the company already has, they are able to make better informed decisions; enhancing the evolution process. Companies already have a large amount of knowledge about the domain, partially implicit, mainly in the expert's minds, and partially explicit, in the form of documents and repositories. Yet, few companies know how to capture knowledge effectively, and fewer companies know how to reuse that knowledge (Domb and Radeka 2009). Decision making therefore fails to take advantage of the knowledge the company already has.

The main problem is that knowledge is usually not captured effectively. The amount of information available is overwhelming, yet finding the information needed to cope with one's work may require cross search of tens of documents and the relevant information may be hidden in a footnote on the last page of a document.

Creating simple overviews and sketches seem to have recently fallen out of favour, particularly with the advent of ubiquitous computing, information and modern representation technologies. Some companies however have already identified the need for simple yet effective ways to capture information. An 'A3 report' is a tool that Toyota Motor Corporation uses to propose solutions to problems, give status reports on ongoing projects, and report results of information gathering activity. Toyota uses it to systematically guide problem-solvers through a rigorous process, document the key outcomes of that process and propose improvements (Sobek II and Jimmerson 2004, 2005). The challenge is how to reduce the large amount of information spread within the company to manageable proportions, and how to present it in an easy to use way without losing essential details in the process.

In the following sections, the study case; an MRI system will be introduced. Barriers to evolution, obtained from a survey done at Philips Healthcare will be discussed, and our approach to deal with them, based on the creation of A3 Architecture Overviews will be presented. Finally, its application as the new MRI System Designs Specification, and lessons learned will be described.

## Industrial Case: MRI System

Magnetic resonance imaging (MRI) is a medical imaging modality that detects small changes in the magnetism of the atom's nucleus. An MRI system requires a multidisciplinary design team with competences in areas such as mechanics, electronics, physics, software and clinical science (Weishaupt, Köchli, and Marincek 2006). All the disciplines have to work together on different aspects of the design. However, people are usually specialized in a single discipline, and each discipline uses its own vocabulary and communication means. This adds up to the complexity of the design process in a large company such as Philips.


**Figure 1 Philips MRI Evolution (intermediate releases not included)**

As shown in Figure 1, since Philips released the first commercial scanner back in the 80's, despite the challenges, Philips has successfully evolved it several times leading to the present system. The main architecture of the system and the design principles behind it have remained almost unchanged compared to the original system, while implementations and technologies used have changed completely in those 30 years. If "*the test of a good architecture is that it will last*" (Robert

Pinrad, 1993), we can argue that Philips MRI architecture is a good one. The complexity of the system however, has increased exponentially while the organization has grown gradually. Learning curve of new employees is large and steep, while many senior experts that have been working since prototype days will soon be leaving the company. The need to reuse existing knowledge to provide guidance and prevent problems is more relevant than ever. Taking all this into account, we believe the MRI system is an ideal case to study the evolution barriers of complex systems.

## System Evolution Barriers

To better understand challenges to system evolution in an industrial environment, we have conducted a survey to Philips Healthcare employees. The target of this questionnaire was the MRI development organization (~250 employees), where 35 people (~1/7 of the population) filled in a questionnaire with ~40 questions. The questionnaire addressed the main development challenges and the effectiveness of the current way to consolidate design knowledge.

For the analysis, as shown in Table 1, a classification according to job title and MRI experience was made[1]. In most questions the surveyed was asked to fill in whether he/she agreed or disagreed with the statement presented. In some questions quantification was requested. Questions that were left empty were considered to be 'don't know' answers, and there was room in the survey to express additional concerns about the topic under discussion. Based on the responses obtained from the questionnaire, a detailed analysis of each question was performed.

[1] The Domain Expert group may lack representation. It could be argued that this group could be aggregated to other group, however we have left this group independent as their input is quite different from the rest of the population, deserving special attention. There are few domain experts within Philips.

JOB TITLE

| | |
|---|---|
| **Manager / Leaders** | **8** |
| **Architects** | **5** |
| **Engineers** | **10** |
| **Designers** | **7** |
| **Domain Experts** | **2** |
| **Other** | **3** |
| **TOTAL** | **35** |

MRI EXPERIENCE

| | |
|---|---|
| **<5 years experience** | **4** |
| **5<years<10 experience** | **13** |
| **10<years<20 experience** | **9** |
| **>20 years experience** | **9** |
| **TOTAL** | **35** |

**Table 1 Philips Healthcare Surveyed Employee Profile[2]**

As shown in Table 2, the analysis provided; a) **Question / Statement from questionnaire**; b) **General analysis from response,** describing general findings extracted from this question; c) **Analysis per working title,** describing findings per working title group. To know which group agrees/disagrees with the question / statement, positive responses (strongly agree & agree) were collected by working title; d) **Analysis per MR experience,** describing findings per MR experience group**. P**ositive responses are collected by MR experience; e) **Conclusions,** providing a compilation of individual findings.

From the questionnaire it was found that main evolution barriers are; managing system **complexity**, **communication** across disciplines and departments, finding the necessary **system information**, lack of **system overview**, and ineffective **knowledge sharing**. Those barriers were identified as the root cause of many development problems and bad decisions when dealing with new developments.

[2] Credibility statistics were included in the detailed analysis. They are not depicted here as our main interest is the insight obtained from the survey.

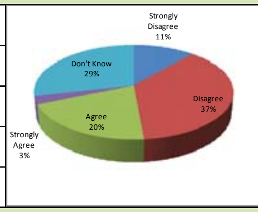
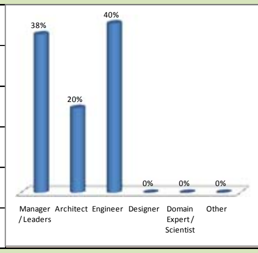
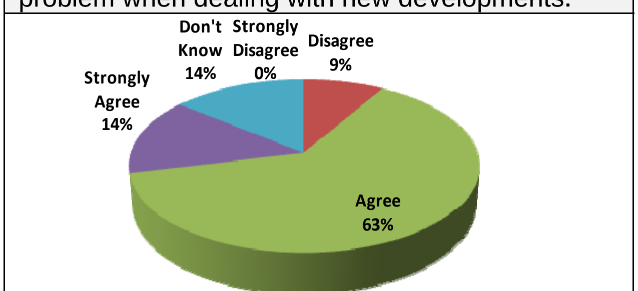
| | | | | |
|---|---|---|---|---|
| The SDS provides the necessary knowledge to understand MR principles outside my domain of expertise | | | | a) |
| General | | | Findings | b) |
| Strongly Disagree | 11% |   | There is some tension here. Ther is a group that thinks it does provide the necessary knowledge, however, the mayority think it does not. It is worth to notice that a considerable group thinks it does not provide the knowledge. | |
| Disagree | 37% | | | |
| Agree | 20% | | | |
| Strongly Agree | 3% | | | |
| Don't Know | 29% | | | |
| Per working title (Strongly Agree/Agree) | | | Findings | c) |
| Manager / Leaders | 38% |   | Seems that the SDS only provides knowledge to Manager and Engineerts. | |
| Architect | 20% | | | |
| Engineer | 40% | | | |
| Designer | 0% | | | |
| Domain Expert / Scientist | 0% | | | |
| Other | 0% | | | |
| Per MR experience (Strongly Agree/Agree) | | | Findings | d) |
| <5 Years experience | 0% |   | The more experience, the less knowledge the SDS provides. | |
| 5< Years <10 experience | 38% | | | |
| 10< Years <20 experience | 22% | | | |
| Since MR Proton | 11% | | | |
| Conclusions | | | | e) |
| There is some tension here. Ther is a group that thinks it does provide the necessary knowledge, however, the mayority think it does not. It is worth to notice that a considerable group thinks it does not provide the knowledge.Seems that the SDS only provides knowledge to Manager and Engineerts. The more experience, the less knowledge the SDS provides. | | | | |

**Table 2 Survey Analysis**

***Question:*** MRI system complexity is a problem when dealing with new developments.

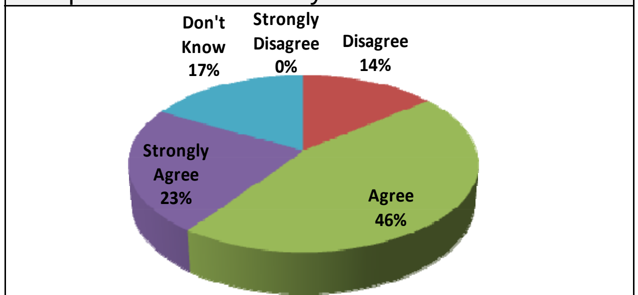



***Remarks:*** All disciplines think alike. Experienced employees feel the same as new employees.

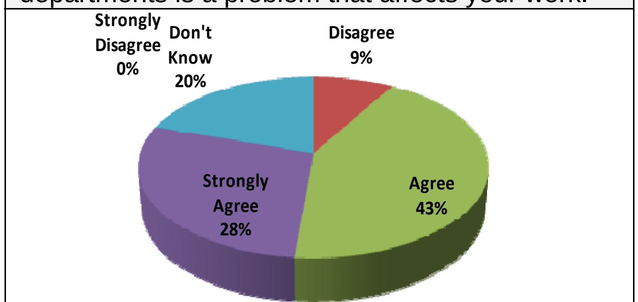
**Figure 2 System Complexity**

As shown in Figure 2 we see that system complexity is perceived as a problem when dealing with new developments[3]. This problem affects all disciplines alike, regardless the experience employees have.

***Question:*** Communication across disciplines is a problem that affects your work.




***Question:*** Communication across departments is a problem that affects your work.




***Remarks:*** All disciplines think alike. Having more experience does not ease the communication problem.

**Figure 3 Communication across Disciplines and Departments**

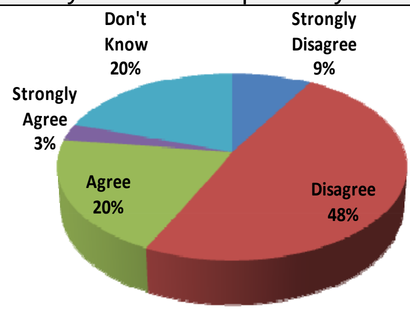
From Figure 3, we see that communication across disciplines and departments is a problem that affects people's work. We found that as different disciplines and departments have different views and interests about the system, the absence of a common view make hard for employees to understand other points of view.

As shown in Figure 4, finding the information in the company to cope with one's work is perceived as a problem. Most employees cannot easily find the information they need. Managers and domain experts seem to suffer this problem less than other groups, however designers cannot find the information at all, while most architects and engineers have also difficulties finding the information. Experience does not help finding the

[3] This may not be surprising taking into account that Philips MRI group has ~250 developers, 3 main development sites across the word, MRI system uses ~50 different technologies, has ~7 million lines of code, etc.

information at all, on the contrary, seems to be more difficult.

***Question:*** You can easily find the system information you need to cope with your work.

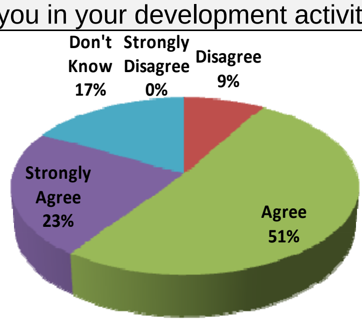



***Remarks:*** Managers and Domain Experts seem to suffer this problem less than the rest of the disciplines. Experienced employees have more difficulties finding the information than newly employees.

**Figure 4 Finding System Information**

As an example, we found that the ample majority of employees did not know the budget they have for a design aspect and the rationale for it. Although all architects knew the relation between design principles and derived budgets, almost no designer or engineer knew this relation. This kind of knowledge was found to be related to experience; the more experience employees have, the more clear this relation is.

***Question:*** Having a System Overview supports you in your development activities




***Remarks:*** Engineers is the group that most lack this system overview. Many Designers don't have a system overview either. Experience does not play a role.

**Figure 5 Need of Overview**

Without any doubt, as shown in Figure 5, having a system overview is considered very important to support development. Although half of the employees claimed to have a system overview, there was a large group which didn't have it. Whereas architects had this overview (due mainly to experience) engineers and many designers did not. Those overviews however were mostly only in their minds, and not documented nor explicit.

***Question:*** Have you or your team had situations in which having more available knowledge of a specific design principle would have prevented a problem or helped to make a better decision?

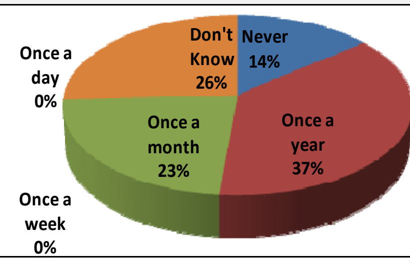



**Figure 6 Knowledge Sharing**

Many employees claimed they were familiar with most MRI design principles. While all architects and most engineers were aware of them, only a small group of designers claimed to knew them (14%). It was clear that the more experience the more familiar employees became with design principles. Yet, from Figure 6 it is shown that not having enough knowledge of those design principles caused many problems and bad decisions. With this finding, we prove management that there is a clear link between the lack of knowledge sharing and many problems or bad decisions that could have been prevented if an effective way to capture and share this knowledge had been in place.

The reaction to the survey findings was, as stated by Philips' management, *"you have <u>not</u> discovered anything new; however you have shown that the magnitude of the issue is <u>bigger</u> than we thought, and consequently deserves special attention"*. After some discussions with representatives from other companies about those findings, we believe this is a common situation in most companies.

### *Philips MRI SDS*

With the questionnaire, we also investigated how effective current ways to capture design knowledge was according to employees. A System Design Specification (SDS) is used by companies in the development process to consolidate design specifications, to support 'development memory' and for educational purposes. It is usually the **main description of the system's design**. It is meant to specify how requirements are met. It serves to consolidate the partitioning of the system into design entities; mapping of requirements onto system elements and define interfaces between them, budget between components when they need to cooperate, description of the behaviour, etc. SDS vary on structure and style from company to company, but they all have one thing in common; they are large text documents with few drawings in them.

From the questionnaire we found that approximately half of the organization was familiar with the SDS. Clearly most employees believe the SDS is meant for designers and architects and to some extent by engineers. Managers were clearly not considered a user of the SDS (yet we found they use it more than any other group). As shown in Figure 7, current SDS is seldom used, mostly once a year by the majority and once a month for a small group. One reason for this lack of use, as shown in Figure 8 might be that most employees do not find the SDS useful.

***Question:*** You use the system design specification (SDS)…

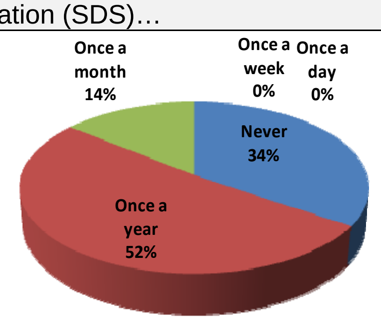
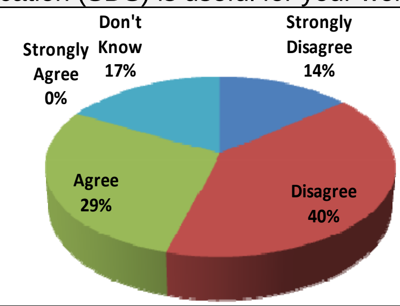



**Figure 7 SDS Use**

As shown in Figure 8, only 29% of employees found some use for it; designers did not find current SDS document useful at all, while architects and engineers found it seldom useful. Only half of managers and domain experts, which are not targeted users of the SDS, found it useful. In addition, we found that the SDS document was only useful for employees with little experience in MRI.

***Question:*** Current system design specification (SDS) is useful for your work



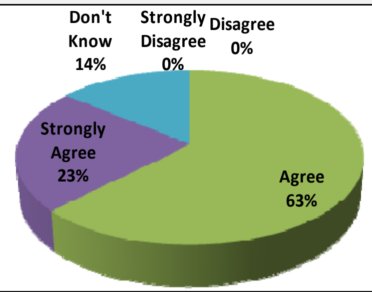

***Remarks:*** Designers do not find the document useful at all, while Architects and Engineers find it seldom useful. Only Managers and Domain Experts find it useful. It seems to be more useful to employees with little experience in MRI.

**Figure 8 SDS Utility**

Regarding whether the SDS provides enough knowledge about design principles outside the user's domain of expertise, there was some tension here. There was a group that thinks it does provide the necessary knowledge (23%); however, the majority thought it does not (48%). Seems that the SDS only provides this kind of knowledge to managers and engineers. We found that managers obtain the overview they need from the SDS. Remarkably, as shown in Figure 9, almost all employees think the SDS use should be encouraged, even when they think it is not useful.

When looking for alternatives to the SDS, employees seemed troubled. 40% of employees stated that there were probably better ways than the SDS, however for many there were hardly better ways (31%) and for some there are no other alternatives (9%). Architects have found their way to find the information about the system they need without relying on the SDS. Designers and engineers on the other hand, find very hard to find the information they need for their work. Managers see the SDS as the main source to get insight on the system (that may be the reason why the use it more than designers and architects).

***Question:*** The use of the system design specification (SDS) should be encouraged within the organization.




***Remarks:*** All disciplines think alike.

**Figure 9 SDS Value**

From all mentioned above, we can conclude that although the SDS is perceived as very important to provide the overview needed to the MRI development group, it fails to fulfil its purpose.

## Overcoming Evolution Barriers

As stated in (Retching and Maier 2000), "*if you do not understand the existing system, you can't be sure you're re-architecting a better one*", it is to say, the first step towards evolving a system is understanding the existing system. (Churchman 1968) stated that *"how can we design improvement in large systems without understanding the whole system, and if the answer is that we cannot, how is it possible to understand the whole system?"*, highlighting the need of keeping a system view to evolve or improve a system. Maintaining a system's viewpoint is important to see how the parts fit into the larger picture and affects other parts of the system.

However, even with a system view, from the psychology field we have learnt that; "*If the concepts in the mind of one person are very different from those in the mind of the other, there is no common model of the topic and no communication*" (Taylor and Fiske 1975). Every person sees the world differently. Mental representations of reality are therefore different, and each individual tends to believe his or her representation is the 'right' one. Hence, for effective communication a common model that represents the system close to the concept in the mind of the reader is needed. The most widely-used form of communication is the drawing. Drawings and visual representations range from rather general descriptions that give an 'overview' of the system, to the most specific that use precise details. The graphical medium can contain a very dense amount of information, and yet readers can pick it up quickly because of the pictorial representation.

Finally, it should also be taken into account that we humans can only handle a limited amount of information; an overview is needed. In an overview, only relevant information is present (Bonnema and Borches 2008). This overview should be structured, in order to speed up communication and aid in establishing shared understanding.

### *A3 Architecture Overviews*

The main goal of an A3 architecture overview is to have a manageable representation of the knowledge related to a system aspect, enabling stakeholders to reason and communicate the consequences of system changes. For that, we have proposed an method to collect, abstract and present knowledge to support decision making during the evolution of complex systems (Borches and Bonnema 2010). The method leads towards the creation of A3 Architecture Overviews. This method causes multiple pieces of information from different sources to be integrated into a coherent picture of the situation. This may not be the perfect solution to overcome evolution barriers, but we do think it is a step into the right direction.

An A3 (metric equivalent of 11” x 17”) is used as a means to keep only relevant information and provide overview. The point of brevity is to force synthesis of the knowledge. The A3 paper size works well for presenting the essential elements of a system topic, with enough information to make a decision about it. Larger sizes contain too much information, and the large paper format can become cumbersome. An A3 has enough room for a concise chunk of knowledge and fits well within the average person’s field of view. Readers may focus on one part of it at a time, but they can always see the whole. The guiding principle behind the A3 is to include whatever information is needed to create a complete picture of the issue at hand, and eliminate everything else until only the essentials remain.

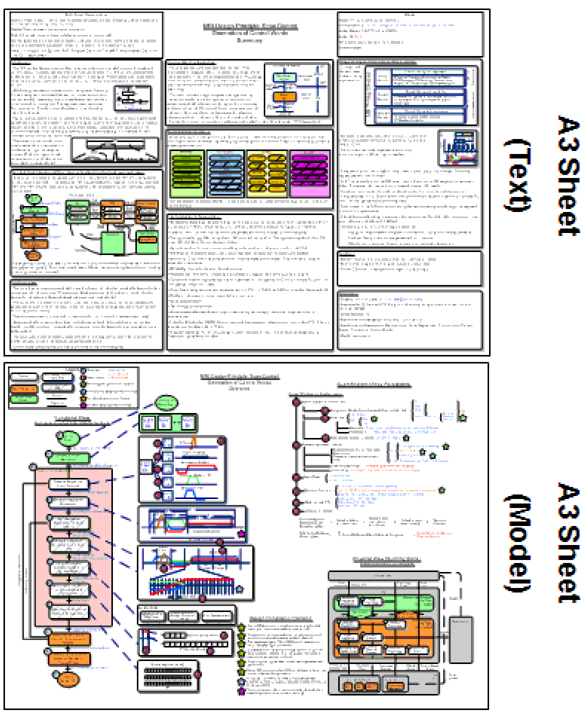



**Figure 10 A3 Architecture Overview example**

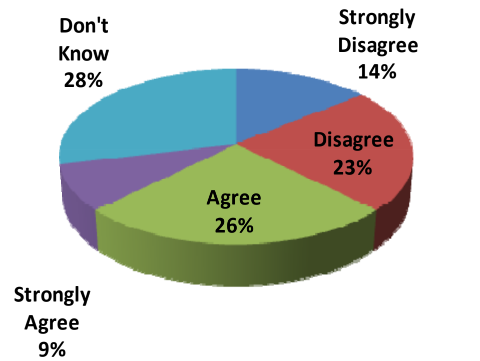
The flow of the A3 Architecture Overview is, as shown in Figure 10, on the A3 textual view from top-to-bottom and left-to-right. Each section is clearly labelled and enclosed in a box. In the A3 model view, in the left part is always the **functional view** and the **visual aid**, while in the right-bottom is the **physical view**, and in the right-top is the **quantification view**. **Design constraints and choices** are written in the available room of the A3. A system view is always used as a starting point. The model view facilitates alignment of thinking among stakeholders because the drawings become the point of discussion, pointing to the part they agree or disagree with. The text view support the model view by providing additional structured information to clarify and extend the information provided by the model. This view also provides links to other resources such as experts or documents to broaden knowledge.

Providing structure to the A3 improves readability and comprehension. Common elements in the A3 help the reader identify at a glance whether or not the architecture overview of this system aspect is of any interest, and find out quickly where the specific information is.

## *Application: New Style SDS*

From the questionnaire it was concluded that a change in the SDS format was required. As shown in Figure 11, whether to stick to a text document or move to a model format seemed unclear. From the analysis we found that managers and domain experts preferred a text-based document, while targeted SDS users (designer, architects and engineers) wanted to move to a model-based description of the system. Regarding whether to use a standard formal notation, as shown in Figure 12, we found that many preferred not to use them. We discovered that those who where in favour of standard formal notations were mostly employees with a software background (which are already familiar with standard notations such as UML). It was concluded that the model-based description should not use standard formal notation as they may lead to communication barriers.

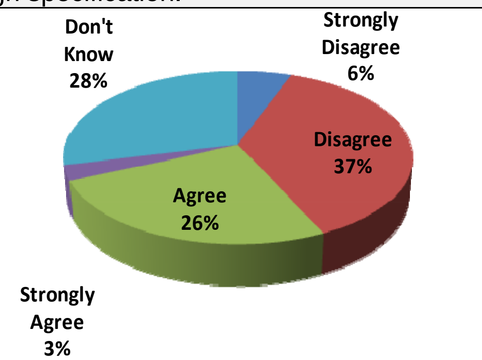
***Question:*** A text document is preferred to a model-based description for the system design specification.




***Remarks:*** Managers and Domain Experts prefer to stick to text-based documents, while most Designers and Architects prefer to move to a model-based description. Many Engineers also prefer a model-based description.

**Figure 11 Preferred Format**

***Question:*** Standard formal notation (e.g. SysML, UML) should be used in the system design specification.




***Remarks:*** Employees with software background prefer to use standard formal notations, while employees with a different background prefer not to use them.

**Figure 12 Standard Formal Notation**

From all mentioned above, it was decided that the A3 Architecture Overview style would be introduced as a way to consolidate the system knowledge and becoming the new SDS style. A 'proof of concept SDS' was developed to assess the benefits and concerns of the new style. For this proof of concept SDS, seven A3 Architecture Overviews were created for three different MRI system aspects. They were used in ongoing projects to evaluate their utility.

## Lessons Learned

It was stated by users that one of the main values of the A3 Architecture Overviews is that they enable to get more insight on the system. This in itself has a great value during the development process as *"one insight is worth a thousand analysis"* (Charles W. Sooter, 1993).

Although we have not reduced system complexity, we hope to have leverage its effects by providing a manageable way to describe the system. Complex designs are now described in structured A3s that are accessible to all employees.

For project meetings, A3 architecture overviews were populated among the members. The first reaction of those not used to the A3 layout was to complain about the new format (hard to fit in the screen, problems with the printers, etc). However in later meetings we observed that them all had read and studied the A3 provided (maybe out of curiosity), while they didn't read the equivalent text document that was also provided. This situation happened several times, leading us to the conclusion that the A3 is the maximum amount of information employees are willing to read to prepare for a meeting or discussion.

People attended meetings with plenty of annotations in the A3, triggering discussions and improving the A3 contents, proving that it is a good tool for rich discussions. The model view helped discussions while the text part helped broaden the information on individual use. People of different backgrounds were able to use them without much explanation. Unlike the equivalent views provided in SysML formats, discussions in the A3 model view started right away. It is to say, we had less waste of time through more focused and productive meetings.

From the management point of view, it become clear that this new style improved maintainability and upgradeability of the design specification. New A3s could be added without having to touch the ones already created, and future SDS could reuse much of existing A3s.

## Acknowledgements

The research is conducted in cooperation with the MRI group of Philips Healthcare. We thank all the experts from Philips Healthcare for their support and contributions. We want to thank specially Phil van Liere for the time and effort dedicated to this project. We also want to thank the support of Gerrit Muller and other members of the Darwin project.

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## Biography

**P. Daniel Borches** received his Master's degree in Telecommunication Engineering from the University of Madrid Carlos III in 2004. He has worked several years in companies such as Telefonica R&D and Nokia. From 2006 he is working at Philips Healthcare Netherlands while doing his Ph.D. at the University of Twente. The main focus of his research is Systems Engineering and Systems Architecting applied in the industrial sector.

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