TOWARDS USING THE FUNCTIONAL RESONANCE ANALYSIS METHOD TO BALANCE RESILIENCE AND ADAPTABILITY – A CASE STUDY OF MIGRATING A SOFTWARE PRODUCT INTO THE CLOUD

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Abstract

Cloud computing provides computing resources over the Internet. It has not only advantages such as cost savings but also introduces companies to new risks, e.g. less control over the infrastructure. These risks require companies to become more resilient while increasing their adaptability. To increase the resilience and adaptability, companies need to have complementary organisational changes when adopting cloud computing. Organisational changes are, however, difficult to carry out as explained by the envisioned world problem. By using the Functional Resonance Analysis Method (FRAM) this paper describes how a software vendor migrated one of their software products into the cloud. Two FRAMs were created, one before the migration and one after it, to show which organisational functions were changed in order to accommodate the new technology and wich remained unchanged in order to retain organisational elements employees and customers value. By finding this balance the software vendor was able to use the move to the cloud to become more resilient while increasing their adaptability.

1 INTRODUCTION

Cloud computing is a combination of technologies to provide remotely hosted computing resources. Next to offering many opportunities to software vendors, such as enabling them save costs by outsourcing infrastructure, it also introduces them to new kinds of risks. On the one hand, software vendors take over responsibilities previously held by the customer. Before the cloud, customers would install the software vendor's product in their own data centre and be responsible for it. In the cloud, the product is hosted with the cloud provider and managed by the software vendor. On the other hand, software vendors outsource tasks to the cloud provider over which they have only a limited amount of control. In case the cloud provider's infrastructure fails, the software vendor can do nothing but wait until it is restored. Therefore, cloud computing requires software vendors, and companies generally, to become more resilient while increasing their adaptability in order to be prepared for these new kinds of risks.

Becoming more resilient and adaptable while adopting cloud computing, or any new technology, is challenging, which can be explained by the envisioned world problem. The envisioned world problem states that it is difficult to anticipate the effects of technological change (Woods & Dekker, 2000). In other words, companies do not always know beforehand what organisational changes need to be carried out in order to adopt a new technology successfully. This paper suggests decomposing the envisioned world problem into two categories in order to provide a more structured investigation. The first category, *use uncertainty,* captures the fact that companies increasingly struggle to predict how new software products and technologies will be used because the market evolves more rapidly. People expect to use the latest technologies because they also use them in other areas, e.g. at home (Bughin, 2012) and some of these technologies can be used without the company knowing about them or having feasible ways of controlling the use, e.g. smartphones (Baxter et al., 2012, Manyika et al., 2013). The second category, *technology uncertainty,* captures the fact that technologies, like cloud computing, take away control from companies and give it to a third party over which they have only a limited amount of control. Companies also rely more on bigger and more connected systems (or systems of systems) that are vulnerable to unforeseeable and cascading failure events, e.g. when Amazon's cloud is having an outage it becomes headline news (Northrop et al., 2006).

This paper proposes to use the Functional Resonance Analysis Method (FRAM) to investigate the effects companies experience by use and technology uncertainty during the adoption of a new technology.

Furthermore, this paper argues that companies that are able to dampen the effects of use and technology uncertainty are in a better position to become more resilient while increasing their adaptability. The FRAM, although initially developed for risk assessments and accident investigations, is an ideal tool to investigate the impact of use and technology uncertainty on resilience and adaptability as the FRAM focuses on what a system does rather than how it is structured. In order for companies to become *more* resilient (as companies can only be more or less resilient but never be truly resilient) it has to be made an inherent part of everyone's daily activities. Thus, a higher level of resilience can only be achieved by what people do (where the structure of the system can only support them in doing it, Roberts, 1990). The same can be argued for adaptability.

This paper is structured as follows. The next section explains the implications of use and technology uncertainty on the resilience of companies to understand how they can react to and anticipate organisational changes. The third section describes the elements and steps of a FRAM analysis. The fourth and fifth section describe how the FRAM has been used to analyse organisational changes of a software vendor from the Oil & Gas industry that moved to the cloud. The final section concludes this paper to suggest further research.

2 INCREASING RESILIENCE AND ADAPTABILITY UNDER UNCERTAINTY

By combining ideas from Normal Accident Theory (NAT, Perrow, 1984), High Reliability Organisations (HRO, Roberts, 1990), and dependability (Laprie, 2008) resilience can be defined as the adjustment of a systems functioning to maintain its dependability during changing conditions (Werfs & Baxter, 2013). This definition stresses the close link between the notions of resilience and adaptability: the more resilient a company becomes, the more adaptable they are likely to be (it does not, however, work the other way around!). When companies ignore use and technology uncertainty or do not deal with the effects appropriately, they are likely to experience a negative impact on their resilience and adaptability, as explained in the following.

In the notion of resilience, successes *and* failures both stem from performance variability. Resilience has to be actively maintained over time by adapting: both reacting to change (through feedback loops) as well as anticipating change (through feedforward loops, Hollnagel et al., 2006). A failure can be evaded, for example, when people, systems or organisations are able to use the information, resources and time that is available to anticipate potential risks and make approximate adjustments to their behaviour (Hollnagel, 2009). It can, therefore, best be understood as something a person, system, or organisation does rather than something it has. In today's complex and dynamic environment the conditions of work (i.e. how a system operates) never completely match the way they were designed because it takes several years to implement a system; a time in which the environment and conditions continue to change (Hollnagel & Woods, 2005). People, therefore, play a vital role in maintaining resilience, because they are the ones who are flexible and adaptable by adjusting their behaviour to new information, resources or time constraints (properties that are often lacking in technological systems, Ignatiadis & Nandhakumar, 2007).

People, however, can sometimes become *brittle* in performing their jobs resulting in a decrease in resilience and adaptability. Rasmussen developed the idea that people go through three stages of skilfulness (1983). At the beginning, people perform their jobs on a *knowledge* basis. They face unfamiliar situations and need to analyse the environment, develop plans, and test them. Testing can be done by trial and error, for example. Once people get more familiar with situations, they move to *rule-based* behaviour. People have developed procedures, either through experience or adopted from other people. They are, however, still able to describe explicitly what they are doing. People are not able to describe what they are doing when they move to *skill-based* behaviour. At this stage they are able to perform their jobs in a more automated manner and without conscious attention (Rasmussen, 1983).

In less uncertain environments, rule- and skill-based behaviour is desirable. As risks can be clearly identified companies aim to address and control these as efficiently as possible e.g. by developing procedures. In uncertain environments, e.g. created through the use of cloud computing, rule- and skill-based behaviour are less helpful. In these situations, companies will want to aim for knowledge-based behaviour, as people will be required to constantly analyse the environment and adjust their behaviour according to new information. Problem solving skills like trial and error become more important so that companies are able to react to and anticipate new circumstances quickly and head off problems that appear at the horizon (e.g. when the cloud provider changes the services they offer or customers demand a new product feature).

Knowledge-based behaviour is also necessary for employees (and customers) to decide on an individual level how they need to adapt to the new technology and what organisational elements they would like to retain. Moving to the cloud can create a lot of uncertainty among employees and sometimes also customers. Employees, for example, are concerned with their skills and daily routines and if the new technology will affect these. The notion of socio-technical systems suggests that companies need to find a balance between adapting the organisation to the new technology and retaining organisational elements employees and customers value (Trist, 1981). Finding a balance can help companies decrease the impact they experience from use and technology uncertainty. For cloud computing, for example, companies need to listen to their employees and customers to understand what they expect from cloud computing (to reduce the impact of use uncertainty). Otherwise, companies run into the risk that employees and customers take their own actions and, for example, rent cloud services that have not been approved by the company. At the same time, companies need to adapt the organisation to react to the fact that they cannot influence what the cloud provider does and how often the cloud resources are changed or updated (to reduce the impact of technology uncertainty). The FRAM can assist companies in finding a balance between adapting and retaining organisational elements to successfully decrease the impact of use and technology uncertainty.

3 ELEMENTS AND STEPS OF A FRAM ANALYSIS

The FRAM is a systemic approach that builds on the notion of resilience (Hollnagel, 2012). Situations are analysed by identifying functions that are necessary for everyday activities. The *functions,* shown in FRAM as hexagons, are abstractions to capture work routines and related resources, tangible and intangible, e.g. people, material, information, etc. Every function has six aspects that connect functions with each other: **I**nput, **O**utput, **P**recondition, **C**ontrol, **R**esource, and **T**ime.

The first step in a FRAM analysis is the identification of functions that are of importance or interest (e.g. *Marketing* could be a function). It is often advantageous to concentrate on high-level functions at first and go into more detail in later stages of the analysis. It is not important which function is identified first. In a FRAM analysis there are not always clear start and end functions. Furthermore, the aspects of the functions ensure that all necessary functions are identified, regardless of the first function that is being identified.

Once an initial set of functions has been identified, they need to be described in more detail by defining (some of) their aspects. The *Input* is used or transformed by the function to produce the Output. The Input also starts a function. The *Output* is the result of what the function does. With the Output the function is completed. The *Preconditions* have to be true or verified in order for a function to start. The *Control* aspect regulates or supervises a function so that the desired (or planned) Output is produced. The *Resources* are consumed when the function is executed. The *Time aspect* captures the different ways in which time can affect a function. For example, a function may need to be carried out before, after, or in parallel to another function.

Functions need to have at least an Input or Output. Only the Output of a function can be connected to aspects of other functions, i.e. connecting Precondition with Control is not allowed. It is often useful not to describe all aspects of a function at first, as this can make the analysis complicated and it is easy to loose sight of the bigger picture. Background functions, for example, can be used instead to capture aspects of a system that are important but not the focus of the analysis. Background functions only have an Input *or* Output and can be considered a placeholder for future analyses (background functions are grey in FRAM).

Once all functions and aspects deemed appropriate have been described, the performance variability of the system is analysed. The way in which the analysis of performance variability is integrated into the FRAM is partly explained by its name. The method focuses on the analysis of functional resonance (hence the name Functional Resonance Analysis Method). Failures in today's systems emerge because the performance of functions vary (due to technological, human or organisational elements) and sometimes the variabilities reinforce each other causing the variability of one function to be higher than expected and making it fail (which means that the failed function produces the Output too late, not at all, or imprecise, Hollnagel, 2012).

4 ORGANISATIONAL CHANGES OF A SOFTAWRE VENDOR MOVING TO THE CLOUD

To understand how use and technology uncertainty affect a software vendor that migrates their software product into the cloud and hence how they affect the resilience and adaptability of a software vendor, a FRAM analysis has been carried out with a SME software vendor from the Oil & Gas industry. The software vendor, in the following referred to as project partner or PP, develops and distributes a high-value project management software product. The PP hopes to develop new competitive advantages by being in the cloud, expand into new international markets and enable customers to use the product more quickly.

The FRAM has been applied to the PP in two steps. First, a FRAM showing functions and aspects before moving to the cloud was created with the help of the Managing Director. Second, the created FRAM has been adapted to show the functions and aspects after the migration into the cloud (again with the help of the Managing Director). In addition, data from a 12-month multi-stage study with the PP was used, in which the PP was interviewed several times during the migration process (see Werfs et al., 2014). In the following the main functions and aspects of the before and after cloud migration FRAMs will be explained.

The *before cloud migration* FRAM is shown in Figure 1. The two background functions, *Create customer profile* and *Customer extends contract*, shown in grey, constitute the start and end functions of the FRAM. The function *Acquire customer* converts potential customers into actual customers. The Output of this function is the accepted proposal of the PP by the customer. In addition, the customer receives a list of requirements that describe what kind of hardware and access to databases the product needs in order to be installed in the customer's data centre. The function *Customer sets up product environment* is responsible for setting up the hardware and access to databases. This function is outside of the PP's control and the customer has the final responsibility. Only when this function is completed and the Output (*Customer's data centre is ready*) has been produced, can the next function *Consult customer* start (i.e. it is a Control aspect). The *Consult customer* function tailors the product to the specific needs of the customer (reflecting the customer's business processes). After the function has been completed, the customer is able to use the product. The two last remaining functions, *Service customer* and *Increase customer satisfaction*, support the customer in their short and long term use of the product. *Service customer* deals with everyday problems users might encounter, e.g. a report is not produced as expected. *Increase customer satisfaction* tries to retain customers by convincing them to buy upgrades or new products. To achieve that goal, the function uses the customer history that is the Output of *Service customer* to know what issues the customer's users struggle with and what new features they might desire, for example.

Two functions in Figure 1 experienced performance variabilities before the migration to the cloud. *Customer sets up product environment* sometimes produces the Output too late because customers often fail to configure necessary hardware for the product in time. S*ervice customer* sometimes produces the Output imprecise because customers often fail to install updates properly or they do not install them at all.

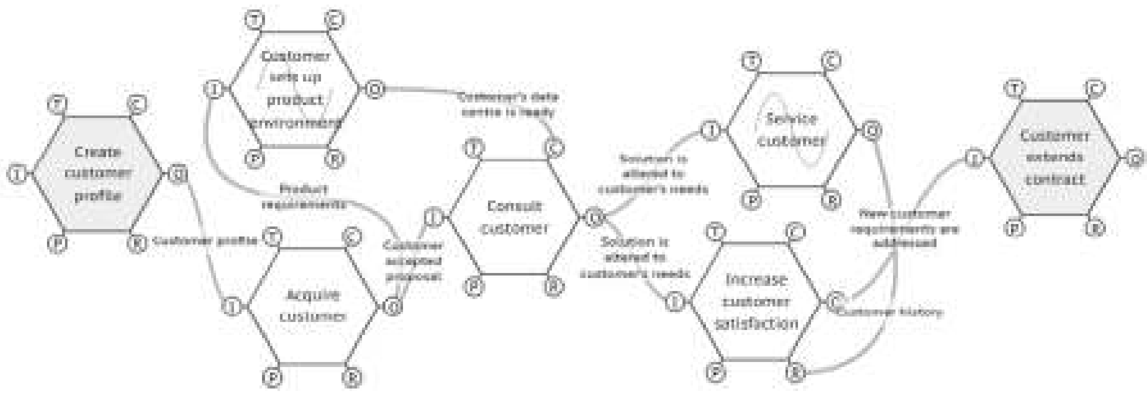

Figure 1. *Before cloud migration FRAM: visualisation of the PP's functions and aspects before the cloud. The text boxes on the lines show the description of the aspects*

By migrating the product into the cloud, two aspects of the relationship between the PP and their customers have changed. First, customers access the cloud-based product through a web-browser and do not have to install anything in their own data centre. Instead, the product is hosted with a cloud provider that provides the raw computing resources, such as servers, storage, network, on which the product runs and the PP manages the product installations of all customers. Second, because the product is now managed by the PP, the PP is also responsible for the uninterrupted operation of the product. Whereas previously, when the user of a customer encountered a problem they would contact their own IT department, they now contact the PP.

To reflect the changes in the relationship between the PP and their customers, the PP had to make several changes to functions and aspects (see Figure 2 for the *after cloud migration* FRAM). The PP made some of the changes to address the previously identified performance variabilities. The performance variability in *Customer sets up product environment* could be eliminated as the function was replaced by *Initiate cloud environment*. *Initiate cloud environment* acquires the resources from the cloud provider (a task that can be automated and thus will only take a few minutes to complete for every customer). The performance variability in *Service customer* could be dampened by a move to the cloud as the PP is now responsible for installing updates. To do this appropriately and in a timely manner, the PP had to introduce two additional functions that service the product installations of all customers (1) in case updates need to be installed (function: *Upgrade customer solution*) or (2) customers experience problems with the product (function: *Maintain solution*).

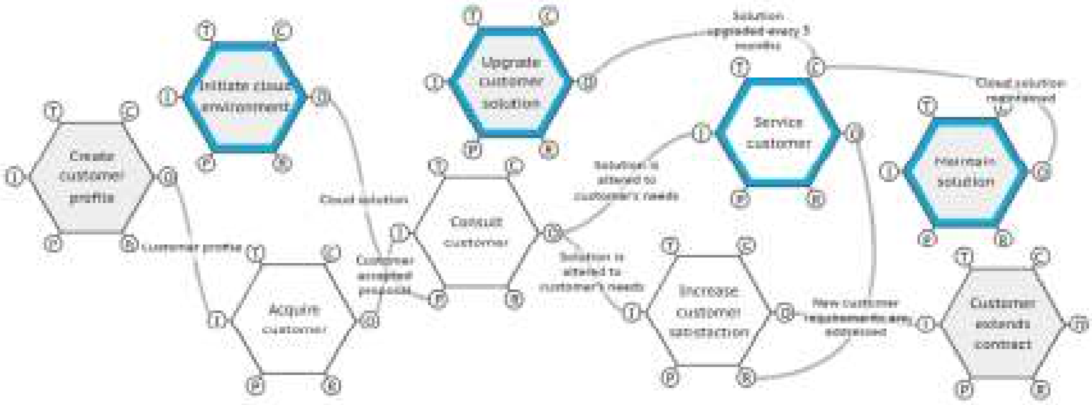

Figure 2. *After cloud migration FRAM: visualisation of the PP's functions and aspects after the migration into the cloud. Functions that changed or have been newly introduced are highlighted by a blue frame*

5 DISCUSSION

The Managing Director of the software vendor stated during the study that the goals for adopting cloud computing were clear. How to change the organisation to achieve the goals, however, was not clear at the beginning. Therefore, the software vendor adopted an ad-hoc approach in which they would only plan from step to step and adjust them based on new information, i.e. knowledge-based behaviour. The software vendor employed knowledge-based behaviour both on an organisational and individual level to (1) achieve a balance between adapting the organisation and retaining organisational elements employees and customers value and (2) to set the balance in a way that would dampen the effects of use and technology uncertainty, as explained in the following.

By comparing the before and after cloud migration FRAMs it is possible to understand how the software vendor found a balance between adapting to the new technology and retaining organisational elements employees and customers value. On the one hand, the software vendor wanted to exploit the advantages of cloud computing, i.e. offer the product to customers faster and increase customer satisfaction by managing the product for them. That is why the four functions highlighted in blue in Figure 2 changed. On the other hand, the software vendor wanted to make the move to the cloud as efficient as possible to save time and resources. Furthermore, they wanted to be able to retreat from cloud computing in case adverse effects would have emerged. This strategy was necessary for the software vendor as they have only one core product from which they derive the majority of their revenue. If that product would fail in the cloud or customers would stop buying it, the software vendor would quickly experience financial difficulties. These are the main reasons why the software vendor kept two core functions unchanged: *Consult customer* and *Increase customer satisfaction.* By keeping these two core functions unchanged during the initial move into the cloud, the software vendor reduced the uncertainty employees and customers experienced during the migration to enhance the chances of adopting the new technology successfully. The software vendor might change these functions in the long-term to make them more appropriate for cloud computing.

The balance helped the software vendor in dampening the impact of use and technology uncertainty. In the cloud, the software vendor can monitor more closely how their products are being used. This allows them to dampen the impact of *use uncertainty* by reacting to and anticipating customer expectations and market demands quicker. The software vendor is able to see what functions of their products are being used and by whom, e.g. a manager or a technician. In that way, the software vendor can customise the product for different user roles, for example. In order to dampen the impact of *technology uncertainty* the software vendor had to find ways to work around the loss of control to the cloud provider. The software vendor reported that this can sometimes be an issue with customers as they are concerned with their data now being stored outside of their immediate control. The software vendor, however, managed to turn the implications of technology uncertainty into an advantage. In the cloud, it is easier to provide the product to customers and keep it up to date. This has increased overall customer satisfaction, although customers give away control over their infrastructure. Customers get the latest version of the product without having to do anything themselves. To further deal with the implications of technology uncertainty, the software vendor is working with a niche cloud provider, who is located close by and to whom they have direct contact. The software vendor knows, if something goes wrong, they can go directly to the provider and work with them (in contrast to bigger providers, like Amazon or Microsoft, where SMEs are more anonymous).

6 SUMMARY AND FUTURE WORK

Companies that adopt a new technology, like cloud computing, need to be aware of the effects of use and technology uncertainty. This paper suggested using FRAM to understand what functions are necessary to change in order to adopt the new technology successfully and what functions should remain unchanged because they are valued by employees and/or customers. The experience from the software vendor suggests that finding an appropriate balance helps companies in dealing with use and technology uncertainty to increase the company's resilience and adaptability. By doing before/after comparisons with FRAM, it was possible to assist the software vendor in deciding which functions should focus on resilience and which on adaptability: functions that provide the infrastructure for products need to be very resilient (e.g. *Initiate cloud environment*); functions developing new product features can be more adaptable to allow for the rapid prototyping of new ideas (e.g. *Upgrade customer solution*). FRAM also allowed the software vendor to understand the dependencies in the cloud: the customer relies on the software vendor for the operation of the product, which means that the more resilient the software vendor (and cloud provider) is, the more resilient are the software vendor's customers.

Building on the study presented in this paper, FRAM is currently modified further to help software vendors plan the organisational changes necessary to move to the cloud. The organisational changes are structured by the notion of capabilities. Capabilities combine resources, tangible and intangible, to achieve a specific task. The modified version of FRAM will assist companies in understanding what capabilities currently exist in their organisation, if these will enhance or stifle a move to the cloud, and inform the development of new ones.

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