A fuzzy maturity model for care pathways

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A fuzzy maturity model for care pathways

by

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"Perhaps adjustment and stabilization, while good because it cuts your pain, is also bad because development towards a higher ideal ceases?"

Abraham Maslow

UNIVERSITY OF TECHNOLOGY

Abstract

School of Industrial Engineering

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A fuzzy maturity model for care pathways

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Process thinking in healthcare is needed and has several followers in industry and the scientific world. Its objective is to focus on managing processes in a more standardized way and gaining efficiency by doing this. To research the use and to determine the level of maturity of this development, a maturity model is developed. The proposed maturity model in this research is constructed using expert knowledge and literature. The model consist of 5 criteria and 19 indicators, which are weighted and aggregated using fuzzy logic. The advantage of this aggregation and assessment technique of the constructed maturity methodology is to translate the way humans think and reason into a specific maturity level. The resulting maturity methodology is tested in 11 hospitals for the care pathway of threatening mamma carcinoma. As a result of these case studies, an insight in the relation between quality and maturity is given. Besides this, the obtained insights of the model were used in further development of the model as a tool.

Acknowledgements

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Mark

Eindhoven, August 2015

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Abbreviations

AHP	**A**nalytic **H**ierarchy **P**rocess
BPMM	**B**usiness **P**rocess **M**aturity **M**odel
BVN	**B**orstkanker **V**ereniging **N**ederland (**D**utch **B**reast cancer **A**ssociation)
CBO	**C**entraal **B**egeleidings**O**rgaan (**D**utch **I**nstitute for **H**ealthcare **I**mprovement)
CMM	**C**apability **M**aturity **M**odel
DHD	**D**utch **H**ospital **D**ata
DICA	**D**utch **I**nstituut **C**linical **A**uditing
FAHP	**F**uzzy **A**nalytic **H**ierarchy **P**rocess
FQIMM	**F**uzzy **Q**uantitative **I**ntegreated **M**etric **M**odel
IEC	**I**nternational **E**lectrotechnical **C**ommission
IKNL	**I**ntergraal **K**ankercentrum **N**ederland (**C**omprehensive **C**ancer **C**entre the **N**etherlands)
ISO	**I**nternational **O**rganization for **S**tandardization
ITA	**I**nformation **T**echnology **A**dvisory
MF	**M**embership **F**unction
NCR	**N**etherlands **C**ancer **R**egistry
NKP	**N**etwerk **K**linische **P**aden (**C**linical **P**athway **A**ssociation)
NVZ	**N**ederlandse **V**ereniging van **Z**iekenhuizen (**D**utch **A**ssociation of **H**ospitals)
OMG	**O**bject **M**anagement **G**roup
PEMM	**P**rocess **E**nterprise **M**aturity **M**odel
PTS	**P**atient **T**racking **S**ystem
SAZ	**S**amenwerkende **A**lgemene **Z**iekenhuizen (**C**ollaborating **G**eneral **H**ospitals)
SPICE	**S**oftware **P**rocess **I**mprovement and **C**apability d**E**termination
STZ	**S**amenwerkende **T**opklinische **Z**iekenhuizen

	(**C**ollaborating **T**opclinical **H**ospitals)
TAM	**T**echnology **A**cceptance **M**odel
TUE	**T**echnische **U**niversiteit **E**indhoven
	(**U**niversity of **T**echnology **E**indhoven)
UMC	**U**niversity **M**edical **C**enter

1. Introduction

Dutch healthcare insurers and hospitals recently agreed to reduce the care expenses over the next years as stated by the Dutch government in the new care agreement (Van Den Elsen, 2013). The rules and regulations for healthcare are changing (Kiers, 2014), quality and transparency are becoming more important. For this purpose hospitals are designing quality programs with the objective to improve quality and efficiency, and reduce costs. A practical example is Laurentius hospital in Roermond, which implemented a program with the main focus on: relating turnover to employees, monitoring the care per care unit and developing a care pathway (Stam, 2012). The latter focus point is a technique of process control which standardizes care for a well-defined group of patients (EPA, 2015). Development of a care pathway includes organizing the care and ensuring the content of it (protocols and guidelines)(Schrijvers, 2014).

More and more hospitals in the Netherlands are working with care pathways. Care pathways have the potential to adapt to changing environments and have proven their effectiveness. In 2000 an association, 'Netwerk Klinische paden' (NKP), was founded with the objective to stimulate and support the development and evaluation of care pathways in the Netherlands and Belgium. In the beginning only eight Flemish hospitals were involved, but since 2014 already 102 health organizations in Belgium and the Netherlands are collaborating (NKP, 2015). This growing movement supports the fact that there are health organizations which are currently implementing and/or improving care pathways.

Nonetheless until today there has not been a single hospital in the Netherlands which has totally transformed all their processes into care pathways. One reason for this Vlieger et al. (2013) state, that the effort which is put into the process of constructing a care pathway is disproportioned to the outcomes yet (efficiency increase, quality increase, cost decrease).

Due to the above described lack of proven effectiveness of pathways and the monitoring of its outcomes, there is a need for measurement tools. Studying literature has revealed that there is a known field of measurement perspectives such as quality or performance. However, these perspectives focus more on the outcome of a process (e.g. patient satisfaction, waiting times) than the execution of the process. Another perspective of measuring processes is maturity, in which the focus is on the process itself and its fundamental characteristics for well-organized processes. The characteristics of maturity will indicate if certain quality is guaranteed and maintained during the evolution of a process. With this view on processes it is possible to measure the potential capabilities of a process as well as the process improvement opportunities.

1.1 Problem statement

As mentioned in the introduction and can be concluded from the performed literature review, there is a lack of significant research on the development of maturity measurement models for healthcare. Vlieger et al. (2013) state that there is a demand for monitoring the outcomes of implemented care pathways. Combining these findings, there is a noticeable demand to measure the maturity of current care pathways. However research on the (positive) relation between the performance (outcome) and maturity of a process is scarce, but Raschke and Ingraham (2010) have proven there is a relation.

Following these developments the following research question is formulated:

How can a maturity model be constructed to assess the maturity of a care pathway?

To answer this rather broad question, some subquestions can be formulated.

1. How can the maturity level of a care pathway be measured?

To assess the maturity of a specific care pathway, a selection of useful maturity models is chosen to function as a supportive base for the construction of a new model. The objective of this subquestion is to research the applicability of existing maturity models in healthcare, and how to adopt the useful insights into a new model.

2. Which criteria need to be measured to assess the maturity of a care pathway?
3. How can criteria be assessed and aggregated to determine a specific level of maturity?

Criteria will form the supportive layer for the maturity model and need to summarize the content and abilities in terms of maturity of a specific care pathway.

The following sections will elaborate on the characteristics of this research when answering the above mentioned questions.

1.2 Research methodology

To answer the research question and to achieve the research objective the following research methodology is used (figure 1.1).

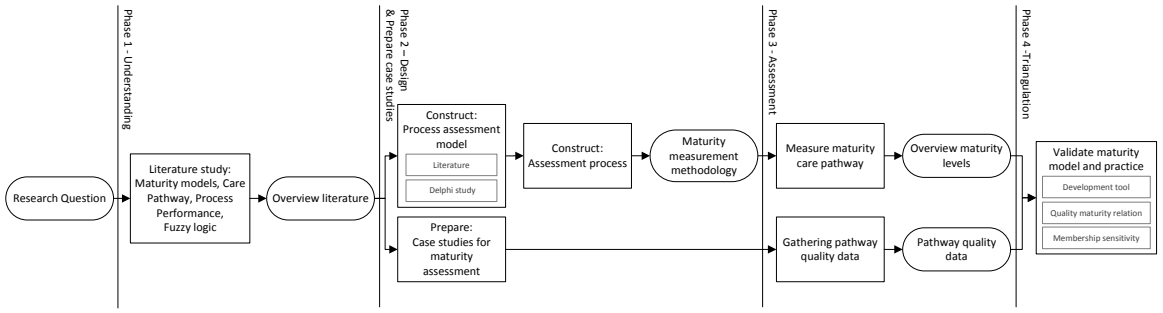

FIGURE 1.1: Research methodology

1.2.1 Phase 1 – Understanding

In phase one the focus was on reviewing literature, resulting in the background information in chapter 1. Literature was found during this stage by using the different definitions for care pathways in several search engines on the internet.

It is possible to construct a maturity model applicable to healthcare, which can fill in the gap mentioned by (Vanhaecht et al., 2006a). Such a model can be designed from best practices, or characteristics that enable a high level of maturity. The model from Hammer (2007) can be a good starting point to help create a care pathway maturity model for healthcare since it is usable and descriptions of the different levels help the assessor to chose the most applicable maturity level for the different indicators. Also the ISO/IEC (2004a) 15504 standard is a guide with a sophisticated project plan to assess maturity. Both systems are assessment framework models for processes and are domain independent (Ehsan et al., 2010). For these reasons the models of Hammer (2007) and ISO/IEC (2004a) will form a good basis to start the development of a healthcare applicable maturity model for care pathways from.

To better understand the human responses and ratings towards maturity, fuzzy logic is an approach which considers the responses of humans as probabilities and not crisp values. This is an advisable method to use in measuring maturity as it is commonly used in literature (Chang, 1996; Cheng et al., 2011; Dai and Guan, 2014; Van Laarhoven and Pedrycz, 1983). An hierarchical structure with different layers is needed to obtain an in-depth maturity grade.

1.2.2 Phase 2 – Design & Data collection

In this phase a selection of existing maturity models is made to support the construction of a care pathway applicable maturity model in this phase. These models are the PEMM from

Hammer (2007) and the ISO/IEC (2004a) 15504 standard. By using the structure of capabilities and characteristics mentioned by Hammer (2007) and following the framework of the ISO/IEC (2004a) standard, a structure for the healthcare maturity model can be built consisting of a process assessment model and assessment process. Other literature is used to inspire the construction of the maturity model. In this research the set variables are the criteria that are the pillars to explain the maturity. On a lower hierarchical level the indicators are grouped to a specific criterion to form the support. The structure and content of the model is further developed, finalized and validated by performing a Delphi study involving nine experts.

Parallel during this step preparations took place to test the maturity model in practice. 11 hospitals were interested in assessing the maturity of their care pathway.

1.2.3 Phase 3 – Assessment

In this phase the constructed maturity model was assessed at different hospitals. The objective of this phase is to test the model in practice and obtain empirical data to validate the model later on in phase four.

Besides this objective the current capabilities and characteristics of a specific care pathway were reviewed and measured as a short-term objective. The technique used for this approach was interviewing a focus group for detailed information and measurement. This resulted in an overview of several case studies with their measured maturity level in chapter 6. The results were also provided to the participating hospitals as feedback in de assessment model as a tool.

Another aspect of the case studies was to obtain information to support the usability of the model as a tool. This is done using a Technology Acceptance Model (TAM) questionnaire which resulted in the development step of the model as a tool, described at section 2.4.

Parallel during this step, available hospital care pathway quality data is collected from several open governmental sources for further analysis in phase four.

1.2.4 Phase 4 – Triangulation

By relating the assessed maturity levels of the hospitals with the corresponding hospital care pathway quality (measured by the Dutch government), a triangulation of measurements can be made to investigate the relation between the measured maturity levels in the case studies and the pathway quality data.

The model is further analysed by validating the sensitivity of the chosen membership functions for the different maturity levels.

The result is a tested and validated maturity model, which has been developed into a measurement tool.

1.2.5 Company involvement

This research was performed during an internship at KPMG in Amstelveen, the Netherlands. The company is widely operating with main services in audit, tax and advisory. After the acquisition of Plexus, the healthcare focus of KPMG has been expanded in the Netherlands.

The internship has taken place in the Enterprise Solutions group within the IT advisory unit. The main objective for IT Advisory is to advise organizations with new technologies which help reduce complexity and create flexibility.

KPMG Plexus is focusing on healthcare where the mentioned strategy and objective also applies to healthcare organizations. KPMG's recent activities in healthcare resulted in interesting insights in e.g. the development of care pathways and their demands, which support the objective of this research.

Therefore, the expertise and knowledge of processes and care pathways within a healthcare organization contribute to the construction of the maturity model. Due to this contribution and the interest in the research outcome, KPMG fulfils the role as sponsor.

1.3 Research scope and goal

The pathway definition used in this research is the one from the E-P-A as can be found in the background information in section 2.1. This definition states that an care pathway is designed for a group of patients with the same care need and the same structural process steps (Vanhaecht et al., 2007).

The definition known in literature of a maturity model, and used in this research is the one from Becker et al. (2009) as stated in section 2.2 were a maturity model includes the sequence of levels to indicate a process its steps of evolving (Becker et al., 2009).

The model constructed is proposing the use in healthcare, but is not bound to a specific diagnosis or treatment process. During the construction of the maturity model, the characteristics of an generic care pathway are taken into account.

Construction of a maturity model, and thus answering the research questions is the main goal of this research. Furthermore, development is started to construct the model as a tool. Besides this, interesting relations and insights were obtained during the several case studies in the field.

1.4 Structure of the thesis

Chapter 2 will start the *understanding phase* with background information on the thesis topic.

The chapters 3 to 5 will answer the subquestions and follow the structure stated in ISO standard (ISO/IEC, 2003). This includes the construction of the maturity measurement methodology

of the *design and prepare case studies phase*. The ISO standard is a well-known maturity framework and lists all the different parts of a maturity model. In chapter 3 the maturity measurement methodology development context is stated which describes the different steps of deployment. The three subquestions will be answered in chapter 4, which includes the construction of the maturity model and practical model format. The set-up of the assessment process is described in chapter 5 and will complete the answering of subquestion three.

In chapter 6, actual case studies are conducted to assess maturity in practice as in the *assessment phase*. These assessment results can be used to verify and validate the model, as well as to gain an inside in the situation of mature care pathways in hospitals within the Netherlands as proposed in the *triangulation phase*.

Chapter 7 will summarize the results of this research. A discussion and conclusion phase in chapter 8 will define the answering of the research questions, limitations of the performed research, and recommendations for further research.

2. Background information

As an introduction of the research topic, background information is collected during a literature study. A systematic search is performed as can be seen in table 2.1. Furthermore articles which outline the different maturity models are found by using the snowball technique starting with the article of Pöppelbuß and Röglinger (2011) as an overview. This technique starts with an article and directs the reader to other interesting articles in the references of that article.

Table 2.1: Systematic literature search results

# articles found	# articles usefull	Search query
93	32	TOPIC: (fuzzy modelling) AND TOPIC: (maturity)
1	1	TOPIC: (fuzzy modelling) AND TOPIC: (maturity) AND TOPIC: (health)
7	5	TOPIC: (fuzzy modelling) AND TOPIC: (process maturity) AND TOPIC: (quality management)
3	3	TOPIC: (fuzzy modelling) AND TOPIC: (process maturity) AND TOPIC: (quality engineering)
1	1	TOPIC: (fuzzy modelling) AND TOPIC: (process maturity) AND TOPIC: (health)

The results of search can be seen in figure 2.1. These articles were used in getting inside knowledge on the topic.

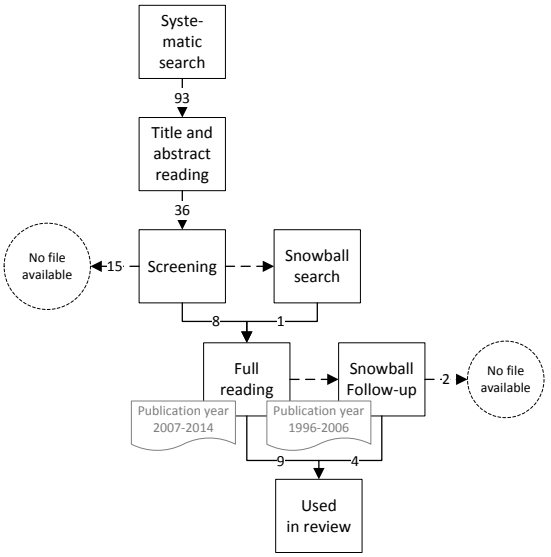

Figure 2.1: Literature search methodology

The definition and current knowledge in the field of care pathways is described and the different types of hospitals in the Netherlands are outlined in the first subsection. Next, the definition of maturity and its use is handled. In the nest subsection an introduction to fuzzy logic and its applications is given. The last section will contain information about the Technology Acceptance Model (TAM).

2.1 Care pathway

Care pathways are nowadays known by the definition of the European Pathway Association (E-P-A)(Vanhaecht et al., 2007):

> A complex intervention for the mutual decision making and organization of predictable care for a well-defined group of patients during a well-defined period. Defining characteristics of pathways include:
> - An explicit statement of the goals and key elements of care based on evidence, best practice and patient expectations.
> - The facilitations of the communication and coordination of roles, and sequencing the activities of the multidisciplinary care team, patients and their relatives; the documentation, monitoring, and evaluation of variances and outcomes.
> - The identification of relevant resources.

From this point on care pathways will be indicated as care pathway, care path or pathway.

Begin early 90s, a shift has been made in healthcare management. From then on the importance of developing and continuously improving healthcare processes were subject of many studies (Vanhaecht et al., 2010). Also the patient took a more central position in the process improvement process, and so was the focus on improving the care and the value for the patient. Through this change the service oriented processes in healthcare became more important. Besides service, the quality of care had to be equal or improved while at the same time, costs should be reduced.

When establishing and developing a care path, the input of different health professional groups is needed (doctors, nurses, allied health professionals, etc.) following the interdisciplinary definition of a care pathway. Also interaction between those health profession groups and their assigned responsibilities are important to develop a well-organized care path (Vanhaecht et al., 2010). Besides this interdisciplinary character the input to design a path must contain evidence from literature (evidence-based key interventions and outcome indicators), operational research and patient involvement methodologies (Vanhaecht et al., 2010).

Vanhaecht et al. (2010) describe a care pathway on 4 different levels of usage: as a concept, model, product, and a quality and efficiency improvement process. The product level is the use of care pathways in organizations, as developed in hospitals. This perspective is the most interesting for this research since the proposed maturity model in this research is developed for this kind of care pathways.

The top level of the product perspective is the *model pathway* as can be seen in figure 2.2. From this view the pathway is based on (inter)national evidence and is not organization specific. The next view is the *operational pathway view* in which the pathway is organization specific, and so

depends on resources and available competences of that specific organization. A lower level, in the aggregation, is the *assigned pathway view* which is patient specific. After discharging the patient the complete pathway can be reviewed from such a perspective (Vanhaecht et al., 2010). The perspective which is used to inform patients and family about the process is a multilevel way.

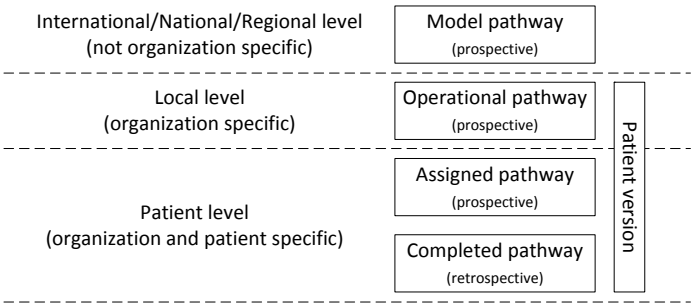

FIGURE 2.2: The four aggregation levels of the pathway following Vanhaecht et al. (2010)

Besides this multilevel aggregation, pathways can also be developed with different degrees of scope and detail. For example, a care pathway which entails the reference of a general practitioner until the end of a treatment in a hospital is a pathway. But also referrals between departments, and the steps within a process are defined as pathways (Vlieger et al., 2013).

The success of an implemented pathway is investigated in many researches. Vanhaecht and Sermeus (2002) developed a 30-step program to help successful implementation of a care path. In addition to this model the NKP (2015) proposed a method with seven phases supporting the implementation and evaluation of a care pathway.

Recent study in KPMG has concluded that a goal-focused approach of developing a new care pathway is essential to achieve a workable care pathway aligned with the practical situation (Vlieger et al., 2013). As, without a clear goal, the project will be too broad and too many details will be documented. Moreover, the documentation of a pathway needs to be useful and not just written guidelines. Such that the documentation of the pathway is concrete and describe "working arrangements between professionals and organizations, special outpatient and inpatient facilities, the information technologies, forms used [...], and so forth" (Berg et al., 2005). Also Mallock and Braithwaite (2005) share this view by saying, "success of pathways requires productive negotiation, agreement, good design and collaborative effort by different stakeholders" (Mallock and Braithwaite, 2005).

Furthermore, Every et al. (2000) state that because care paths are focused on a specific group of patients with the same care need, the results of a patient with a slightly different care need will not present a perfect flow in the developed care path. Some other say that modelled care

pathways represent the ideal situation in most cases, which can not be reached in a normal, less ideal, situation (Velasco et al., 1995). A remark has to be made that these examples are domain dependent areas such as for example Cardiovascular medicine (Every et al., 2000).

All these different pathway outcomes are mostly related to differences in study design or implementation method (Vanhaecht et al., 2006b). In his research Vanhaecht et al. (2006b) performed a systematic review on audit tools, which measure to which extend an implemented care path has met the characteristics of a care path.

2.1.1 Hospitals in the Netherlands

The different types of hospitals in the Netherlands are; university [8](UMC), general [41](SAZ), and top clinical [28](STZ) hospitals (NVZ, 2012). To illustrate the differences in Dutch hospital types, data bars are calculated as average per specific type hospital in 2012 (NVZ, 2012)(figure 2.3).

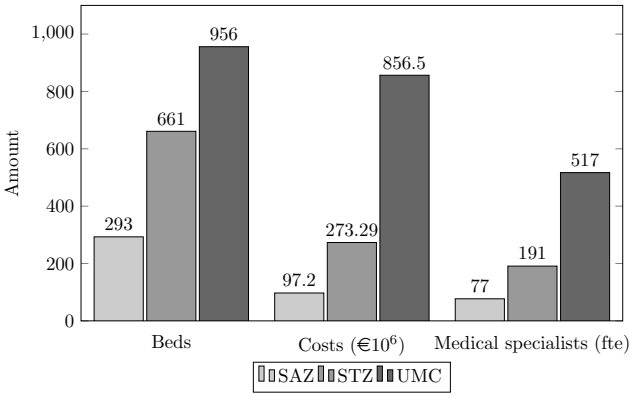

FIGURE 2.3: Averages per type of hospital

2.2 Maturity modelling

In a continuously improving organization managers need to get a grip on the as-is situation and their prospect to be able to steer an organization or process to an improved state. Maturity models are widely used in processes, which are assumed to be predictable, to indicate the flow in which an organization matures (Gottschalk, 2009; Pöppelbuß and Röglinger, 2011). This is mostly done by stage-of-growth models, or also called stage theories which indicate the different stages (Prananto et al., 2003). Becker et al. (2009) describes an maturity model as: "A maturity model is a conceptual model that consists of a sequence of discrete maturity levels for a class of processes in one or more business domains, and represents an anticipated, desired, or typical evolutionary path for these processes" (Becker et al., 2009).

Nowadays a vast amount of maturity models are developed and can roughly be divided into two different maturity model groups, *process maturity models* and *Business Process Management*

(BPM) maturity models. The models which are grouped as process maturity models "refer to the extent to which instances of a distinct process type are managed, documented, and performed" (Pöppelbuß and Röglinger, 2011)(see figure 2.4).

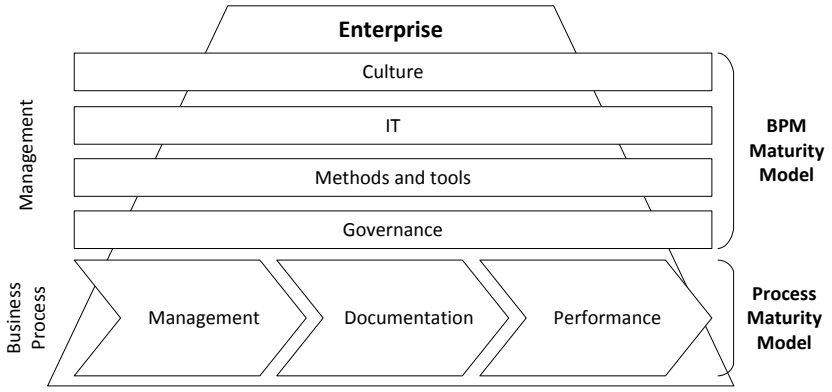

FIGURE 2.4: Different groups of maturity models (Pöppelbuß and Röglinger, 2011)

A derivation of the CMM model, and also a process maturity model, is the ISO/IEC 15504 standard which is made during the Software Process Improvement and Capability Determination project (SPICE). This standard is set by the International organization for standardization (ISO) and the International Electrotechnical Commission (IEC)(ISO/IEC, 2004a). The model is a set of basic components and is easy transferable between processes in different areas. This model can be a great help when a specific 'unknown' process has to be assessed. This model can also be used for two different purposes, as a process improvement initiative or as a part of a process capability determination. However, before using this model a choice has to be made between those two purposes.

The models that have a focus on maturity and capability of the management of processes are the BPM maturity models. These models are mostly organization wide and evaluate the overall culture and innovativeness of an organization. The added value of these models, in comparison to the process maturity models, is the focus on organization outcome. This relation is important since a maturity measurement on its own is not a guarantee for a good organization outcome.

A popular model to evaluated and improve organization wide processes, is the Process Enterprise Maturity Model (PEMM) from Hammer (2007). This framework gives five characteristics which make a process perform well on a sustained basis, and four enterprise capabilities that make the organization able to adapt the processes (Hammer, 2007). The main goal of the method of Hammer (2007) is to control processes, and gain higher process performances by growing in maturity, "Stronger organizational capabilities make for stronger enablers, which allow for better process performance" (Hammer, 2007). Since this method is using such characteristics, it is easy to develop this maturity model organization wide and easy to implement it for different processes. Therefore this method is effective and interesting to use in other areas.

2.3 Fuzzy Logic

Quantitative analyses are mostly done using data that is collected within the organization (e.g. database, documents, and experts). This data is mainly categorized as being nominal, ordinal, interval or rational. When doing qualitative analysis the data is mainly gathered through interviews and subjected to interpretation. The data obtained from this is mainly vague and linguistic, as human beings respond to questions following their own interpretation. One way of dealing with this linguistic and vague terms is by using fuzzy logic, which simply means vague logic.

This method differs from regular methods in the sense that data does not have to be crisp as with classical set theory. Fuzzy logic was introduced by Zadeh (1965). He states that there is a space X of points where x is a generic element in this space $X = \{x\}$. Inside this space there is a fuzzy set A where point x belongs to the fuzzy set A with a certain degree $\mu_A(x)$. This fuzzy set can mathematically be denoted by:

$$A = \{(x, \mu_A(x))|x\epsilon X\} \tag{2.1}$$

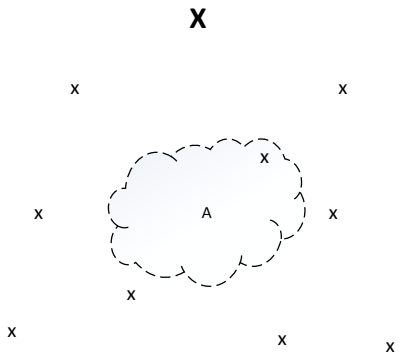

FIGURE 2.5: Illustrative fuzzy set example

This rather abstract definition can be explained by an example (Jang and Gulley, 1995):

The body temperature of a patient in a hospital can have a temperature between 35 and 40 degrees Celsius. The set that we are interested in is the body temperature when having the fever. For this purpose the fuzzy set which we want to know is the set A = "fever body temperature". To value different degrees in this fuzzy set we can "rank" the different temperatures to fever with some degree (e.g. 37 degree of Celsius is in the fever range to a degree of 0.6). Hereby the following holds:

$$A = Fever\ body\ temperature \tag{2.2}$$

$$A = \{(36, 0.2), (37, 0.4), (38, 0.7), (39, 0.85), (40, 0.9)\} \tag{2.3}$$

$$X = [36, 40] \tag{2.4}$$

2.3.1 Triangular membership functions

Triangular membership functions are frequently used in literature because of its simplification and ease to compare and rank through fuzzy arithmetic calculations (Chang, 1996; Cheng et al., 2011; Dai and Guan, 2014; Van Laarhoven and Pedrycz, 1983). The membership functions are expressed as triplets $\tilde{A} = (l, m, u)$ where $l \leq m \leq u$. l, u, and m stand for the lower support, upper support, and modal value of $\tilde{A}$ respectively. The definition of the fuzzy number $\tilde{A}$ on $\mathbb{R}(=(-\infty, +\infty))$ is triangular when its membership function $\mu_{\tilde{A}}(x) : \mathbb{R} \to [0, 1]$ is equal to equation 2.5 (Chang, 1996; Van Laarhoven and Pedrycz, 1983).

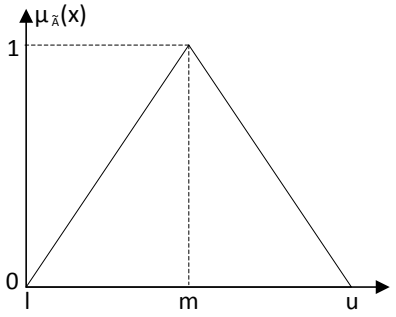

FIGURE 2.6: Triangular membership function

$$\mu_{\tilde{A}}(x) = \begin{cases} \frac{x-l}{m-l} & \text{if } l \leq x \\ \frac{x-u}{m-u} & \text{if } x \leq u \\ 0 & \text{if } x < l \text{ or } x > u \end{cases} \tag{2.5}$$

Arithmetic operations on fuzzy numbers can be defined by the extension principle. If $\tilde{A}$ and $\tilde{B}$ are fuzzy numbers, membership functions of $\tilde{A}(*)\tilde{B}$ is defined as follows, where $*$ stands for any of the four arithmetic operations $(\oplus, \ominus, \otimes, \oslash)$.

$$\mu_{\tilde{A}(*)\tilde{B}}(z) = \sup_{z=x*y} min\{\mu_{\tilde{A}}(x), \mu_{\tilde{B}}(y)\} \tag{2.6}$$

Assuming the intervals to be linear is a common made mistake (Gao et al., 2009; Giachetti and Young, 1997a,b) and multiplication with this perspective is commonly known as the standard approximation. To establish a more precise representation and minimize the error of deviation, small closed intervals are used in multiplication (Giachetti and Young, 1997b). Assume the fuzzy numbers $\tilde{A} = (a_l, a_m, a_u)$ and $\tilde{B} = (b_l, b_m, b_u)$.

Multiplication: $\otimes$

$$\tilde{A} \otimes \tilde{B} = \begin{bmatrix} (a_m - a_l)(b_m - b_l)\alpha^2 + (b_m - b_l)a_l\alpha + (a_m - a_l)b_l\alpha + a_l b_l, \\ (a_u - a_l)(b_u - b_m)\alpha^2 - (a_u - a_m)b_u\alpha - (b_u - b_m)a_u\alpha + a_u b_u \end{bmatrix} \tag{2.7}$$

When substituting the α-cuts and since $a_l \leq a_m \leq a_u$ and $b_l \leq b_m \leq b_u$, we can use the membership function described by (Gao et al., 2009):

$$\mu_{\tilde{A}\otimes\tilde{B}}(z) = \begin{cases} \frac{-(a_l b_m + b_l a_m - 2a_l b_l) + \sqrt{(a_l b_m - b_l a_m)^2 + 4(a_m - a_u)(b_m - b_l)z}}{2(a_m - a_l)(b_m - b_l)} & \text{if } a_l b_l \leq z \leq a_m b_m \\ \frac{-(a_u b_m + b_u a_m - 2a_u b_u) + \sqrt{(a_u b_m - b_u a_m)^2 + 4(a_m - a_u)(b_m - b_u)z}}{2(a_m - a_u)(b_m - b_u)} & \text{if } a_m b_m \leq z \leq a_u b_u \\ 0 & \text{if otherwise} \end{cases} \tag{2.8}$$

2.3.2 Fuzzy maturity evaluation

Fuzzy logic is widely applied in maturity evaluation (Cheng et al., 2011, 2009, 2007; Dai and Guan, 2014; Yang and Wang, 2009). Indicators are commonly used to score the maturity in different aspect. To evaluate and consider the importance of these different indices, experts can be asked to assign weights to the different indices and levels. By doing this the relevance of the metric scores are evaluated in more depth.

Furthermore, the perspective in which the maturity is measured will be discussed. Cheng et al. (2011) proposes a benchmark model, Fuzzy Quantitative Integrated Metric Model (FQIMM) which combines the Quantitative Software Metrics Set (QSMS) and a new fuzzy ranking method instead of the weights discussed earlier (Chang et al., 2006; Cheng et al., 2011, 2009).

In most of the researches that propose a fuzzy maturity model, the maturity part is heavily relying on the Capability Maturity Model Integrated (CMMI). The choice for this specific maturity model is not supported by strong arguments. In most of the researches the challenge to overcome is that the Lead Appraiser (LA), which evaluates different kinds of qualitative sources, is subjective.

2.3.3 Fuzzy Quantitative Integrated Metric Model (FQIMM)

Elaborating on the fuzzy evaluation systems, one can disguised the FQIMM from the other models since this is a method which takes a crisp metric set into account. This will allow the metrics input set to be data driven, when possible.

The system consist of several steps in which the metrics are weighted and translated into a maturity level. The following steps hold for the FQIMM:

1. **Build a fuzzy matrix $\tilde{W}$**
   To obtain the importance of various indicators, the importance is translated into fuzzy weightings which are collected in a matrix $\tilde{W}$.
2. **Build a metrics performance matrix M**
   The scores during a maturity assessment are collected in this matrix. The indicators belonging to a specific criterion are grouped in a performance matrix M.
3. **Compute a practice matrix $\tilde{A}$**
   The crisp scores of the assessment, represented in performance matrix M, are translated into fuzzy numbers in practice matrix $\tilde{A}$. The indicators belonging to a specific criterion are grouped in a performance matrix M.
4. **Aggregate evaluation $\tilde{R}$**
   The fuzzy scores (practice matrix $\tilde{A}$) and weightings of the indicators per criterion ($\tilde{W}$) are multiplied to get fuzzy aggregative evaluation matrix $\tilde{R}$. Each vector in this matrix will represent an fuzzy number for a specific criterion.
5. **Rank results**
   The fuzzy results (aggregate evaluation $\tilde{R}$) are ranked by the adopted method of (Chang et al., 2006) into a maturity score.

The lack of this approach is the ranking method, which is not validated that often in literature. Besides this, Cheng et al. (2011) only asked two experts to give weights for the different indicators.

2.4 Technology acceptance model

To test whether a new technology is accepted by users, an assessment is performed which measures the functioning and the success of a new developed technology. Acceptance is in this perspective the intention to use a product, which is stated to be predictable by the perceived usefulness and ease of use by users (Davis, 1993). The box below explains the variables in more detail.

The perceived usefulness is defined as the degree to which a user believes that using a specific IT technology could improve their job performance. Perceived ease of use is defined as the degree to which a user believes that using specific IT technology is a minimum level of mental effort. Perceived usefulness and ease of use of IT technology influence user's attitude toward technology and are influenced by external variables (e.g. users age, gender etc.). The intention to use will ultimately lead to actual end-user use (Davis, 1989).

To measure this belief, Davis (1989) constructed a technology acceptance model (TAM) in which the main variables, which influence the acceptance of an new technology, can be related.

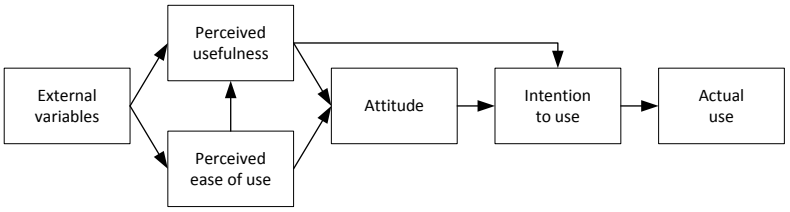

FIGURE 2.7: The Technology Acceptance Model (TAM) as developed by Davis (1989)

Yousafzai et al. (2007) performed a review on 145 papers which were published on the TAM. Following this literature review many studies have proven that there is a positive relation between perceived usefulness, perceived ease of use, attitude, and intention to use. The last mentioned is important for the constructed maturity model, since an accepted model will have an higher intention of usage.

3. Methodology development context

The maturity measurement methodology consist of a maturity process assessment model and an assessment process. The development process of the methodology follows the steps as in the ISO/IEC (2004a) standard described (figure 3.1). Furthermore, the model of Hammer (2007) is used to construct the structure of the measurement framework.

The maturity process assessment model, which can be used to assess maturity of care pathways, is self developed and only supported by existing maturity models proposed by Hammer (2007) and ISO/IEC (2004a). Both systems are assessment framework models for processes and domain independent purposes (Ehsan et al., 2010). The care pathway maturity model is focussing on the healthcare process from a product perspective, as described in chapter 2. Furthermore, it is domain independent in such that the model is generic an can be applied to all kind of pathways. For these reasons the models of Hammer (2007) and ISO/IEC (2004a) will form a good base for the construction of the proposed maturity model.

The text in the model will be in presented in English, for the purpose of not misinterpreting the literature which is used to construct the model. The knowledge and English reading capabilities of the experts who use the model are assumed to be sufficient to understand and use the model.

3.1 Development steps

As stated the maturity methodology consist of a maturity process assessment model and an assessment process. The different steps are represented in figure 3.1 and will be the guidance of the structure in the next chapters.

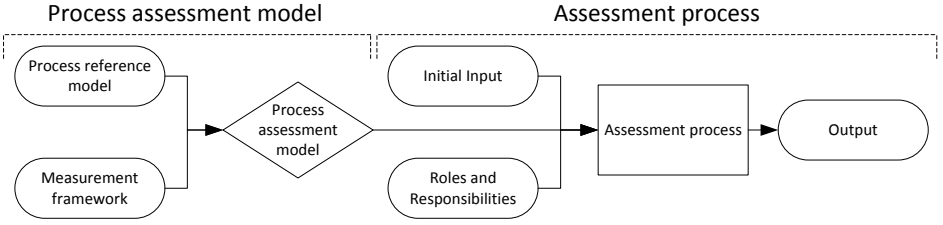

FIGURE 3.1: Development steps of the maturity measurement methodology (ISO/IEC, 2004a)

The assessment model will include the structure of the assessment criteria and indicators as well as the calculation method. A part of the construction of an **assessment model** is determining the domain, scope, purpose, and outcomes of the model. This is done in the *process reference model*. The other part is the *measurement framework* which includes the criteria, indicators, and maturity levels that capture the maturity of the as-is situation. Also the structure and aggregation of these criteria and indicators are part of the measurement framework. These two

parts combined form the process assessment model. However, without an assessment process description, the model is not usable.

The **assessment process** needs to be determined before every assessment. Important is the determination of the *initial input*, *roles and responsibilities*, and *output*. An outline, including key focus points for conducting an assessment are developed as well.

3.2 Development structure

The development steps that were taken are explained in more detail in the next chapters. Chapter 4 will focus on the construction of the maturity process assessment model, including the different elements. Chapter 5 will focus on the development of the assessment process.

4. Process assessment model

In this chapter the development and structure of the assessment model is researched and constructed based on existing theories, concepts, and measures. Furthermore, a reference model is designed and combined with the developed measurement framework into a process assessment model (see figure 4.1).

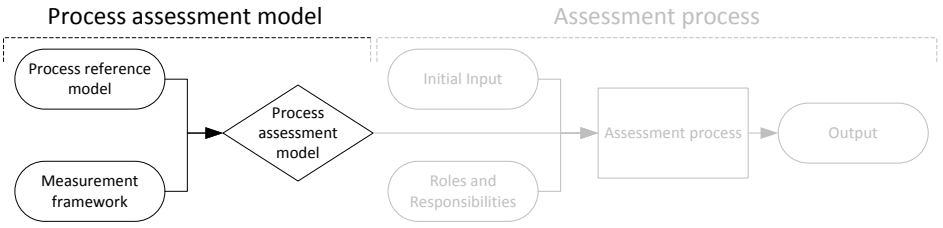

FIGURE 4.1: Major elements of the maturity assessment process, part one (ISO/IEC, 2004a)

4.1 Process reference model

Due to the research question the domain of this model is healthcare. The process of a generic care pathway is subject for measurement of the maturity model. The measurement target variable of the model will be the level of maturity of a generic care pathway.

The community of interest for the development of this model are the following stakeholders with corresponding objective:

- KPMG; a useful and scientifically reliable maturity model to use in practice.
- TU/e; a scientific validated maturity model with fuzzy aggregation approach to measure maturity of care pathways in healthcare.
- Hospitals; a measurement tool which can assess the maturity of care pathways to indicate the areas which could be improved to achieve a higher level of maturity.

All these stakeholders cooperated in setting and validating the right measurement criteria through participating in a Delphi study, as described later on in this chapter. By performing this study the objective is to achieve consensus within the community of interest about the development of the process assessment model.

4.2 Measurement framework

The measurement framework of the process assessment model consist of different maturity levels. These different levels will reflect the maturity of a care pathway, through the degree of presence of specific indicator aspects. In the ISO 15504 standard, the authors suggest to assess if the

different process attributes, which are needed for a certain maturity level, are present in the process (ISO/IEC, 2004a). For the highest level of maturity, all nine attributes belonging to the previous level need to be present. Another example is the Business process maturity model (BPMM) from the Object Management Group (OMG), where five institutional practices need to be present for every process area to be part of a specific maturity level (Weber et al., 2008).

On the other hand Hammer (2007) denotes a fixed set of enablers for the maturity levels. Hereby, the enablers are individually scored on their characteristics. Based on the presence of these characteristics, a specific maturity level for this enabler is determined. The Hammer (2007) model is a continuous maturity model in the sense that the enablers can vary individually in maturity level. The differences between the ISO and PEMM model can be seen in figure 4.2.

The components needed in the different levels of the ISO standard, are represented as individual process attributes. In this manner an organization only needs the process attribute *process performance* to achieve level 1. The extra needed two attributes to achieve level 2 are *performance management* and *work product management*. On the other hand the process and enterprise maturity models, on the right side of the figure, show the respectively five and four enablers which are present in different degrees, to achieve the different maturity levels.

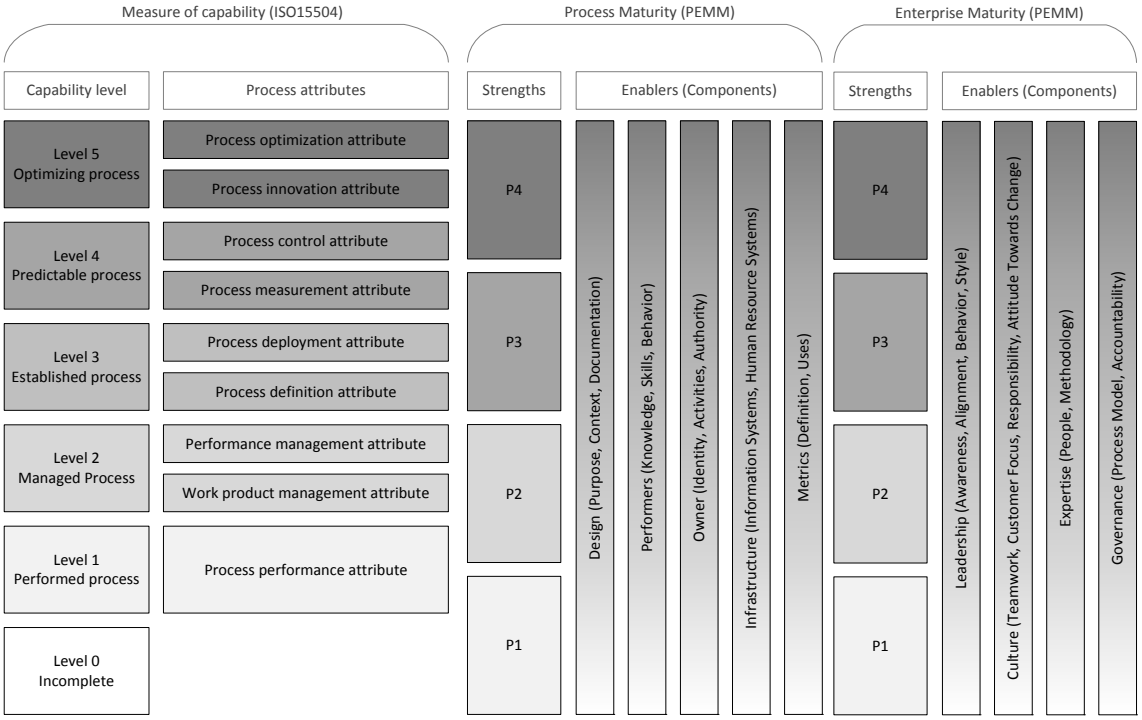

FIGURE 4.2: Structure of ISO15504 and PEMM (Hammer, 2007; ISO/IEC, 2004a)

The approach of both methods is different. The enablers from Hammer (2007) can have different maturity characteristics, where the ISO standard is more about the absence and presence of

attributes. The proposed model in this research handles the care pathway as a specific "process area", as described by Weber et al. (2008). A process area has specific institutional practices that need to be present for certain levels of maturity. In the proposed model these practices are translated into criteria and indicators, which are explained in the next chapter. The degree in which these criteria and indicators are fulfilled dependent on the presence of their characteristics. In this sense that the proposed model considers a specific indicator with characteristics for the different maturity levels. This approach can be seen as continuous, like the one from Hammer (2007). The criteria and indicators will be as supportive as the institutional practices from Weber et al. (2008).

4.2.1 Target levels and hierarchy

The main objective of this model is to assess the *target variable* (V) maturity and thus the evaluation remark set, on which the assessed maturity is scored, will be the following (Yang and Wang, 2009):

$$V = \{V_1, V_2, V_3, V_4\} \tag{4.1}$$

With the levels from bottom till top are: **low** (V_1), **moderate** (V_2), **high** (V_3), **top** (V_4)(Yang and Wang, 2009). The levels differ in the maturity of indicators present in the care pathway.

The *criterion layer* I is the hierarchical layer underneath the target layer and contains the main domains to assess maturity. This layer is constructed for the simple means of comparing different maturity levels and communication towards the stakeholders on corporate level (Pöppelbuß and Röglinger, 2011).

$$I = \{I_1, I_2, I_3, I_4, I_5\} \tag{4.2}$$

A lower abstraction level of indicators is introduced to enable more complexity within a broader scope (Pöppelbuß and Röglinger, 2011). Below a specific criteria there exist a group of indicators. The indicators of the different criteria are denoted as follows with n_i different indicators grouped to one specific criteria I_i, where $n_1 = 5$, $n_2 = 2$, $n_3 = 2$, $n_4 = 6$, $n_5 = 4$.

$$I_i = \{I_{i1}, I_{i2}, I_{...}, I_{in_i}\} \tag{4.3}$$

A more illustrative example is given in figure 4.3. For the purpose of analysing, each element in the hierarchy is considered to be independent of all the others.

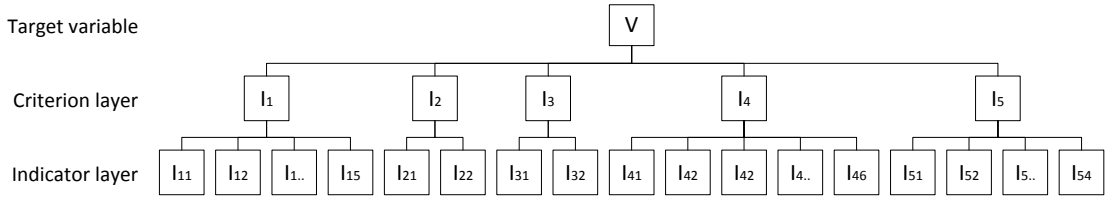

FIGURE 4.3: Example of hierarchy within the assessment model

4.2.2 Maturity criteria

Due to the literature, Vanhaecht et al. (2007) reviewed articles to develop and compare tools for auditing health care processes in terms of being well-organized. In his research he uses the following definition for an audit tool: "A care pathway audit tool should, therefore, focus on such 'key characteristics', ones that can affect patient outcome" (Vanhaecht et al., 2007). Due to this method and other literature, which is mentioned further on, five criteria are developed as can be seen in figure 4.4. The structure of the criteria is designed in a way that the criteria will have an impact on each other in a particular order. *Design* will for example define the *owner & performers* and *infrastructure*. A more mature infrastructure will result in the ability to perform a better *performance control*. The insight gained with better performance control supports the *continuous improvement* and redesign of the pathway. This structure is also visible in the continuous quality improvement circle, plan-do-check-act, developed by Deming (1982). In his cycle, a continuous process movement will lead to an increasing quality (Deming, 1982).

FIGURE 4.4: Care pathway maturity criteria

To get a view on similar maturity model constructions in literature, figure 4.5 shows the structure of the ISO/IEC (2004a) model, Weber et al. (2008) BPMM, and the proposed model. The attributes, goals and criteria are grouped towards matching definition.

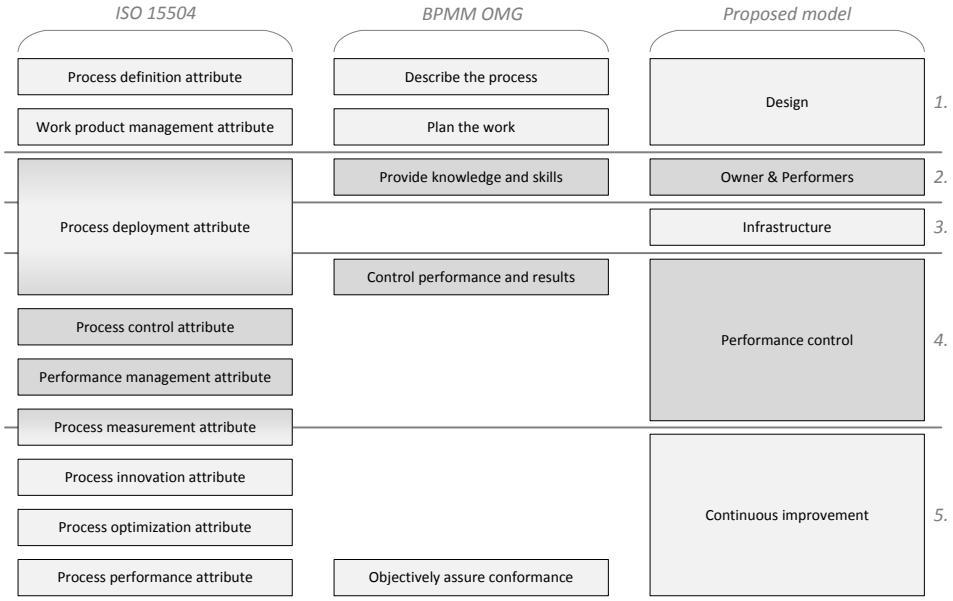

FIGURE 4.5: Different maturity models with corresponding attributes

In figure 4.5 it can be seen that the maturity process attributes in the top of the figure are sorted towards the bottom. This corresponds to the similar structure of the Deming (1982) cycle and the proposed model in which the criteria follow a "Plan" (*Design*), "Do" (*Owner & performers*), "Check" (*Infrastructure*, *Performance control*), "Act" (*Continuous improvement*) cycle. and the institutionalized goals which are not only preconditions for the process, but also provide feedback (Weber et al., 2008).

The **design** criterion is based on the design approach followed when designing the as-is care path. The different aspects of the design phase (e.g. pathway objective, documentation, approach, and used framework) are measured in different indicators. The **owner & performers** criterion is based on the one from Hammer (2007) where it entails "the people who execute the process, particularly in terms of their skills and knowledge" (Hammer, 2007). The **infrastructure** will focus on the information systems, management systems that support the care pathway. Using information systems and having a good system architecture will result and enlarge the ability of monitoring the care path (Hammer, 2007). The **performance control** therefore is an important criteria which connects the objectives of the organization and care path with actual process information. Conducting measurements and using this resulting process information of the care path to developed and improve the designed structure, is part of the **continuous improvement** criterion.

4.2.3 Maturity indicators

Using the criterion level to define the maturity level will be too abstract. Therefore a lower level, with several indicators per criterion, is constructed. To every criterion a set of indicators belong which will scopes the criterion in more detail. These indicators are grouped and only belong to one and only one unique criterion. The final architecture of criteria and indicators are illustrated in table 4.1.

TABLE 4.1: Final maturity criteria and indicators; *[B]: Berg et al. (2005), [dB]: De Bleser et al. (2006), [H]: Hammer (2007), [N]: Nederland (2008), [P]: Plexus (2009), [S]: Schrijvers (2014), [W]: Weber et al. (2008)*

Target (V)	**Criteria** (I_i)	**Indicator** (I_{im})	**Based on**
Maturity	Design	Pathway objective alignment	[P], [H]
		Pathway definition	[P], [H]
		Compliance	
		Decision moments/criteria	[B]
		Design approach	
	Owner & Performers [H]	Owner (Identity)	[H]
		Effective behaviour	
	Infrastructure [H]	Information systems	[H], [N], [S]
		Network of paths	[P]
	Performance control	Metrics definition	[H]
		Metrics uses	[H]
		Structured collection of data	[dB]
		Availability of performance information	
		Availability of real-time information	[S], [P]
		Capacity monitoring	[P]
	Continuous improvement	Stakeholder involvement	[N], [P]
		Awareness	
		Flexibility	
		External objectivity	[W]

Furthermore, each indicator can vary in maturity by selecting one of the four maturity levels. Every maturity level contains a description of the indicator characteristics representing that specific maturity level. The assessor is now able to chose one of the maturity levels which is the best reflection of the as-is assessment situation.

Each indicator below (in bold) is described including the different characteristics of the four different maturity levels. The granularity of the maturity for the indicator layer is obtained from literature, which are stated in table 4.1. However, a validation of the criteria and indicator layer is done in the section 4.2.4.

Pathway objective alignment - The degree by which the objective of the pathway is aligned to the objective of the care delivery to the specific patient group of the pathway. The levels vary

from a design based on a legacy design, till end-to-end development aligned with stakeholder and patient objectives.

TABLE 4.2: Pathway objective alignment maturity level characteristics

Low	Moderate	High	Top
The pathway has not been designed on an end-to-end basis. Functional managers use the legacy design primarily as a context for functional performance improvement.	The pathway has been redesigned from end to end in order to optimize its performance.	The pathway has been designed to fit with other enterprise processes and with the enterprise's IT systems in order to optimize the enterprise's performance.	The pathway has been designed to fit with customer and supplier processes in order to optimize transmural performance.

Pathway definition - The degree in which the design of the path is defined with a clear structure, terminology and roles. The levels vary in definition detail, inclusions of roles, process models, and electronic representation of the pathway used for analysis.

TABLE 4.3: Pathway definition maturity level characteristics

Low	Moderate	High	Top
There is no explicit definition and documentation of the pathway.	The different parts of the pathway, roles and terminology are defined and documented in textual form.	There is a structured and end-to-end documentation of the pathway design including roles, and graphical representations.	An electronic representation of the process design supports its performance and management, and allows analysis of environmental changes and process reconfigurations (Hammer, 2007).

Compliance - The degree in which a pathway is designed taken the laws, regulations, and guidelines (e.g. recognize DBC) into consideration. Levels vary in traceability to the different laws, regulations, and guidelines used. Also ability to change the path when law, regulations and guidelines are changing is important.

TABLE 4.4: Compliance maturity level characteristics

Low	Moderate	High	Top
There is no explicit consideration of laws, regulations, and guidelines in the design of the pathway.	The laws, regulations, and guidelines are explicitly considered in the design, but no traceability is established between the description and the related rules of the laws, regulations, and guidelines.	There is explicit traceability between the pathway description and the rules originating from laws, regulations, and guidelines.	There is explicit traceability between the pathway description and the rules originating from laws, regulations, and guidelines. New and changed rules are continually reflected in the related structure of the pathway.

Decision moments/criteria - The level of detail in the decision moments (objectivity assured) and/or in the criteria of the pathway design. The levels vary between guidelines of decision moments and/or criteria and explicitly described decision moments and/or criteria.

TABLE 4.5: Decision moments/criteria maturity level characteristics

Low	Moderate	High	Top
There is no description of the specific care pathway decisions available.	Just broad lines of the care pathway decisions and criteria are defined in the pathway design.	Decision moments and broad lines of the corresponding criteria are defined in the care pathway design.	Decision moments and the corresponding criteria are defined in the pathway design.

Design approach - The degree in which a structured approach (e.g., a reference framework) is used and different stakeholders were involved during the design of the pathway (transmural care [intern and extern]). These levels vary from involvement of stakeholders till usage of reference frameworks.

TABLE 4.6: Design approach maturity level characteristics

Low	Moderate	High	Top
No specific structured approach [e.g., a reference framework] is used, and there is no indication of the involvement of different stakeholders in the design of the pathway.	No specific structured approach [e.g., a reference framework] is used, but there is an indication of the involvement of different stakeholders in the design of the pathway.	A specific structured approach [e.g., a reference framework] is used, and there is an indication of the involvement of different stakeholders in the design of the pathway.	A specific structured approach [e.g., a reference framework] is used explicitly, and there is an explicit indication of the involvement of different stakeholders in the design of the pathway.

Owner (identity) - The extent to which the pathway ownership structure is effective in improving the pathway performance. The degree of attendance of the pathway owner towards pathway improvements is differentiated in the different levels.

TABLE 4.7: Owner (identity) maturity level characteristics

Low	Moderate	High	Top
The pathway owner is an individual or a group informally charged with improving the performance of the pathway.	There is an official pathway owner role and it is filled with an individual or a group charged with improving the performance of the pathway.	The pathway comes first for the official pathway owner in terms of time allocation, mind share, and personal goals.	The official pathway owner has high degree of creditability and close relation with the enterprises senior decision-making body in terms of changing the process.

Effective behaviour - The degree in which a pathway participant (performer) executes his/her task as described in the pathway design and has knowledge of his/her own part in the pathway process. The levels are different in degree of awareness and knowledge about the performance of the pathway as a whole.

TABLE 4.8: Effective behaviour maturity level characteristics

Low	Moderate	High	Top
Performers know their function/-tasks as described in the pathway design, and perform it correctly but aren't aware of the whole pathway they are part of.	Performers know their function/-tasks as described in the pathway design, perform it correctly and are aware of the whole pathway they are part of.	Performers know and perform their function/tasks as described in the pathway design and know the objective including performance of the care pathway.	Performers know and perform their function/tasks as described in the pathway design and strive to ensure that the pathway process delivers the results needed to achieve the pathway's objective.

Information systems - The degree by which the supporting information systems are integrated (internally and externally) and are designed with the pathways/end-to-end processes in mind. The levels vary in the structure of the information from fragmented towards integrated and inter-enterprise.

Table 4.9: Information systems maturity level characteristics

Low	Moderate	High	Top
Fragmented legacy IT systems support the pathway.	An IT system constructed from functional components supports the pathway.	An integrated IT system, designed with the end-to-end process in mind and adhering to enterprise standards, supports the pathway.	An IT system with a modular architecture that adheres to industry standards for inter-enterprise communication supports the pathway.

Network of paths - The degree in which a path is part of a network of system components and synergy is obtained (e.g. shared IT support, experienced improvements, shared resources). The levels differ from a small set of paths towards pathway oriented and synergy achieving.

Table 4.10: Network of paths maturity level characteristics

Low	Moderate	High	Top
An explicit definition of care pathway exists only for a small set of pathways.	An explicit definition of care pathway is available for a large set of pathways.	A network of care pathways is designed, through integrated systems.	Synergy is established within a network of care pathways through integrated systems and communication channels.

Metrics definition - The degree in which metrics (such as patient satisfaction, throughput time) are uniformly defined in the pathway. The different levels contain quality and cost metrics, patient satisfaction and the alignment between enterprise and pathway objective.

Table 4.11: Metrics definition maturity level characteristics

Low	Moderate	High	Top
The pathway only has some basic cost and quality metrics.	The pathway only has end-to-end process metrics aligned with the pathway objective (e.g. patient satisfaction).	The pathway's metrics are aligned with the pathway objective and enterprise objective (e.g. patient satisfaction, cost).	The pathway's metrics are aligned with the pathway objective, enterprise objective and implemented (e.g. frequent measured patient satisfaction, cost).

Metrics uses - The degree in which the metrics are effectively used to assess the achieved performance. The levels vary from identifying root causes of faulty performance, till usages for day-to-day management and strategic planning.

Table 4.12: Metrics uses maturity level characteristics

Low	Moderate	High	Top
The pathway owner uses the pathway's metrics to track its performance, identify root causes of faulty performance, and drive functional improvements.	The pathway owner uses the pathway's metrics to compare its performance to benchmarks, best-in-class performance, and customer needs and to set performance targets.	The pathway owner presents the metrics to pathway performers for awareness and motivation. They use dashboards based on the metrics for day-to-day management of the pathway.	The pathway owner regularly reviews and refreshes the pathway's metrics and targets and uses them in strategic planning.

Structured collection of data - Degree of structure in data collection (meaningful data variables also in line with the metrics). The levels vary in collection of objective aligned variables used for analysing.

Table 4.13: Structured collection of data maturity level characteristics

Low	Moderate	High	Top
No structured collection of pathway process data exists.	The pathway process data is collected in an unstructured way.	Pathway process data is collected in a structured way for analysing metrics.	Pathway process data is collected in a structured way and using the defined variables needed for analysing metrics.

Availability of performance information - The degree in which pathway process performance information is available for all stakeholders. The differentiation between the maturity levels is to which the information is available for the pathway owner, performers, or all stakeholders.

Table 4.14: Availability of performance information maturity level characteristics

Low	Moderate	High	Top
Pathway process performance information is not available.	Pathway process performance information is available only for the pathway owner.	Pathway process performance information is available for all stakeholders for only certain periods.	Pathway process performance information is always available for all stakeholders.

Availability of real-time information - The degree in which pathway process and patient data is available in real-time. The levels vary between the on request and always real-time availability of pathway process and patient data.

Table 4.15: Availability of real-time information maturity level characteristics

Low	Moderate	High	Top
Real-time pathway or patient information is not available.	Pathway and patient information are available on request.	Patient information is available in real-time but pathway information is available on request.	Pathway and patient information is available in real-time.

Capacity monitoring - The degree by which the capacity of resources involved in the pathway (such as doctors, nurses, beds, tools and other supplies, etc.) is monitored. The levels vary in whether the resources are monitored and the amount of resources that is monitored.

Table 4.16: Capacity monitoring maturity level characteristics

Low	Moderate	High	Top
Pathway resource capacity is not monitored.	Pathway resource capacity is monitored but not continuously.	Capacity for some of the pathway resources is continuously monitored.	Capacity for the majority of the pathway resources is continuously monitored.

Stakeholder involvement - The degree in which the owner and the stakeholders in the pathway chain communicate and indicate improvements of the pathway (internal and external). The levels differentiate in whether stakeholders have the ability to propose improvements.

Table 4.17: Stakeholder involvement maturity level characteristics

Low	Moderate	High	Top
There is no explicit focus and process on the improvement of the pathway.	Stakeholders can mention and communicate points of improvement to the owner of the pathway.	The process owner of the pathway regularly improves the pathway based on the points of improvement from the stakeholders.	The process owner of the pathway continuously improves the pathway based on the points of improvement from the stakeholders, and informs all stakeholders.

Awareness - The degree of awareness a pathway member has in performing tasks and in contributing to the improvement of the pathway as a whole. The levels vary from a narrow improvement focus of the performers till continuously focus on improvements and recognition.

Table 4.18: Awareness maturity level characteristics

Low	Moderate	High	Top
Performers have primary focus on their own function/tasks without any explicit emphasis on pathway improvement.	Performers perform their tasks/-functions and recognize possible improvements in the pathway.	Performers recognize and propose possible improvements in the pathway.	Performers continuously look for signs that the pathway process should change, and they propose improvements to the pathway process (Hammer, 2007).

Flexibility - The degree a specialist in the path is allowed to deviate from the designed procedures and whether this is tracked. The levels vary in whether the specialist is not allowed to deviate from the care pathway till the specialist is allowed to deviate, deviations are tracked and analysed.

TABLE 4.19: Flexibility maturity level characteristics

Low	Moderate	High	Top
Specialists are not allowed to deviate from the designed procedure.	Specialists are allowed to deviate from the designed procedure but deviations are not tracked.	Specialists are allowed to deviate from the designed procedure and these deviations are only tracked.	Specialists are allowed to deviate from the designed procedure and these deviations are tracked and analysed.

External objectivity - The degree in which the pathway is externally reviewed and audited (against laws, regulations, guidelines, etc.). The different levels distinguish in no audits, internally audited, externally audited, and the use of an established governance body for the purpose of auditing.

TABLE 4.20: External objectivity maturity level characteristics

Low	Moderate	High	Top
The pathway is not audited internally or externally.	The pathway is audited externally.	The pathway is audited internally and externally.	There is an established governance body and the pathway is audited internally and externally on predefined periods.

4.2.4 Validation of criteria and indicators

Some of the indicators assigned to the different criteria are newly developed and assigned based on the available literature and other written knowledge. Besides this, the granularity of the maturity for the indicators is obtained from literature and other written knowledge as well. Using expert knowledge is a good way of validating these findings (Okoli and Pawlowski, 2004). A Delphi study is performed with several experts in the field to accomplish this validation. Furthermore, this technique is mostly used to establish consensus between experts (Hasson et al., 2000; Linstone et al., 1975) and theory building (Okoli and Pawlowski, 2004), which supports the development of the model *content validity*.

Another focus of the Delphi study is to assign different weights to the indicators based on their importance towards maturity of care pathways, "Its effect on the sensitivity of the decision function with respect to the corresponding criterion"(Kaymak and van Nauta Lemke, 1998). Determining different weights for the indicators can enlarge the difference of the indicators and give more meaningful depth, besides this, it creates a less subjective model (*face validity*).

4.2.4.1 Delphi study

The selection of the group of experts is indicated to be of great importance to the success of the study (Powel, 2003). Thus a selection of participants for the study with different backgrounds is selected, as can be seen in table 4.21. As Okoli and Pawlowski (2004) states a minimum valid number of experts in a Delphi is set to be 10. However, the number of experts needs to be aligned with the scope of the problem and resources availability (Delbecq et al., 1975;

Fink et al., 1984; Hasson et al., 2000). The Delhi study is often used to generate ideas about a subject, and the more experts involved in this process the higher the amount of generated ideas. Since the objective of this Delphi study is to validate the already proposed findings, and assign weights to them, a group of nine experts is selected. The group consist of experts with different perspectives and different backgrounds (industry and academia).

Table 4.21: Delphi study experts

	Academia	**Industry**	**Expertise**
Hacettepe University	1		Healthcare process maturity models[a]
IKNL	1	1	Healthcare
KMPG - Plexus		2	Healthcare[b]
KMPG ITA		1	Healthcare processes
MC Group		1	Hospital care processes
TU/e	2		Healthcare process maturity[a]
	4	**5**	

[a](Tarhan et al., 2015a,b)
[b](Plexus, 2009; Vlieger et al., 2013)

The background information and knowledge field of the several experts is stated below.

Dr. at Hacettepe University, experienced in model-based assessment and improvement of software processes. Focuses on software quality, software development methodologies, software measurement, business processes, and process management.

Researcher and consultant at IKNL, quality institute for oncological and palliative research and practice. IKNL collaborates with healthcare professionals and managers and patients to achieve continuous improvement of oncological and palliative care. They also advice in development of care pathways and have their own reference framework.

Consultants at KPMG - Plexus, expertise in the field of healthcare advisory. Due to time availability only one of the two experts was able to assign weights to the indicators in round three of the Delphi study.

Consultant at KPMG (ITA), advisory of enterprises towards an efficient and effective information technology solution.

Quality and security policy maker at MC Group, organization of three associated general hospitals in the Netherlands. Due to time availability this expert was only able to perform the last round of the Delphi. This expert participated only in the Delphi study.

Dr. and MSc at TU/e, focus on modelling, improvement, governance and compliance of business processes, and software management in healthcare.

The experts are individually interviewed to enrich the quality of the answers and to give immediate support during the Delphi rounds when requested. For this reason face-to-face interviews are preferable above a survey method.

The number of rounds for this study is determined by taking the available time and needed verification steps into consideration. Another aspect which is considered is the commitment of the experts in the different rounds till the end of the Delphi study. This latter aspect is fed by the interest involving the questions in the different rounds (Buck et al., 1993; Hasson et al., 2000). As stated by De Bruin and Rosemann (2005), a balance between valuable input and achieving consensus has to be established in sufficient number of rounds. A vital and important procedure in the Delphi study is that in the consecutive rounds, the participant will get feedback in the form of statistical results of the previous round, to indicate the degree of consensus on the different indicators (Hasson et al., 2000). Considering this and the objective of this study, the number of rounds is set to three and the following actions hold as stated in the schema in appendix A.

The focus of the first two rounds was to achieve consensus on the different criteria, indicators, including descriptions, and the hierarchical order of the criteria and indicators towards maturity. To achieve a systematic output of the rounds, the experts rated the indicators by: *1. Stay*, *2. Change*, *3. Can go*. When an indicator is correct due to the experts judgement *1. Stay* is used. *2. Change* is used when the position in the hierarchy or description need to change. *3. Can go* is used when the indicator is not a good aspect of the construct care pathway maturity. The results were analysed after every round and the indicators were adjusted towards a certain decision rule. In literature there is a lack of clarity on defining a decision rule for consensus in a Delphi study (Powel, 2003). In this Delphi study a threshold was set for the first two rounds. When more than 80% of the experts rated a specific indicator as *1. Stay*, the indicator would stay in the model. For the indicators with a consensus of 80% or lower for *1. Stay*, the other 20% in combination with the comments made by the experts were leading. In this manner some of the indicators changed in description or position towards the criterion layer, and some were left out in the next version of the model.

The focus in the third round was on assigning weights to the different indicators. These weights will indicate the importance of that indicator towards maturity.

Round 1 - The Delphi starts with individual face-to-face meetings of an hour with the experts to explain the study. Besides the rating of the indicators, the experts were also allowed to add new indicators as mentioned in the Delphi schema in appendix A.

After analysing the results, decisions were made as can be seen in appendix B. The indicator *evidence based* was combined with *design methodology* into *design approach*, since the two individual indicators were measuring the same aspect. The indicator *documentation* was moved

towards the criterion *granularity*, since the emphasis of this indicator was more on the granularity of the care pathway. The indicator *model of work procedures* was added to the indicator *documentation*. The indicator *individual tasks* was moved to the criterion *performers*, since it focusses more on the performers in the care pathway. The opposite action was applicable to the indicator *owner (identity)*. The indicators *accountability* and *relations* were rejected, based on the measurement focus of *behavior*. The indicator *frequent measure & improve cycle* was moved towards knowledge. Indicators *expertise level* and *multi teams* were rejected based on to much detail in the measurement foci. The criteria *monitoring* and *knowledge* changed in name. Also two new indicators were added after the first round. Based on these changes a new version of the model was constructed as shown in appendix C.

Round 2 - In the second round of the Delphi the participants were asked to perform the same task as in the first round. This assessment round was performed during an hour face-to-face interview. At the start of this meeting the participants were given feedback on the first round as illustrated in figure B.1 in appendix B.

Based on the comments made, the criterion *granularity* was rejected due to the vague focus of the criterion, but the related indicators where moved to other criteria. The criterion *performers* changed in name. The indicator *aim* changed to *pathway objective alignment* and *pathway definition* to represent a better relation between the objective of the enterprise and the care pathway. The indicator *clear defined process steps and end* and *compliance with guidelines* changed only in name. Indicator *individual tasks* was compared with *decision moments/criteria* and rejected. *Architecture* was too technical and rejected. *Network paths* changed in name. The indicators of the criterion *performance control* changed only in name. Indicator *availability information* moved towards the criterion *performance control*. The indicators *communication* and *awareness* were integrated into *stakeholder involvement*. Indicator *frequent measure & design improve cycle* was rejected, due to similar level of detail of measurement in the criterion *continuous improvement*. This second round resulted in the decisions as can be seen in appendix C. Also a new indicator was added after this round. Based on these changes a new version of the model was constructed as in appendix D.

Round 3 - As can be seen in appendix A, the third round includes the determination of the different weights belonging to the different indicators. These weights were given by the experts in the last face-to-face meeting. These weights will indicate the importance towards maturity in the judgement of the experts. The response of the experts is used in its linguistic form. Five linguistic terms are adopted and translated into fuzzy numbers to quantify the expression (see figure 4.6 and table 4.22). A linguistic variable is "a variable whose values are words or sentences in a natural or artificial language" (Zadeh, 1975a,b). This method and the use of triangular fuzzy numbers is adopted from, for instance, the method Cheng et al. (2011) propose.

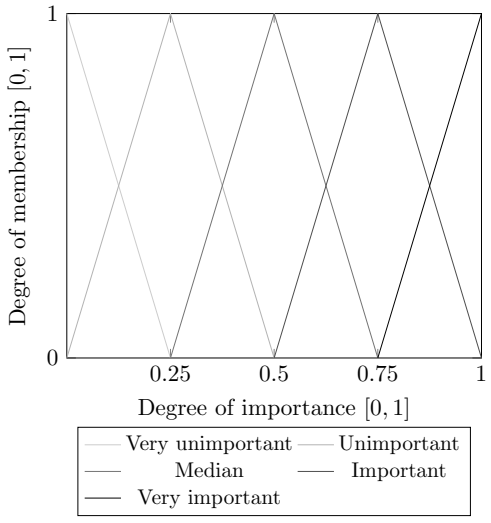

FIGURE 4.6: Fuzzy membership functions of importance (Cheng et al., 2011)

TABLE 4.22: Fuzzy numbers membership functions of importance (Cheng et al., 2011)

Linguistic valuables	Membership functions
Very unimportant	(0.00, 0.00, 0.25)
Unimportant	(0.00, 0.25, 0.50)
Median	(0.25, 0.50, 0.75)
Important	(0.50, 0.75, 1.00)
Very important	(0.75, 1.00, 1.00)

Final weight determination - The aggregation is done using the arithmetic mean of the weights, which is most suitable for this situation (Kaymak and van Nauta Lemke, 1998). The arithmetic mean is a special case of the generalized averaging operators which is defined in equation 4.4 (Kaymak and van Nauta, 1993). In the equation, k is the total numbers of experts who rated the specific indicator. In the case of an arithmetic mean, the goal function is equally sensitive to absolute changes in the membership values ($s = 1$).

$$D_t(s) = \left(\frac{1}{k} \sum_{c=1}^{k} \mu_{tc}^{s} \right)^{1/s} \tag{4.4}$$

Interpreting this formula, the fuzzy numbers can be calculated for the different weights $\tilde{w}_{ij} = (l_{ij}, m_{ij}, u_{ij})$, where i is the criterion and j is the indicator.

$$l_{ij} = \left(\frac{1}{k} \sum_{c=1}^{k} l_{ijc} \right),\ m_{ij} = \left(\frac{1}{k} \sum_{c=1}^{k} m_{ijc} \right),\ u_{ij} = \left(\frac{1}{k} \sum_{c=1}^{k} u_{ijc} \right) \tag{4.5}$$

This results in a specific fuzzy number per individual indicator (see appendix D). An example process of this determination is given in table 4.23 for the indicator *pathway objective alignment* (I_{11}).

When aggregating the weights of the different indicators j to their assigned criterion i, the following membership functions for the different criteria can be calculated (figure 4.7). In this figure the importance towards maturity of the different criterion is graphical represented. Criterion *owner & performers* is most important, where *infrastructure* is least important, towards maturity, of the different criteria.

TABLE 4.23: Delphi round 3 weights for the indicator *pathway objective alignment* (I_{11})

Criteria (I_1)	**Indicator** (I_{11})	**Weight per expert**		**Final weight** ($\tilde{w}_{11}$)
Design	Pathway objective alignment	Important	(0.50, 0.75, 1.00)	(0.625, 0.875, 1.000)
		Very important	(0.75, 1.00, 1.00)	
		Very important	(0.75, 1.00, 1.00)	
		Important	(0.50, 0.75, 1.00)	
		Very important	(0.75, 1.00, 1.00)	
		Very important	(0.75, 1.00, 1.00)	
		Important	(0.50, 0.75, 1.00)	
		Important	(0.50, 0.75, 1.00)	

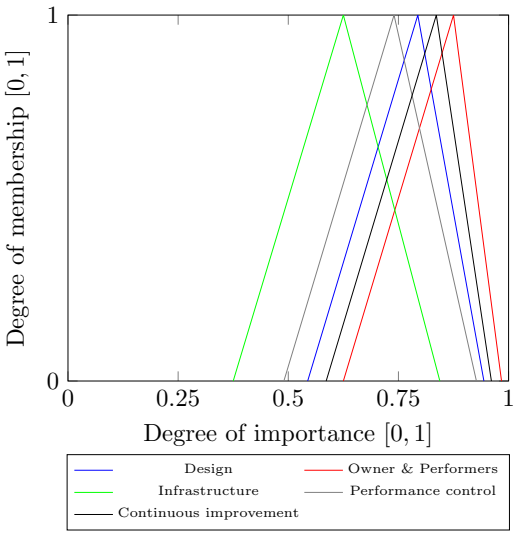

FIGURE 4.7: Resulting membership functions of importance per criterion

4.2.4.2 Consistency analysis

To test the internal consistency of the rated importance per indicator, the Cronbach's alpha was calculated with 19 indicators and 8 experts included. The α score was 0.75 which is satisfactory between 0.7 and 0.9 (Cronbach and Thorndike, 1971; Tavakol and Dennick, 2011). This implies that consensus is met on the selection of the right indicators and criteria, thus the Delphi round achieved its objective.

4.2.5 Scoring scale

To assess the maturity of a specific pathway, the individual indicators are scored following a scoring system. In this system, the assessor is asked to choose one of the four different maturity levels for each indicator. Since the different levels consist of different characteristics, the level borders become crisp, and so does the answering. The chosen maturity level reflects the as-is situation of the care pathway the best. Only one maturity level is allowed, since the levels are not build on to each other. This means that when maturity level high is best reflecting the as-is situation, the characteristics of the levels low, moderate, and top are not or less reflecting the assessed situation. The chosen level gets an 1 score and the other levels 0. The scores per

indicator is an vector M:

$$M_{ij} = \Big[\text{low}_{ij}, \text{moderate}_{ij}, \text{high}_{ij}, \text{top}_{ij}\Big] \tag{4.6}$$

For example, if the first indicator of the criterion *Design* is scored high this will result in the following vector:

$$\tilde{M}_{11} = [0, 0, 1, 0] \tag{4.7}$$

4.2.6 Fuzzy aggregation construct

To achieve a single total maturity level for the assessed pathway, the interpretation of humans about the different maturity levels need to be taken into account. Fuzziness is used to achieve this objective and aggregate the different scores in this multi criteria decision situation by using fuzzy weights for the different indicators as explained in the last round of the Delphi study.

As stated in the reference framework in section 4.2.1, the target variable is the main focus of the assessment and is defined by the target evaluation variable maturity (V), which is divided into 4 levels (equation 4.1). The layer underneath the target layer is the criterion layer (I), which contains 5 criteria (equation 4.2). Belonging to the different criteria are sets of indicators which are defined at the indicator layer (I_i), which contains 19 indicators in total (equation 4.3).

To aggregate the different scores and weightings of all the indicators the fuzzy quantitative integrated metric model (FQIMM) of Cheng et al. (2011) is used. The objective of the individual weights in this model is to rate the indicators in more depth towards maturity. Other models suggest pairwise comparison of the individual indicators. In this method the indicators are ordered in an ordinal order and it is not possible to have two indicators with the same level of importance towards maturity. To avoid this strict ordinal order the method of Cheng et al. (2011) suits best. Furthermore, since the different levels of maturity are not building on to each other the user is permitted to choose one of the levels which is most applicable, and so the scores are crisp. The FQIMM takes this into consideration.

Step 1 - To get the importance of the different indicators towards pathway maturity, experts are asked to assign weights to the different indicators in the third round of the stated Delphi study (see section "Delphi study" in chapter 4). The weightings are linguistic so the matrix $\tilde{W}$ is a fuzzy number as can be seen in figure 4.6 and table 4.22.

The weights are represented as the weight of indicator I_{ij} in matrix $\tilde{W}_i$, where $i = [1, 2, 3, 4, 5]$, $n_1 = 5$, $n_2 = 2$, $n_3 = 2$, $n_4 = 6$, $n_5 = 4$, and j the specific indicator:

$$\tilde{W}_i = \Big[\tilde{w}_{i1}, \tilde{w}_{i2}, ..., \tilde{w}_{in_i}\Big] \tag{4.8}$$

Step 2 - The input during the maturity assessment of the care pathway consists of linguistic maturity levels for each indicator. During the assessment the applicable level for the assessed

as-is situation is determined. These scores are represented in a performance matrix M (equation 4.6). Where the value is either 1 for one of the levels (low, moderate, high or top). The rest of the elements in M_{ij} will be 0.

$$M_i = \begin{bmatrix} M_{i1} \\ M_{i2} \\ ... \\ M_{in_i} \end{bmatrix} = \begin{bmatrix} \text{low}_{i1} & \text{moderate}_{i1} & \text{high}_{i1} & \text{top}_{i1} \\ \text{low}_{i2} & \text{moderate}_{i2} & \text{high}_{i2} & \text{top}_{i2} \\ ... & ... & ... & ... \\ \text{low}_{in_i} & \text{moderate}_{in_i} & \text{high}_{in_i} & \text{top}_{in_i} \end{bmatrix} \tag{4.9}$$

Step 3 - The input of the assessment in matrix M is re-organized into an integrated fuzzy numbers matrix $\tilde{A}$. Every assessed indicator has a score (low, moderate, high, top) which relates to a fuzzy number for that specific level. The fuzzy numbers will translate the vagueness of the crisp levels of maturity to a overlapping degree of maturity. The scores of the assessment (M) are multiplied with the membership functions of the corresponding levels as can be seen in figure 4.8 and table 4.24.

$$\tilde{A}_i = M_i \otimes \begin{bmatrix} (0.00, 0.00, 0.33) \\ (0.00, 0.33, 0.67) \\ (0.33, 0.67, 1.00) \\ (0.67, 1.00, 1.00) \end{bmatrix} = \begin{bmatrix} \tilde{a}_{i1} \\ \tilde{a}_{i2} \\ ... \\ \tilde{a}_{in_i} \end{bmatrix} \tag{4.10}$$

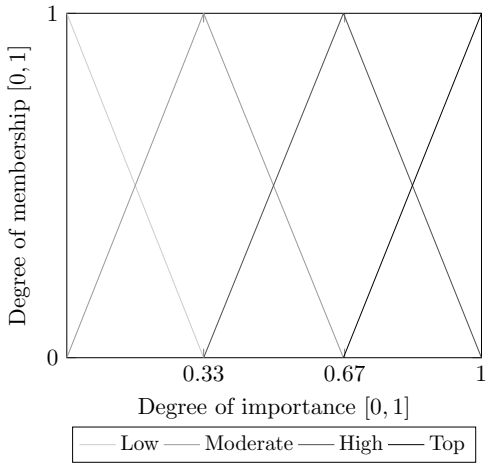

FIGURE 4.8: Membership functions of maturity

TABLE 4.24: Fuzzy numbers of maturity levels

Linguistic valuables	Membership functions
Low	(0.00, 0.00, 0.33)
Moderate	(0.00, 0.33, 0.67)
High	(0.33, 0.67, 1.00)
Top	(0.67, 1.00, 1.00)

Step 4 - To aggregate the input of the different indicators towards the importance, the matrices are multiplied. The result is a fuzzy aggregative evaluation matrix $\tilde{R}$ with fuzzy numbers $\tilde{R}_i$

per criterion.

$$\tilde{R}_i = \tilde{W}_i \otimes \tilde{A}_i = \left[\tilde{w}_{i1}, \tilde{w}_{i2}, ..., \tilde{w}_{in_i}\right] \otimes \begin{bmatrix} \tilde{a}_{i1} \\ \tilde{a}_{i2} \\ ... \\ \tilde{a}_{in_i} \end{bmatrix} \tag{4.11}$$

Step 5 - Ranking of the aggregate evaluation matrix R. For the ranking of the overall maturity $\tilde{R}$, the different aggregated evaluation per criterion $\tilde{R}_i$ are aggregated by the arithmetic mean as in the formula in 4.4. Where k is the total number of criteria, and $(s = 1)$ still holds.

Ranking the triangular membership functions is done following the method of Chen (1985). This method uses the maximizing and minimizing sets for total utility to rank fuzzy numbers in a more sensitive way (Chen, 1985). There are shortcoming to this method in special cases, but due to the triangular shape of the maturity levels this method can be used. The methods makes use of the Euclidean distance and can easily calculate the distance and rank two fuzzy numbers. Each time the fuzzy number for a specific criterion is ranked towards the fuzzy numbers of maturity as in in figure 4.8 and table 4.24.

There are four different fuzzy maturity level numbers ($\tilde{A}_1$, $\tilde{A}_2$, $\tilde{A}_3$, and $\tilde{A}_4$) and one criterion fuzzy number ($\tilde{R}_i$). These numbers are triangular with coordinates $(l_i, 0)$, (m_i, q_i), and $(u_i, 0)$ as in figure 4.9. The membership functions are as in equation 2.5 but adjusted to this situation:

$$\mu_{\tilde{A}_i}(x) = \begin{cases} \left(\frac{x-l_i}{m_i-l_i}\right) q_i & \text{if } l_i \leq x \leq m_i \\ \left(\frac{x-u_i}{m_i-u_i}\right) q_i & \text{if } m_i \leq x \leq u_i \\ 0 & \text{if otherwise} \end{cases} \tag{4.12}$$

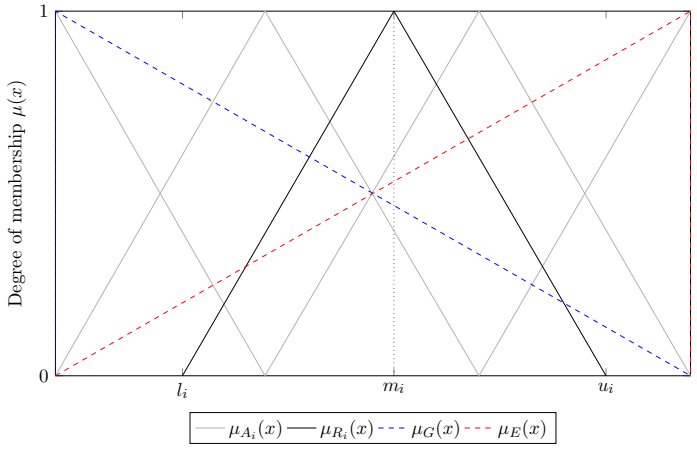

FIGURE 4.9: Ranking method of triangular membership functions following Chen (1985)

Chen (1985) proposes a maximizing set E and minimizing set G, where p is a integer which can be varied to suit risk adjustment of the application (e.g. $p > 1$ risk prone, $p < 1$ risk-averse)

and q is the maximum membership degree of the function. Due to the neutral character of the ranking method, $p = 1$ is used.

$$\mu_{\tilde{E}}(x) = \begin{cases} \left(\frac{x - x_{min}}{x_{max} - x_{min}}\right)^p q & \text{if } x_{min} \leq x \leq x_{max} \\ 0 & \text{if otherwise} \end{cases} \tag{4.13}$$

$$\mu_{\tilde{G}}(x) = \begin{cases} \left(\frac{x - x_{max}}{x_{min} - x_{max}}\right)^p q & \text{if } x_{min} \leq x \leq x_{max} \\ 0 & \text{if otherwise} \end{cases} \tag{4.14}$$

and

$$\begin{aligned} U_{\tilde{E}}(i) &= \sup_x(\mu_{\tilde{A}_i}(x) \wedge \mu_{\tilde{E}}(x)) \\ &= \left(\frac{u_i - x_{min}}{q_i(x_{max} - x_{min}) - q(m_i - u_i)}\right) q q_i \end{aligned} \tag{4.15}$$

$$\begin{aligned} U_{\tilde{G}}(i) &= \sup_x(\mu_{\tilde{A}_i}(x) \wedge \mu_{\tilde{G}}(x)) \\ &= \left(\frac{x_{max} - l_i}{q_i(x_{max} - x_{min}) - q(m_i - l_i)}\right) q q_i \end{aligned} \tag{4.16}$$

We obtain the formula to rank the different criterion fuzzy membership functions R_i in the equation of Chen (1985). The x_{min} and x_{max} are the minimum of the lower bounds, and maximum of the upper bounds of the different maturity levels respectively. The *low*, *middle*, and *upper* values of the specific criterion are l_i, m_i, and u_i respectively. q and q_i are both one since the maximum degree in all membership functions is equal to one.

$$\begin{aligned} U_T(i) = \frac{q q_i}{2} * &\frac{u_i - x_{min}}{q_i(x_{max} - x_{min}) - q(m_i - u_i)} \\ + \frac{1}{q_i} - &\frac{x_{max} - l_i}{q_i(x_{max} - x_{min}) + q(m_i - l_i)} \end{aligned} \tag{4.17}$$

The ranks resulting are the degree towards maturity and have a certain membership degree towards a maturity level.

TABLE 4.25: Fuzzy numbers of the rank per criterion

	Membership functions			Rank
I_i	l_i	m_i	u_i	$U_T(i)$
Design	l_1	m_1	u_1	$U_T(1)$
Owner Performers	l_2	m_2	u_2	$U_T(2)$
Infrastructure	l_3	m_3	u_3	$U_T(3)$
Performance control	l_4	m_4	u_4	$U_T(4)$
Continuous improvement	l_5	m_5	u_5	$U_T(5)$
Overall maturity	l_T	m_T	u_T	$U_T(overall)$

4.2.6.1 Practical example

In this example fictive data is used to explain the steps made in the model.

Step 1 - The value of importance towards maturity of the indicators belonging to criterion *design* are represented as fuzzy numbers in matrix $\tilde{W}_1$. All the different example weights can be found in table 4.26.

$$\tilde{W}_1 = \Big[(0.6, 0.85, 1.0), (0.6, 0.85, 1.0), (0.75, 1.0, 1.0)(0.65, 0.9, 1.0), (0.5, 0.75, 1.0)\Big] \tag{4.18}$$

.

TABLE 4.26: Maturity criteria and indicators example

Target (V)	**Criteria** (I_i)		**Indicator** (I_{ij})	Weight ($\tilde{w}_{ij}$)
Maturity (V)	Design (I_1)	(I_{11})	Pathway objective alignment	$(0.60, 0.85, 1.00)$
		(I_{12})	Pathway definition	$(0.60, 0.85, 1.00)$
		(I_{13})	Compliance	$(0.75, 1.00, 1.00)$
		(I_{14})	Decision moments/criteria	$(0.65, 0.90, 1.00)$
		(I_{15})	Design approach	$(0.50, 0.75, 1.00)$
	Owner & Performers (I_2)	(I_{21})	Owner (Identity)	$(0.60, 0.85, 1.00)$
		(I_{22})	Effective behaviour	$(0.70, 0.95, 1.00)$
	Infrastructure (I_3)	(I_{31})	Information systems	$(0.40, 0.65, 0.90)$
		(I_{32})	Network of paths	$(0.45, 0.70, 0.85)$
	Performance control (I_4)	(I_{41})	Metrics definition	$(0.45, 0.70, 0.95)$
		(I_{42})	Metrics uses	$(0.70, 0.95, 1.00)$
		(I_{43})	Structured collection of data	$(0.50, 0.75, 1.00)$
		(I_{44})	Availability of performance information	$(0.45, 0.70, 0.90)$
		(I_{45})	Availability of real-time information	$(0.40, 0.65, 0.90)$
		(I_{46})	Capacity monitoring	$(0.40, 0.65, 0.90)$
	Continuous improvement (I_5)	(I_{51})	Stakeholder involvement	$(0.70, 0.95, 1.00)$
		(I_{52})	Awareness	$(0.65, 0.90, 0.95)$
		(I_{53})	Flexibility	$(0.50, 0.75, 0.95)$
		(I_{54})	External objectivity	$(0.50, 0.75, 0.95)$

Step 2 - The metrics performance matrix includes the scores of the assessments for a assessed care pathway, where one of the levels is either 0 or 1. The following matrix contains the assessment results for the criterion *Design*.

$$M_1 = \begin{bmatrix} 0 & 0 & 1 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4.19}$$

Step 3 - The practice matrix $\tilde{A}$ is calculated. Every assessed indicator has an score (low, moderate, high, top) which relates to a fuzzy number. These membership functions (see figure 4.24) of the corresponding scores are multiplied. The following is the case for the criterion *Design*.

$$\tilde{A}_1 = M_1 \otimes \begin{bmatrix} (0.00, 0.00, 0.33) \\ (0.00, 0.33, 0.67) \\ (0.33, 0.67, 1.00) \\ (0.67, 1.00, 1.00) \end{bmatrix} = \begin{bmatrix} (0.33, 0.67, 1.00) \\ (0.00, 0.33, 0.67) \\ (0.00, 0.33, 0.67) \\ (0.33, 0.67, 1.00) \\ (0.67, 1.00, 1.00) \end{bmatrix} \tag{4.20}$$

Step 4 - Aggregate to the evaluation matrix $\tilde{R}_i$ by multiplication of the practice matrix $\tilde{A}_i$ and the weights $\tilde{W}_i$ (Cheng et al., 2011). The equation below is the evaluated fuzzy number of criterion *design*.

$$\begin{aligned} \tilde{R}_1 &= \tilde{W}_1 \otimes \tilde{A}_1 \\ &= \Big[(0.6, 0.85, 1.0), (0.6, 0.85, 1.0), (0.75, 1.0, 1.0), (0.65, 0.9, 1.0), (0.5, 0.75, 1.0)\Big] \otimes \begin{bmatrix} (0.33, 0.67, 1.00) \\ (0.00, 0.33, 0.67) \\ (0.00, 0.33, 0.67) \\ (0.33, 0.67, 1.00) \\ (0.67, 1.00, 1.00) \end{bmatrix} \\ &= \Big[(0.15, 0.51, 0.87)\Big] \end{aligned} \tag{4.21}$$

The results are listed in table 4.27 and a sample of the two multiplied membership functions for "Owner & Performers" is given in figure 4.10. As can be seen in this figure the multiplication of the two triangular membership functions of *practices* $(\tilde{a}_{21}, \tilde{a}_{22})$ and *weights* $(\tilde{w}_{21}, \tilde{w}_{22})$ is not an triangular membership function any more since the line between l and m and u is approximately not linear.

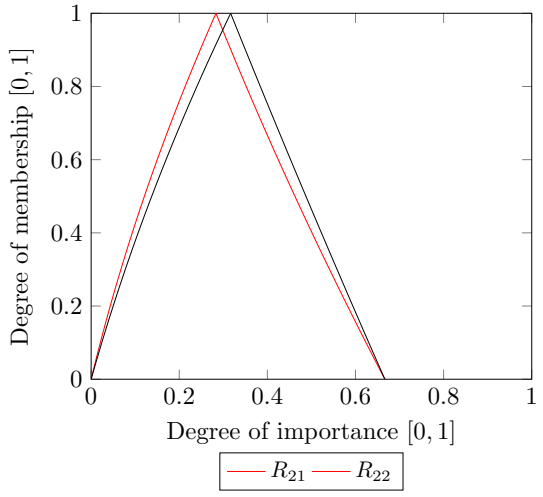

FIGURE 4.10: Results of ranking membership functions "owner & performers"

TABLE 4.27: Fuzzy numbers of aggregation example

I_i	R_i	Membership functions
Design	R_1	(0.15, 0.51, 0.87)
Owner Performers	R_2	(0.00, 0.30, 0.67)
Infrastructure	R_3	(0.00, 0.11, 0.44)
Performance control	R_4	(0.08, 0.37, 0.78)
Continuous improvement	R_5	(0.10, 0.42, 0.80)
Overall	R_T	(0.07, 0.34, 0.71)

Step 5 - To rank the results, equation 4.17 is used.

$$U_T(i) = \frac{1}{2} * \frac{u_i - x_{min}}{x_{max} - x_{min} - m_i + u_i} + 1 - \frac{x_{max} - l_i}{x_{max} - x_{min} + m_i - l_i} \tag{4.22}$$

The different maturity levels for criteria are shown in figure 4.11 and table 4.28. For all the fuzzy numbers and aggregations see appendix E.

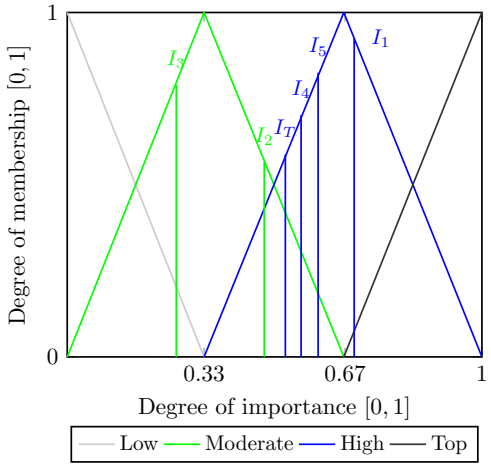

FIGURE 4.11: Maturity membership functions and results

TABLE 4.28: Fuzzy numbers of the rank per criteria example

I_i	$U_T(i)$
Design	0.692
Owner Performers	0.475
Infrastructure	0.263
Performance control	0.564
Continuous improvement	0.605
Overall maturity	0.526

4.3 Practical model format

The above describe model was first translated on to an A4 sheet and contained the structure, criteria, indicators, and maturity levels (see appendix F). This sheet was used for the assessments in chapter 6.

To test if the practical model would be used in practice, Technology Acceptance Model (TAM) questions were used to improve the practical model as a tool.

The TAM consist of several questions which measure the concept as can be seen in the figure 2.7. 18 clinical experts, who had used the model, were asked to rate the several statements (as in appendix G with a rating between 0 - *completely untrue* till 10 - *completely true*. The background of the clinical experts can be found in table 6.1. However, the limitation of this method is that it is adopted, and the questions are not validated which means that the results will be less powerful.

4.3.0.2 Consistency analysis

Before started the development of the maturity model as a tool some requirements were checked that support the findings. First the internal consistency of the answers of the 18 clinical experts towards the TAM were validated using RapidMiner Studio, as can be seen in table 4.29.

TABLE 4.29: Reliability in answers to TAM questions

Constructs	No. of items	Item mean	Standard deviation	Coefficient α	Corrected item-total correlation (min)
Perceived usefulness	4	6.48	2.02	0.33	0.43
Perceived ease of use	4	6.76	1.63	0.69	0.46
Intention to use	2	7.22	1.64	0.74	0.88

As can be seen in table 4.29 the Cronbach's alpha is above 0.7 for "intention to use" which is good (Cronbach and Thorndike, 1971; Tavakol and Dennick, 2011). Unfortunately for the construct "perceived usefulness" and "perceived ease of use" the Cronbach's alpha is not satisfied, this is supported with the fact that the standard deviation is relative high. The low Cronbach's alpha scores can be declared by the low corrected item-total correlations, which is slightly ideal (> 0.4) (Gliem and Gliem, 2003). However these scores indicate that the constructs exist of the right items.

The item means are above an average score, which indicates a slightly positive attitude towards the use of the model. Further development of the practical model format could enlarge these scores. For this reason the practical format of the maturity model is developed towards a tool.

4.3.1 Maturity assessment tool development

The proposed process assessment model is set up in an workable excel file. This excel sheet contains all the calculations and an user form in which the user can state the output of the assessment.

The file also contains a speedometer representation of the final maturity level including the maturity levels for the different criteria. An example of this representation is given in appendix H figure H.3, where the different 'speed' levels from left till right indicate *low*, *moderate*, *high*, and *top*. The rankings in the speedometer are represented in a fuzzy way, since the needle of the speedometer can vary between levels and within a specific maturity level. Some screenshots of the complete maturity assessment tool are given in appendix H.

4.3.2 User guide

The use of assessment tool is rather simple. The first sheet of the excel file contains an introduction, definition of the used terms, and references to the resources used.

The next sheet will contain a overview of the scored indicators. The scores can be given by a click on the button "Assess Maturity". This will open a user form were the indicators are stated per criterion. The assessor can click the appropriate maturity level of which the characteristics describe the as-is situation the best.

The assessor can end the assessment at the last tab of this user form by clicking the button "Add and calculate". By clicking this button the program will calculate the maturity levels and grades. The speedometers on this sheet will indicate the maturity of the different criteria and the overall maturity.

When using the tool, the requirements of the assessment process in chapter 5 will hold.

5. Assessment process

In this second part of the maturity measurement methodology, the focus is on the assessment process in general (see figure 5.1). This process will consist of a description of the desired input during the assessment as well as the requirements for reliable output. The roles and responsibilities are also listed to clarify the different stakeholders and requirements during the assessment. Furthermore the actual assessment process is defined and constructed.

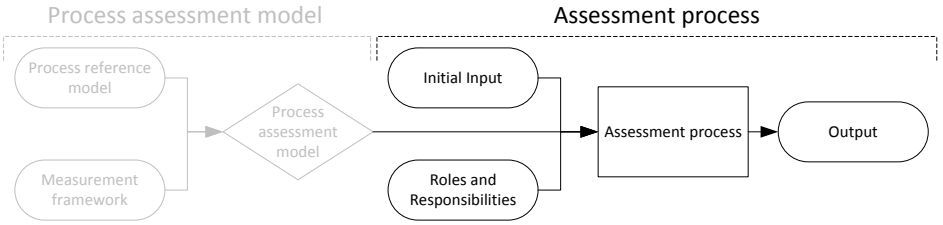

FIGURE 5.1: Major elements of the maturity assessment process, part two (ISO/IEC, 2004a)

5.1 Roles and responsibilities

Commitment of the sponsor needs to be assured to get access to sufficient resources (ISO/IEC, 2003). Including the availability of the key personnel for interviews and artefacts for examination (ISO/IEC, 2004b). To accomplish this, enough information and instructions need be sent to the participates in the assessment. Another action for the researcher is to ensure that the interview achieves it purpose (ISO/IEC, 2004b).

Different roles that can be involved in an assessment are:

- Nurse practitioner in care pathway team (performer)
- Surgeon in care pathway team (performer)
- Quality manager (owner/developer)
- Program manager (specific for care product)
- Other specialist (performer)

The requirement for the focus group to assess the maturity of the chosen care pathway is that there is at least one member of the focus group who was involved in the design phase of the specific assessed care pathway.

5.2 Initial input

Before performing an assessment, the initial input needs to be approved by the sponsor of the assessment. This can be accomplished by sending the information about the assessment process, suggested in the previous section (ISO/IEC, 2003).

The translation of the input provided by the assessment participants is done using fuzzy logic. Several techniques which are used to structure the capabilities are mentioned in the earlier section 4.2.6.

The input is reflecting the as-is situation of the assessment participant and can be represented in a metrics matrix $\tilde{m}$, as explained in chapter 4.

Another important aspect is the determined objective of the assessment. The objective can vary for different enterprises (e.g. analysing different care pathways within a specific enterprise, benchmarking with other enterprises).

5.2.1 Assessment scope

Part of the assessment scope is determining the chosen care partway. The model is developed to assess maturity of care pathways and so this will be the level of capability to perform an assessment at (ISO/IEC, 2004b). Which means that care pathway maturity is divided into capability levels that correspond to different degrees of maturity.

Documenting the characteristics of this pathway is part of the assessment and sets the scope in more detail. Characteristics including complexity can influence the assessor and how the judgement is made (ISO/IEC, 2004b).

Besides this, the perspective of the provided input needs to be determined. This will include setting the time-frame of assessment to the as-is situation or the start-up phase of the care pathway.

Due to the scope of the assessment the confidentiality of the output use needs to be agreed upon by the assessment sponsor and assessor. In the example of benchmarking, it is possible that the assessment sponsor agrees on anonymizing the used output.

5.2.2 Assessment approach

The last requirement that needs to be determined as initial input is the approach of assessments. In the framework of ISO/IEC (2004b), two approaches are applicable which are adopted for the proposed model.

Self-assessment is a method managed by the enterprise unit itself as being the assessors (ISO/IEC, 2004b).

Independent assessment is performed when external assessors outside the enterprise (unit) perform the assessment. An external assessment committee can improve the independence based on the purpose, scope, and context of the assessment (ISO/IEC, 2004b).

Besides these different approaches a structure of key sources of the assessment pathway is needed to get an overview of the assessment situation. This is needed to select the right assessment participants and ensure that the input of the assessment participants is accurate. Some constraints can influence the approach. The availability of key resources and assessment participants needs to be taken into account. Related to this availability of key resources, the duration and the objective of the assessment need to be determined and communicated to the assessment participants.

5.3 Output

The information which is the input of the assessment participants during the assessment, and the output of the assessment phase needs to be documented. Documenting the output and recording the assessment profile will enhance the objectivity of the assessment and facilitates verification for the assessment participants and third parties. An assessment profile includes the date, pathway profile, and key resources of the assessment.

6. Model validation

In this second part of the thesis, the focus will be on testing the maturity methodology in practice. This will include determining the parts of the assessment process in section 6.1, as well as the analysis of the maturity assessment results in section 6.2. Furthermore, the maturity assessed grades and their relation and correlation towards quality data is analysed in section 6.3. Section 6.4 will support the validation of the model by analysing the model parameter maturity membership functions.

To test the maturity measurement methodology, a small group of hospitals is selected for in-depth case studies. Voss et al. (2002) state that when testing a theory from case studies, case selection needs to be based on replication logic instead of sampler logic. For this research the choice is made to select different types of hospitals, to analyse the difference in hospital type specific maturity. The sampler logic is less present in this approach, since there are not many hospitals selected per type. Therefore, the results per type will not be a statistical representation for that specific hospital type. However, the different hospital types are represented as can be seen in table 6.1 and some differences between those types should be possible to measure.

6.1 Assessment process

In this phase, the parts of the assessment process are determined for several case studies, as defined in the assessment process description in chapter 5.

6.1.1 Roles determination

The hospitals which were approached for participation in these case studies are mainly associated with the Dutch Institute for Healthcare Improvement (CBO). These hospitals are already familiar with the definition of care pathways and are interested in development and implementation of care pathways. The selected hospitals are approached by phone and email, and were asked for interest in participation. Of the 25 hospitals which had been called, eleven hospitals were willing to assess their care pathway in more detail.

All the eleven meetings took place within one month time. Initially a nurse practitioner, surgeon, and policy maker were invited to join the meetings. In most of the assessed hospitals, the responsible specialists for the care pathway differ, as can be seen in table 6.1. This made the planning of the meetings with the right specialists difficult. Therefore, different roles were present in the different meetings. However, this choice was made to ensure that the specialist with the most knowledge and know-how of the assessed care pathway was present. By using focus groups consisting of members with different backgrounds and knowledge the assessment is more in-depth, and representative information about the actual status of the process was collected.

TABLE 6.1: Case study characteristics (N=11)

Region	ID	Type[a]	Turnover[b]	Employees[b]	Role 1	Role 2	Role 3
Gelderland	1.	UMC	€979.5 mln.	7706	Nurse practitioner		
Utrecht	2.	STZ[d]	€417.2 mln.	3382	Surgeon oncologist		
North Holland	3.	STZ	€340.4 mln. (2013)	2751 (2013)	Nurse practitioner		
Friesland	4.	STZ	€305.8 mln.	2640	Program manager and NP		
Gelderland	5.	STZ	€282.1 mln.	2670	Program manager oncology	Surgeon oncologist	
North Brabant	6.	STZ	€262 mln.	2458	Nurse practitioner	Unit manager	
Limburg	7.	STZ	€225.3 mln. (2013)	2056 (2013)	Secretary oncology program	Program manager oncology	Nurse practitioner
Gelderland	8.	SAZ	€133.2 mln.	1264	Nurse practitioner	Manager quality & development	
Limburg	9.	SAZ	€129.4 mln.	1145	Quality policy advisor		
Drenthe	10.	SAZ	€106.7 mln. (2013)	868 (2013)	Coordinator care pathways		
North Brabant	11.	SAZ[c]	€113.7 mln. (2013)	966 (2013)	Nurse practitioner	Care path owner	Client department

[a] NVZ (2012)
[b] KvK (2014)
[d] Based on enterprise website (2015)
[c] Based on merged top-clinical hospitals (2015)

Besides this, the eleven selected hospitals were corresponding to the different types of hospitals in the Netherlands. The difference in types, as illustrated in figure 2.3, is also visible in the amount of turnover and employees, as stated in table 6.1. To illustrate these differences, figure 6.1, and figure 6.2 show the amounts. Hospital 8, 9, 10, and 11 are SAZ hospitals and have less turnover and employees in comparison to the STZ and UMC hospital(s). The turnover of the assessed UMC with 979.5 million Euros is almost 1.5 times more than an average STZ, and 3.4 times more than an average SAZ.

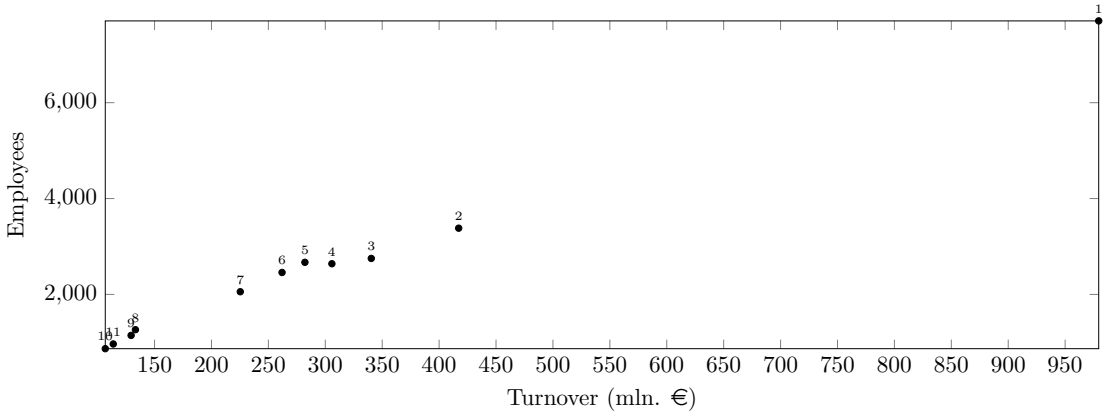

FIGURE 6.1: Characteristics of assessed hospitals (scatters)

6.1.2 Input determination

The scoring of the different indicators is done in a semi-structured interview with focus groups per hospital. To prevent the scoring in the different hospitals from subjectivity, the assessor (researcher) was present in all the meetings. This also means that the assessor is collecting

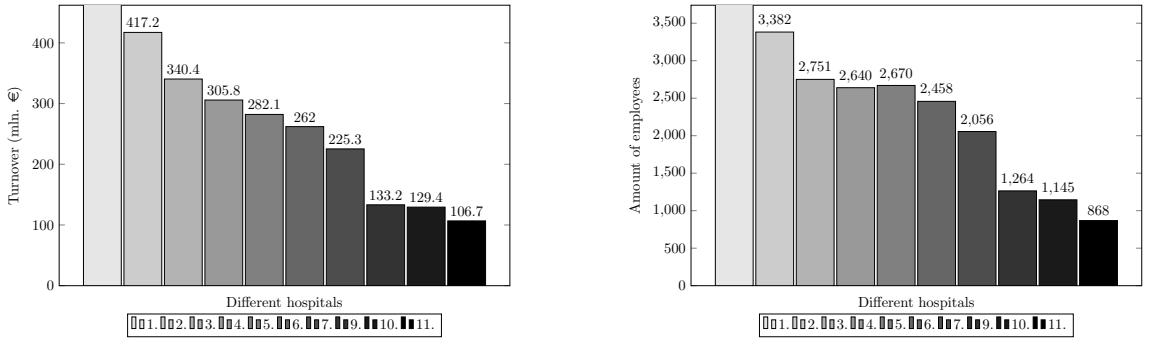

FIGURE 6.2: Characteristics of assessed hospitals (bars)

the input of the different meetings in the same way. The roles of the key personnel in this assessment are described in table 6.1.

Besides this, the hospitals were updated 2 weeks before the meeting took place with information about the meeting. This included the planning, required requisites (care pathway documentation), and preparation document. This preparation document included definitions about the terms used in the model and the assessment input, as recorded by the assessor. To clarify the methodology in more detail, the document also contained the pathway maturity assessment model, as in appendix F. By providing the model beforehand, the hospitals were able to prepare for the meeting.

6.1.2.1 Scope

The kind of care pathway selected for this assessment is mamma carcinoma, or in vernacular, breast cancer. This disease is elective care, which makes the process dependent on decisions made by specialists. The decisions made during this process are multidisciplinary, which makes it suitable for care pathway implementation. This disease has been researched many times and official quality and performance standards are developed and measured (DHD, 2013; NCR, 2013; Zorginstituut, 2013). In all of the selected hospitals a mamma carcinoma care pathway is present (see table J.1 in appendix J).

In 2013, 3161 women died in the Netherlands due to mamma carcinoma. The chance to be diagnosed with mamma carcinoma is 8.3% for female between the age of 20 and 80 and 9% for female between 45 and 80 (NCR, 2013).

The scope of the mamma carcinoma care pathway is defined by specific start and end statuses. This entails the process from incoming request for a diagnosis till the follow-up cycle at the end of the process as can be seen in the simplified example that Van Hoeve et al. (2014) constructed (figure 6.3). The assessed care pathways can differ in flavour and local deviations from the one in figure 6.3.

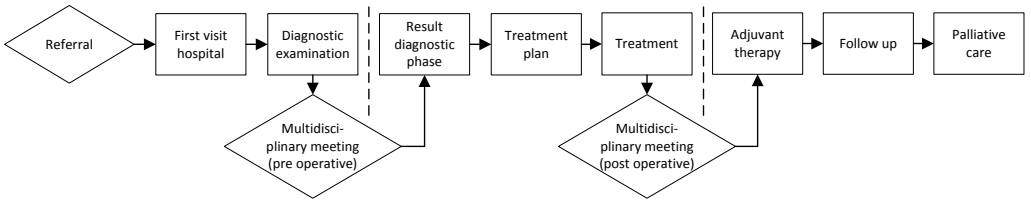

FIGURE 6.3: Simplified mamma carcinoma care pathway following Van Hoeve et al. (2014)

6.1.2.2 Approach

The possible methods to collect data are self-assessment and independent assessment, where independent assessment is chosen considering the first time use of the model and the objective of the case studies. Semi-structured interviews are most appropriate when doing such an independent assessment.

6.1.3 Output

During the assessment, different kinds of data form the output of the assessment. First, the assessment process output which is the result of the different assessments. This output is an metric matrix with scores for every indicator based on the input of the specialists.

The input of the specialists consist of the mentioned requisites as well as an answer on the questions asked by the assessor. The objective of these questions was to obtain information about the as-is situation of the care pathway. The information provided by the specialist is recorded and coded against theoretical codes. These codes are the indicators and corresponding characteristics. An example of the coded raw interview data translated into a metric set can be seen in appendix I.

Extra findings resulting from these meetings are stated in the following section.

6.1.3.1 Interview findings

During the different assessments, the input of the specialists was leading when scoring the different indicators. Besides the needed information required for determining the score, extra interesting information was recorded. This information is stated below, grouped into categories which subjects were mentioned most often. These categories vary from *motivation* of implementing a care path, *design* characteristics of the implemented care path, *auditing* of the care path, *monitoring* the care path information, *metrics* defined and used in monitoring the care path, *availability of pathway performance data*, and *collaboration* between other hospitals and care pathways. Due to the anonymous use of the collected data during the different meetings, the different hospitals will be named by using the numbers as pseudonyms described in the reference table 6.1.

Motivation - The motivation is the start for a hospital to design a care pathway. In the situation of hospital 4, the pathway is developed to replace the "clinical pathway" of mamma carcinoma. The pathway motivated more process thinking then the protocols and check-lists in the former situation. In this manner the pathway is now a broad guideline of the process. Other hospitals wanted to have more control on their pathway and used this perspective to develop the care pathway. With the development of their care pathway a better alignment with the new information system is possible in hospital 3. Hereby the pathway supports electronically analysis of the performance and efficiency of the pathway. The main motivation for all the hospitals is the ability to better analyse the performance of the pathway and to develop a more efficient pathway process.

Design - The design of the care pathways is in most of the hospitals done with help of a framework, institution, or training. The hospitals designed their pathways between 2009 and 2015, with an exception for hospital 4 (2001). This indicates a young and growing movement of pathway developments for this specific care type.

Since the IKNL has developed an framework to design an pathway, this framework is used in hospital 4, 9, and 5. However, hospital 5 and 9 had to revise the format of the framework to make it compatible with their quality document system. Another framework was developed by KPMG Plexus and was used in hospital 8. On the other hand, hospitals used the training of the CBO to gain skills for designing care pathways. Another institution which research care pathway implementations is the NKP. Besides training sessions, they also deliver measurements for care pathways, which they did for hospital 11.

During this design phase hospital 2, 5, 6, 8, 9, and 11 actively had close contact with all their stakeholders. This ensured an aligned development and aligned expectations. The stakeholders consist of clinical experts, specialists, and in most cases patients.

Auditing - Auditing is done to ensure the quality and a certain standard of care delivery. Most hospitals are requested to participate in such a study, and deliver performance information. Auditing can take place in two forms, internal and external.

The internal auditing is mostly done by an steering committee within the hospital. These committees are care dependent and exist of different expertises and specialists. In hospital 2, and 11 the steering committee meets twice a year, and in hospital 3 and 5 they meet every two months. Based on these meetings the pathway can be revised. In hospital 4 and 9 the pathway is revised every other year and meetings are planned when there is an urge to review the path. Hospital 1 has an internal governance body who measure and audit the pathways hospital wide.

Another form of auditing is externally. External audits are mostly done when requested through different auditing institutes. These main institutes include the Comprehensive Cancer Centre the Netherlands (IKNL), Dutch Institute Clinical Auditing (DICA), Pink Ribbon ("Roze lintje"). On the other hand insurers also request process and quality measures to analyse the care

path and use the outcomes as arguments in negotiation about funds. Another form of external review is a patient committee, which reviews and advices the care pathway steering committee on a regular base in most of the hospitals. In hospital 11 this committee meet every other year.

So there is an urge to control the pathway and benchmark the performance to ensure a certain quality. Based on these findings the motivation to monitor and benchmark these results are mainly from the external institutes.

Monitoring - Since the motivation of some hospitals is to get more control on there performance, the pathway monitoring is important. Almost all of the assessed hospitals work with a steering committee who monitors the performance and quality of the care path mamma carcinoma on a frequent base to understand its behaviour. Data is collected and transformed in most cases to information. This information is used to steer and manage the pathway, and is in most of the hospitals available on request within the IT facility of the hospital. However, this information is always an overview of the past performance and not a current or prospective view. In most hospitals the primary function of this information is the input for the care inspection institutions, such as the DICA.

However, most of the earlier described steering committees meet every week to discuss the throughput times, waiting times and possible bottlenecks. This method is time-consuming but effective as mentioned by hospital 7. In the situation of hospital 1, the internal quality system warns when a check needs to be performed once a year. More actively warned, are the specialists in hospital 8 where the specialists get weekly updates and warnings provided by management when the process performance is below a set of criteria. Another example of more accurate information view is the situation in hospital 2, where they introduced a "patient tracking system" (PTS). This system was only operating for the surgery part of the pathway process, but there is an ambition to expand the system through the whole pathway. This system is the objective of hospital 8, which they want to achieve with implementing a new global information system.

Metrics - When monitoring, most hospitals monitor the metrics which they need to report to the DICA. A few hospitals developed extra metrics which they found interesting and usable for day-to-day management and strategic development. About the total amount of metrics needed to measure, exist mixed feelings. Most of the clinical specialists are hesitant towards more administrative steps in the treatment process, because of the extra time that the steps take to perform. On the other hand the experts and managers are interested in getting an inside in the pathway performance and quality by analysing this extra data. In hospital 8 they arranged extra time for manual monitoring steps, which helps the specialists to monitor their performance without having less time available for their patients.

Hospital 5, 8, and 9 state that without an fully alignment and integration of the pathway into the electronic patient information system, it is not possible to automatically monitor and measure

useful pathway process metrics. Furthermore, the electronic patient information systems are mainly healthcare process generic and thus the systems miss care product specific metrics to analyse the specific care pathway in more depth.

Availability of pathway performance data - In most of the measured hospitals the pathway performance data is available within the IT department on request. The most important data, which is needed to steer on, is available during the monitoring meetings mentioned earlier. The clinical experts stated that such information is important at the right time, but not every single minute of the day. These statements are interesting because they are contradicting to the characteristics at some mature levels of some indicators in the model (e.g. real-time data). In situation of hospital 11, the information system is in place to view performance data, but using its full capacity requires effort and is in this phase a lower priority.

Collaboration - In most situations the hospitals are collaborating with several other hospitals in the region. The main objectives for these collaborations are the shared expertise, knowledge , productivity, and capacity. Also the external and internal auditing is a shared motivation to form such a group.

Concluding these several findings, one can see that the hospitals strive towards a more transparent care pathway. After all, the motivation for the implementation of a care pathway is to be able to analyse and develop the process. Where the care pathway is mainly designed in a structured way and based on a framework, the fundamental information systems to collect data and calculate performance information is lacking in most hospitals. The information systems in place are mainly used for providing the necessary DICA information, to ensure a prove for the national quality standard. Being able to steer the performance of a pathway, the structure of the pathway needs to be integrated with the information system in use. As can be concluded from the assessments, the maturity scores for the indicator *information systems* (weight (0.41,0.66,0.91) indicate a maturity level between moderate and high.

6.2 Assessment results

The results of the assessment are given as feedback to the hospitals. This feedback was represented in the new model format, as described in 4.3.2. An extra tab was created to show the maturity scores of the 11 anonymised hospitals.

6.2.1 Maturity findings

As can been seen in table 6.2, the difference in overall maturity levels between the different types of hospitals is not clearly visible. The maturity levels of top clinical hospitals (STZ) are between 52% and 85% where the range between maturity levels for the general hospitals (SAZ) is between 64% and 72%, so due to the range the differences in maturity are bigger between top clinical hospitals (STZ).

TABLE 6.2: Case study maturity assessment results

		UMC	STZ						SAZ			
Source	**Indicators**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
2015 - Maturity model assessment (%)	Design, $U_T(1)$	72	71	67	72	81	91	55	72	77	74	44
	Owner & Performers, $U_T(2)$	46	77	61	46	61	100	76	61	73	63	90
	Infrastructure, $U_T(3)$	62	59	11	50	59	70	71	38	62	77	62
	Performance control, $U_T(4)$	47	69	46	47	50	73	59	68	72	62	56
	Continuous improvement, $U_T(5)$	72	95	68	68	67	87	75	81	75	75	75
	Overall, U_T	60	74	52	57	64	85	67	64	72	70	66

The averages per hospital type are represented in figure 6.4. The total maturity averages are 60%, 67%, and 68% for UMC, STZ, and SAZ respectively and presented in figure 6.4 (UMC(black), STZ(blue), SAZ(yellow)). A remark here is that the average of UMC includes only one hospital, which makes the statements concerning the UMC type hospitals in general not realistic. This representation is also used in the practical model format as explained in 4.3. The results show that maturity over the types of hospitals holds for the *owner & performers*, *performance control*, and *continuous improvement* criteria. The maturity for the criteria *design* and *infrastucture* is for all types almost the same. These findings combined show that the bigger the hospital is on average per hospital type, the lower the overall maturity and the maturity of the mentioned criteria is on average, where top clinical hospitals have more divers overall maturity levels for this type.

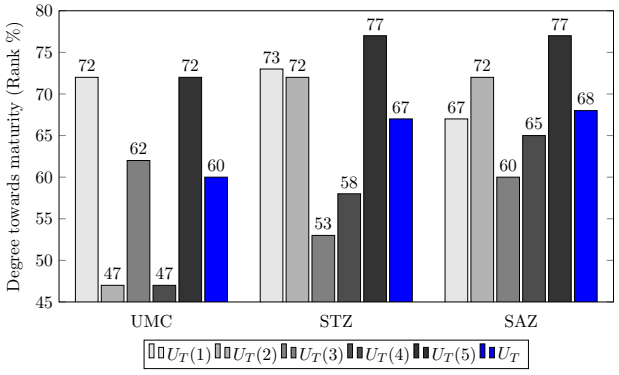

FIGURE 6.4: Ranks per assessed hospital

6.3 Maturity and quality relation

Besides the analysis of the different maturity results, an analysis is done in which collected public hospital quality data and the assessed maturity scores are tried to connect to each other. This data is all publicly available and therefore traceable. Several institutions are approached for meta data of hospital quality, but due to the high costs attached to those information requests and the zero budget for this research, the public data is chosen to be sufficient. The connection is not based on any statistical evidence due to the small sample size of 11 case studies. Further research is recommended for analysis on this topic.

Quality data (2013) is found for ten of the eleven hospitals (DHD, 2013). The data for the missing hospital is due to the fuse of two individual hospitals in 2013. All the ten assessed hospitals have participated in the Dutch Breast Cancer Audit and delivered their related results over the year 2013 (DHD, 2013). Furthermore the ten hospitals include a pre- and post-operative multidisciplinary meeting in their care pathway for mamma carcinoma. The waiting times between diagnose and start neo-adjuvant chemotherapy is measured and stated in table J.1 in appendix J (DHD, 2013).

Other quality data is obtained from the "zorginzicht.nl" website, which is a transparent open database with several indicators for performance and quality (Zorginstituut, 2013).

The table in appendix J entails the usable variables in the collected datasets (DHD, 2013, 2014; Zorginstituut, 2013, 2014). These variables are all used in national laws, regulations, and guidelines (Nederland, 2008). The last rows of the table indicate the assessed maturity scores of the different criteria and the overall maturity level as presented in table 6.2.

In some hospitals the pathway is designed, without the involvement of an stakeholder with a patient perspective. Due to the fact that patient involvement is a characteristic for the indicator *design approach*, there should be an impact on the criterion *design* which is not clearly visible. This means that the measurement of the criterion *design* is not reflecting this quality score.

The data collected on the waiting times is from a public database maintained by DHD (2014). An chemotherapy within five weeks after PA-diagnoses is a norm which the hospitals need to pursue. The ranges in the achievements of this norm in the assessed hospitals vary from 63% till 100%. It can be said that a lower percentage indicates a lower level of quality judgement. Figure 6.5 indicates the waiting time against the overall maturity level, where the right figure is a close-up of the interesting area in the left figure. The overall maturity is chosen because the waiting time is supposed to be not directly related to a specific criterion.

As can be seen in this figure, the results are scattered and no substantiated relation can be indicated between the quality measures and the assessed overall maturity scores. However, the results of the averages per hospital type show the same regulation as in the maturity analysis (UMC(black), STZ(blue), SAZ(yellow)). An decrease in hospital size indicates an increase in percentage of new diagnosed patients who had chemotherapy within five weeks after PA-diagnose.

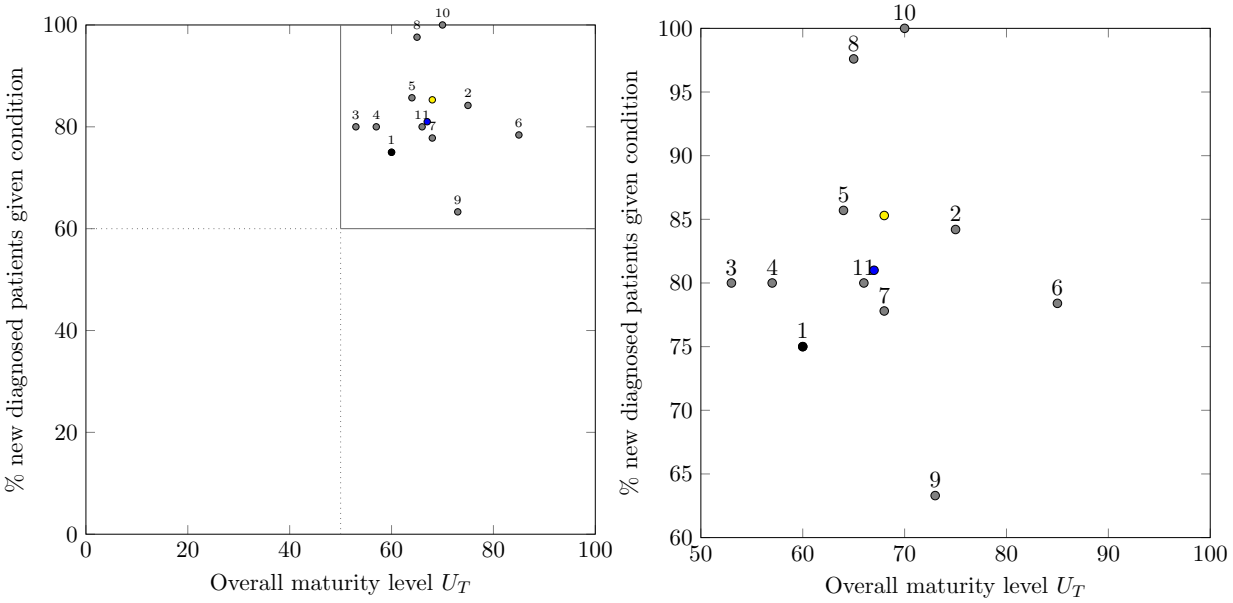

FIGURE 6.5: Percentage of new diagnosed patients who had chemotherapy within five weeks after PA-diagnose against overall maturity level [UMC(black), STZ(blue), SAZ(yellow)]

Another quality norm is the percentage patients with remainders of cancer tissue after surgery. Were a higher percentage, so more remainders, indicates a lower level of quality judgement. For the understandability of figure 6.6 the reversed value of this percentage is taken, such that a higher percentage means higher quality. Where the right figure is a close-up of the interesting area in the left figure.

In figure 6.6 one can see that an increase in maturity level indicates a decrease in the level of quality and thus more patients with remainders left after surgery. This behaviour is contradicting to a positive relation between maturity and quality, as suggested by (Raschke and Ingraham, 2010). Also the averages of the maturity assessed for the hospitals types are contradicting to what we have seen in the other quality attribute (UMC(black), STZ(blue), SAZ(yellow)). Therefore, this particular analysed relation can suggest that when the statement of Raschke and Ingraham (2010) is true, the maturity can not be measured with the proposed methodology in this research. On the other hand the maturity assessment methodology can be correct and the relation suggested by Raschke and Ingraham (2010) does not hold for these 11 hospitals.

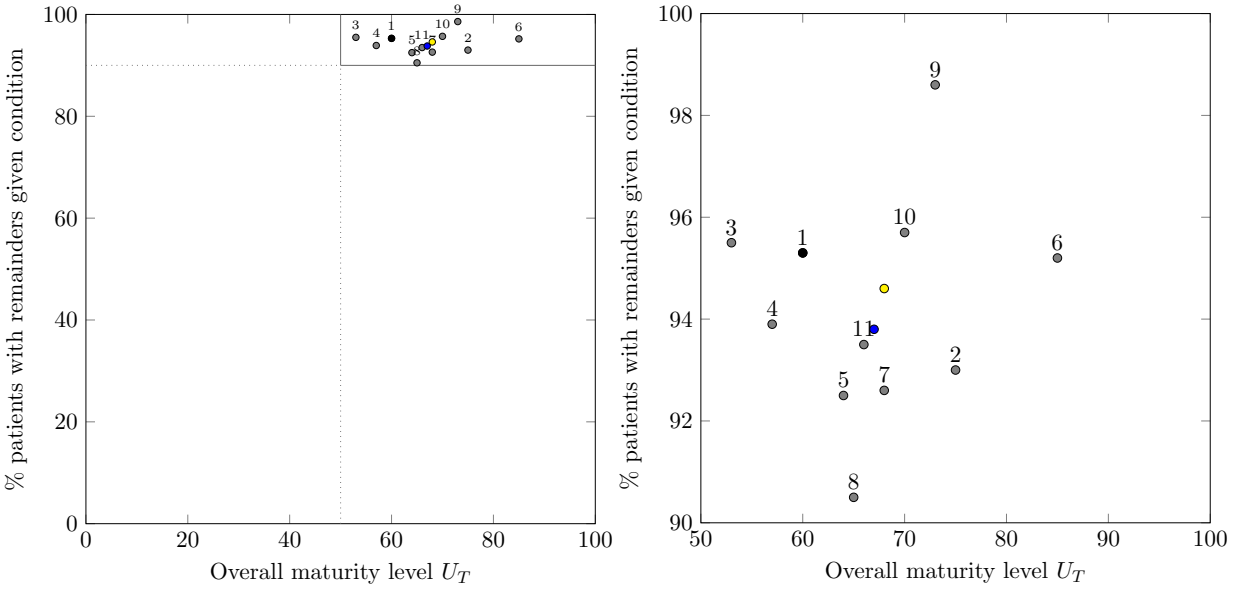

FIGURE 6.6: Percentage patients with remainders of cancer tissue after surgery [UMC(black), STZ(blue), SAZ(yellow)]

6.3.1 Pink Ribbon quality standard

A well-known quality standard for mamma carcinoma care is the Pink Ribbon (Nederland, 2015a). This international well-known mark is popular among hospitals which provide mamma carcinoma care. A collection of 63 attributes indicate if a hospital will receive a pink ribbon certificate. Of these 63 attributes, 13 attributes are considered as most important by the Dutch Breast cancer Association (BVN) (Nederland, 2015a). All the attributes are originally part of the national laws, regulations, and guidelines for mamma carcinoma care (appendix K). The quality scores of hospitals in the Netherlands are represented in the breast cancer monitor. To be able to analyse this quality standard, the data is extracted from the breast cancer monitor (Borstkankerzorg, 2015).

The attributes are real, numeric, nominal, and integer data types. An quantitative analysis is done using Rapid miner, an open source predictive analytics platform. To investigate if the defined four maturity levels are visible in the quality data, clustering is performed on these quality attributes. With clustering several hospitals with similar characteristics on the same quality attributes are grouped into a cluster. When the maturity scores and quality scores are related, one should expect the same division of clusters corresponding to specific maturity levels.

6.3.1.1 Cluster analysis

Of the 63 available attributes, 55 attributes were selected, as can been seen in appendix K figure K.1. The other attributes were left out due to their equality in the quality scores for all the

11 hospitals. Clustering is done using K-mean. A Bregman Divergences measure types and Squared Euclidean Distance for the divergence method is used as a first analysis.

The clusters compared to the degrees of maturity for the criterion *design* are represented in figure 6.7. Here we can see that cluster 3 includes the only level 2 maturity scores and therefore this cluster indicates a separate cluster for level 2 scores on the criterion *design*. However, the level 3 scores are spread across the clusters 0, 1, and 2. An alignment between a specific cluster with the same quality characteristics and the maturity scores of 55 and higher for design is not possible. The same divers scores of maturity over the cluster 0, 1, 2 are visible for *owner & performers* maturity levels (figure 6.8). For this criterion it is not possible to assign quality clusters to maturity scores.

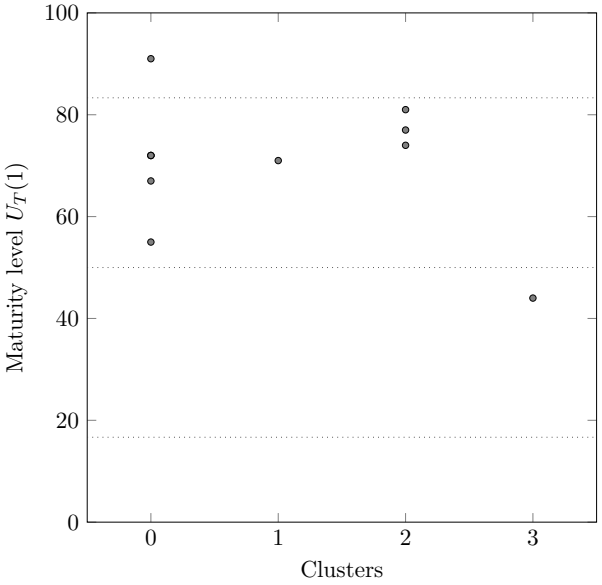

FIGURE 6.7: Clusters and maturity levels *design*

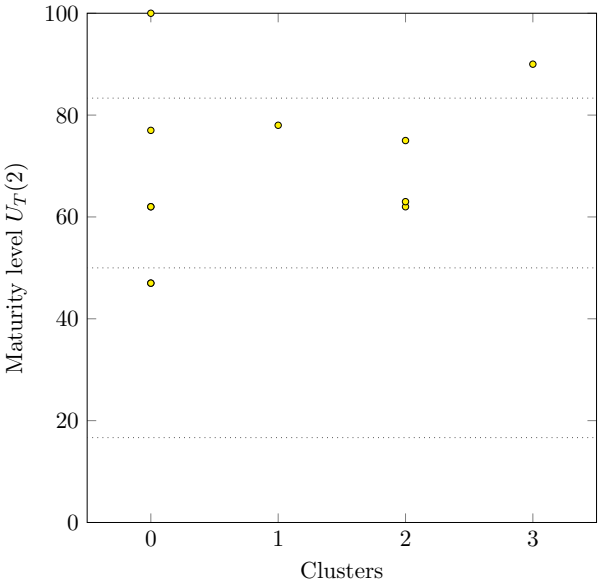

FIGURE 6.8: Clusters and maturity levels *owner & performers*

When comparing the clusters towards the maturity for the criterion *infrastructure* (figure 6.9), cluster 0 include scores of maturity level 1, 2, and 3, which indicated no alignment. The same holds for the clusters of criterion *performance control*, which are divers as well (figure 6.10).

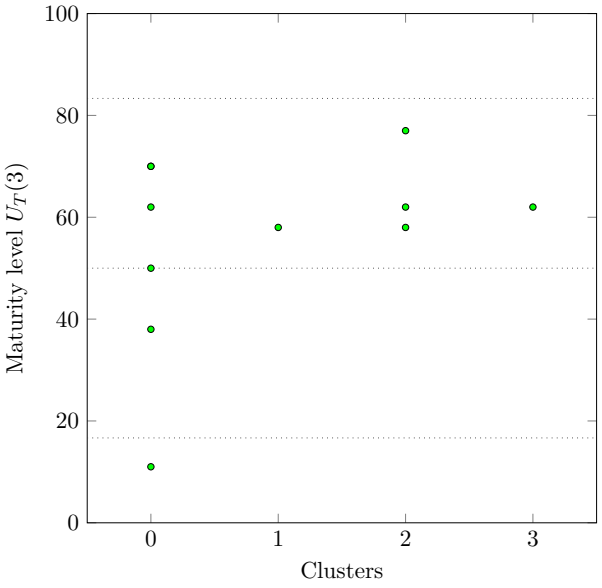

FIGURE 6.9: Clusters and maturity levels *infrastructure*

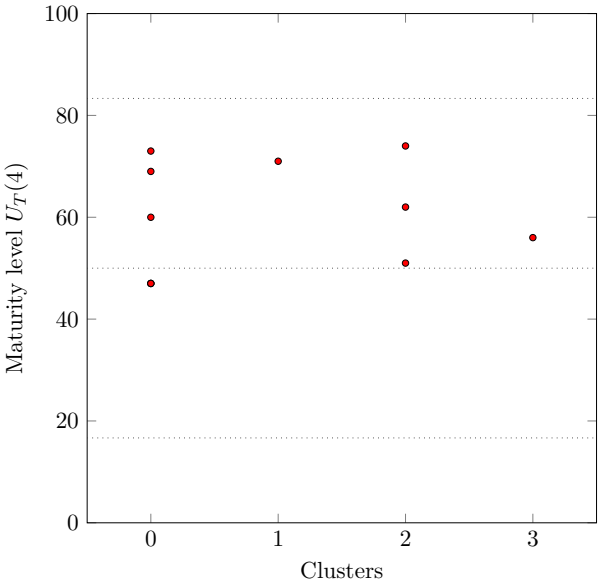

FIGURE 6.10: Clusters and maturity levels *performance control*

The clusters compared to the criterion *continuous improvement* don't show a specific cluster per maturity level (figure 6.11). When analysing the clusters compared to the *overall* maturity scores in figure 6.12, cluster 0 includes the three lowest overall maturity scores. One could state that this cluster belongs to level 3 scores, but on the other hand the range of maturity between 63 and 77 is spread out over the different clusters which contradicts the first statement. The maturity score of 85 is not an unique cluster where this is the only score with a divergent maturity level 4.

The results of this cluster analysis are not supporting the statement made by Raschke and Ingraham (2010). A reason for this could be the different maturity levels, which are not sensitive enough due to there range. This could change for example when moving the border between level 3 and 4 up to 90. In this case, the criterion *continuous improvement* will cause a single cluster for the highest maturity score. This sensitivity will be further analysed in the following section. Nonetheless, this means that the quality clusters don't support relation between quality and maturity.

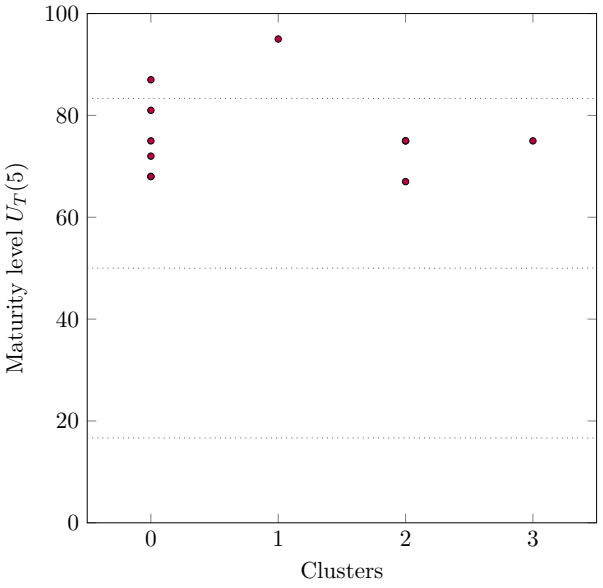

FIGURE 6.11: Clusters and maturity levels *continuous improvement*

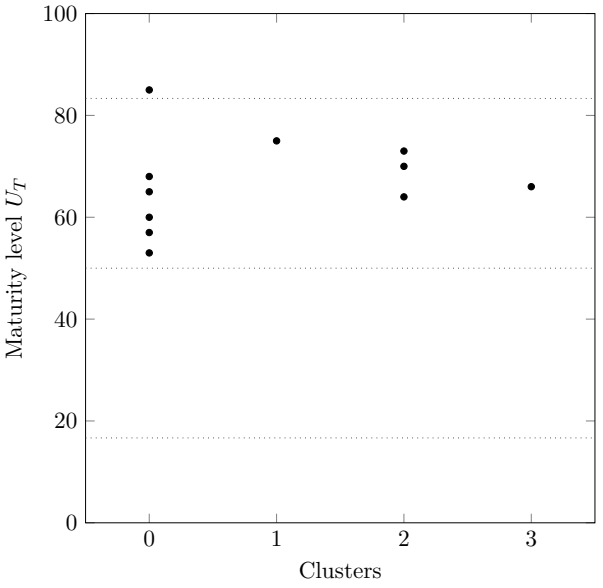

FIGURE 6.12: Clusters and maturity levels *overall*

6.3.1.2 Correlation analysis

To analyse the quality attributes and maturity in more detail, a correlation matrix is constructed for a more in-depth analysis. In this correlation matrix the correlation is visible between the maturity scores per criterion and the attributes. The correlations higher than 0.5 or lower than -0.5 are listed in table K.2. Most of the interesting correlations are of data type real.

A high correlation, 0.83, is the one between the criterion *design* and "percentage of patients with MRI included in the neo-adjuvant chemotherapy". So when patients get an MRI during the treatment in a care pathway, this pathway will probably also score better on the maturity of the criterion *design*.

An interesting negative correlation of -0.86 is the one between the criterion *infrastructure* and the nominal data type attribute "treatment program lymphedema". This attribute indicates if the hospital has an treatment program for lymphedema. Only hospital 3 and 8 don't have such a program at there hospital location but have them at other locations. This can be related to the low maturity scores on the criterion *infrastructure*, 11 and 38 respectively.

The attribute "percentage of patients who know their contact person after treatments" is for 0.65 correlated with the criterion *Performance control*. The higher the amount of people that know who there contact person is, the higher the maturity of that care pathway. And visa versa. This attribute is dependent on the information of the pathway process which is provided to the patient.

The criterion *continuous improvement* has also a high correlation of 0.74 with "percentage of patients who know their contact person after treatments". So the score on this quality attribute becomes more important towards the maturity of care pathways. Another high correlation of 0.8 is the one with the integer attribute "amount of direct reconstructions sept. 2013 to oct. 2014". This means that the higher the maturity level is, the higher the amount of direct reconstructions that took place between September 2013 and October 2014.

As proposed by the three individual correlations between the criteria *performance control*, *continuous improvement*, and the quality attribute "percentage of patients who know their contact person after treatments", there is a correlation of 0.69 towards the *overall maturity* as well with this attribute (figure 6.13). The other correlations with *overall maturity* are of data type nominal and less interesting, since they are correlated less then 0.67.

A small conclusion of these findings is the correlation of almost all criteria with the attribute "percentage of patients who know their contact person after treatments". This indicates the importance of the involvement of the patient into the pathway procedure. This observation is in line with the objective of the "pink ribbon" (Nederland, 2015b), stimulating patient oriented mamma carcinoma care. This correlation indicates that the model is measuring maturity in a patient centred way.

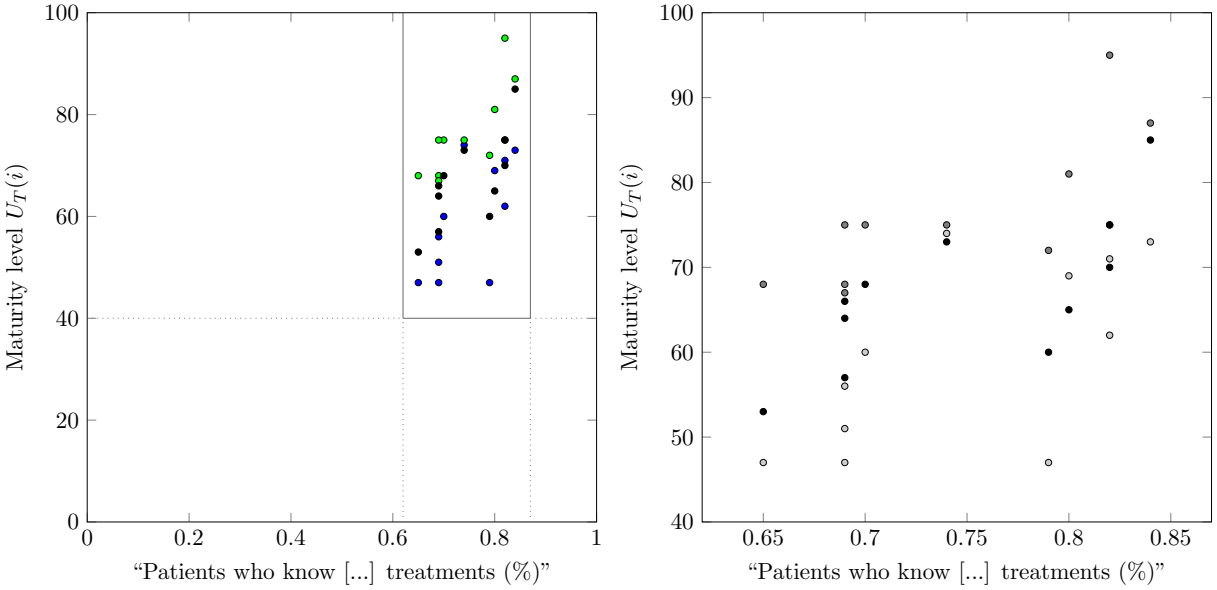

FIGURE 6.13: Relation between maturity scores and quality attribute [*performance control*=blue, *continuous improvement*=green, *overall maturity*=black]

6.4 Maturity membership functions sensitivity

The chosen maturity membership functions for the maturity levels are parameters of the model and have an impact on the assessment results when translating the assessed metrics set into a

maturity score. To validate these functions and analyse their impact, a sensitivity analysis is done.

It is possible that the membership functions for the maturity levels need to have smaller intervals as in figure 6.14, or just bigger as in figure 6.15. The more narrow functions still have the same optimum, $m_i(x) = 1$ for $x = (0, 0.33, 0.67, 1)$. In the example with wider functions, the optimums are shifted. In this example the optima are $x = (0.38, 1), (0.63, 1)$.

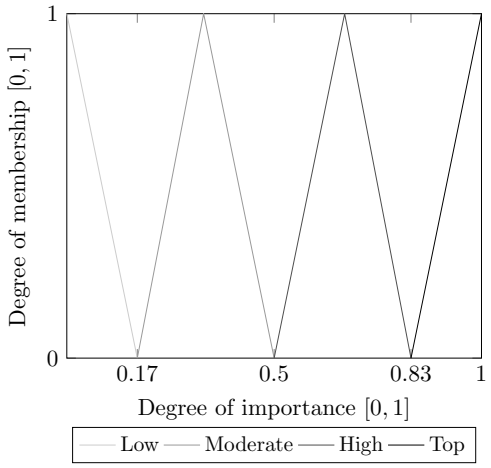

FIGURE 6.14: Smaller membership functions of maturity

TABLE 6.3: Fuzzy numbers of small membership functions

Linguistic valuables	Membership functions
Low	(0.00, 0.00, 0.17)
Moderate	(0.17, 0.33, 0.50)
High	(0.50, 0.67, 0.83)
Top	(0.83, 1.00, 1.00)

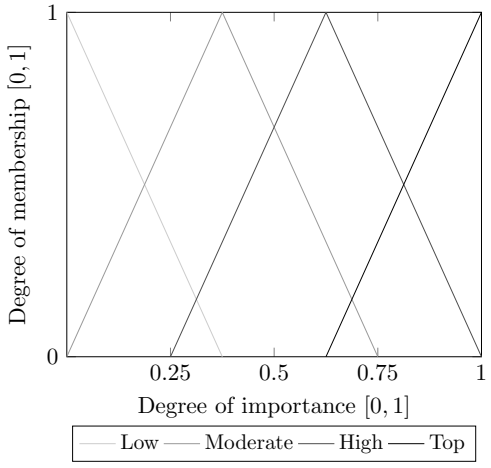

FIGURE 6.15: Bigger membership functions of maturity

TABLE 6.4: Fuzzy numbers of big membership functions

Linguistic valuables	Membership functions
Low	(0.00, 0.00, 0.38)
Moderate	(0.00, 0.38, 0.75)
High	(0.25, 0.63, 1.00)
Top	(0.63, 1.00, 1.00)

If the membership functions change in comparison to the current used membership functions for the different maturity levels, this would have the following results, where the metric scores are high and moderate respectively (table 6.5).

For a metric set consisting of all high scores, it can be seen that the results for more narrow functions will be higher except from the criterion *infrastructure*. This could be due to the steeper slopes on either side of the functions. On the other hand, when the functions are wider, the overlap between the functions is larger and this results. And lower maturity scores on all *criteria*.

A metric set consisting of all moderate scores will result in opposite maturity effects in comparison to a metric set consisting of high scores. The more narrow functions have smaller maturity scores towards the current results. The wider functions have higher maturity values.

As can be concluded from both metric sets, the interval of the functions have an effect on the maturity results. The example with bigger intervals in the functions results in bigger differences towards the current maturity scores than the example with smaller intervals. This due to the steeper and less steep slopes of the membership functions. By adjusting the parameter maturity membership function the model is flexible.

TABLE 6.5: Results sensitivity membership functions

	Metrics: High			Metrics: Moderate		
	Current	Smaller	Bigger	Current	Smaller	Bigger
i	$U_T(i)$	$U_T(i)$	$U_T(i)$	$U_T(i)$	$U_T(i)$	$U_T(i)$
1	0.774	0.789	0.735	0.467	0.451	0.509
2	0.791	0.808	0.750	0.475	0.460	0.518
3	0.651	0.649	0.622	0.398	0.375	0.436
4	0.692	0.695	0.660	0.423	0.402	0.462
5	0.753	0.764	0.715	0.454	0.437	0.495
Overall	0.733	0.741	0.697	0.444	0.425	0.485

Another possibility to adjust the parameter is to divided the maturity into three or five levels, instead of the proposed four. When the amount of levels is limited to three, the will be less variability in the scores. However, when there are six maturity levels, the maturity scores will be more divers. When considering a fuzzy representation as in the maturity tool (figure H.3), the score will be represented on a scale and not in crisp categories. Due to this fuzziness the number of levels is not that important any more.

Another aspect which can be varied in the parameter maturity membership is the shape of the functions. More research is needed on this topic to support the other shapes and there possible improvements on the model results. As showed, the ranges of the membership functions will have an impact on the maturity results.

7. Research results

In this research a maturity model is constructed with the help of experts in the field and with the research of literature, which will ensure the reliability of the model. The model is constructed following a Delphi study and, as can be concluded from the several rounds, consensus is achieved on the model structure and the content of different layers in the model. The consensus will ensure the content and construct validity, which measure if the model measures all the aspects of care pathway maturity and the construct care pathway maturity respectively.

Aggregation considering the human interpretation is reached due to the fuzzy aggregation approach. The assigned weights of the different indicators give the aggregation and structure more value and emphasize those indicators that have a high importance towards maturity. The final ranking method is a judgement of the resulting fuzzy numbers towards the membership functions of the different maturity levels. The sensitivity of the model parameter maturity level membership functions are analysed and validated towards flexibility of the model.

Representation of the assessment result is kept fuzzy by the use of speedometers, as developed for the model as a tool in figure H.3 in appendix H. This will enlarge the understandability and easiness to use the model as a tool in practice. Information on the use of the model in care pathway situation is provided in a user guide in section 4.3.2.

Due to interest in practical use, the model is tested and validated in 11 different hospitals in the Netherlands. During these meetings, several common interests and behaviours are listed. Apart from this information, the output of the assessment is fed into the maturity model as the defined metric input set, which resulted in the following degrees towards maturity, as can been seen in figure 7.1.

The results describe the differences in maturity as it is assessed by the model in eleven hospitals in the Netherlands. Figure 7.1 states the degree towards a mature pathway (%) per assessed hospital, where the gray columns indicate the different maturity levels per criteria (*design*, *owner & performers*, *infrastructure*, *performance control*, and *continuous improvement*) and the concluding blue column indicates the overall maturity for that specific hospital. The differences are visible between the different criteria, but the overall maturity flattens it out due to its averaging character.

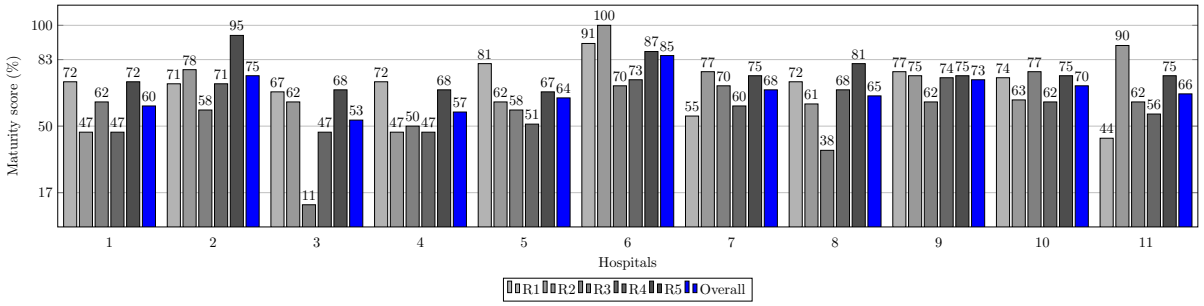

FIGURE 7.1: Rank percentages towards different criteria grouped per hospital

8. Discussion and conclusion

8.1 Discussion

This research contributes to the field of maturity of care pathways by the construction of a maturity measurement model. The approach to achieve this, is done by formulating the following research question:

How can a maturity model be constructed to assess the maturity of a care pathway?

The answering of this question is reached through developing a maturity model and answering the following sub-questions in parallel.

1. How can the maturity level of a care pathway be measured?

The literature review and research has shown that the maturity of a care pathway can be measured using a hierarchical structure of criteria and indicators. These indicators need to be measured using a maturity scale of four levels.

2. Which criteria need to be measured to assess the maturity of a care pathway?

The criteria and indicators that best represent and measure the maturity in care pathways are constructed and validated using literature and expert knowledge in a Delphi study. In this approach the criteria and indicators are tested and related to practice, and current vision of the experts towards the topic of maturity and care pathways is researched. This in combination with the literature will enlarge the validity of the constructed maturity model.

3. How can criteria be assessed and aggregated to determine a specific level of maturity?

Literature has shown that four levels of maturity is useful to measure process maturity (Hammer, 2007). The use of four levels of maturity will give the user an overview of the characteristics per level and why a certain level is most applicable to the situation of assessment. To aggregate this assessment output into a single maturity level for the care pathway as a whole, fuzzy logic is used in an effective manner. The use of fuzzy numbers will appreciates the fuzziness of the definition of maturity, and the interpretation of it by humans.

During this research some limitations were present during the research. The following section will elaborate on these aspects.

8.2 Limitations

A vulnerability of the model is the possible over-positive or over-negative behaviour of the assessor when a self assessment is done. To limit this, the different levels in the model are descriptions of the different characteristics per situation to choose from when scoring. Also

the different interpretations of the model and its levels are tried to be minimized, by using different characterised level description. In such that the case study assessments are done by the researcher himself to understand the situation of the assessment better, and to score the maturity of the care pathway together with the specialists to minimize this vulnerability.

Another aspect is the small sample size used in the case study assessments. The objective of these assessments was to practically test the model, which is achieved. But the statistical validation and testing need to be done in more detail and with a larger sample size. Besides this, a first step is made relating the maturity results towards quality (section 6.3).

At last the hospitals which were interested to participate in the assessment were already intrinsic motivated to test and validate their pathway. It is possible that this encourages the volunteers to give the best representation of the pathway and besides over-positive scoring, assign volunteers interested in maturity measurement to the participation just to provide input instead of participants with knowledge about every aspect of the care path.

Due to this limitations the following recommendations are made for further research.

8.3 Recommendations

Since every research is not perfect there are some recommendations left to motivate new, and further research.

First of all, statistical studies should be done to support the relation of maturity towards quality and performance. With performing this research the verifiable importance can be shown to enterprises in healthcare to assess the maturity of their care pathway maturity.

Second, the used membership functions in the aggregation construct can be validated in more detail and further investigated to confirm the triangular shape used. Or new applicable shapes of membership which can be proposed.

Third, the usability of the model can be enlarged by translating the model into the assessment situation specific language. This will minimize the misinterpretation of the model and its content when performing a maturity assessment.

8.4 Research conclusion

Constructing a model that can measure maturity of care pathways, was the objective of this research. The approach to develop a practical model and assessment tool is due to the lack of research as describe in literature, and based on the relevance in current healthcare developments (Kiers, 2014; Van Den Elsen, 2013; Vanhaecht et al., 2006a). A hierarchical assessment model is constructed with different layers. The results show a constructed maturity measurement model consisting of five criteria and 19 indicators. The criteria and indicators measure the capability

of a pathway to ensure quality and performance in the long term (Hammer, 2007; Raschke and Ingraham, 2010; Tarhan et al., 2015a). The different maturity levels represent the as-is situation of the care pathway, when the model is used. This will help and support pathway owners to monitor, evaluate, and eventually improve their pathway. The model can be used in practice but statistical validation needs to be performed to enlarge its usefulness.

A first step towards validation in terms of acceptance and intention to use, to support the practical value is done. Besides this, the performed research motivates further research to investigate the relation of maturity and outcome (e.g. quality and performance).

Concluding this part with the added scientific value of the model which strived to enlarge the knowledge field of maturity in healthcare. Furthermore it motivates the practical use of scientific new developed knowledge as an instrument, to improve operational processes.

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Appendix A. Delphi study structure

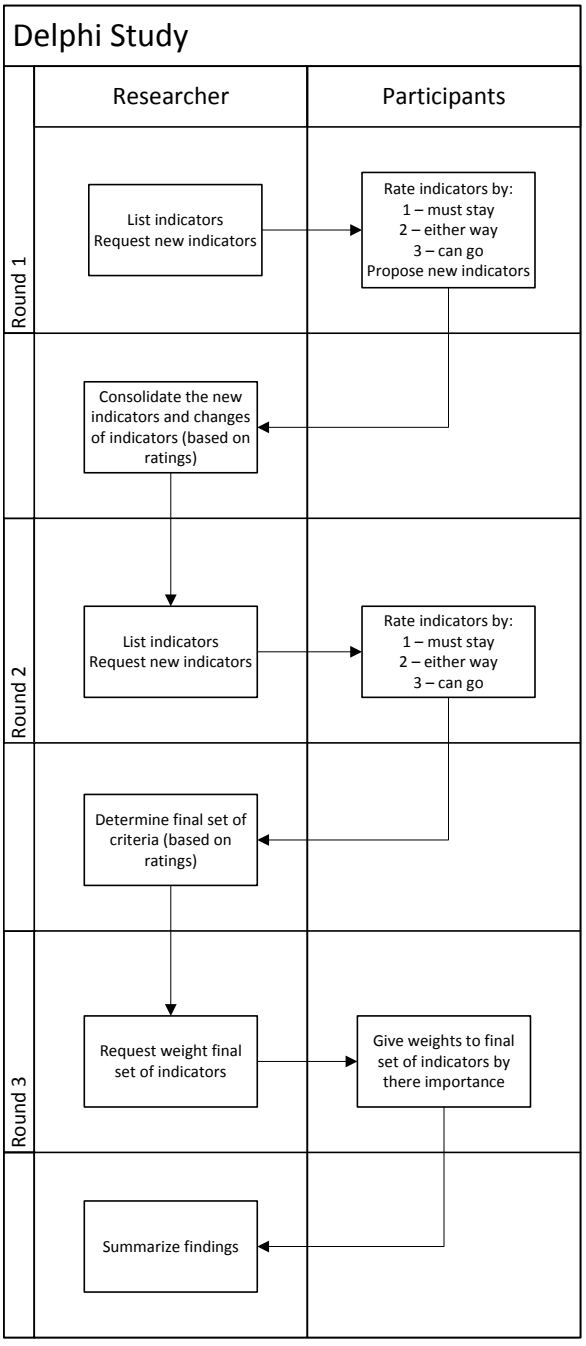

FIGURE A.1: Schema Delphi rounds based on De Bruin and Rosemann (2005)

Appendix B. Results Delphi round 1

TABLE B.1: Maturity criteria and indicators; *[A]: Analytics (2015), [B]: Berg et al. (2005), [dB]: De Bleser et al. (2006), [H]: Hammer (2007), [N]: Nederland (2008), [P]: Plexus (2009), [S]: Schrijvers (2014), [W]: Weber et al. (2008)*

Target (V)	**Criteria** (I_i)	#	**Indicator** (I_{im})	**Based on**	**Result**
Maturity	Construct	1.	Aim	[P]	Stay
		2.	Evidence based	[N]	Can go
		3.	Design methodology		Stay
		4.	Clear defined process steps and end	[P]	Stay
		5.	Compliance with national guidelines		Stay
		6.	Documentation	[H]	Change
	Granularity	7.	Terminology	[B]	Stay
		8.	Model of work procedures	[B]	Change
		9.	Decision moments/criteria	[B]	Stay
		10.	Individual tasks	[B]	Change
	Performers [H]	11.	Owner (Identity)	[H]	Change
		12.	Behavior	[H]	Stay
		13.	Accountability		Can go
		14.	Relations		Can go
	Infrastructure [H]	15.	Information systems	[H], [N], [S]	Stay
		16.	Architecture	[A]	Stay
		17.	Network paths	[P]	Stay
	Monitoring	***new***	Targets		
		18.	Metrics		Stay
		19.	Availability information	[S]	Stay
		21.	Systematic collection of data	[dB]	Stay
		21.	Capacity monitoring	[P]	Stay
		22.	Patient info about position care pathway	[P]	Stay
		23.	Frequent measure & improve cycle	[N], [P]	Change
	Knowledge	24.	Expertise level	[N], [P]	Can go
		25.	Multi teams	[N]	Can go
		26.	Awareness		Stay
		27.	Communication		Stay
		new	External objectivity	[W]	

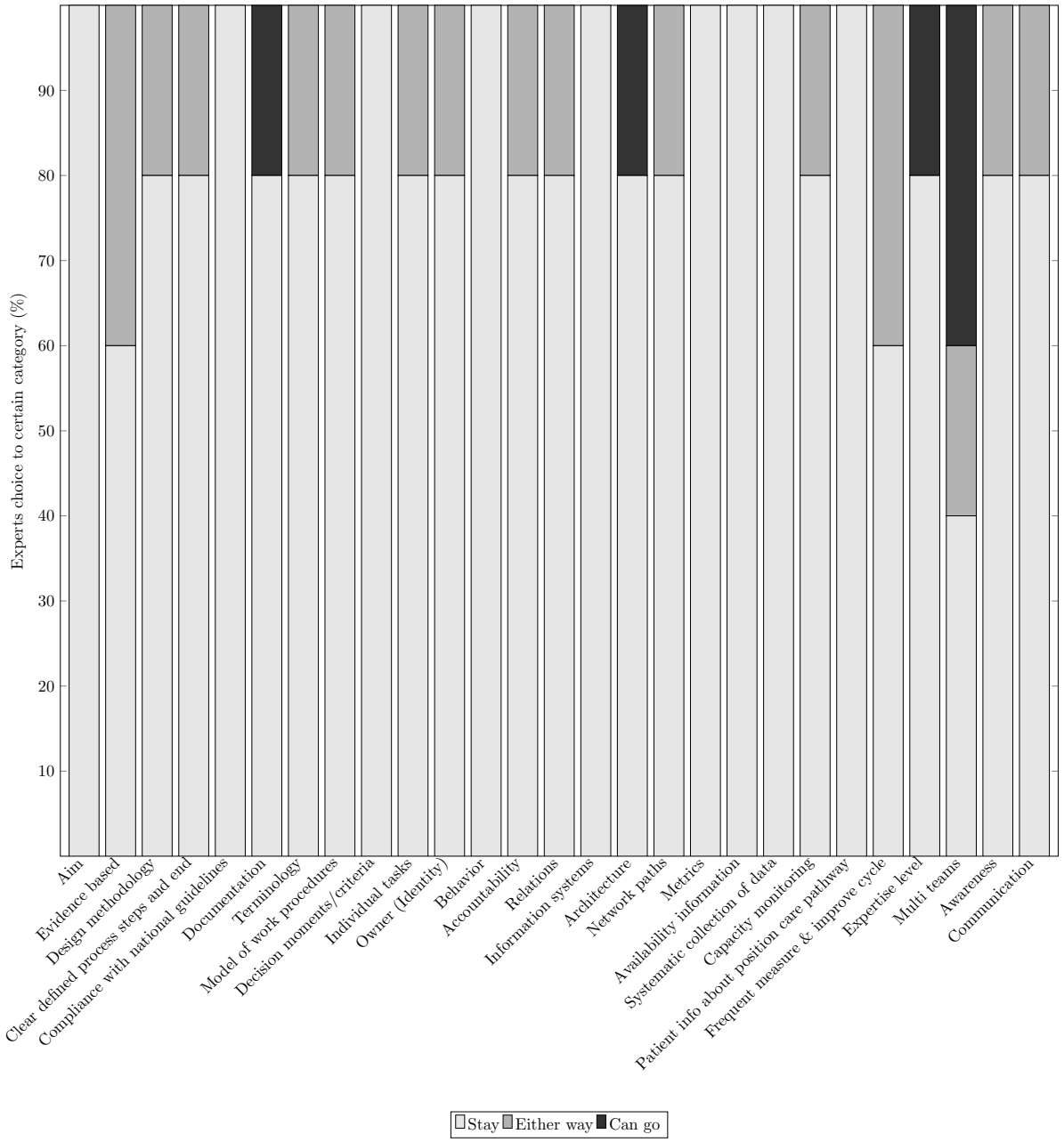

FIGURE B.1: Results Delphi round 1

Appendix C. Results Delphi round 2

TABLE C.1: Maturity criteria and indicators; *[A]: Analytics (2015), [B]: Berg et al. (2005), [dB]: De Bleser et al. (2006), [H]: Hammer (2007), [N]: Nederland (2008), [P]: Plexus (2009), [S]: Schrijvers (2014), [W]: Weber et al. (2008)*

Target (V)	**Criteria** (I_i)	#	**Indicator** (I_{im})	**Based on**	**Result**
Maturity	Design	1.	Aim	[P]	Change
		2.	Design approach		Stay
		3.	Clear defined process steps and end	[P]	Change
		4.	Compliance with guidelines		Change
	Granularity	5.	Owner (Identity)	[H]	Change
		6.	Terminology	[B]	Change
		7.	Documentation	[H], [B]	Change
		8.	Decision moments/criteria	[B]	Change
	Performers [H]	9.	Individual tasks	[B]	Can go
		10.	Behavior	[H]	Stay
	Infrastructure [H]	11.	Information systems	[H], [N], [S]	Stay
		12.	Architecture	[A]	Can go
		13.	Network paths	[P]	Change
	Performance control	14.	Targets		Change
		15.	Metrics		Change
		16.	Systematic collection of data	[dB]	Change
		17.	Instant information view	[S]	Change
		18.	Capacity monitoring	[P]	Stay
		19.	Patient position monitoring	[P]	Change
	Continuous improvement	20.	Availability information		Change
		21.	Communication		Change
		22.	Awareness		Change
		23.	Frequent measure & design improve cycle	[N], [P]	Can go
		24.	External objectivity	[W]	Stay
		new	Flexibility		

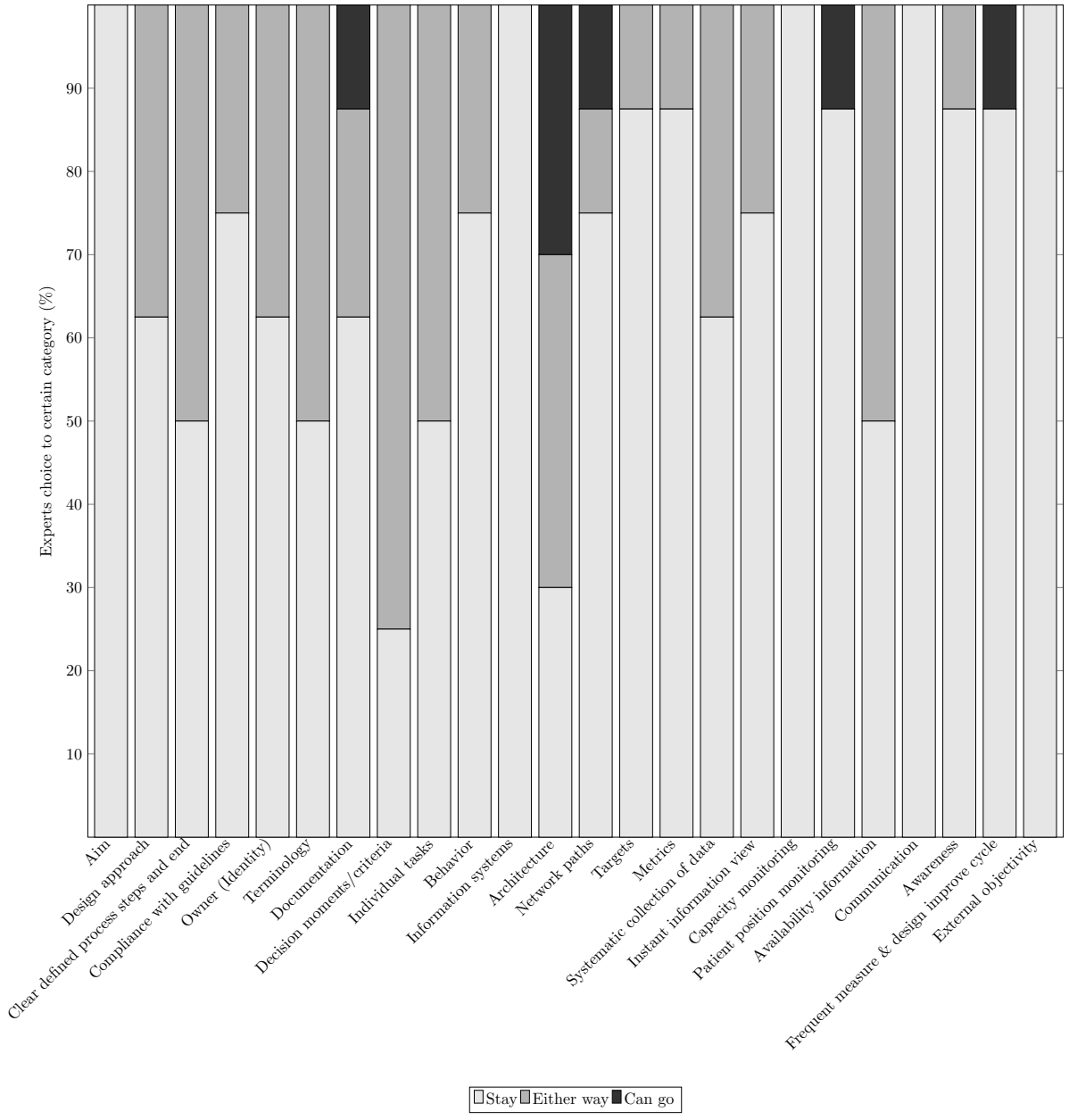

FIGURE C.1: Results Delphi round 2

Appendix D. Results Delphi round 3

TABLE D.1: Maturity criteria and indicators; *[B]: Berg et al. (2005), [dB]: De Bleser et al. (2006), [H]: Hammer (2007), [N]: Nederland (2008), [P]: Plexus (2009), [S]: Schrijvers (2014), [W]: Weber et al. (2008)*

Target (V)	**Criteria** (I_i)	#	**Indicator** (I_{im})	**Based on**	**Weight**
Maturity	Design	1.	Pathway objective alignment	[P], [H]	(0.625, 0.875, 1.000)
		2.	Pathway definition	[P], [H]	(0.531, 0.781, 0.969)
		3.	Compliance		(0.531, 0.781, 0.875)
		4.	Decision moments/criteria	[B]	(0.469, 0.719, 0.875)
		5.	Design approach		(0.563, 0.813, 1.000)
	Owner & Performers [H]	6.	Owner (Identity)	[H]	(0.594, 0.844, 1.000)
		7.	Effective behaviour		(0.656, 0.906, 0.969)
	Infrastructure [H]	8.	Information systems	[H], [N], [S]	(0.406, 0.656, 0.906)
		9.	Network of paths	[P]	(0.344, 0.594, 0.781)
	Performance control	10.	Metrics definition	[H]	(0.563, 0.813, 0.969)
		11.	Metrics uses	[H]	(0.688, 0.938, 1.000)
		12.	Structured collection of data	[dB]	(0.531, 0.781, 1.000)
		13.	Availability of performance information		(0.438, 0.688, 0.875)
		14.	Availability of real-time information	[S], [P]	(0.344, 0.594, 0.844)
		15.	Capacity monitoring	[P]	(0.375, 0.625, 0.875)
	Continuous improvement	16.	Stakeholder involvement	[N], [P]	(0.688, 0.938, 1.000)
		17.	Awareness		(0.656, 0.906, 0.969)
		18.	Flexibility		(0.563, 0.813, 0.969)
		19.	External objectivity	[W]	(0.438, 0.688, 0.906)

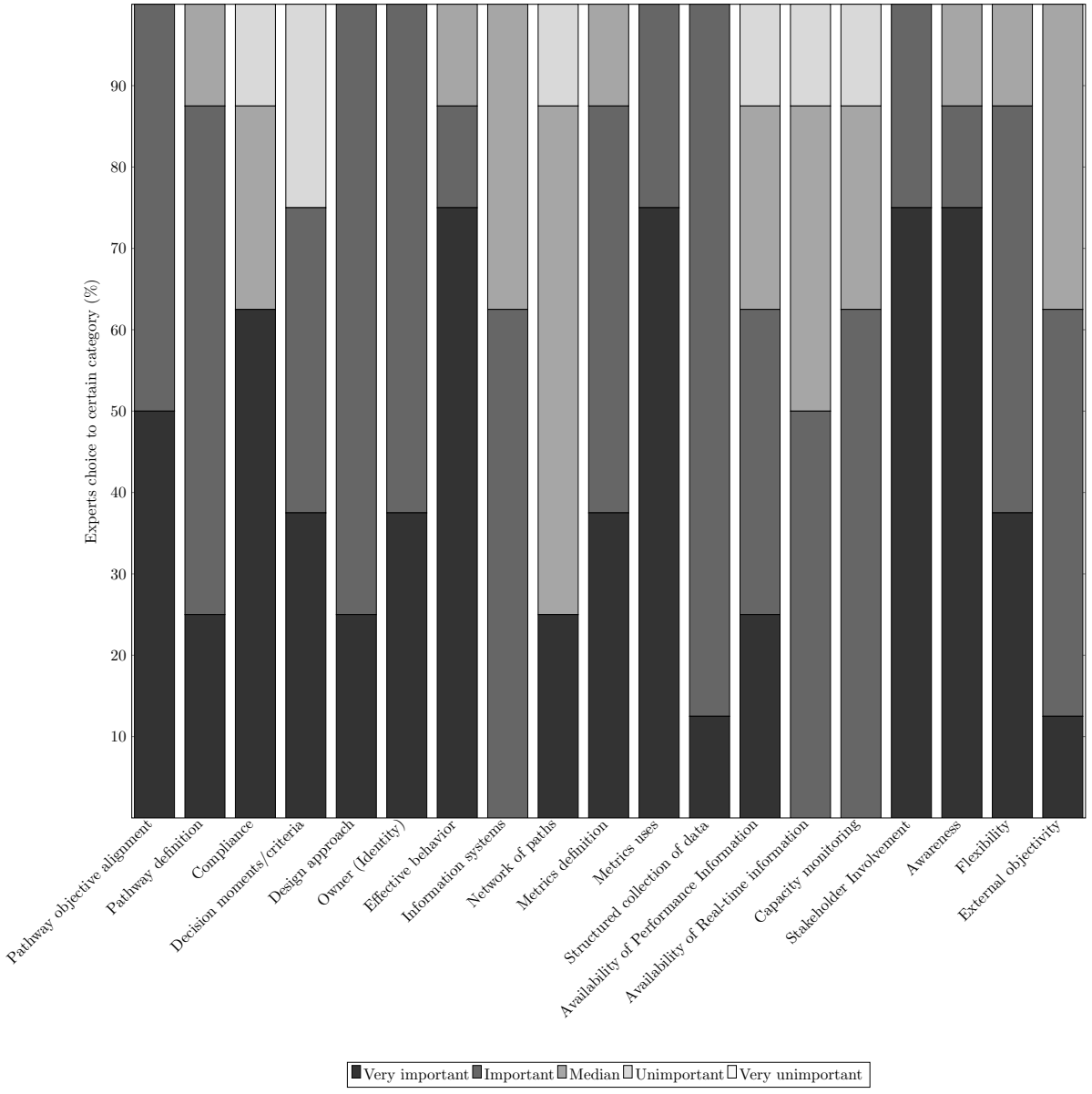

FIGURE D.1: Results weights Delphi round 3

Appendix E. Results fuzzy example

Table E.1: Structure and results fuzzy example

Target (V)	**Criteria** (I_i)		**Indicator** (I_{ij})	Metrics (m_{ij})	Weight ($\tilde{w}_{ij}$)	Int. input ($\tilde{a}_{ij}$)	Aggr. evaluation ($\tilde{r}_i$)	Rank ($U_T(i)$)	(V_i)	Overall maturity	Rank (U_T)	(V)
Maturity (V)	Design (I_1)	(I_{11})	Pathway objective alignment	$(0, 0, 1, 0)$	$(0.60, 0.85, 1.00)$	$(0.33, 0.67, 1.00)$	$(0.15, 0.51, 0.87)$	(0.692)	High	$(0.07, 0.34, 0.71)$	(0.526)	High
		(I_{12})	Pathway definition	$(0, 1, 0, 0)$	$(0.60, 0.85, 1.00)$	$(0.00, 0.33, 0.67)$						
		(I_{13})	Compliance	$(0, 1, 0, 0)$	$(0.75, 1.00, 1.00)$	$(0.00, 0.33, 0.67)$						
		(I_{14})	Decision moments/criteria	$(0, 0, 1, 0)$	$(0.65, 0.90, 1.00)$	$(0.33, 0.67, 1.00)$						
		(I_{15})	Design approach	$(0, 0, 0, 1)$	$(0.50, 0.75, 1.00)$	$(0.67, 1.00, 1.00)$						
	Owner & Performers (I_2)	(I_{21})	Owner (Identity)	$(0, 1, 0, 0)$	$(0.60, 0.85, 1.00)$	$(0.00, 0.33, 0.67)$	$(0.00, 0.32, 0.67)$	(0.475)	Moderate			
		(I_{22})	Effective behaviour	$(0, 1, 0, 0)$	$(0.70, 0.95, 1.00)$	$(0.00, 0.33, 0.67)$						
	Infrastructure (I_3)	(I_{31})	Information systems	$(0, 1, 0, 0)$	$(0.40, 0.65, 0.90)$	$(0.00, 0.33, 0.67)$	$(0.00, 0.11, 0.44)$	(0.263)	Moderate			
		(I_{32})	Network of paths	$(1, 0, 0, 0)$	$(0.45, 0.70, 0.85)$	$(0.00, 0.00, 0.33)$						
	Performance control (I_4)	(I_{41})	Metrics definition	$(0, 1, 0, 0)$	$(0.45, 0.70, 0.95)$	$(0.00, 0.33, 0.67)$	$(0.08, 0.37, 0.78)$	(0.564)	High			
		(I_{42})	Metrics uses	$(0, 0, 1, 0)$	$(0.70, 0.95, 1.00)$	$(0.33, 0.67, 1.00)$						
		(I_{43})	Structured collection of data	$(0, 1, 0, 0)$	$(0.50, 0.75, 1.00)$	$(0.00, 0.33, 0.67)$						
		(I_{44})	Availability of performance information	$(0, 1, 0, 0)$	$(0.45, 0.70, 0.90)$	$(0.00, 0.33, 0.67)$						
		(I_{45})	Availability of real-time information	$(0, 0, 1, 0)$	$(0.40, 0.65, 0.90)$	$(0.33, 0.67, 1.00)$						
		(I_{46})	Capacity monitoring	$(0, 0, 1, 0)$	$(0.40, 0.65, 0.90)$	$(0.33, 0.67, 1.00)$						
	Continuous improvement (I_5)	(I_{51})	Stakeholder involvement	$(0, 1, 0, 0)$	$(0.70, 0.95, 1.00)$	$(0.00, 0.33, 0.67)$	$(0.10, 0.42, 0.80)$	(0.601)	High			
		(I_{52})	Awareness	$(0, 0, 1, 0)$	$(0.65, 0.90, 0.95)$	$(0.33, 0.67, 1.00)$						
		(I_{53})	Flexibility	$(0, 1, 0, 0)$	$(0.50, 0.75, 0.95)$	$(0.00, 0.33, 0.67)$						
		(I_{54})	External objectivity	$(0, 0, 1, 0)$	$(0.50, 0.75, 0.95)$	$(0.33, 0.67, 1.00)$						

Appendix F. Assessment model (first version)

Criteria	Indicator	Definition	Low	Moderate	High	Top	Ref.
Design	*Pathway objective alignment*	The degree by which the objective of the pathway is aligned to the objective of the care delivery to the specific patient group of the pathway.	The pathway has **not been designed** on an end-to-end basis. Functional managers use the **legacy design** primarily as a context for functional performance improvement.	The pathway has been **redesigned from end to end** in order to optimize its performance.	The pathway has been **designed** to fit with **other enterprise processes** and with the **enterprise's IT systems** in order to optimize the enterprise's performance.	The pathway has been **designed to fit with customer and supplier processes** in order to optimize transmural performance.	[P], [H]
	Pathway definition	The degree in which the design of the path is defined with a clear structure, terminology and roles.	There is **no explicit definition** and **documentation** of the pathway.	The different parts of the pathway, roles and terminology are **defined** and **documented** in **textual** form.	There is a **structured** and **end-to-end documentation** of the pathway design including roles, and graphical representations.	An **electronic representation** of the process design supports its performance and management, and **allows analysis** of environmental changes and process reconfigurations. [H]	[P], [H]
	Compliance	The degree in which a pathway is designed taken the laws, regulations, and guidelines (e.g. recognize DBC) into consideration.	There is **no explicit consideration** of laws, regulations, and guidelines in the design of the pathway.	The laws, regulations, and guidelines are **explicitly considered** in the design, but **no traceability** is established between the description and the related rules of the laws, regulations, and guidelines.	There is **explicit traceability** between the pathway description and the rules originating from laws, regulations, and guidelines.	There is **explicit traceability** between the pathway description and the rules originating from laws, regulations, and guidelines. New and changed rules are **continually reflected** in the related structure of the pathway.	
	Decision moments/ criteria	The level of detail in the decision moments and/or in the (objectivity assured) criteria in the design of the pathway.	There is **no description** of the specific care pathway decisions available.	Just **broad lines** of the care pathway **decisions and criteria** are defined in the pathway design.	**Decision moments and broad lines of the corresponding criteria** are defined in the care pathway design.	**Decision moments and the corresponding criteria** are defined in the pathway design.	[B]
	Design approach	The degree in which a structured approach [e.g., a reference framework] is used and different stakeholders were involved during the design of the pathway (transmural care [intern and extern]).	**No specific structured approach** [e.g., a reference framework] is used, and there is **no indication of the involvement of different stakeholders** in the design of the pathway.	**No specific structured approach** [e.g., a reference framework] is used, but **there is an indication of the involvement of different stakeholders** in the design of the pathway.	**A specific structured approach** [e.g., a reference framework] is used, and there is **an indication of the involvement of different stakeholders** in the design of the pathway.	**A specific structured approach** [e.g., a reference framework] is used **explicitly**, and there is an **explicit indication of the involvement of different stakeholders** in the design of the pathway.	
Owner & Performers [H]	*Owner (Identity)*	The extent to which the pathway ownership structure is effective in improving the pathway performance.	The pathway owner is an individual or a group **informally charged with improving** the performance of the pathway.	There is an ***official*** pathway owner role and it is filled with an individual or a group **charged with improving** the performance of the pathway.	The pathway comes first for the ***official*** *pathway* owner in terms of **time allocation**, **mind share**, and **personal goals**.	The ***official*** pathway owner has high degree of **creditability** and **close relation** with the enterprise's senior decision-making body in terms of changing the process.	[H]
	Effective behavior	The degree in which a pathway participant (performer) executes his/her task as described in the pathway design and has knowledge of his/her own part in the pathway process.	Performers **know their function/tasks** as described in the pathway design, and perform it correctly but **aren't aware** of the **whole pathway** they are part of.	Performers **know their function/tasks** as described in the pathway design, perform it correctly and **are aware** of the **whole pathway** they are part of.	Performers **know and perform their function/tasks** as described in the pathway design and **know the objective including performance** of the **care pathway**.	Performers **know and perform their function/tasks** as described in the pathway design and **strive** to ensure that the pathway process delivers the results needed to **achieve the pathway's objective**.	
Infrastructure [H]	*Information systems*	The degree by which the supporting information systems are integrated (internally and externally) and are designed with the pathways/end-to-end processes in mind.	**Fragmented legacy IT systems** support the pathway.	An **IT system constructed from functional components** supports the pathway.	An **integrated IT system**, designed with the end-to-end process in mind and adhering to enterprise standards, supports the pathway.	An **IT system with a modular architecture** that adheres to industry standards for **inter-enterprise communication** supports the pathway.	[H], [N], [S]
	Network of paths	The degree in which a path is part of a network of system components and synergy is obtained (e.g. shared IT support, experienced improvements, shared resources).	An explicit definition of care pathway exists only for a **small set** of pathways.	An explicit definition of care pathway is available for a **large set** of pathways.	A **network of care pathways** is designed, through **integrated systems**.	**Synergy** is established within a network of care pathways through **integrated systems and communication channels**.	[P]
Performance control	*Metrics definition*	The degree in which metrics (such as patient satisfaction, throughput time) are uniformly defined in the pathway.	The pathway only has some **basic cost and quality metrics**.	The pathway only has **end-to-end process metrics aligned** with the **pathway objective** (e.g. patient satisfaction).	The pathway's **metrics are aligned** with the **pathway objective** and **enterprise objective** (e.g. patient satisfaction, cost).	The pathway's **metrics are aligned** with the **pathway objective**, **enterprise objective** and **implemented** (e.g. frequent measured patient satisfaction, cost).	[H]
	Metrics uses	The degree in which the metrics are effectively used to assess the achieved performance.	The pathway owner uses the pathway's metrics to **track its performance**, **identify root causes of faulty performance**, and **drive functional improvements**.	The pathway owner uses the pathway's metrics to **compare its performance to benchmarks**, **best-in-class performance**, and **customer needs** and to **set performance targets**.	The pathway owner **presents** the metrics to pathway performers **for awareness** and **motivation**. They use **dashboards** based on the metrics for **day-to-day management** of the pathway.	The pathway owner **regularly reviews and refreshes** the pathway's metrics and targets and uses them in **strategic planning**.	[H]
	Structured collection of data	Degree of structure in data collection (meaningful data variables also in line with the metrics).	**No structured collection** of pathway process data exists.	The pathway **process data is collected in an unstructured way**.	Pathway **process data is collected in a structured way for analyzing** metrics.	Pathway **process data is collected in a structured way** and using the **defined variables needed for analyzing** metrics.	[dB]
	Availability of Performance Information	The degree in which pathway process performance information is available for all stakeholders.	Pathway **process performance information is not available**.	Pathway **process performance information is available** only for the **pathway owner**.	Pathway **process performance information is available** for **all stakeholders** for only **certain periods**.	Pathway **process performance information is always available** for **all stakeholders**.	
	Availability of Real-time information	The degree in which pathway process and patient data is available in real-time.	Real-time pathway or patient information is **not available**.	Pathway and patient information are available **on request**.	**Patient information** is available in **real-time** but **pathway information** is available **on request**.	**Pathway and patient information** is available in **real-time**.	[S], [P]
	Capacity monitoring	The degree by which the capacity of resources involved in the pathway (such as doctors, nurses, beds, tools and other supplies, etc.) is monitored.	Pathway resource capacity is **not monitored**.	Pathway resource capacity **is monitored** but **not continuously**.	Capacity for **some of the pathway resources** is **continuously monitored**.	Capacity for the **majority of the pathway resources** is **continuously monitored**.	[P]
Continuous Improvement	*Stakeholder Involvement*	The degree in which the owner and the stakeholders in the pathway chain communicate and indicate improvements of the pathway [intern and extern].	There is **no explicit focus** and **process** on the **improvement** of the pathway.	**Stakeholders can mention** and **communicate points of improvement** to the owner of the pathway.	The process owner of the pathway **regularly improves** the pathway based on the **points of improvement from the stakeholders.**	The process owner of the pathway **continuously improves** the pathway based on **the points of improvement from the stakeholders**, and **informs all stakeholders**.	[N], [P]
	Awareness	The degree of awareness a pathway member has in performing tasks and contributing to the improvement of the pathway as a whole.	Performers have **primary focus on their own function/tasks without any explicit emphasis on pathway improvement**.	Performers perform their tasks/functions and **recognize possible improvements** in the pathway.	Performers **recognize and propose possible improvements** in the pathway.	Performers **continuously look for signs** that the pathway process should change, and they **propose improvements** to the pathway process. [H]	
	Flexibility	The degree a specialist in the path is allowed to deviate from the designed procedures and is tracked when changes are made.	Specialists are **not allowed to deviate** from the designed procedure.	Specialists **are allowed to deviate** from the designed procedure but **deviations are not tracked**.	Specialists **are allowed to deviate** from the designed procedure and these **deviations are only tracked**.	Specialists **are allowed to deviate** from the designed procedure and these **deviations are tracked and analyzed**.	
	External objectivity	The degree in which the pathway is externally reviewed and audited (against laws, regulations, guidelines, etc.).	The pathway is **not audited** internally or externally.	The pathway is **audited externally**.	The pathway is **audited internally and externally**.	There is an **established governance body** and the pathway is **audited internally and externally** on **predefined periods**.	[W]

Figure F.1: Assessment model sheet (first version)

Appendix G. Technology Acceptance Model questions

Perceived usefulness

1. Maturity represented in this way would be difficult for users to understand.
2. I think this assessment approach provides an effective solution to assess maturity.
3. Using this type of maturity models would make it more difficult to communicate maturity to end-users.
4. Overall, I found the maturity model in this experiment to be useful.

Perceived Ease of Use

5. Learning to use this way of assessing maturity would be easy for me.
6. I found the way the maturity assessment is represented as unclear and difficult to understand.
7. It would be easy for me to become skillful at using this way of assessing.
8. Overall, I found this way of assessing maturity difficult to use.

Intentions to Use

9. I would definitely not use this method to measure maturity of care pathways.
10. I would intend to use this way of measuring maturity of care pathways in preference in the future.

Appendix H. Screenshots of the maturity assessment tool

Introduction

This excel tool will support the assement of the maturity of your care pathway. Some information regarding the several definitions is stated below as well as a describtion "how to use the model".

How to use the model

1. Use the button **"Assess maturity"** in the sheet **"Assessment"**.
2. Score for every indicator in each tab the maturity level which is most applicable for your care pathway situation.
3. Use the button **"Add and calculated"** to aggregate the results into maturity levels.
4. The speedometers will indicate the degree of maturity for the different criteria and the overall maturity of your care pathway.

Model	***Information***
Care Pathway Maturity Model (CPMM)	A maturity model is a conceptual model that consists of a sequence of discrete maturity levels for a class of processes in one or more business domains, and represents an anticipated, desired, or typical evolutionary path for these processes (Becker et al., 2009)

Definition	***Information***
Care pathway	'A complex intervention for the mutual decision making and organization of predictable care for a well-defined group of patients during a well-defined period. Defining characteristics of pathways include: an explicit statement of the goals and key elements of care based on evidence, best practice and patient expectations; the facilitations of the communication and coordination of roles, and sequencing the activities of the multidisciplinary care team, patients and their relatives; the documentation, monitoring, and evaluation of variances and outcomes; and the identification of relevant resources' European Pathway Association (E-P-A).

References used in the model

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3. De Bleser, L., Depreitere, R., WAELE, K. D., Vanhaecht, K., Vlayen, J., & Sermeus, W. (2006). Defining pathways. Journal of nursing management, 14(7), 553-563.
4. Hammer, M. (2007). The process audit. Harvard business review, 85(4), 111.
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6. Plexus, K. (2009). Scherp aan de wind. Deventer.
7. Schrijvers, G. (2014). Zorgpaden in ziekenhuis. from http://guusschrijvers.nl/wp-content/uploads/2014/09/Zorgpaden-in-ziekenhuis-lezing-Guus-Schrijvers-9-sept-2014.pdf
8. Weber, C., Curtis, B., & Gardiner, T. (2008). Business process maturity model (BPMM) version 1.0. Needham, MA.

FIGURE H.1: Screenshot of introduction sheet

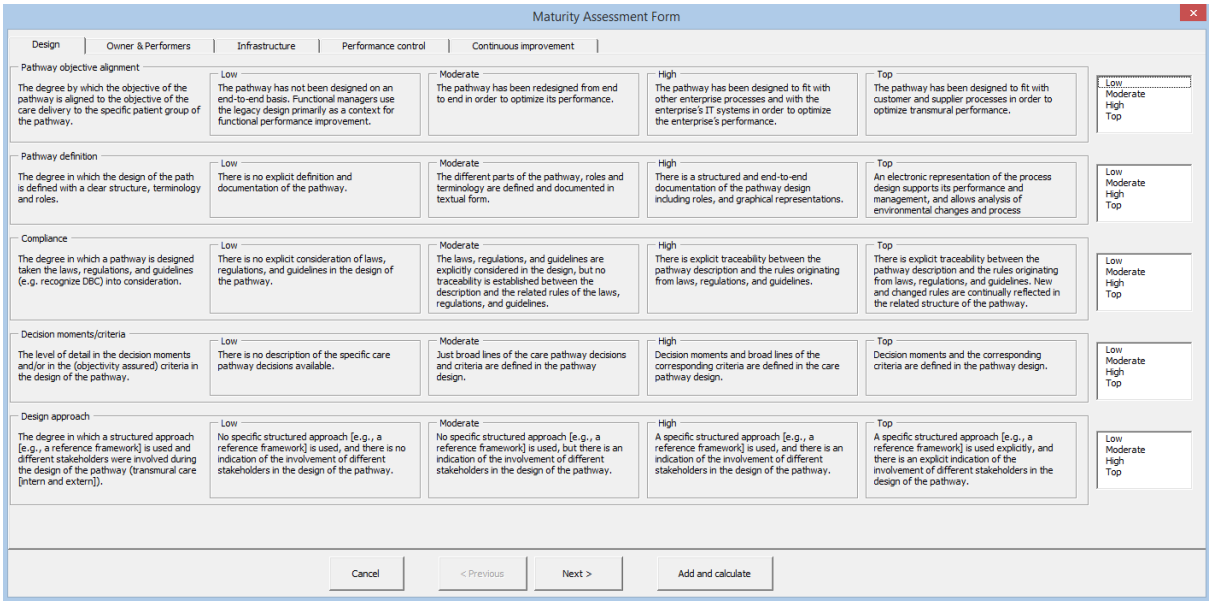

FIGURE H.2: Screenshot of user assessment form

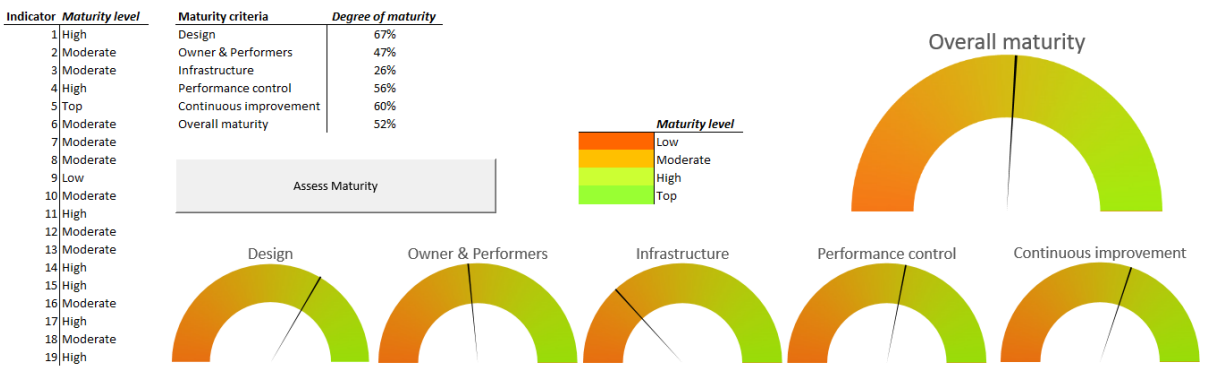

FIGURE H.3: Screenshot of maturity results sheet

TABLE I.1: Assessment results case study hospital 6

Target (V)	**Criteria** (I_i)	**Indicator** (I_{ij})	**Interview coding**	Metrics (m_{ij})	Int. input ($\bar{a}_{ij}$)	Aggr. evaluation ($\bar{r}_i$)	Rank ($U_T(i)$)	(V_i)	Overall maturity	Rank (U_T)	(V)
Maturity (V)	Design (I_1)	(I_{11}) Pathway objective alignment	The design of the pathway is done taking the enterprise objective into consideration. The enterprise IT system is used as a positive effect in the pathway design.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$	$(0.321, 0.735, 0.944)$	(0.910)	Top	$(0.280, 0.671, 0.932)$	(0.852)	Top
		(I_{12}) Pathway definition	An electronical representation of the pathway indicates bottlenecks and allows analysis of the steps in the design.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
		(I_{13}) Compliance	The is a explicit traceability between the laws, regulations, and guidelines in order to continually reflect the pathway and the related guidelines.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
		(I_{14}) Decision moments/criteria	The decision moments/criteria are listed in detail in the electronical representation of the model.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
		(I_{15}) Design approach	The approach of IKNL is used during the design phase. Stakeholders are actively involved in the design and further development.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
	Owner & Performers (I_2)	(I_{21}) Owner (Identity)	The pathway has a owner in the form of an specialist, which meet every month with other specialist in the pathway. The specialist is assigned to a specific objective for the path (in relation with enterprise objective).	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$	$(0.417, 0.875, 0.984)$	$(1, 044)$	Top			
		(I_{22}) Effective behaviour	The specialist are responsible to a part of the objectives and therefore manage each other on the achievement of their objective. Knowledge about the function and task as well as the enterprise objective is needed.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
	Infrastructure (I_3)	(I_{31}) Information systems	The IT system used in the hospital and for this situation allows the users to make self build-in functions to support the analysis and management of the pathway.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$	$(0.182, 0.516, 0.844)$	(0.704)	High			
		(I_{32}) Network of paths	The pathway meetings are grouped and synergy is established between the paths. The design approach is used in other pathways and thus expertise and knowledge is shared.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
	Performance control (I_4)	(I_{41}) Metrics definition	The metrics used in this path consist of self developed metrics and standard DICA indicators. The performance and analysis is used and revised for achievement of enterprise objective.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$	$(0.194, 0.538, 0.927)$	(0.734)	High			
		(I_{42}) Metrics uses	The use of dashboards is allowed by the IT system and thus the management of the different indicators is achieved.	$(0, 0, 1, 0)$	$(0.23, 0.63, 1.00)$						
		(I_{43}) Structured collection of data	The collection of the process and performance data is done by the system where specialist give input.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$						
		(I_{44}) Availability of performance information	The information of the pathway is viewable by different stakeholders and these stakeholders can view the information after specific periods, when data is updated.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$						
		(I_{45}) Availability of real-time information	Patient data is available and viewable in real-time when requested in the system, pathway information is viewable on request but not in the system.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$						
		(I_{46}) Capacity monitoring	The capacity of the different resources is monitored but not needed to view when managing the pathway.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$						
	Continuous improvement (I_5)	(I_{51}) Stakeholder involvement	The improvement of the pathway is done in joint meetings where different stakeholders are involved in. This is done monthly and reviewed based on IKNL data.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$	$(0.286, 0.690, 0.961)$	(0.870)	Top			
		(I_{52}) Awareness	The awareness of the performers is achieved by the shared responsibility for the different objectives.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						
		(I_{53}) Flexibility	The specialists and experts are allowed to deviated for the care pathway, the changes are tracked but not analysed.	$(0, 0, 1, 0)$	$(0.33, 0.67, 1.00)$						
		(I_{54}) External objectivity	There is a department responsible for the internal audits, primarily clinical. Besides this there are external audits when requested.	$(0, 0, 0, 1)$	$(0.67, 1.00, 1.00)$						

Appendix J. Quality information and results case study assessments

Table J.1: Quality information and assessment results

		UMC	STZ						SAZ			
Source	**Indicators**	1	2	3	4	5	6	7	8	9	10	11
2013 - Zorginstituut (2013)	Presence of a mamma carcinoma pathway.	yes	yes[a]	yes	yes	yes	yes	yes	yes	yes	yes	-
	During the design of the care pathway a stakeholder was involved with a patient perspective.	yes	yes[a]	no	yes	no	yes	yes	yes	yes	yes	-
	Working surgeons in hospital.	28	17[a]	12	17	11	12	10	9	8	7	13[b]
	How many surgeons were operating primarily mamma carcinoma (invasive and/or DCIS) in the financial year?	2	3[a]	3	3	3	5	4	4	3	3	-
2013 - DHD (2013)	Percentage patients with new diagnosed mamma carcinoma, where the treatment of neo-adjuvant chemotherapy is started within five weeks after PA-diagnoses (%).	83	100[a]	63	100	80	70	91	86	89	100	100
2014 - DHD (2014)	Percentage patients with new diagnosed mamma carcinoma, where the treatment of neo-adjuvant chemotherapy is started within five weeks after PA-diagnoses (%).	75	84.2[a]	80	80	85.7	78.4	77.8	97.6	63.3	100	80
	How many patients wit primarily mamma carcinoma (invasive and/or DCIS) were treated by the surgeons at the hospital in the financial year 2014?	179	348[a]	218	191	137	174	204	167	136	138	280
	Percentage patients with remainders of cancer tissue after surgery (%).	4.7	7[a]	4.5	6.1	7.5	4.8	7.4	9.5	1.4	4.3	6.5
	Percentage patients of who is unknown if cancer tissue is left after surgery (%).	0	0[a]	0	0	0.9	0	0	0	0	1.4	0
2015 - Maturity model assessment (%)	Design ($U_T(1)$)	72	71	67	72	81	91	55	72	77	0	44
	Owner & Performers ($U_T(2)$)	46	77	61	46	61	100	76	61	73	0	90
	Infrastructure ($U_T(3)$)	62	59	11	50	59	70	71	38	62	0	62
	Performance control ($U_T(4)$)	47	69	46	47	50	73	59	68	72	0	56
	Continuous improvement ($U_T(5)$)	72	95	68	68	67	87	75	81	75	0	75
	Overall (U_T)	60	74	52	57	64	85	67	64	72	0	66

[a] All locations
[b] (Zorginstituut, 2014)

Appendix K. BVN monitor attributes

Table K.1: BVN monitor attributes

Subject	Attributes	Analysed
Algemeen	Eventuele bijzonderheden:	
	Behandelingen op locatie:	
	Diagnose en nazorg	X
	Operatie	X
	Chemotherapie	X
	Radiotherapie	X
	Ziekenhuis voldoet aan minimumeisen BVN	
	Voldoet aan deelname patiënttevredenheidsonderzoek	
	Onderscheidend t.o.v. andere ziekenhuizen:	
Mammateam	Aantal patiënten met een primair mammacarcinoom behandeld in 2014	X
	Gecertificeerde specialisten (+)	
	Samenstelling multidisciplinair mammateam volgens eis BVN	X
	% patiënten besproken en verslag digitaal vastgelegd voor start behandeling (norm minimaal 90%)	X
	% patiënten postoperatief besproken en verslag digitaal vastgelegd (norm minimaal 90%)	X
	Patiënten met uitgezaaide borstkanker besproken in MDO	X
Diagnostiek	Diagnostiek (triple-onderzoek) op 1 dag	X
	Histologische punctie (echogeleide) op dezelfde dag	X
	Stereotactische punctie op dezelfde dag	X
	Uitslag triple-onderzoek op dezelfde dag	X
	Uitslag histologische punctie op dezelfde dag	X
	Min. 95% van de patiënten geeft aan binnen 10 dagen de uitslag te ontvangen	X
	Aanvullende onderzoeken: (+)	
	% patiënten bij wie er volledige pathologie verslaglegging is vastgelegd (norm minimaal 90%)	X
	Uitslag van pathologieverslag beschikbaar voor patiënt	X
	% patiënten met een BI-RADS eindcategorie in de verslaglegging (norm minimaal 90%)	X
	Mogelijkheid invriezen van tumorweefsel op de ziekenhuislocatie?	X
Behandeling	% patiënten binnen 5 weken geopereerd (norm minimaal 90%)	X
	% patiënten binnen 5 weken gestart met chemotherapie	X
	% patiënten met achtergebleven kankerweefsel na borstsparende operatie (norm maximaal 15%)	X
	Mogelijkheid gelijktijdig uitvoeren borstamputatie en reconstructie (directe reconstructie)	X
	Aantal directe reconstructies sept. 2013 t/m okt. 2014 (+)	X
	Mogelijkheid reconstructie met lichaamseigen weefsel (2e operatie)	X
	% patiënten met een MRI bij primaire operatie	X
	% patiënten met een MRI bij neo-adjuvante chemotherapie	X
	% patiënten met neo-adjuvante systemische therapie prebehandeling gezien door radiotherapeut	X
	% patiënten binnen 5 weken gestart met overige behandelingen:	
	Min. 80% van de patiënten geeft aan dat de gevolgen van eventuele behandelingen zijn besproken	X
	Mogelijkheid voor hoofdhuidkoeling	X
	Hulpprogramma lymfoedeem	X
	Actieve deelname wetenschappelijk observationeel onderzoek	X
	Actieve deelname wetenschappelijk klinisch onderzoek (trials)	X
	% patiënten dat aangeeft altijd te weten bij wie zij terecht kunnen na afronding van de behandelingen	X
Informatie en begeleiding	Informatie over borstkankerzorg op website ziekenhuis	
	Gespecialiseerd verpleegkundige is vast aanspreekpunt	X
	Er is een telefoonnummer voor spoedvragen beschikbaar	X
	Emailadres voor vragen	X
	Hoe is de patiënt geïnformeerd over de bereikbaarheid van het aanspreekpunt?	X
	Behandelplan altijd op papier aan de patiënt meegegeven	X
	Informatie beschikbaar over mammaprint/ genprofiel	X
	Speciaal (voorlichtings)materiaal voor laaggeletterden	X
	Speciale polikliniekuren met een tolk	X
	Gebruik van een signaleringsinstrument voor psychosociale zorg	X
	% patiënten dat aangeeft altijd de gelegenheid heeft om vragen te stellen	X
	% patiënten dat aangeeft dat dingen altijd begrijpelijk werden uitgelegd	X
	% patiënten dat aangeeft dat zorgverleners altijd voldoende tijd hadden	X
	% patiënten dat aangeeft dat zorgverleners hen altijd serieus nemen	X
Behandeling specifieke doelgroep	Jonge vrouwen en vruchtbaarheid	X
	Mannen	X
	Geriatrische problematiek	X
	Erfelijke belasting	X
	Zeldzame indicaties (inflammatoire, triple negatief)	X
Erfelijkheid	Min. 95% van de patienten geeft aan dat er is gevraagd naar erfelijke factoren	X
	Is er een polikliniek familiaire tumoren?	X
	Beschikbaarheid schriftelijke informatie	X

TABLE K.2: Correlation matrix

Criteria	ID	Description	Type	Corr.
Design	36	Behandeling, % patiënten met een MRI bij neo-adjuvante chemotherapie	Real	0.833187
	52	Informatie en begeleiding, Speciaal (voorlichtings)materiaal voor laaggeletterden	Nominal	0.685686
	26	Diagnostiek, Uitslag van pathologieverslag beschikbaar voor patiënt	Nominal	0.534875
	50	Informatie en begeleiding, Behandelplan altijd op papier aan de patiënt meegegeven	Nominal	0.534875
	15	Mammateam, % patiënten besproken en verslag digitaal vastgelegd voor start behandeling (norm minimaal 90%)	Real	0.510163
	44	Behandeling, % patiënten dat aangeeft altijd te weten bij wie zij terecht kunnen na afronding van de behandelingen	Real	0.500320
	12	Mammateam, Aantal patiënten met een primair mammacarcinoom behandeld in 2014	Numeric	-0.503650
	62	Behandeling specifieke doelgroep, Erfelijke belasting	Nominal	-0.515000
	59	Behandeling specifieke doelgroep, Jonge vrouwen en vruchtbaarheid	Nominal	-0.539180
	60	Behandeling specifieke doelgroep, Mannen	Nominal	-0.707910
	61	Behandeling specifieke doelgroep, Geriatrische problematiek	Nominal	-0.707910
	63	Behandeling specifieke doelgroep, Zeldzame indicaties (inflammatoire, triple negatief)	Nominal	-0.707910
Owner & Performers	59	Behandeling specifieke doelgroep, Jonge vrouwen en vruchtbaarheid	Nominal	0.716802
	26	Diagnostiek, Uitslag van pathologieverslag beschikbaar voor patiënt	Nominal	0.565149
	50	Informatie en begeleiding, Behandelplan altijd op papier aan de patiënt meegegeven	Nominal	0.565149
	8	Algemeen, Behandelingen op locatie: Radiotherapie	Nominal	0.526044
	55	Informatie en begeleiding, % patiënten dat aangeeft altijd de gelegenheid heeft om vragen te stellen	Real	0.503739
Infrastructure	57	Informatie en begeleiding, % patiënten dat aangeeft dat zorgverleners altijd voldoende tijd hadden	Real	0.646865
	56	Informatie en begeleiding, % patiënten dat aangeeft dat dingen altijd begrijpelijk werden uitgelegd	Real	0.606125
	58	Informatie en begeleiding, % patiënten dat aangeeft dat zorgverleners hen altijd serieus nemen	Real	0.542263
	40	Behandeling, Mogelijkheid voor hoofdhuidkoeling	Nominal	0.532962
	16	Mammateam, % patiënten postoperatief besproken en verslag digitaal vastgelegd (norm minimaal 90%)	Real	-0.517700
	41	Behandeling, Hulpprogramma lymfoedeem	Nominal	-0.857910
Performance control	44	Behandeling, % patiënten dat aangeeft altijd te weten bij wie zij terecht kunnen na afronding van de behandelingen	Real	0.647349
	26	Diagnostiek, Uitslag van pathologieverslag beschikbaar voor patiënt	Nominal	0.628409
	50	Informatie en begeleiding, Behandelplan altijd op papier aan de patiënt meegegeven	Nominal	0.628409
	40	Behandeling, Mogelijkheid voor hoofdhuidkoeling	Nominal	0.580708
	15	Mammateam, % patiënten besproken en verslag digitaal vastgelegd voor start behandeling (norm minimaal 90%)	Real	0.556791
Continuous improvement	33	Behandeling, Aantal directe reconstructies sept. 2013 t/m okt. 2014 (+)	Integer	0.796311
	44	Behandeling, % patiënten dat aangeeft altijd te weten bij wie zij terecht kunnen na afronding van de behandelingen	Real	0.741527
	39	Behandeling, Min. 80% van de patiënten geeft aan dat de gevolgen van eventuele behandelingen zijn besproken	Nominal	0.681254
	12	Mammateam, Aantal patiënten met een primair mammacarcinoom behandeld in 2014	Numeric	0.533420
Overall maturity	44	Behandeling, % patiënten dat aangeeft altijd te weten bij wie zij terecht kunnen na afronding van de behandelingen	Real	0.689992
	26	Diagnostiek, Uitslag van pathologieverslag beschikbaar voor patiënt	Nominal	0.671332
	50	Informatie en begeleiding, Behandelplan altijd op papier aan de patiënt meegegeven	Nominal	0.671332
	40	Behandeling, Mogelijkheid voor hoofdhuidkoeling	Nominal	0.577951
	15	Mammateam, % patiënten besproken en verslag digitaal vastgelegd voor start behandeling (norm minimaal 90%)	Real	0.514363