A Strategic PACS Maturity Approach

Rogier van de Wetering

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1

GENERAL INTRODUCTION

1.1 PICTURE ARCHIVING AND COMMUNICATION SYSTEMS (PACS)

WORLDWIDE healthcare systems today face strong pressure to improve clinical quality, enhance and improve service efficiency, expand access and reduce costs [1-4]. Healthcare is a critical social and economic component of modern society, and the adoption and effective use of Health Information Systems crucial to its success [4-8].

Medical informatics – as a cross-sectional or bridging discipline – has established itself in recent years and forms one of the bases for medicine and healthcare today [5, 9-11]. Consequently, considerable responsibility rests on this research field for improving the health of people, through valuable contributions to high-quality, efficient healthcare and to innovative research in biomedicine and related health and computer sciences [5]. While this research field is continuously evolving, the utilization of the rapidly growing results and possibilities of non-invasive digital imaging systems in clinical applications and related research and development work are seriously demanding and challenging [12, 13].

As investments in healthcare are generally large and process critical in the case of medical imaging technology, the need for structured implementation, measurement approaches and holistic evaluation methods is expanding [14, 15]. The fact that hospitals around the world are re-evaluating their current PACS implementations reflects this demand [16]. The definition of PACS – "a workflow-integrated imaging system designed to streamline operations throughout the entire patient-care delivery process" – implies that it is a broad term encompassing many related, but different, components and systems related to medical imaging and clinical practice [17].

In essence, PACS acquires medical images digitally from several modalities in the radiology department (e.g. computed tomography, magnetic resonance imaging, ultrasound, plain X-ray), stores them in central data repositories, enables (post)processing, analysis and image interpretation and makes imaging data available on display upon request by, for instance, referring clinicians. This foundation for the all-digital practice of radiology [18] touches upon every single part of the imaging workflow chain and associated sub-steps that affect the quality of imaging services and clinical outcomes [19, 20].

The first PACS was introduced more than two decades ago to reduce reliance on film-based radiology departments [21]. PACS and image management systems and networks have since their gradual uptake worldwide become integrated components of today's healthcare delivery systems [22] and can, therefore, be considered the fundamental infrastructure for digital diagnostic imaging and information management systems. Since PACS directly affects patient care, clinical workflow and clinical effectiveness [23], we highlight the value of an integrated approach that supports the process of maturing (i.e. from an immature stage of growth/maturity towards a next level, see section 1.3.1) PACS into hospital operations and defining synergetic effects (e.g. improved productivity, enhanced workflow efficiency, diagnostic efficacy and improved patient outcomes).

This general introductory chapter provides an overview of the dissertation's content and sets out the principal concepts of this research. Furthermore, the main research question (MRQ) and associated sub-questions, dissertation structure and a general outline are presented.

1.2 AN ACKNOWLEDGED OMISSION IN THE SCIENTIFIC LITERATURE

Hospitals create a need to rapidly adapt Information Systems and Information Technology (IS/IT) to new conditions that are consciously set by a hospital's rapidly changing environment [24, 25]. Not surprisingly, the alignment of IS/IT (see section 1.3.2 for an elaboration on the concept of alignment) with business strategy goals and objectives – across multiple sites, facilities and departments – has emerged as a key topic in present day healthcare organizations [26].

As image management technology and the radiology practice grows and evolves, the importance of strategic direction and preparation for the future are becoming more significant for hospitals and their departments at both strategic and operational levels [27]. Nowadays, many hospitals are strategically planning and preparing for future radiology needs [27] by re-evaluating their radiology IS/IT portfolios and looking to replace (or upgrade) their original imaging networks with state-of-the-art equipment to enhance overall system performance [16, 28]. This process is driven, on the one hand, by the current volumes of imaging data produced by advanced modalities such as computed tomography and magnetic resonance imaging devices that have major impacts on the common IS/IT architecture. On the other hand, more extensive and efficient, cost-effective, scalable and vendor-independent infrastructure PACS solutions have been developed, overcoming the inherent technical and practical limitations of earlier generations of PACS deployments [29]. PACS, nowadays, is generally considered a well-matured technology and offers hospitals customized archiving solutions and reading stations that fulfill the needs of most users [14, 30-32].

In the past, applied evaluation methods have proven valuable to assess the impacts of PACS on hospital and radiological workflows [30, 33-39], although it has been argued that PACS benefits should be evaluated from different angles and that the inclusion of clinical and not-for-profit goals make such evaluation even more relevant [40]. Imaging workflow chains and the associated sub-steps that affect the quality of imaging services and clinical outcomes are imperative as are the criteria to be applied to the evaluation of systems [19, 20]. Therefore, studies using different evaluation angles and stakeholders are becoming more common [14, 15, 41].

The trend towards system evaluation using appropriate models and techniques heightens the prospect of greater accountability and system success in hospitals [40]. As such, effective implementation and evolvability strategies are required for the successful adoption and maturation of PACS, and that requires a broader scope than just an implementation strategy focused on technological considerations. Organizational and human factors and the involvement of key actors in the process are principal factors for successful adoption [42]. Surprisingly, topics concerning maturity [43] (i.e. classifying PACS according to its stage of development and evolutionary plateau of process improvement) and organizational alignment (i.e. investments made in organizational domains related to PACS should be balanced out in the organization to obtain synergizing benefits) [44] for PACS evaluation have rarely been explored [43, 45]. This makes it rather difficult to harmonize or 'align' PACS goals, objectives and improvement activities with the hospital's strategic agenda. Furthermore, in practice, we see that strategic planning approaches towards PACS and PACS (re)deployment are lacking, both in hospital boardrooms as well as in the literature. Most contributions in the domain of strategic plans for PACS solely elaborate on the transition from a 'non-PACS' environment towards a fully digital radiology and diagnostic imaging environment [31, 46, 47]. While the parts concerning the operational planning of PACS are addressed, the strategic/situational investment and activity steps required to evolve from the current system implementation (as is) towards a higher level of maturity are not.

In this thesis, we develop such an integral (i.e. holistic) model to empirically assess the maturity and organizational alignment of PACS and its impact upon PACS performances – defined as the multifactorial impacts and benefits produced by the application of PACS in terms of hospital efficiency and clinical effectiveness with respect to PACS workflow and patients' clinical journeys [48] – in hospitals. We build upon existing research and related work in the field of PACS deployment to understand how hospitals can evolve and mature their PACS from immature stages of maturity (this includes a checklist for evolving to the next level [49]) to explain and further enhance PACS performance. From this, we aim to understand the multifactorial nature of PACS performance and how this can be evaluated from an integral perspective. A third and final objective is to elucidate optimization strategies and guidelines for practice based upon the empirical application of this model.

No prior studies have attempted to empirically validate an alignment and maturity framework concerning PACS and medical IS/IT with a considerable degree of complexity, coherence and causality, and thereby little scientific knowledge is available about the mechanisms that govern PACS performance and deployment success in hospitals [20]. There is a pressing need for IS/IT frameworks [4] capable of rigorous evaluation so that future strategic plans and investments can be better informed and that attention shifts towards the social and organizational facets of health information technology. The holistic approach set forward in this dissertation makes our work rigorous and provides a framework for clinical and medical informatics practice.

1.3 AN OVERVIEW OF CONCEPTS

1.3.1 IS/IT MATURITY

The concept of IS/IT maturity and adoption goes back to the early 1950s [50-53]. Since then, various maturity models have been developed to plan and assess the evolution of IS/IT in organizations. Within the field of information systems, Nolan and Gibson [54, 55] are considered the founders of the stage-based maturity perspective. From research on the usage of IS/IT in large US organizations, they proposed a model initially containing four stages of growth. Later, two more stages were added to the initial model. The stages are initiation, contagion, control, integration, data management and maturity. The six-stage model represents the level of IS/IT expense for an organization in relation to the stages of increasing the sophistication and maturity of IS/IT. According to this model, IT adoption or IT management will see a gradual uptake by a relatively small group (of organizations) at the beginning. This adoption phase is subsequently followed by a large group and finally by a smaller group that stays behind in terms of the adoption of emerging technologies. In general, this pattern of adoption is called an S-curve since it resembles a cumulative frequency distribution of adoption by different groups [56].

This stage-based concept has been further extended and applied to organizations by many others [52, 57-59]. Examples of maturity models are the Capability Maturity Model (CMM) for software development [49], the Supply Chain Management Maturity Models [60], the Business Process Maturity Model [61], the Stage Maturity Model which Light and Holland [62] developed for Enterprise Resource Planning systems, a stage model for Intranet implementation by Damsgaard and Scheepers [63], and so on.

In general, IS/IT maturity models provide insight into the structure of elements that represent process effectiveness in organizations [64]. They set out a roadmap of how to evolve from one level of maturity to the next [57]. While most organizations tend to evolve from one stage to the next, some organizations take strategic leaps to higher levels of development [59]. Gluck, Kaufmann and Walleck [65] indicate that formal strategic planning evolves along similar lines and phases among different organizations, with an accompanying effectiveness of strategic decision-making. This maturity process takes place at varying rates of progress and is different for each organization operating in different markets [66].

While the stage-based hypothesis is popular for describing the maturity and growth of information systems and has received substantial attention from academia, empirical support for its validity as an explanatory structure is unconvincing [67, 68]. Furthermore, stage-based theories are often criticized for being over-simplistic with regard to the assumed set of consistent (i.e. sequential) stages [67, 68]. For instance, according to De Bruin and Rosemann [69], CMM integration is an improvement model because it provides software organizations with guidance on how to gain control of their processes and it can help improve the maturity of these processes (of developing and maintaining software). In a recent meta-analysis on the effects of the CMM, however, Galin and Avrahami [70] were only able to identify three studies that provided details on productivity gains when an organization progresses to CMM level 2 and only 12 studies that provided details on productivity gains when an organization progresses to CMM level 3.

1.3.2 COMPLEMENTARITY THEORY AND ALIGNMENT MECHANISMS

The theory of complementarity was introduced by Edgeworth, who defined activities as complements "*if doing (more of) any one of them increases the returns to doing (more of) the others*" [71]. To avoid unfamiliar concepts in this section, we limit attention to the concept of complementarity and do not focus on formal theories from branches of mathematics known as 'lattice theory' and 'supermodularity.'

Complementarity theory assumes that the individual elements of a strategic planning process (i.e. the variables) cannot be individually optimized to achieve a better performance [72, 73]. Consequently, the impact of a system of complementary practices will be greater than the sum of its parts because of the synergistic effects of bundling practices together. The theory's strong formal (mathematical) notion provides punctual and analytical appropriateness to frequently indefinable notions of 'fit' and 'synergy' (i.e. intuitive ideas of synergies and systems effects) among the components of organizational strategies and its operational structures [73], and it has gained considerable attention in recent years in IS/IT research and other interdisciplinary fields [73, 74].

In spite of its attractiveness, complementarity theory solely demonstrates the results of 'Edgeworth' complements (i.e. synergetic effects) and typically does not explain its synergistic effects and mechanisms beyond general descriptions of 2+2=5 [75].

In the business and strategic management literature, complementarity is often labeled as 'fit' [76] or strategic alignment. Strategic alignment has been a major concern for executives and IT practitioners for decades and refers to applying IS/IT in an appropriate and timely way, in harmony (i.e. complementarity between activities) with business strategies, goals and needs [77]. It is a central element of strategic planning, the process by which organizations develop and deploy a competitive long-term strategy in which internal resources are integrated into external opportunities [78].

The classic Strategic Alignment Model (SAM) of Henderson and Venkatraman [44] is undoubtedly the most cited concept within this field and has also been extended by others [77, 79, 80]. Their model implies that a systematic process is required to govern continuous alignment between business and IS/IT domains, i.e. to achieve ‘strategic fit’ as well as ’functional integration.’ The SAM (see Figure 1-1) has been extended by theorists, industry and consulting [80], who have all defined ‘fit’ as the balance or equilibrium of different organizational dimensions and ‘external fit’ as strategy development that is based on environmental trends and changes. The model does, however, have its limitations.

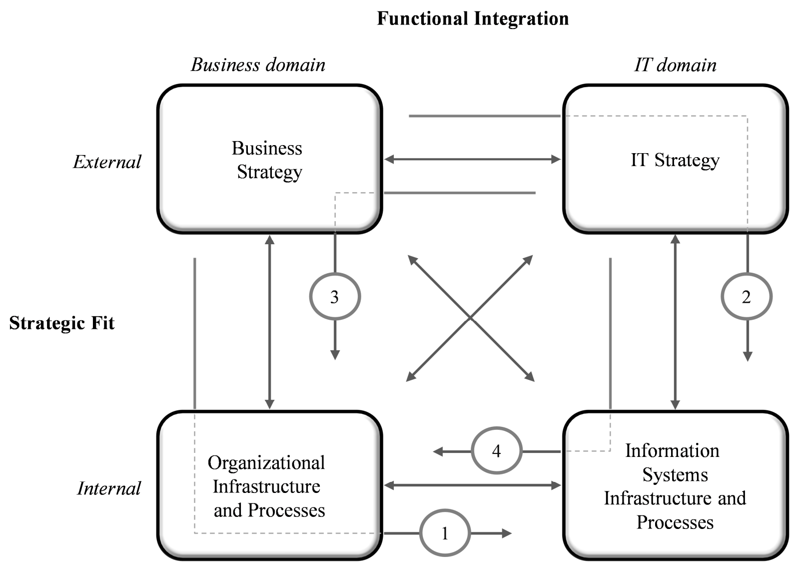

Fig. 1-1 The SAM

For instance, the SAM (as well as other extensions of the model) is not able to monitor or measure maturity and/or performance, and relations in the model are not operationalized or clearly defined [81]. This was improved by Scheper [81], who extended the SAM by combining it with the MIT 90s model [82, 83] and defining various organizational domains that are essential to be aligned.

In contrast to the SAM, Scheper also defined levels of incremental maturity for each of the five domains, creating a multidimensional maturity matrix (Cf. Sledgianowski et al. [84] for an equivalent approach). Hence, he claimed that alignment (i.e. the degree of leveling between organizational domains) could be practically measured and assessed by the comparative levels of maturity on each of the five dimensions.

Scheper’s framework and its foundations have also been applied among the fields of Customer Relationship Management, Product Lifecycle Management and e-procurement [85-87].

1.3.3 COMPLEXITY THEORY AND COMPLEX ADAPTIVE SYSTEMS

The field of Complex Adaptive Systems (CAS) [88-90] and complexity theory – including research on themes such as co-evolutionary concepts, self-organized emergent behavior and structure – has its roots in physics, mathematics and evolutionary biology. It is based on the fundamental logical properties of the behavior of non-linear and network feedback systems, no matter where they are found [91]. CAS are considered collections of individual agents with the freedom to act in ways that are not always totally predictable (non-linear), and whose actions are interconnected so that one agent's actions change the contexts for other agents. Complexity theory incorporates fundamental concepts such as phase changes, fitness landscapes, self-organization, emergence, attractors, symmetry and symmetry breaking, chaos, self-organized criticality, generative relationships and increasing returns to scale [92].

CAS theories presume that the adaptation of systems to their environments emerge from the adaptive efforts of individual agents that attempt to improve their own payoffs [93]. Commonly referenced examples include the weather systems, financial markets, human immune system, colonies of termites and organizations including hospitals and healthcare systems in general [88, 94-98]. CAS challenge traditional management assumptions and perspectives on organizational behavior, and the key principle of this perspective is the notion that "at any level of analysis, order within a system is an emergent property of individual interactions at a lower level of aggregation" [91]. Complexity theory builds upon other systems theories[1] [100-102] and sets forward plausible underlying mechanisms for system change and (non-)equilibrium states.

A number of authors have stated that complexity theory can be considered a valuable instrument to cope with organizational and IS/IT changes in non-linear turbulent environments, including healthcare [88, 91, 93, 94, 96, 98]. Both complexity science and CAS are applicable to the field of information systems in that IS/IT act like CAS. As whole entities and with respect to their mutually interdependent parts, they go through a series of adaptation/re-adaptation cycles [89]. This idea applies particularly well for the organization of medical practice, including the deployment of PACS or other related medical IS/IT. Here, we use the idea that both CAS and complexity theory provide new perspectives for dealing with the emergent nature of IS/IT in organizations [89], more specifically the dynamics of (PACS) maturity, alignment and performance in hospitals. The basic thought is that they feed a 'holistic' or 'complex' theoretical framework that fits the diversity of organizational components and interactions among the many agents involved in clinical and IT practice using PACS.

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[1] Complexity science and CAS thinking search for generative simple rules in nature that underpin complexity and do not embrace the radical holism of systems theory [99].

1.4 RESEARCH QUESTIONS

Elucidating from the previous sections, the MRQ of this dissertation is:

'how can hospitals mature their PACS?'

This dissertation addresses an important omission in the PACS literature and medical informatics in general by elaborating the concepts of maturity, organizational alignment (i.e. fit) and complexity perspectives to understand how key benefits and PACS performance in clinical practice can be achieved [40].

Achieving the strategic alignment of PACS and pursuing its intended goals and objectives within hospitals seems an intricate and poorly examined process and currently lacks scientific grounds and methods. This thesis acknowledges the importance of such a method and devotes much attention to method development – theoretical constructs and relationship, the ontological adequacy of proposed relationships – and simultaneously accounts for empirical application.

The relevance of this research is of a scientific as well as practical and societal nature. With this research, the body of knowledge concerning the maturity and alignment of PACS in hospitals is extended to define the mechanisms that drive PACS performance in hospitals. With this knowledge, hospitals can formulate strategies and roadmaps to further enhance the performance of the adopted PACS system. This is important since many filmless facilities fail to achieve higher productivity levels and operational efficiency gains because of such deployment and the subsequent evolvability and maturity complications.

Hence, to address the MRQ, this dissertation contains three related sub-research questions:

> <u>RQ1</u>: *How can the impact of PACS on hospital workflow be evaluated?* This research question is posed because the adequacy of traditional business perspectives and models for the holistic evaluation of PACS workflow impacts – and their sufficiency to capture the complexity of public hospitals' multiple goals – has been questioned. Mainstream scientific literature focuses on single issues within PACS implementations and evaluations and this has made it difficult to gain a clear understanding of the overall PACS workflow impacts. The multiple goals of hospitals require appropriate evaluation techniques for IS/IT, and PACS in particular. Therefore, a richer understanding of PACS workflow outcomes is required to enable a more diverse understanding of outcomes.
>
> This question touches various research topics and, therefore, associated research questions are:

> 1a) *How can a holistic approach be applied to the evaluation of PACS?*
> 1b) *What are the impacts of PACS deployment on a hospital's workflow?*

RQ2: *How can a model be developed for the strategic situational planning of PACS technology in hospitals?* This second research question is of particular value since PACS and medical imaging technology are maturing and the importance of organizational maturity and the effective deployment of PACS in hospitals are becoming significant. Although the PACS is now a well-established technology, achieving noteworthy operational efficiencies within filmless environments, it remains a high-cost venture. Therefore, a method for implementing and maturing PACS in hospitals is a prerequisite and would be valuable to any type of hospital. This makes it relevant to investigate how PACS maturity can be modeled, measured and assessed within hospitals. Furthermore, it is equally important to define and describe distinctive strategies for PACS situational planning that allow decision-makers in hospitals to decide which situational approach (i.e. dependent on hospital-specific resources, capabilities and the use of PACS) best suits their hospital's current situation and future ambition and what in principle is needed to evolve through the different PACS maturity levels.

Consequently, associated research questions are:

> 2a) *How can the maturity stages of the PACS domain be defined and modeled?*
> 2b) *What integrated strategies enable the strategic planning of PACS deployment within a hospital?*

RQ3: *How can the relationship between maturity and the organizational alignment of PACS within hospitals and the multifactorial performance of PACS be understood from a complexity perspective?* Finally, this third research question specifically considers the relationship between, on the one hand, the maturity and organizational alignment of PACS and, on the other hand, the impact on PACS performance (defined by multifactorial impacts and the benefits produced by the application of PACS). We claim that there is a gap in the research field, both theoretically and empirically, to describe and explain PACS performance variations in hospitals from a holistic perspective. Moreover, the process of harmonizing or 'aligning' the intended goals, objectives and improvement activities of PACS with the hospital's strategic agenda and operational workflow still seems a poorly examined process lacking scientific grounds. Therefore, a method that supports this alignment process and simultaneously identifies how synergetic effects (i.e. enhancements in PACS performance) within hospital operations can be achieved is valuable. This could

potentially be applied as a useful checklist to systematically identify the improvement areas for hospitals in the PACS domain. However, such a method has not yet been developed, empirically applied or validated.
Based on the empirical application of such a method (or model) – incorporating the triangular construct of maturity, alignment and PACS performance – (evidence-based) enhancement guidelines can be derived for strategic planning PACS maturity. Many opportunities are present to apply the theories and perspectives from the field of IS/IT research to PACS, which has a long and specific focus on exploring what is often called the 'critical success factors' of IS/IT in organizations. One such opportunity is to apply complementarity theory and organizational alignment principles to PACS evaluation. Complexity theory and CAS theory can both serve as another contribution to the analysis and understanding of PACS performance in hospitals. Hence, a validated holistic approach to PACS performance by enriching the concept of PACS maturity – including the various ideas from the IS/IT field – with business/IT-alignment and complexity theory could provide a framework for clinical practice.

Given the broad and in-depth scope of RQ3 concerning the theories, methods and empirical application, associated research questions are:

- 3a) *What defines the multifactorial nature of PACS performance?*
- 3b) *Which mechanisms govern situational effective maturity by the organizational dimensions related to PACS in hospitals?*
- 3c) *Which theory complements systems maturity and organizational alignment?*
- 3d) *How can the hypothesized relationships among (PACS) maturity, alignment and performance be holistically modeled and empirically validated?*
- 3e) *What is the relationship between (PACS) maturity and organizational alignment in terms of performance?*
- 3f) *Which guidelines for strategic maturity planning can be gleaned from hospitals, and radiology departments in particular, by applying the complexity perspective as a foundation of our integrative framework?*

1.5 OUTLINE OF DISSERTATION

The research questions listed in section 1.4 are addressed in various chapters throughout this thesis. Figure 1-2 provides an overview of the structure of this dissertation. It consists of three interrelated parts that address the MRQ and the various sub-research questions:

- The first part explores the impacts of PACS on hospital workflow using a holistic approach that provides fundamental features for assessing PACS from various perspectives.

- The second part of this thesis synthesizes the PACS literature on maturity and evolvability in hospitals and defines the PACS Maturity Model (PMM). The PMM describes five levels of PACS maturity and the corresponding process focus. This is subsequently extended as a strategic planning method for PACS deployment, based on the elaboration of the strategic alignment concept and the maturity growth path concepts for the PACS domain.

- Finally, the third part develops an extended perspective on PACS performance by enriching the concept of PACS maturity and business IT complementarity principles with systems and complexity theory and empirically validating the hypothesized relationships of the model. Furthermore, general guidelines for strategic PACS maturity for hospitals, and radiology departments in particular, are outlined.

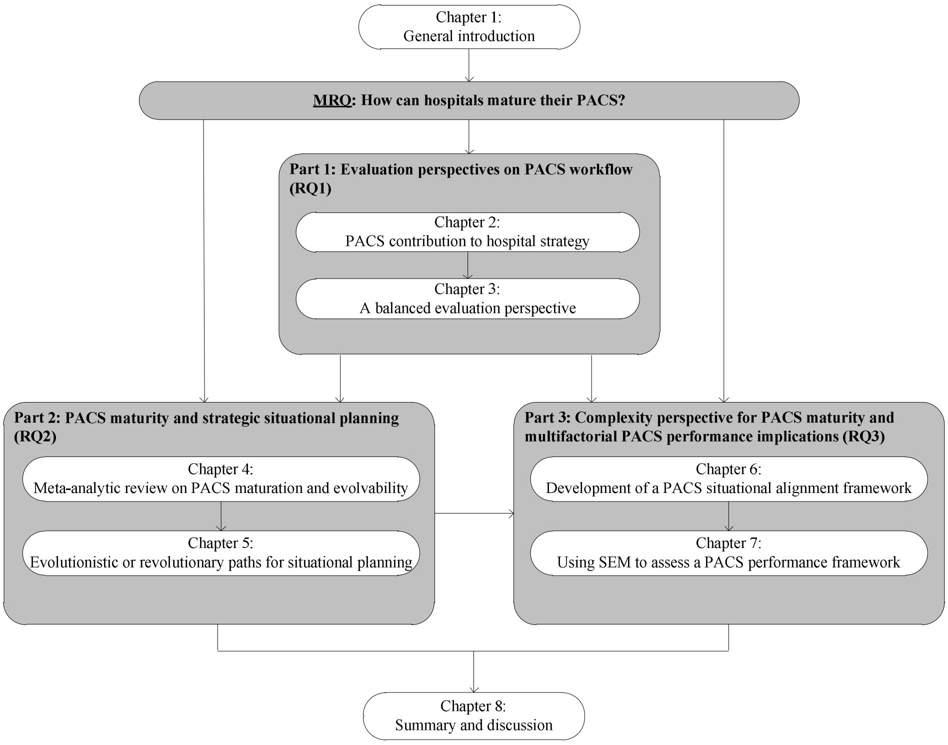

Fig. 1-2 Thesis structure overview

This '*introductory chapter*' provides an overview of the dissertation's content, sets out the principal concepts of this research, addresses the research questions and provides a general outline of the thesis.

1.5.1 PART I: EVALUATION PERSPECTIVES ON PACS WORKFLOW

'Chapter two' investigates the adequacy of traditional business perspectives and models for the holistic evaluation of PACS workflow impacts and captures the multiple strategic goals of hospital-wide PACS implementation. An expanded model is developed, which is a much more appropriate tool for examining PACS systems. In doing so, a classical Balanced Scorecard (BSC) is modified (i.e. the PACS-BSC model) to reflect the nature of the clinical values of hospital strategy. The framework is consistent with Kaplan and Norton's original intentions of assessing performance in terms of strategy while enabling a holistic evaluation of PACS that is relevant to a hospital's not-for-profit and clinical strategies. Chapter two was originally published as:

(I) *Van de Wetering, R., Lederman, R., and Firth, L. Examining hospital strategy in relation to PACS workflow outcomes. In the Twelfth Americas Conference on Information Systems Proceedings. Paper 335, 2006* and

(II) *Lederman, R., Van de Wetering, R., and Firth, L., PACS contribution to hospital strategy via improved workflow, in Encyclopaedia of Healthcare Information Systems, Wickramasinghe, N. and Geisler, E., Editors. 2008, Medical Information science reference: Hershey, New York.*

'Chapter three' subsequently applies the developed model to a major public hospital that implemented a hospital-wide PACS to improve its workflow and patient care. Empirically, this model was applied as an evaluation instrument through a series of in-depth interviews with PACS users. The outcomes suggest that PACS improves hospital workflow considerably and that the organizational alignment (i.e. fit) of PACS in hospitals is an important critical success factor. This chapter was originally published as:

Van de Wetering, R., Batenburg, R., Versendaal, J., Lederman, R., and Firth, L., A balanced evaluation perspective: picture archiving and communication system impacts on hospital workflow. Journal of Digital Imaging, 2006. 19(Suppl. 1): p. 10–7.

1.5.2 PART II: PACS MATURITY AND STRATEGIC SITUATIONAL PLANNING

'Chapter four' reviews and analyses the PACS literature on maturity and evolvability in hospitals, resulting in an overview of the relevant developments concerning the maturity of PACS. This chapter also looks at the development of a maturity model for PACS technology. From the results of a meta-analytic review on PACS maturity and evolvability, the PACS Maturity Model (PMM) is proposed, which describes five levels of PACS maturity and the corresponding process focus. Chapter four was originally published as:

Van de Wetering, R. and Batenburg, R.S., A PACS maturity model: a systematic meta-analytic review on maturation and evolvability of PACS in the hospital enterprise. International Journal of Medical Informatics, 2009. 78(2): p. 127–140.

'Chapter five' proposes a strategic planning method for PACS deployment. This method builds upon the previously developed PMM based on the elaboration of the strategic alignment concept and the maturity growth path concept in the PACS domain. In doing so, the literature on strategic planning for IS/IT and PACS maturity is first reviewed. Second, the PMM is extended by applying four different strategic alignment perspectives whereupon two types of growth paths (evolutionistic and revolutionary) are applied that focus on an improvement roadmap for the PMM.

This roadmap builds a path to evolve from one level of maturity to the next. This extended method for PACS strategic planning defines various distinctive strategies for PACS strategic situational planning and allows decision-makers in hospitals to decide which approach best suits their hospital's current situation and future ambition and what in principle is needed to evolve through the different maturity levels. This chapter was originally published as:

Van de Wetering, R., Batenburg, R., and Lederman, R., Evolutionistic or revolutionary paths? A PACS maturity model for strategic situational planning. International Journal of Computer Assisted Radiology and Surgery., 2010. 5(4): p. 401–409.

1.5.3 PART III: COMPLEXITY PERSPECTIVE FOR PACS MATURITY AND MULTIFACTORIAL PACS PERFORMANCE IMPLICATIONS

'Chapter six' develops a rigorous perspective and method that supports the process of situationally aligning PACS. In developing such a method, this chapter combines

existing PACS maturity perspectives (i.e. continuous evolvability process from immature stages of growth/maturity towards another level) with the concept of business/IT-alignment (i.e. investments made in organizational domains related to PACS should be balanced out in the organization to obtain synergizing benefits). From this, a framework and associated survey is incrementally developed to empirically assess a hospital's current PACS maturity and alignment regarding different strategic directions. The second goal of this chapter is to systematically examine the applicability of this framework and instrument, and attentively explore its implications in terms of the maturity and alignment of PACS performance at various pilot hospitals. This chapter was originally accepted as:

Van de Wetering, R., Batenburg, R., Oudkerk, M., Van Ooijen, P.M.A., Brinkkemper, S., and Scheper, W., A situational alignment framework for PACS. Accepted for publication in the Journal of Digital Imaging, November 2010.

'Chapter seven' develops an integrative model to empirically assess, on the one hand, the maturity and organizational alignment of PACS and, on the other hand, their impact on multifaceted PACS performance. Here, we aim to build upon the PMM and the previously developed alignment framework. This integrative model enriches the concept of IT maturity and business/IT-alignment with systems and complexity theory. These theories contribute to a holistic approach that fits with the complex nature of enterprise-wide PACS and the complexity of hospitals as complex organizational systems of medical practice.

From this conceptual model – which is both extended and sparse enough to explain and understand PACS performance variations in hospitals – an integral hypothesis is generated. We statistically test this hypothesis (and thereby our perspective) using Structural Equation Modeling (SEM) with data from 64 hospitals within the Netherlands. In addition, we provide some general strategic guidelines for optimization concerning PACS deployment and maturity. These objectives all contribute to the scientific literature on strategic and situational planning and the practical evolution of PACS maturity in hospitals. This chapter was submitted as:

Van de Wetering, R., Batenburg, R., Brinkkemper, S. and Scheper, W. Using structural equation modeling to assess an integrative PACS performance model: complexity implications in achieving multifactorial PACS performance, submitted for publication 2010.

Finally, *'chapter eight'* contains a summary of this dissertation and answers the MRQ and the three associated sub-research questions. In addition, the implications of our findings for science and practice will be elaborated upon and avenues for future research presented.

1.6 LIST OF ACRONYMS

PACS Picture Archiving and Communication System

BSC Balanced Scorecard

IS/IT Information Systems and Information Technology

SAM Strategic Alignment Model

PMM PACS Maturity Model

PISA PACS Integrated Situational Alignment framework

CAS Complex Adaptive System

SEM Structural Equation Modeling

Part I:

Evaluation perspectives on PACS workflow

2

PACS CONTRIBUTION TO HOSPITAL STRATEGY VIA IMPROVED WORKFLOW

With the increasing need to evaluate health spending comes a need for frameworks that capture the multiple goals of hospitals. There is a need to rethink the application of theoretical approaches to investigating information systems in light of the objectives of medical practitioners using practical technologies. The Balanced Scorecard (BSC) has been successfully applied to hospital environments, but not to Picture Archiving and Communication Systems (PACS) which are among the most important e-health implementations in hospital environments in the past decade or more. Therefore, this research investigates if the BSC adequately captures the multiple strategic goals of a hospital-wide PACS implementation. We conclude that the BSC is not adequate to capture the key features that need to be evaluated. An expanded model, the PACS-BSC model is proposed as a much more appropriate tool for examining such systems. This expanded model is developed as a resource for both researchers and practitioners.[1]

2.1 INTRODUCTION

Since Strassman's [103] exposition of the 'productivity paradox' there has been increased attention paid to justification and evaluation of investments in Information Systems and Information Technology (IS/IT). Observed outcomes from practice have called for theoretical explanations in order to construct a generalized view of IS. In the hospital environment we see that there is a pressing need for frameworks adequate to the tasks of evaluating increasingly expensive implementations. Because hospitals have multiple stakeholders and multiple strategic goals, to be adequate a framework needs to address these multiplicities. One promising framework is Kaplan and Norton's [104-107] BSC.

The BSC framework evaluates performance by translating key elements of strategy into performance measures such as financial and customer perspectives. As the selection of performance measures is determined by the context in which the evaluation is to take

[1] This work was originally published as: (I) Van de Wetering, R., Lederman, R., and Firth, L. *Examining hospital strategy in relation to PACS workflow outcomes*. In *the Twelfth Americas Conference on Information Systems Proceedings*. Paper 335, 2006 and (II) Lederman, R., Van de Wetering, R., and Firth, L., *PACS contribution to hospital strategy via improved workflow*, in *Encyclopaedia of Healthcare Information Systems*, Wickramasinghe, N. and Geisler, E., Editors. 2008, Medical Information science reference: Hershey, New York. p. 1041–1047.

place, the BSC has the flexibility to apply to a range of organizations and to a range of IS/IT implementations.

BSC has been used to evaluate hospital performance and the implementations of IS/IT in hospital and medical contexts by several authors [1, 108-110]. However, PACS, which is one of the most important system implementations in the past few years in the area of e-health and the transmission of health data, have not been evaluated using BSC. Rather, most evaluations of PACS have tended to focus on single issues like clinical communication, quality improvement, image availability, speed of service and workflow simplification and automation and the associated gains that are important to the patient's overall journey [20, 38, 111-113].

The focus on single issues within PACS implementations has made it difficult to gain a clear understanding of the overall workflow impacts of a PACS implementation. Moreover, the literature does not relate well to the intangible value created for the patient by the patient care benefits of PACS, which is an important component of the hospital's strategy overall and as it relates to IS strategy in particular[114].

Therefore, this chapter investigates the adequacy of BSC for a holistic evaluation of the workflow impacts of a PACS implementation. It asks whether a theoretical model such as BSC adequately captures the reality of how such technology is used. The approach taken is radical in that it is built on a consideration of the fundamentals of hospital strategy. The BSC is then modified to incorporate qualitative themes rather than performance 'measures' to reflect the fundamentally qualitative nature of the clinical values of hospital strategy. In so doing, this chapter develops a framework that is at once consistent with Kaplan and Norton's original intentions of assessing performance in terms of strategy while enabling a holistic evaluation of PACS that is relevant to hospital's not for profit and clinical strategies.

2.2 BSC & EVALUATION IN HOSPITALS

The BSC is a set of measures that provides managers with a comprehensive framework that translates a company's strategic objectives into a coherent set of performance measures that is [104, 105] a comprehensive view of the business. As originally developed by Kaplan and Norton, the BSC includes performance measures from four perspectives, supplementing the financial perspective with those of the internal business process, the customer, and learning and growth within the organization. The four performance measures are:

1. Financial perspective: "How should we appear to our shareholder?" Performance measures include operating income and return-on-investment.
2. Internal Business Process perspective: "At which business processes must we excel?" Performance measures include rework rates, cycle-times and process costs.
3. Customer perspective: "How should we appear to our customers?" Performance measures include customer satisfaction, and retention.

4. Learning & Growth perspective: “How will we sustain our ability to change and improve?” Performance measures include employee skills, retention and satisfaction.

The comprehensive view drawn from these four performance measures can then be presented as a single management report that reflects many of the elements of a company’s competitive agenda: becoming customer oriented, shortening response time, improving quality, emphasizing teamwork, reducing new product launch times, and managing for the long term [104]. Not only does the BSC provide a measurement framework that improves alignment of actions to the strategic goals of an organization, it also provides a platform for identifying priorities. These priorities can then be used to guide management in the achievement of objectives [115].

However, the BSC is not a template that can be applied to business in general or even industry-wide. Rather, it is intended that different market situations, product strategies, and competitive environments employ different scorecards – differing in terms of performance measures [105]. Each organization’s unique reason for an IS/IT implementation, and therefore different perspectives on measuring success, is reflected in the use of a BSC that includes appropriate performance measures. BSCs are particularly appropriate for organizations in industries such as healthcare where there is a more diverse set of performance measures than in the business and academic sectors [116]. Therefore, the BSC’s design flexibility makes it applicable to the evaluation of a broad range of organizations and implementations, and suitable to evaluation within the health sector. A range of perspectives have been used to generate performance measures used in BSC applications within the health sector such as patient satisfaction, clinical outcomes, functional health status and cost to evaluate outsourcing [117]. Other studies cite growth, customer satisfaction, system integration, low-cost provision, clinical outcomes, financial goals, patient satisfaction and research and teaching [116].

We argue that these adaptations of the BSC to healthcare are successful because the modifications are in line with the organizational strategies of the health sector, consequently there is a value in a BSC which is specifically targeted towards PACS.

2.3 HOSPITAL STRATEGY

Healthcare systems today face strong pressure to improve clinical quality, enhance service, expand access, and reduce costs [1, 115]. Moreover, hospitals and other healthcare institutions are facing critical issues with respect to strategy formulation. These issues are different to those faced by commercial corporations largely because they reflect non-financial components of hospitals core business such as improvements in the effectiveness of clinical care, a streamlined patient journey and overall workflow [118].

‘Strategy’ in the corporate sense popularized by Porter is “the creation of a unique and valuable position, involving a different set of activities different from rivals” [119]. Following from Porter’s earlier work, three fundamental strategies for competitive advantage are identified: low cost, product differentiation and niche market [120, 121] expand these to six strategic uses of IT: breakthrough unit costs for customers, service-based differentiation, micromarketing management, shorter time to market, transfer of experience; and new level of partnership. The idea of strategy as a way of positioning the organization so as to attract customers and compete with rivals is central to these approaches.

However, the relevance of corporate strategy to hospitals that have a commitment to clinical excellence and a commitment to public responsibility, has been questioned [118]. Where clinical and not-for-profit considerations are fundamental to organizational strategy, Liedtka suggests that Andrews's concept of strategy is more relevant:

> *"a pattern of decision in a company that determines and reveals its objectives, purposes, or goals, produces the principal policies and plans for achieving those goals, and defines the range of business the company is to pursue, the kind of economic and human organization it is or intends to be, and the nature of the economic and non-economic contribution it intends to make to its shareholders, employees, customers, and communities* [122, p.56]."

Given this richer concept of strategy, Andrews argues that there are four elements to be considered together to determine strategy, and that each of these suggests a question from the organization's perspective:

i. What the market wants in terms of industry opportunities and threats – what might we do?
ii. The organization's competence – what can we do?
iii. The aspirations and values of executives in charge of the organization – what do we want to do?
iv. The organization's obligation to society – what should we do?

Liedtka [118] argues that, in the health context, it is clinical as well as executive preferences that must be considered. Liedtka summarizes these elements and questions in a diagram that emphasizes the fact that the elements of strategy may be classified as either market-driven or non-market driven, and as internal or external (Figure 2-1). According to Liedtka, the incompatibility of Porter and his followers' concept of strategy for hospitals lies in Porter's exclusive focus on market driven elements of what the organization can do and the threats and opportunities that the organization faces.

Clinical excellence and service to the community are key factors for public hospitals [123]. These factors are important determinants of clinicians' acceptance, use and 'ownership' of IS/IT in hospitals. Clinicians appropriate technologies to the extent that they support and enhance workflow in ways that improve the patient's clinical journey. Attempts to impose IS/IT that do not result in such positive workflow outcomes for patients lead to poor morale and resistance.

Consequently, BSC evaluations of IS/IT implementations in hospitals need to incorporate a wide range of non-market performance measures because they reflect the non-market elements of the hospital's strategic perspectives. Thus a model for the evaluation of health systems based on Andrew's approach seems more appropriate.

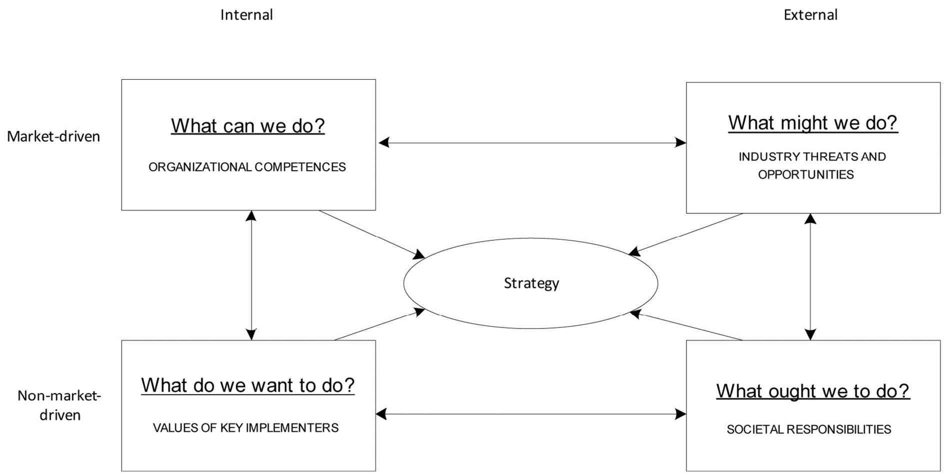

Fig. 2-1 Andrew's model of the strategy formulation process, adapted from [118]

2.4 THIS STUDY

2.4.1 METHOD

In order to develop an appropriate set of performance measures for the BSC in the PACS environment, and to understand those measures in a practical context, a study was undertaken of a PACS implementation in a large public hospital in Australia (identity withheld) offering the full suite of medical inpatient and outpatient services. Following a Mini-PACS implementation in 1995, a hospital-wide implementation was undertaken in 2004.

The study involved in-depth, semi structured interviews with users of PACS in several locations throughout the hospital. The interviews were loosely framed around a set of questions designed to encourage participants to talk about three interrelated issues:

i. the goals and strategies of the hospital;
ii. the importance of workflow to those goals and strategies; and
iii. how well they believed that the PACS implementation helped improve the workflow and subsequently to achieve those goals and strategies.

The interview data was supported by internal and publicly available documents that explored the vocation of the order of nuns running the hospital as well as the policy and mission of the public health system.

Interview data were entered on Nvivo and coded using the open and axial techniques recommended by Miles and Huberman [124]. The open coding enabled the large amount of text to be organized according to nodes and so to begin to understand its contents. The axial coding enabled the researchers to rethink their nodes and check that they had not forced data into pre-conceived patterns to suit the theory. In so doing, the researchers looked for causes and consequences and for natural clusters of the nodes [125].

2.4.2 FINDINGS AND DISCUSSION

Four measurement perspectives were found. The four perspectives relate to one another, as do Kaplan and Norton’s original perspectives. The first two are directly analogous to two of Kaplan and Norton’s original perspectives (internal business processes and customers, respectively). The latter two are more radical modifications to reflect the non-market context of the hospital environment in which PACS is implemented:

- A *Clinical Business Process perspective* that captures the major clinical impacts on workflow has been included because the outcome – speed of service – is of central importance to workflow analyses. The workflow implications of PACS impacting on clinical business processes not only relate to automation [126], but also to the productivity of radiologist, technologist and the clerical staff [37, 39], report-turnaround-times [127] and changes in communication between radiologist and clinicians [112, 128]. This perspective is consistent with the original BSC perspective: “At which business processes must we excel?”

- A *Patient perspective* that captures the impact of PACS on the production of value for the patients along the workflow is included because queues and bottlenecks are symptoms of poor patient throughput. The workflow implications that are directly patient-related include reduction in delays, and an increase in timely care as well as throughput time of patients [2, 33, 129]. This perspective is consistent with the original BSC perspective: “How should we appear to our customers?”

- A *Quality and Transparency perspective* that captures the level of monitoring and status checking possible in the system is included because the literature suggests that improved workflow quality and transparency give higher diagnostic value. Quality workflow would imply that variations in the workflow that may harm patients would be eliminated. While it has been found that automation leads to improvements in workflow quality [130], PACS can also eliminate steps in the workflow, making it more simple and transparent

[20, 113]. Given that bottlenecks can arise throughout the workflow [131], transparency can promote better outcomes by enabling status checking. This is aided by the impact of PACS on reducing rates at which images need to be retaken [111, 132] and the almost complete elimination of faulty exposures [128]. This radical departure from Kaplan and Norton's original four perspectives reflects the fact that hospitals not only need rapid workflow, but they must have quality checks that imply a quality and transparency of workflow. It reflects an emphasis on Andrews perspective of "what do we want to do" and "what should we do?" when hospitals are focused on workflow as a way of enhancing patient care. This perspective asks "are we maintaining and enhancing the quality and transparency of our workflow?"

- An *Information Systems perspective* that captures the impact that PACS has on the enabling power of the information system is included. This is because the literature suggests that PACS impacts upon the information systems potential to contribute to workflow execution. PACS impacts on the overall contribution of IS to workflow by making images accessible and available [33, 34, 38, 133, 134], by providing new ways for radiology departments to cooperate [21, 135], by eliminating paper work and through integration [136, 137]. An important aspect of workflow is the down-time of the system, and the associated loss of records [138]. This is a somewhat radical departure from Kaplan and Norton's original four perspectives. This perspective provides an aggregated view of these issues and asks "Does the IS assist in the execution of the workflow?" This change was made to reflect the fact that PACS typically does not stand alone. Rather, in its relationship with existing systems it can be integrated to streamline processes, or can slow processes through parallel systems.

These perspectives indicate another radical deviation from Kaplan and Norton's original BSC in which the perspectives indicated performance measures. While performance measures, with their essentially qualitative implications, are relevant to financial and corporate internal business process perspectives, it has been found that they may not be adequate for some enterprise-wide applications [35]. When it comes to hospital goals of clinical excellence the outcomes may be difficult to quantify because they have aspects that are essentially qualitative. It is hard to measure the intangible value created by PACS to patients, radiologist, and clinicians in terms of quantitative measures. It requires a broader understanding.

Therefore, the perspectives outlined here should be considered as incorporating qualitative themes rather than performance 'measures'. This makes it necessary to have a qualitative method for understanding the values of the outcomes associated with many elements of the perspectives.

2.4.3 PACS-BSC MODEL

Given the four perspectives that were found to capture the strategy in the particular case at hand, the proposed BSC to evaluate the impact of a PACS implementation on workflow in a hospital are:

1. Clinical Business Process perspective
2. Patient perspective
3. Quality & Transparency perspective
4. Information System perspective

These have been identified as consistent with the hospital strategy as indicated by the users of PACS, other hospital officials, and the documents reviewed. These measures are consistent with the literature on workflow associated with the patient's clinical journey. Taken together, these perspectives give the following framework: the PACS-BSC model as seen in Figure 2-2. The PACS-BSC model enables the holistic investigation of PACS impacts in that it captures the essential impacts on workflow.

The model demonstrates interdependency of the four perspectives and the relationship with the vision and strategy of a hospital. This is in accordance with Norton and Kaplan's original intentions in that the four perspectives complement each other, and there is not one perspective that alone represents strategy – yet it is a significantly improved approach for specifically evaluating PACS. Moreover, the PACS-BSC invites qualitative assessment that reflects the qualitative nature of not only the perspectives, but also of the strategy and vision of hospitals.

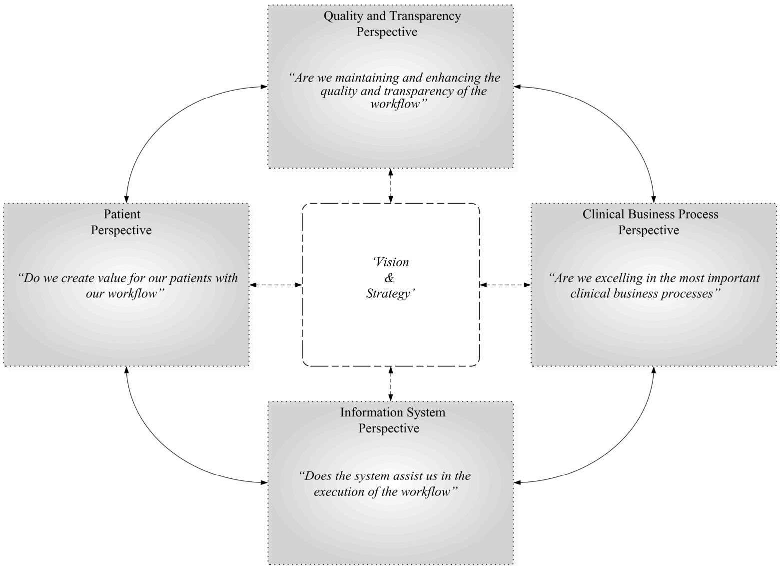

Fig. 2-2 PACS-BSC model

2.5 FUTURE TRENDS

This chapter highlights an important issue in health that will become increasingly important in the future: the multiple goals of health care providers require a context-specific concept of strategy and appropriate evaluation techniques. The finding that fundamentally BSC is appropriate as a starting point, although not adequate to capture the complexity of public hospitals' multiple goals, suggests that conventional models from business system evaluation may be able to be modified meaningfully and valuably for health. This is good news, as it avoids the need to start from scratch in order to avoid the misleading application of "off the shelf" conventional models that are inadequate to evaluate health contexts.

The trend toward evaluation using appropriate models and techniques heightens the prospect of greater accountability and system success in health. With the growing trend to see health information systems as integral to combating ill health and breaking in ill health/poverty nexus in the least developed nations, the need for appropriate evaluation is pressing.

2.6 CONCLUSION

The balanced scorecard allows adaptation to the specific needs of hospitals in order to evaluate organizational performance and IS/IT implementations. Because the implementation process is undertaken for reasons consistent with IS and organizational strategy that is largely non-market, it should be evaluated in non-market terms. Clinical goals and not-for-profit components should therefore be primary when evaluating IS/IT implementations in hospitals.

Our approach is radical in that it is built on a consideration of the fundamentals of the hospital strategy, and valuable in that it results in the PACS-BSC model. Consistent with the qualitative nature of major aspects of hospital strategy, the new model incorporates qualitative themes rather than quantitative performance measures. While changing the perspectives to fit the hospital context, and changing the quantitative focus of the performance measures to qualitative themes may be radical, there is no change to the essential nature of the BSC model. Rather, the new model retains Kaplan and Norton's intention to evaluate outcomes from the perspective of the organization's strategy and to be flexible to whatever those outcomes and strategy may be. Thus the PACS-BSC model is a holistic method to evaluate PACS impact on workflow that is relevant to hospital's not-for-profit and clinical strategies.

Retaining the original robustness of the BSC with regard to a radical review of organizational strategy and to the evaluation of qualitative outcomes, the PACS-BSC will be used to evaluate the impacts of PACS on workflow within hospitals. The authors argue that valid outcomes require a radical review of models in terms of purpose, concepts and structure and are currently undertaking empirical research to test the new model.

The application of the BSC framework and theories of strategy to PACS within the hospital environment has enabled both a richer understanding of the workflow outcomes, and a refinement of the BSC. The PACS-BSC, as developed, has enabled a more diverse understanding of outcomes from the staff's various perspectives. The use of qualitative interview methods in conjunction with quantitative survey methods has enabled an unearthing of outcomes as observed by the staff. Therefore, it is concluded that the academic tool kit with various theories and methods enables a clearer view of reality, while reality enables the appropriate refinement of theory.

3

A BALANCED EVALUATION PERSPECTIVE: PACS IMPACTS ON HOSPITAL WORKFLOW

Around the world hospitals are faced with both budget and regulatory pressures forcing them to re-examine the way clinical practice is carried out. Proposed technologies that provide workflow enhancements include Picture Archiving and Communication Systems (PACS), but is PACS really effective in improving hospital workflow and the flow on to patient care, and how should this be evaluated? An acknowledged and successful approach for organizational evaluation is the Balanced Scorecard (BSC), providing the fundamental features for assessing organizations from various perspectives. In this research the impact of PACS on the workflow of a large public hospital in Melbourne, Australia is examined using an adapted version of the BSC. Empirically, this model was applied as evaluation instrument through a series of in-depth interviews with PACS users. Results show that PACS did improve hospital workflow considerably, and that the organizational alignment of PACS in hospitals is an important critical success factor.[1]

3.1 BACKGROUND

Hospitals are moving towards film-less operations commonly investing in PACS [139]. PACS goes beyond the operational boundaries of radiology by supporting different departments to access medical images and reports and hence to optimize patient care [35] and thus considered as not just a repository of data, but a “workflow-integrated imaging system that is designed to streamline operations throughout the entire patient care delivery process” [140]. Furthermore, effective use of PACS can shorten the time for diagnosis, improve the efficiency and quality of the overall healthcare delivery process and make the workflow as simple as possible [20, 113, 130, 140]. However, while it is known that PACS makes images earlier available, hard evidence to support the connection between earlier receipt of images, clinical decision making and clinical action through PACS images, is lacking [38, 133].

There is an emerging need for evaluating PACS implementations since healthcare providers are facing both growing demand for improved care and higher expectations of service delivery [2]. Until now, the diversity in PACS implementations leads to difficulties in applying standard methods for the evaluation of PACS. Some studies

[1] This work was originally published as: Van de Wetering, R., Batenburg, R., Versendaal, J., Lederman, R., & Firth, L. (2006). A balanced evaluation perspective: picture archiving and communication system impacts on hospital workflow. *Journal of Digital Imaging*, 19 (Suppl. 1), 10–17.

provide insights concerning the value of PACS in terms of return-on-investment (ROI) and other kinds of quantitative measurements [33, 35, 37, 38]. It is questionable however, if these measures are most adequate for measuring payoffs yielded by an enterprise-wide PACS implementation since it neglects the intangible value created for stakeholders [35, 141]. Although it is recognized that general technological and organizational advances have been achieved over the last decades with the implementation of PACS, there is less consensus about the level of impact on patient care. Studies predominately focus on the quantitative, analytical aspects, while most of the potential gains are of a qualitative nature and thus hard to quantify. In addition, evaluations tended to focus on specific parts of the workflow implications of PACS implementations with a death of holistic evaluations.

This chapter is based on a case study at a major public hospital in Melbourne, Australia which recently implemented a hospital-wide PACS in order to improve their workflow and patient care. The hospital is a major teaching, research and tertiary referral center situated in Melbourne's central business district and provides a wide variety of community services. The hospital includes around 450 beds, 42 wards, 16 operating theatres and employs approximately 3000 employees across 19 discrete campuses. It performs roughly 65000 imaging exams (from all modalities) annually. In the early nineties the hospital commented a PACS implementation in several departments, and recently it expanded the system hospital-wide. This implementation was never evaluated however, despite the impression that it has a positive impact on patients, staff and a broad range of processes throughout the hospital. In 2004, the initiative for evaluation was taken, providing an opportunity to investigate the impacts of a PACS on the workflow of the hospital and to apply a holistic approach to an evaluation of the PACS system.

3.2 METHODS

A successful approach to an integral evaluation of organizational performance is the BSC as developed fifteen years ago by Kaplan and Norton [106, 142]. The BSC is a performance management model that provides executives with a comprehensive framework that translates a company's strategic objectives into a coherent set of measures. This provides a comprehensive view of the business's most relevant issues. In its original design, the BSC includes performance measures from four interrelated perspectives: (1) Financial, (2) Internal Business Process, (3) Customer and (4) Learning and Growth. The BSC is concerned with evaluating performance both with regard to return to shareholders and relationships with customers. The learning and growth perspective provides the impetus to sustain the ability to change and improve the other perspectives. The four different perspectives oblige senior managers to jointly reflect on operational measures. Hence, the BSC also indicates whether improvement in one area may have been achieved at the expense of another.

Much interest in the BSC currently exists within the healthcare industry. As the industry experience with the BSC grows and successes are shared, the use of the BSC in healthcare is expanding [116, 142]. Although the BSC has been applied for organizational evaluations in healthcare [116], it has never been applied in the evaluation of PACS in hospitals.

The implementation of the BSC allows organizations to adapt the different perspectives that are relevant to how they measure success based on the organization's strategy and vision. Consequently, the scorecard creates performance measurements tailored to the needs of organizations and links them with strategic plans. The BSC is therefore adaptive by design, and thus should be applicable to the evaluation of a broad range of organizational components, including PACS implementations.

Since strategy is central to the BSC, it is important to consider hospital strategy before applying it to PACS. It has been suggested that for hospitals a focus on the non-market driven components of the corporate strategy formulation process is most important. Therefore, the aspirations and values of executives in charge of the organization and the organization's obligation to society are central [118]. Following this, in this research the BSC is adapted to incorporate a wide range of non-market performance measures according to the hospital's strategic perspectives. Secondly, in order to evaluate a PACS implementation, the BSC requires an adaptation that incorporates components that are essential to the workflow of a patient's clinical journey. Therefore, in this research the perspectives of the BSC were transformed based on their relevance to workflow, PACS and consistent with hospital strategies. This leads to the following translation of the original BSC perspectives:

1. Clinical Business Process, as a translation of the internal business process perspective.
2. Patient, as a translation of the customer perspective.
3. Quality and Transparency, as a translation of the financial perspective.
4. Information Systems, as a translation of the learning and growth perspective.

The first two perspectives are similar to the original BSC, but the Quality and Transparency and the Information System perspective are radically transformed compared to the original financial and learning and growth perspective respectively. To fit the PACS evaluation, they now capture considerable changes in simplicity and transparency of workflow, the extent to which one can monitor and check the status of patients in the clinical process and the importance of the system as an enabler of the workflow. If the four perspectives are connected as in the BSC, a new framework is obtained: the PACS-BSC model (see Figure 3-1). Although the adaptation process was theory driven, the majority of claimed and frequently mentioned benefits by large PACS vendors concerning workflow impacts can be mapped on each of these four perspectives. This justifies the adjustments made to the original BSC. Because, hospital goals of clinical excellence and community service are outcomes that are difficult to quantify as are the intangible value created by PACS to patients, radiologist, and clinicians in terms of quantitative measures, we decided to elaborate the outlined perspectives as qualitative "themes" rather than quantitative performance "measures".

Instead of defining standard performance measures, our evaluation of PACS will be guided through the use of “principal themes” that originate from literature. Hence, this leads to a qualitative method for describing and analyzing the outcomes associated with most elements of our PACS-BSC model. Despite these modifications, the PACS-BSC model remains in accordance with Norton and Kaplan’s original intensions of the BSC in that the four perspectives complement each other and all are related to the central vision and strategy. These four perspectives and their relationship are shown in Figure 3-1:

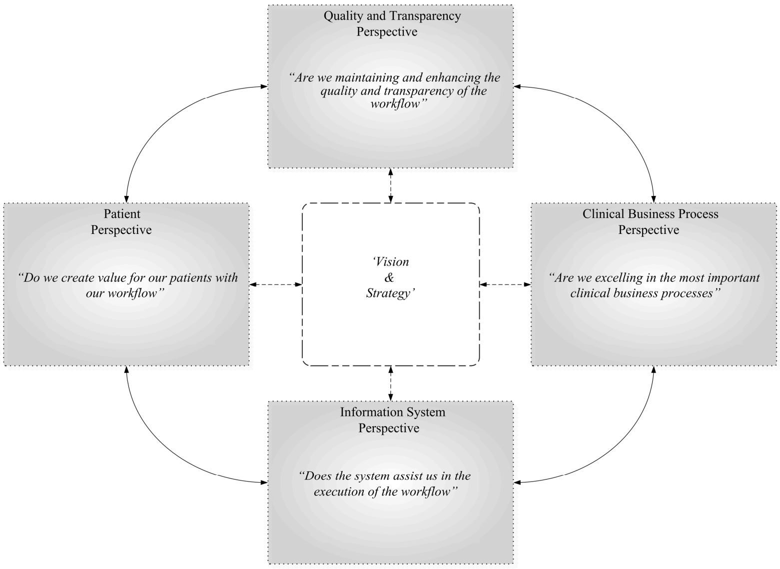

Fig. 3-1 PACS-BSC model

Data was collected through a series of in-depth, semi-structured interviews with PACS users and other medical staff at a large public hospital in Melbourne, Australia. The research was conducted under the approval of the University of Melbourne, Department of Information Systems Human Ethics Advisory Group. Interviewees were selected using a systematic, non-probabilistic technique in order to maximize insights from different respondents who cover each PACS-BSC model perspective. This resulted in a variety of responses that contributed valuable insights concerning the impact of PACS on specific aspects of the hospital workflow. A total of 11 interviews where held with staff members, project management and executives from different departments including medical imaging, emergency department, the cardiothoracic care center and physiotherapy. The interviews were recorded using a digital audio recorder with consent. These recorded interviews were then transcribed and provided to the interviewees for confirmation purposes. In order to analyze these data thoroughly and to use them to validate the PACS-BSC model, qualitative coding was used [124]. The data were reviewed on three different occasions using open, axial and selective coding respectively. Open coding is a first step in providing a high-level overview of the data. The second pass (axial coding) is mainly about critically reviewing the initial codes and searching for missing elements. These new codes are created subsequently and other codes are adjusted when new insights arise during this process. The final phase of the coding process is selective coding that consists of systematic linking the different categories. The three coding techniques where used for the analysis process in an iterative way: new codes and themes appeared after new interviews and new insights were gained through each method of coding.

3.3 RESULTS

The coding process performed on the 11 interview records resulted in the following selective codes, categorized according to the four perspectives of the PACS-BSC model:

i. *Clinical Business Processes*: Diagnosis Process, Time Savings & Image-Based Clinical Action, Organizational Communication and Examination Request & Report-Turnaround-Time.
ii. *Quality and Transparency*: Simplicity & Transparency, Quality of Workflow and Agile Workflow.
iii. *Information System*: Availability & Accessibility, PACS Integration and System Robustness.
iv. *Patient*: Patient Waiting Time and Patient Throughput & Flow.

Below, these codes are discussed in more detail, including excerpts from the interviews to clarify the particular views of respondents.

From all interviews, it was confirmed that with the implementation of PACS, the diagnosis process has changed considerably in terms of efficiency and value for work. Images are all in digital, browser based format. Radiologists analyze the images on their computer screen rather than to hang films on a viewing-box. The following excerpt from a radiologist clarifies this view:

> *"I can display them how I want to display them and adjust windows and levels and in some respects it is actually much easier for me to stack the images, just one on top of the other and singing through them."*

All authorized staff can access images simultaneously once they are stored into PACS which has been beneficial for staff. Previously, only radiologists had access to the images and provided reports to other hospital workers who did not necessarily see the original image. Because of the hospital-wide PACS, all staff can now access the images simultaneously allowing collective decision making concerning proper treatment of patients. However, while the ability to make a shared diagnosis has improved, no conclusive evidence was reported concerning considerable time savings for clinicians and earlier initiation of image-based clinical action. Some respondents however, stated that PACS made the treatment of patients easier, since they don't have to wait for radiology to produce images and don't have to go down to the library to search for specific film-bags.

Interviewees explained that in some cases PACS made the treatment of patients quicker. However, the total clinical treatment remains highly dependent on a lot of other organizational factors too, such as doctor availability, busyness of the department, availability of operating rooms, seriousness of the complaint, patient flows and whether an official report of the radiologist is required. PACS does lead to less verbal organizational communication between the departments and a reduced need for communication. All information is stored into the system and the status concerning data is real-time available for all authorized staff. Significant clinical cases that are brought up either by the radiologist or the clinicians are still communicated face-to-face. Doctors from the emergency department can directly discuss a patient with the colleague who will be looking after the image up on the ward.

Also, clinico-radiological meetings that take place in the hospital are done in a more efficient manner. In accordance with the mentioned efficiencies above, several steps that make up the overall report-turnaround-time have been improved. The examination requesting process is still the same, although more incoming requests for imaging were noticed. After the images have been acquired and stored into PACS, they can be accessed by the radiologist who also has immediate access to the request which is scanned into the system.

Workflow at the hospital has become simpler and transparent as a result of the PACS implementation. Nearly all steps have been eliminated that were associated with the hard-copies and film bags. Images are stored into a central image databases and made accessible to all the departments through a web-server.

> *"…it removes a lot of the steps in the workflow, all of the film-handling steps are taken out of the workflow and that makes the workflow simpler…"*

Even though less physical steps are involved in the examination of patients in radiology, closely monitoring these steps in terms of quality has become more important. So, it has become essential to check whether images have actually arrived from the PACS system to the right patient map/directory. PACS allows status checking of patients and examinations from any computer in the hospital along the workflow. This was seen as a major help in terms of patient and time management. Clinicians and nurses can easily check whether the image has been taken, stored and reported by the radiologist. Also, PACS changed work scheduling in some areas of the hospital. Radiologists schedule their reporting session more efficiently now that they don't have to worry about hanging any of the films and the film bag.

Improvements in the quality of the workflow were noticed since less retakes of images are required. Films don't get lost anymore and the images can always be reported. Moreover, it was mentioned in many interviews that images get reviewed more frequently than before and there are less missed diagnosis. Specifically, the fact that images don't get lost and stolen anymore, was often referred to as the most valuable aspect of the new workflow in terms of patient care. In some cases the hardcopies were also hidden by clinicians.

> *"Residents or registrars or other clinicians would take the films because they didn't want them to get lost and then they would hide them somewhere."*

In addition, staff can now retrieve images easily from the web-server without wasting valuable time on chasing film bags. Therefore, the workflow has become more agile resulting in less in physical movement. This frees up time for clinicians and other medical staff to do other things. Also, interviewees emphasized that images often were not reviewed in the past because people were too busy doing other things.

The availability and accessibility of images was mentioned in all interviews as one the most important aspects of PACS. The system provides simultaneous accessibility to medical images and provides the means for better communication, diagnosis and clinical treatment. Furthermore, medical staff is not pulled away from the patient. Most respondents explained that the images load within seconds and from the time they are taken in radiology, they are usually available within minutes. Although PACS provides earlier accessibility, the efficiencies cannot always be used to its full potential. Data suggests that it is highly dependent on how fast a patient comes back from an imaging exam, if an official report from the radiologist is needed and the availability of doctors. Furthermore, before the PACS implementation there were often arguments between clinicians and radiologist about whether films should be up with the clinicians or in radiology for diagnosis and reporting. PACS considerably changed these problematic deliberations as the images are simultaneously available everywhere and don't impede on another's workflow.

The integration of PACS with other IS/IT like the radiology –, hospital – and clinical information system further enhanced the process of accessing images, request and pathology reports at the same time. Also a decline in paperwork was mentioned in the interviews. Due to the integration of PACS, staffs have access and are able to view relevant information for their practice during the whole continuum of the workflow while not incurring additional delays. The system can deal with high levels of users accessing information, but has crashed several times. This, however, has not resulted in any substantial problems according to interviewees. The system is reliable and robust enough to store more data every year and contributes to overall hospital workflow execution.

> *"It is a very robust system, there are a lot of redundancies build into it, but it is not foolproof and depending on the problem that happens, there is a planned contingency."*

There have been slight improvements in waiting time for patients to receive their exams and results, due to PACS and several other improvements made in radiology. Patients don't have to wait and sit in the department for any films to be developed before they are released. Patients get their scan done and shortly after that they can be directed back to the referring clinician or where ever they need to go. With reference to these impacts, estimations vary between 5 to 10 minutes on average that are saved for each individual patient in radiology. This allows radiographers to do extra exams and increase patient throughput. Nevertheless, most interviewees were hesitant in mentioning specific time savings in receiving exams and suggested that most gains were due to the post-processing capabilities of PACS.

> *"I think the patient waiting time to receive the test may have only reduced slightly, but in terms of receiving results the waiting is certainly reduced significantly."*

The patient throughput is not solely determined by the use of PACS technology. It is dependent on many factors that contribute to efficiencies in radiology and the patient's overall journey in the hospital. A common view held by respondents was that improvements in throughput were also due to improved capabilities of the different modalities and other improvements throughout the entire hospital. Also, an increase was noted in the total amount of examinations after the implementation, but the physical throughput of patients has not been improved remarkably by PACS. It has made the patient flow more patient-centered in the continuum of clinical care.

> *"More like the possibility for throughput has been increased. I mean, I think we're still doing the same similar number of patient numbers anyway. I think it is still a fairly static number of episodes per year. It goes up by percentage every year…"*

Regarding this subject the interviewees suggests that there are several impediments to patient throughput that are not necessarily related to PACS or medical imaging in general. Even though workflow has been streamlined in certain areas, there are still time consuming processes that are inevitable. For instance, there is still the amount of time to bring a patient to the medical imaging equipment and to perform the exam. Furthermore, there is also the time to bring a patient back if that would be necessary. Consequently, PACS improves parts in what was once a lengthy and inefficient process, but can't eliminate many of the steps that make up most of the time to do an exam.

With respect to the selective codes of the four perspectives of the PACS-BSC model, results show that all aspects have been improved either considerably or in a minor way through the PACS implementation. Time Savings & Image Based Clinical Action and Patient Throughput & Flow showed relatively small improvements. Respondents suggested that several factors like the busyness of a department, the availability of operating rooms and patient flows have detrimental impact on these aspects.

3.4 DISCUSSION

In this investigation we evaluated the impact of PACS on the workflow of a large public hospital according to four interrelated perspectives of the PACS-BSC model. The framework, analysis and results presented in this chapter set out the impact of PACS on workflow in a rich sense and provide insights into the complex dependency of PACS and other important aspects of hospital operations. The majority of the qualitative data suggests that improvements in workflow execution do result from a PACS implementation. However, there are still some important aspects concerning the clinical treatment of patients that require careful attention such as the earlier initiation of clinical action with PACS and patient throughput.

Reports can now be rendered in real-time which has a positive impact on both the quality of patient care and the perception of radiology services by referring clinicians. The impact of PACS on processes and the quality of work was shown to be considerable. All authorized staff can access digital images simultaneously allowing them to make contributions in decisions concerning the proper treatment of a patient which is an issue not previously uncovered in research. Although the process of diagnosing has been improved, no evidence supports changes in clinical decision making and earlier initiation of clinical action and this is consistent with the literature [38, 133]. In fact, it has been argued that organizational factors other than PACS have a determining role on the initiation of image-based clinical action [38]. In order to gain full advantage of PACS, the system needs to be carefully aligned with organizational dimensions as proposed by theories of alignment [44].

In accordance with current research on simplification and transparency of workflow after PACS implementations [20, 113] analysis demonstrated multiple steps have been eliminated making the workflow as simple as possible. While the findings of this research support literature [130] stating that a first affect that one can expect from automation is an increase in quality and that it becomes easier to manage all the different activities of a department. PACS impacts on the overall contribution of IS/IT to workflow by making images early accessible and available [38, 133, 134]. This is shown in this research through analysis of the outcomes of PACS concerning availability and accessibility. Integration appears to be important since PACS does not stand alone. Rather, it is the interrelationship and integration with existing IS/IT that can streamline processes, or can prevent the slowing of processes through parallel systems by for instance storing the same data. Important from an Information System perspective in terms of workflow is the amount of down-time of PACS and the associated loss of records [133, 138]. For a large part it determines if processes can continue or not and therefore it is crucial that the system is robust.

Although some scholars argue that there is no significant difference in the number of examinations taken per patient between conventional and film-less radiology [37], findings show that there has been an increase in the total amount of examinations over a time span of 20 months after the implementation. This allows for a better patient throughput and is coherent with prominent literature [33]. Analysis also shows that there have been slight improvements in waiting time for patients to receive exams and their results. Notwithstanding these improvements, the interviewees suggest that physical throughput of patients has not been improved much. Apparently, PACS does not help to resolve these issues much by only providing earlier accessibility to images. According to the Patient perspective the impact of PACS is all about patient centeredness in the continuum of clinical care. The workflow has been improved in certain areas allowing patients to flow more smoothly through the entire patient care delivery process and the main challenge should be to minimize unproductive time and reach higher utilization levels with all the modalities in order to optimize patient throughput.

3.5 CONCLUSION

The obtained selective codes from the data analysis fit effortlessly on each of the proposed perspectives of the PACS-BSC model. Although this model is applied to a single case, the codes do validate the expanded model.

The conclusion is that the PACS-BSC model is fundamentally suited to evaluate PACS implementations in public hospitals from different angles and that the inclusion of clinical and not-for-profit goals in the strategy may make the evaluation more relevant. While the inclusion of qualitative themes rather than quantitative performance measures suggests different research methods, the model remains consistent with Kaplan and Norton’s intention of providing a single report to evaluate outcomes relevant to the organizational strategy.

Although various efficiencies have been reported in this study, important issues still remain unanswered. Since PACS is a system designed to streamline operations throughput the entire patient care delivery system, one would expect that it significantly makes a difference in terms of throughput and clinical action as well. Theories on business/IT-alignment, organizational fit and adoption of IS/IT can help understand why certain key elements in clinical practice have not been realized [44].

Part II:

PACS maturity and strategic situational planning

4

A PACS MATURITY MODEL: A SYSTEMATIC META-ANALYTIC REVIEW ON THE MATURATION AND EVOLVABILITY OF PACS IN THE HOSPITAL ENTERPRISE

With PACS and medical imaging technology maturing, the importance of organizational maturity and effective deployment of PACS in the hospital enterprise are becoming significant. The objective of this chapter is twofold. Firstly, PACS literature on maturity and evolvability in the hospital enterprise is analyzed, resulting in an overview of the relevant developments concerning maturity of PACS. Secondly, this chapter looks at the development of a maturity model for PACS technology. Using structured search queries, we identified 34 papers reporting relevant aspects of maturity and evolvability of PACS. From the results of a meta-analytic review on PACS maturity and evolvability, we propose a model – the PACS Maturity Model (PMM) – that describes five levels of PACS maturity and the corresponding process focus. We argue that this model can help hospitals to gain insights into their (strategic) objectives for growth and maturity with regard to PACS, the electronic Patient Record (ePR) and other health information systems. Moreover, the proposed model can be applied as a valuable tool for organizational assessments, monitoring and benchmarking purposes. Hence, the PMM contributes to an integral alignment model for PACS technology.[1]

4.1 INTRODUCTION

The field of healthcare and medical informatics has gradually evolved through a number of stages and established itself in recent years. The field is very broad and includes advances that have been made in medical imaging technology, e.g. PACS, information systems, image-guided surgery and therapy, computer-aided diagnosis (CAD), decision-support systems and the electronic Patient Record (ePR) [9-11]. The field is still evolving although some claim that the area of PACS has matured and is no longer cutting-edge [140, 143]. Others claim that PACS has been introduced into clinical practice too soon, and with too much hype, and research and development are very much in need now [13]. The utilization of the rapidly-growing results and possibilities

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of non-invasive digital imaging systems in clinical application, and related research and developing work, are also serious challenges [12, 13]. Moreover, Hood and Scott [23] mention that to date there is little published information concerning the clinical impact of PACS in the working environment.

The concept of PACS was introduced as early as 1982 and after more than twenty years of research, development and implementations, PACS has become an integrated component of today’s healthcare delivery system [22]. PACS can therefore be considered as the fundamental infrastructure for digital diagnostic imaging and information management systems. PACS originated as an image management system for improvement for the efficiency of radiology practice and evolved into a hospital-integrated system dealing with multimedial information. The integration of many different types of information requires the technology of multimedia: hardware platforms, information systems and databases, communication protocols, display technology and system interfacing and integration [31].

There are many definitions for PACS, ranging from simple Information Systems and Information Technology (IS/IT) used for digitizing images to enterprise-wide image management systems and integrated workflow systems that streamline all operations throughout the whole patient-care delivery process. For instance, Huang [140] defines PACS as a workflow-integrated imaging system that is designed to streamline operations throughout the entire patient-care delivery process. Anderson and Flynn [144] did a systematic literature review of a broad range of topics about PACS. They defined PACS more from a technical point of view: PACS are high-speed, graphical, computer network systems for the storage, retrieval and display of radiological images. As the definitions indicate, PACS is a very broad term encompassing many related, but different, components and systems related to medical imaging for clinical practices [17]. PACS can thus be both very simple and be a more complex enterprise-wide system.

Although PACS is now a well-established technology, achieving a filmless environment with PACS is still a high-cost venture [32]. A successful method for implementing and aligning PACS in the hospital enterprise would therefore be a prerequisite, and insight into the current and desired level of maturity of PACS valuable to the hospital.

So, how can PACS maturity be modeled, measured and assessed, and what is known from current research on this fundamental topic in medical informatics?

Theories on IS/IT maturity and adoption are well established in business and IS/IT literature going back to the early 70’s. The concept of the stage hypothesis was introduced by Nolan [55] in 1973, extended [54] and frequently discussed and adapted [57, 67, 145-147]. In general, the IS/IT maturity models provide insight into the structure of elements that represent process effectiveness of IS/IT in organizations [64].

In this research we develop a model that can be used to assess the alignment and maturity of PACS, and PACS deployment performance within hospital enterprises. Since PACS is a system designed to streamline operations through the entire patient-care delivery system, one would expect that it makes a significant difference in terms of throughput and clinical action as well. It is suggested that theories on business/IT-alignment, organizational fit and adoption of IS/IT can help us to understand why certain key elements in clinical practice have not been [40] achieved. In a first step to construct an integrative implementation/alignment framework for PACS, insight into the levels of maturity of PACS is a prerequisite. Next to the organizational aspects [79, 81] the framework should enable the quantification of PACS maturity including its relation to PACS deployment performance. In this chapter, we present the results of an extensive and systematic literature search that is performed in order to construct such a model that sets out PACS maturity and evolvability in the hospital enterprise.

To the best of our knowledge, we are the first in this as so far there is no reference to a recognized maturity model for PACS, and thus no valuable tool for empirical research.

4.2 OUTLINE OF THE CHAPTER

The next section reviews the history of the PACS and sets out the relevant developments concerning IS/IT maturity and the maturity of hospital information systems. The method for our structured literature search is detailed in section 4.4. Section 4.5 presents the review of maturity and evolvability of PACS literature and section 4.6 proposes growth levels for PACS and a PACS maturity model based on a meta-analytic approach. Finally, we discuss both the opportunities and limitations of this study and the constructed PACS maturity model (section 4.7).

4.3 BACKGROUND

4.3.1 PACS HISTORY

The concept of a PACS was introduced more than 2 decades ago and the desire to store medical images digitally stems from well-known limitations in the film-based radiology departments [21]. The initial development of diagnostic imaging started over 50 years ago with the utilization of image-intensifier TV systems for fluoroscopy and the development of gamma camera for radionuclide imaging. Over the years much research has been done on electronic imaging, magnetic resonance imaging (MRI), positron emission tomography (PET), single-photon emission computed tomography (SPECT), the development of computed tomography (CT), ultrasound imaging and PACS [148].

A PACS acquires medical images digitally from several modalities in the radiology department (e.g. CT, ultrasound, MRI, and plain X-ray), stores them in central data repositories/databases and makes them available upon request by, for instance, referring clinicians. Since the medical images are now in browser-based format, they can be made available for viewing almost instantaneously throughout the entire hospital and even beyond the boundaries of hospitals to off-site radiologists and other institutions using secure broadband internet connections.

Nowadays the PACS industry is a well-matured industry and offers archiving solutions and reading stations that fulfill the needs of the users [30]. The Integrating the Healthcare Enterprise [149] also provides hospitals with a solid framework that from a technical point of view ensures that different information systems – including HIS, RIS, EMR – are well integrated. PACS are deployed in most academic centers and many private practices are joining the ranks of the digital radiology revolution [143]. A recent survey on E-business in 2006 among 18 European countries, conducted by Empirica by order of the European Commission, posed the basic question for hospitals as to whether they use PACS or not. The (unweighted) result of this enquiry is presented in Figure 4-1. Large differences between countries appear from these data. Only 10 per cent of French hospitals say they use PACS as against almost 70% of Finnish hospitals. It is difficult to discover a definite systematic adoption pattern within this list of countries in terms of their geographical location, economic position, healthcare system or ICT usage. This remains an interesting topic for further research. At this point, it can be noted that among a large number of European countries the use of PACS in hospitals is at a certain level but is still – given the European average of 33% – in its growing stage.

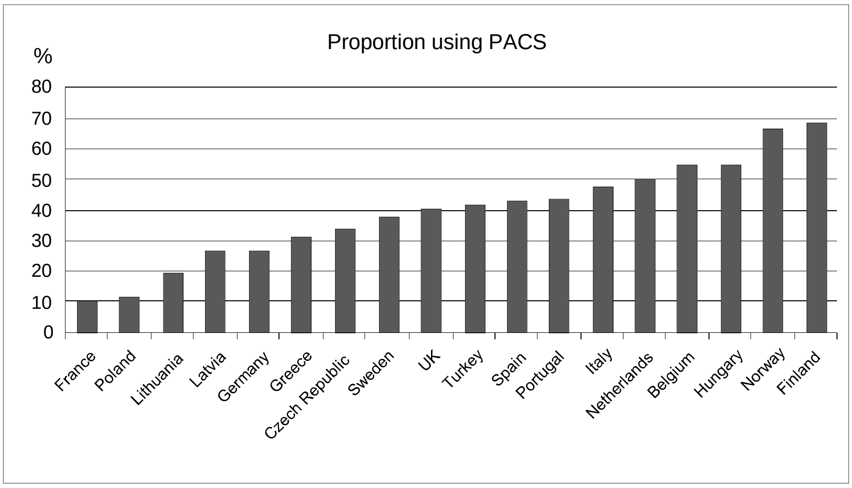

Fig. 4-1 PACS usage in Europe

The highest rate of adoption is seen in the Scandinavian countries of Norway and Finland. This comes as no surprise, since Scandinavia leads the global industry with the highest average adoption rates of digital solutions in healthcare.

Some scholars consider PACS to be a mature technology, but not all of the key issues have been resolved [143]. For instance, there is a wide variety in features and capabilities of software products. The systems are complex, and costly to acquire, replace, maintain and repair. The performance of these systems directly affects patient care and (clinical) workflow and clinical effectiveness in the working environment [23]. Samei et al. [143] therefore suggest that careful attention should be paid to the selection of a system that meets certain needs and requirements. With recent developments in terms of integration of PACS with other technologies and add-ins like chat and messenger services and emailing functions [150], PACS still requires attention. Moreover, utilization of the rapidly-growing results and possibilities of non-invasive digital imaging systems in clinical application and related research and developing work, are serious challenges [12].

4.3.2 INFORMATION SYSTEM MATURITY

The concept of IS/IT maturity and adoption is well-known in business literature and goes back to the early 70's. Within the field of information systems Nolan and Gibson [54, 55] are considered to be the founders of the IS/IT maturity perspective. From research on the usage of IS/IT in large US organizations, they proposed an evolutionary model initially containing four stages of growth. Later, two more stages were added to the initial model. The stages are: initiation, contagion, control, integration, data management and maturity. The six-stage model represents the level of IS/IT expenses for an organization in relation to the stages of increasing sophistication and maturity of the IS/IT. According to this model, IT-adoption or IT-management will see gradual uptake by a relatively small group (of organizations) at the beginning. This adoption phase is subsequently followed by a large group, and finally by a smaller group that stays behind in terms of adoption of emerging technologies.

In general, this pattern of adoption is called an S-curve, since it bears resemblance to a cumulative frequency distribution of adoption within different groups [56].

First published in 1989 by Watts Humphrey, and later by the Software Engineering Institute (SEI) at Carnegie Mellon, the Capability Maturity Model (CMM) – later superseded by the CMM integrated – has become an established model in the field of information systems development. CMM has been established by SEI to help organizations enhance and boost their software processes and has been recognized as a standard maturity model.

The CMM provides software organizations with guidance on how to gain control of their processes. It can help improve the maturity of these processes (of developing and maintaining software). The latest version of CMM is the CMMI (Capability Maturity Model Integration). To exemplify a staged representation five designated levels have been defined (see

Table 4-1). Each maturity level is a defined evolutionary plateau of process improvement and includes a checklist to evolve on to the next level [49].

Maturity Stage	Clarification
Initial	• Carry out work on an ad hoc basis • Formal processes unclear • Poor control • Effort of a few enterprising individuals instead of the whole organization
Repeatable	• Depend on policies for managing a software process and measures • Processes of the organizations stay institutionalized through experience instead of detailed procedures
Defined	• Engineering activities and processes of management are formally defined • Newer methods and tools can be added
Managed	• Detailed measures of the software process and product quality are collected • Setting quantitative goals • New sets of tools are added / adjustments are made to existing processes
Optimizing	• Focus on continuous process improvement • Instead of correcting defects, a firm stalls future defects and addresses the key to those defects by planning advance

Table 4-1 Maturity levels of the CMMI

According to De Bruin and Rosemann [69], CMMI is an improvement model because it provides a roadmap to get to the next level of maturity. In a recent meta-analysis on the effects of the CMM, Galin and Avrahami [70] were only able to identify three studies that give details on productivity gains when an organization progresses to CMM level 2 and only twelve studies that provide details on productivity gains when an organization progresses to CMM level 3.

In general, the IS/IT maturity models provide insight into the structure of elements that represent process effectiveness of IS/IT in organizations [64]. The concept of defining stages of development and growth has been further extended and applied to organizations. Examples are the stage maturity model which Light and Holland [62] developed for Enterprise Resource Planning (ERP) systems and a stage model for Intranet implementation by Damsgaard and Scheepers [63].

Health information systems (HIS) have been around for more than two decades, and tremendous progress in medicine as well as informatics has been realized since then [151]. Haux identifies several lines of development for HIS:

- the shift towards computer-based processing and storage, as well as the increase of data processing;

- the shift from local to global information system architectures;
- besides professional use of the HIS, that of patients and health consumers as well;
- the usages of the data not only for patient care and administrative purposes, but also for healthcare planning and clinical research;
- the shift of focus from mainly technical HIS problems to those of change management as well as of strategic information management;
- a shift from (predominantly) alpha-numerical data to clinical images and even now also to data on the molecular level;
- the steady increase of new technologies to be included in order to enable continuous monitoring of the health status of patients.

Similar development stages can be found in Vogel [141], who outlines several phases of investments in IT in healthcare. With each phase of IT investment in healthcare greater expectations and more complex systems environments are produced in which subsequent IT-investments are being made.

4.4 METHODS

4.4.1 STRUCTURED LITERATURE SEARCH

As a starting-point, the review of the literature employed search queries using keywords in OMEGA, the central search engine of Utrecht University containing thousands of digital journals from different disciplines and accessing over 13 billion full-text papers. Publishers included are Ebsco, Elsevier Science Direct, JStor, SpringerLink, IoP, ArXiv, Karger, Pubmed Central, Project Muse and DOAJ Lund. A literature search was also performed by means of Scholar (Google).

The following structured queries were performed:

- PACS, digital radiology, diagnostic imaging, + {*maturity* | *evolution* | *progression* | *stages* | *growth* | *development*}

The queries resulted in a long list of retrieved scientific papers, of which in total 131 concern the PACS domain. Subsequently, inclusion criteria relevant to a particular PACS study were determined based on their theoretical and practical value for our research purpose rather than statistical validity. These papers were then screened for relevance for the purpose of this investigation by use of the following criteria:

- Elaboration on the application of PACS other than the basic PACS functionality (acquisition, storage, distribution and display);
- Focus on the usage and application process of PACS in the hospital, not merely on PACS technology and outcome;

- Description of the evolutionary / maturity process of PACS in the hospital (enterprise);
- The study is empirically applied, tested and / or validated in hospitals and clinics (health systems);
- The study mentions organizational aspects relevant to the application of PACS in the hospital.

All the papers retrieved through structured queries were manually matched against the above inclusion criteria. After the application of these criteria, the total of papers to be reviewed was 25 references. To enhance the reliability of our applied research strategy, and to make sure that all relevant papers were included for our review purpose, a second researcher performed the above queries. After manual matching of the inclusion criteria another 2 papers [152, 153] were retrieved.

These papers were retrieved with a structured query, and several other papers were selected from main publications and positioning papers referring to several important publications and researches on different aspects of PACS usage. This resulted in the inclusion of another 7 papers and books [22, 31, 130, 154-157] for review in this study. In the end, 34 papers were selected through the above search strategy and were input for our literature review for PACS maturity and evolvability. All papers included in the study were published between 1996 and 2007.The review method applied to the selected papers is described in sections 4.4.2 and 4.4.5.

4.4.2 QUALITATIVE META-ANALYSIS

A qualitative meta-analysis approach [158, 159] is performed in order to analyze the literature, define maturity levels for PACS and construct a model based on the reviewed literature. Standard meta-analysis commonly compares and combines quantitative studies in order to obtain generalizable outcomes [160]. Its counterpart, qualitative meta-analysis, is less matured, although the method is gaining in popularity and there is a growing body of knowledge of this qualitative method [161-163]. Here, we apply qualitative meta-analysis by three distinct analytical phases: (1) meta-theory, (2) meta-method and (3) meta-data-analysis [158, 164]. These three steps form the basis for the process whereby new theorization can be generated [165].

For the meta-data-analysis phase, we adapted the approach for qualitative meta-analysis as presented in the metaethnography from Noblit and Hare [158] and a study by McCormick et al. [162]. As the first step, common ground and interest for research purposes were created by exploration of the PACS literature. We then retrieved many studies for analysis purposes (see method, section 4.4.1). After that, the studies were read iteratively. As the synthesis developed, studies were read and reread to check all the relevant topics and interpretations. This resulted in an overview of the relevant literature concerning the trends in PACS maturity and evolvability (see section 4.5). Subsequently, PACS process focuses were identified and structured according to initial stages of maturity resulting in a schematic overview of PACS process focus and initial structure for maturity levels. In our quest for a maturity model, we raised questions, reread studies in order to enrich the current interpretations of the study and synthesize them. This step in the meta-analysis resulted in an ordered schema of maturity levels with the associated process focus and scientific references. Next, we related the maturity levels and tried to identify relationships and dependencies. This was done iteratively by skipping back-and-forth between the different analytic steps in the process. This fundamental step in the analysis process allowed us to achieve full richness and understand the complexity of the data. The application of this back-and-forth method in the final step provided interpretation for the constructed model while preserving the original meaning and outcomes of the studies that were involved.

These phases and steps in the meta-analysis-process enabled us to gain a comprehensive understanding of PACS literature from a maturity and evolvability perspective. This does not imply that we have created a ‘new truth’ concerning PACS; rather we claim to reflect on the current PACS literature in a new way. The main result of this will be an integrated maturity model for PACS based on meta-analytic grounds, as will be presented below.

4.5 Trends in PACS Maturity and Evolvability

Our systematic literature study sets out theoretical and empirical contributions in order to provide an overview of the maturity levels of PACS technology in the hospital enterprise. As a result of the meta-analysis, the synthesis provided a new overview of the relevant literature. More specific, we identified three trends of PACS maturity and evolvability:

1. Radiological and hospital-wide process improvements;
2. Integration optimization and innovation;
3. Enterprise PACS and the ePR.

The retrieved articles (see section 4.4.1) and other base resources are structured and presented in the following subsections.

Trend 1: radiological and hospital-wide process improvements

PACS technologies

Using PACS, hospitals can distribute imaging data using web technologies and web servers to access, view and even manipulate PACS images in an intranet and internet environment. Furthermore, components[2] architecture and technologies have a predominance in high performance primary diagnostic imaging display workstations [166]. A combination of both distribution methods allows for access, viewing and manipulation of imaging data more simply than by use of display workstations.

The integration of PACS in a filmless radiology environment results in less circulation of paper work, and that enhances the reliability of the reports [136, 137]. Because of its focus on medical images, however, PACS is restrictive in managing (hospital) workflows. The evolution of PACS towards a system that can handle workflow management requires important alterations [130]: the emphasis should be less on images and more on multimedia documents. Software for viewing images has to coexist with administrative tools on diagnostic workstations. More advanced usage of PACS supports patient folder management by event trigger mechanisms [31]. The PACS controller and archiving server manages the patient studies in folders and contains all relevant images, reports and impressions. A folder remains online at workstation during the patient’s stay or visit. Such a patient folder can be seen as the prelude to an ePR, only with a focus on imaging. Main modules of a folder are archive management, network management and display/server management.

Li [167] did an analysis on the evolution of display technologies in PACS applications and (clinical) workflow and distinguished three phases:

1. During phase 1, the focus was centered on the individual hospital department and optimized the ability to display on a stand-alone workstation;
2. In phase 2, the focus shifted towards clinical and enterprise workflow and image viewing workflow was optimized for workstation presentation;
3. For the last phase – the modern period – standardization and enterprise integration have become key words where institutional/regional enterprise level, multi-vendor and PACS/RIS integration have become main themes.

PACS implementation

One of the major drawbacks of early PACS implementations was the proprietary, vendor-specific design of image and data communication between individual PACS components [21]. With the early PACS implementations, hanging protocols on workstations were primitive, lacking user control over series placement, window/level settings, and the zoom factor and panning required [168].In principle, the early PACS implementations focused primarily on providing the basic PACS functions (image retrieval, viewing) and often even failed to do that [21]. These issues have been

[2] Component software architecture is a static framework (set of conventions) that provides a kind of a software system and the conventions, policies, mechanisms for composing itself with subsystems, or component parts that can populate the architecture. It defines how the parts relate to each other including constraints governing how they can relate.

overcome by second generation PACS implementations that favor a gradual implementation in the field where it is technically feasible, economically possible and contributes to medical knowledge [169-171].

Workflow consequences

Although workflow changes are apparent, Siegel and Reiner [113] suggest that the transition to filmless operation alone results in a relatively small gain in productivity if it is not accompanied by a redesign of the basic departmental workflow. This requires a high level of integration of the various imaging information systems and HIS and RIS.

Historically, PACS runs on a separate patient database, which may not match the implemented RIS database within a hospital. If this is the case, PACS may not contain information about exams scheduled in the RIS entity, making efficient prefetching and distribution of imaging data impossible [21]. Initially, within radiology hard-copy films were replaced by soft-copy images, although navigation remained relatively static. In this phase, many radiologists did not take full advantage of the workflow and interpretation opportunities available. Workflow enhancement can be seen in the usage of dynamic soft-copy reading and stack modes further enabling the ability quickly and efficiently to display comparison studies using automated hanging protocols and allowing radiologists to navigate rapidly through cross-sectional imaging data sets (using cine loops). This evolution continued towards more complex and advanced techniques that can process large volumetric data sets into 2-dimensonal and 3-dimensional reconstructions (for further review see [171]).

Crowe and Sim [172] describe a RIS/PACS implementation that is considered to be of assistance in clinical decision-making in a wide variety of clinical areas and patient management, and this is consistent with other studies. See, for instance, [12]. PACS therefore not only provides workflow transformation within the hospital enterprise, it also assists in the clinical process of diagnosis and decision-making.

To describe the evolution of workflow in radiology departments, Fu et al. [173] identified four application levels:

1. The first level is the traditional environment that is based on handwriting paper and printed films;
2. The second level is a mixed and transitional radiology environment, where radiologists input text in a computer, but still read traditional hardcopy films on light boxes and use independent RIS systems;
3. At the third application level, Fu describes the true soft reporting and verification systems – even based on digital high resolution 4-screen portrait monitors and/or dual projectors with two large screens, which have achieved satisfactory effects;
4. At level 4 there is an integrated digital consulting and teaching environment based on satellite and web-based technology for telemedicine, teleradiology and medical education [see also 12, 31].

Clearly, the initial stages are more focused on the infrastructure and the latter are more oriented towards efficient PACS workflow, process integration and alignment within the hospital. Efficient PACS workflow in an integrated healthcare IT environment and quality assurance/control procedure are generally omitted, however [173].

Trend 2: integration optimization and innovation

Integration

During the development and the initial implementations of PACS and digital imaging network in hospitals, signs of PACS evolution and the possibilities for new developments and applications were clearly visible [153]. For instance, next to the development of advanced workstations and distributed medical networks, the clinical value of integrating imaging data with other image-related data into a medical record was also seen to result in adequate patient care. The rise of the internet and the extension of computerized medical records and the accessibility to other relevant clinical and image-related data through the use of multimodality workstations were recognized to have a significant impact on clinicians' and physicians' work.

By integration of PACS with the radiology information system (RIS) and other information systems in radiology, it is possible to recover statistical information allowing for a quantitative control mechanism. According to [152], this will help detect critical points in the hospital service workflow. Moreover, by integration of PACS with the HIS and RIS, the diagnosis process can be optimized, since clinical diagnosis, radiological reports and patient history are necessary at the PACS workstation to complement the imaging data at hand. The integration of the HIS, RIS and PACS image data and all related text information acquired can be managed in such a way that it is useful to a radiologist during the diagnostic process [31].

As an example of integration, PACS can optimally support the non-clinical application of the imaging system by providing electronic teaching files conforming to new MIRC (Medical Image Resource Center) standards [174]. Using this process design, hospitals can use PACS for close collaborations in teaching and research. Moreover, the construction of a medical content repository for teaching files and e-learning can function as a knowledge management system [175]. The integration of medical informatics and online learning repositories (e-learning) can be employed in many advanced applications, such as knowledge management, telemedicine, home-care, etc.

Since PACS contains large amounts of imaging data, Huang [22] argues that advantage can be taken of this valuable resource through the investigation of innovative clinical service, research and education using the concept of imaging informatics. Moreover, a PACS implementation allowing simultaneous presentation and post-processing capabilities of medical images plays a central role in making quick and reliable clinical decisions non-invasively and is effective in the diverse fields of consultation, education, tele-evaluation and post-processing [12].

Technological advances

With the trends towards PACS integration optimization many technological advances are made, and some emerging technologies such as computer-assisted readings (CAR) and computer-aided diagnosis can be incorporated [23]. Not only should PACS be able to incorporate new technologies/advances in terms of technical requirements, PACS can also act as a central image provider for post-processing and workflow of clinical and research medical images. As medical imaging became crucial to other departments outside radiology (for instance in the diffusion and perfusion MR imaging for stroke detection in neurology), PACS has become a clinical collaboration tool. In this respect, some call PACS an “inter-disciplinary tool” [176].

To sum up, technological advances with PACS and examples of how this is applied in clinical collaboration include the following:

- Computer-assisted bone age assessment that can be integrated with clinical PACS for advanced image analysis purposes. In PACS, a CAD (computer-aided diagnosis) based on phalangeal and carpal bone growth can be developed to assess the bone age [22, 31, 177];
- Computer-assisted / aided diagnosis and cuing and the adoption of intelligent application of informatics [156]. The adoption of CAD will become routine in the coming years, especially in the detection of lung nodules and breast cancers;
- Full field digital mammography (FFDM) benefits of computer-aided detection, computer assisted classification and PACS can be realized [154]. The integration and application of breast imaging and PACS are associated with several challenges with respect to (soft copy) image display and interpretation, communication and storage, since FFDM requires high resolution monitors to enable the physician to visualize the minute details for accurate diagnosis;
- Three-dimensional (3D) imaging services as well as the workflow involved in integration of 3D imaging services with PACS and radiology information systems are serious challenges for hospitals [155];
- Image-assisted surgery system (IASS) is designed on the concept of an image-integrated ePR and use of existing knowledge of PACS and the associated medical imaging informatics infrastructure [31]. IASS allows patient-centered images and data to be staged at the server and delivered to the workstation for review before, during and after surgery;
- Intelligent data-mining will also take on greater importance with PACS [171]. It will allow for image processing and data extraction that will ease the interpretation process for radiologists even before the current data sets are presented to them. Mining objects include (radiology) reports, correlative imaging studies and electronic medical records.

Trend 3: enterprise PACS and ePR

Owing to data exchange standards (HL7/DICOM), PACS can be integrated with Departmental IS and the HIS and this provides a basis for a communication platform in medicine, constituting an ePR The ePR supports an interdisciplinary treatment of patients by providing data of findings and images from clinics treating the same patient [178].

While the PACS evolution mainly focused on imaging data and integration with RIS, the parallel evolution of electronic medical records supporting all the other clinical electronic documents led to the integration of imaging data with the rest of the patient record [135]. This integration improves the accuracy and efficiency of patient management and is enabled by the functional integration of medical data from different sources. Moreover, the experience of many practitioners shows that it is essential to integrate PACS imaging data in the patient's medical record in order to maximize the efficiency and clinical effectiveness of the system [20].

With enterprise PACS, the patient becomes the main focus of the operation and a single identifier (e.g. patient name or ID) is sufficient for any healthcare provider in the enterprise to retrieve the patient's comprehensive record [140]. At the enterprise level many hospitals and clinics put the emphasis on sharing enterprise integrated resources and streamlining daily (clinical) operations. In doing so, it is not necessary for all parties to have specialized services like radiology, since these kinds of services can be shared among all the entities in the enterprise through, for instance, teleradiology [31].

In such an environment, images can be managed as an integral part of the ePR, so that clinicians will be able to use the same ePR front end to access images without having to learn new tools and user interfaces and use consultation and conferencing capabilities. This process improves the quality of medical treatments and care [32].

At such a development stage conventional hospital information systems, radiology information systems or other IS/IT are no longer sufficient, but the electronic patient record will prevail. Currently, the majority of the ePR's are not fully effective since they haven't incorporated images. See also [179, 180].

With the ePR the patient's record goes with the patient and information can easily be retrieved across different systems within the enterprise. Enterprise PACS should therefore have a direct connection with a central ePR server in order to distribute images and related data in a timely manner to a healthcare provider at the proper time and location [31]. An ePR requires a longitudinal, interoperable patient-specific record of all relevant imaging data, diagnostic reports and numerous other data resources, including several legacy systems [157]. Successful adoption and integration of these systems into the hospital enterprise is a considerable task.

A maturity-based typology in this context is provided by Whittick [157], who proposed a digital imaging electronic health record progression (DI/EHR) framework consisting of seven stages and several domains that constitute (DI/EHR). It describes the progression from printed film towards cross-jurisdictional DI/EHR using several intermediary stages. The stages are:

1. Film/paper;
2. Modality storage/CD;
3. Dept. PACS/RIS;
4. Organization PACS/RIS;
5. Multi-Organization Shared PACS;
6. Regional Shared DI-r;
7. Jurisdictional DI/EHR.

The stages are intended to express where a specific organization or jurisdiction may be. Moreover, Whittick does not suggest that organizations must progress through the stages sequentially. Although the model proposes several stages of progression for PACS, they are not all related to the maturity of PACS processes and their application within the hospital enterprise.

4.6 THE PACS MATURITY MODEL (PMM)

In this section we build upon the results of the previous literature review concerning PACS maturity and evolvability, in order to construct a framework for maturity levels for PACS in the hospital enterprise. Following the meta-analytic approach, five levels of PACS maturity can be extracted from original resources:

I. PACS Infrastructure

The initial level can be described as the basic and unstructured implementation and usage of image acquisition, storage, distribution and display. At this maturity level many technical and organizational problems arise with PACS owing to the lack of implemented standards in physical interfaces with the radiological sources, image and transfer formats and the dramatic changes that would result from PACS implementations [168].

II. PACS Process

At the second maturity level most of the initial pitfalls have been covered by second generation PACS implementations [169-171]. The focus of the “PACS Process” maturity level is on effective process redesign, optimizing manual processes in radiology and initiating transparent PACS processes outside radiology. The focus, however, at this maturity level, is still only on medical images and is therefore restrictive in managing (hospital) workflows. The transition to filmless operation alone results in a relatively small gain in productivity if it is not accompanied by a redesign of the basic departmental workflow. This requires a high level of integration of the various imaging information systems and HIS and RIS [113].

III. Clinical Process Capability

The “Clinical Process Capability” maturity level is represented by the evolution of PACS towards a system that can handle workflow and patient management [130], hospital-wide PACS distribution, communication and image-based clinical action. The evolution to this level requires important alterations in terms of PACS processes, extending the scope beyond imaging data and the level of integration of health information systems like HIS, RIS and PACS. At this level the clinical applicability of PACS begins to pay off by providing the imaging and associated (medical) documentation to clinicians, operating theatres, outpatient clinics and in some cases even outside the boundaries of the hospital.

IV. Integrated Managed Innovation

The fourth level of maturity is “Integrated Managed Innovation” which can be characterized by the initial integration of PACS into the ePR and cross-enterprise exchange of digital imaging data and supporting documentation.

This maturity level goes beyond clinical process capabilities with the adoption of emerging technologies like CAR and CAD, resulting in decision support for clinical PACS usage. At this maturity level integrated PACS solutions are also applied for statistical information [152], intelligent data-mining purposes and quantitative control mechanisms [31]. Basically, the “integrated managed innovation” maturity level forms a bridge between the optimization of internal clinical PACS processes and the wider adoption within an ePR and enterprise PACS chain(s).

V. Optimized Enterprise PACS Chain

The final maturity level is the “Optimized Enterprise PACS Chain”. At enterprise level, and with PACS fully integrated into the ePR, the system can be maximized for efficiency purposes and clinical effectiveness [20].

Key process characteristics at this development stage include the following: large system integrations, PACS and web-based technology, see also [166], image distribution though web-based ePR [31]. Moreover, at this level the adoption within the wider ePR and healthcare facility integration is continually optimized and the operational improvements yield process innovations and overall efficiencies in the continuum of the patient-care delivery process.

A structured overview of the different PACS maturity levels with the associated PACS process focus and used references can be found in the Appendix II.

If we summarize the PACS maturity levels, together with the associated process focus and the relationship between the distinct levels of maturity, and depict this as a figure, the following maturity model appears (Figure 4-2):

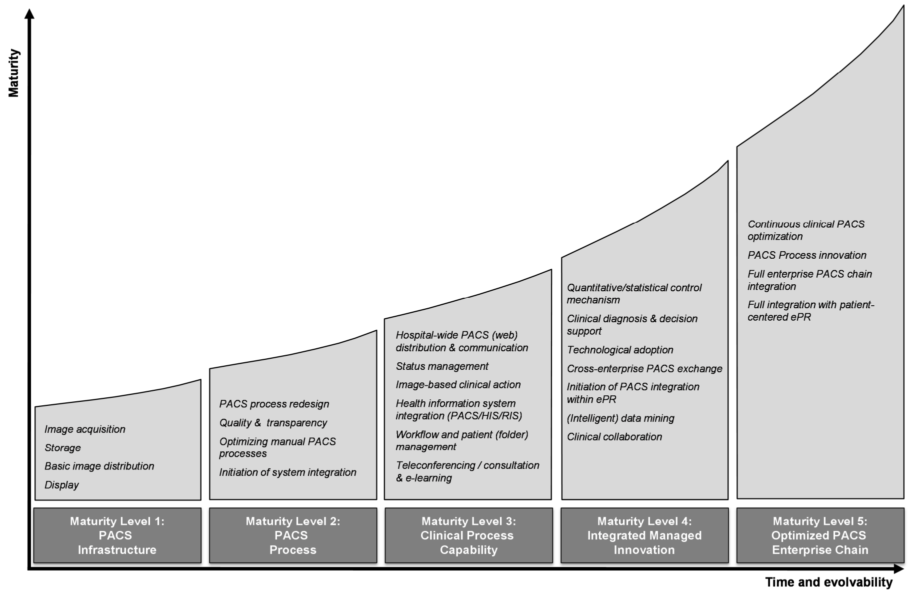

Fig. 4-2 PACS maturity model (PMM)

With the progression towards the highest PACS maturity level, the operational (workflow) efficiency, IT-integration, and effective and qualitative care using PACS technology expand. This is because of effective process redesign and optimization of underlying clinical processes and workflows, and the integration of PACS within a larger hospital enterprise (strategy). It goes without saying that this is not an easy task to achieve and it takes time to evolve.

With this progression, the level of retrieving more timely and accurate information for clinicians, physicians and hospital management increases as well. The process execution across the continuum of care improves patient care, allowing for real-time diagnosis, decision-support, inter-disciplinary processes, integration within the ePR, (intelligent) data-mining activities, continuous clinical optimization and so on. It should be noted, however, that high quality service, efficiency and clinical effectiveness of the PACS system can only be realized if an ePR is integrated with PACS. This integration enables a consistent working environment for clinicians, nurses and management and the opportunities for (e)consultation, for instance, teleconferencing [20, 179].

If we look thoroughly at Figure 4-2, we can also trace the three PACS trends that were identified in section 4.5: (1) radiological and hospital-wide process improvements, (2) integration optimization and innovation and (3) enterprise PACS and the ePR. These three PACS trends overlap the maturity levels since they have a broader scope than just one distinct level of maturity. Trend 1 overlaps maturity levels 1, 2 and a part of maturity level 3. The integration optimization and innovation trend overlaps maturity levels at part of level 2, 3 and part of level 4. The final PACS trend encloses maturity levels 4 and 5.

In some cases we could use the retrieved studies to define a certain maturity level on a one-to-one basis. Other studies, however, addressed PACS process for several maturity levels. For this reason, some references are allocated to multiple maturity levels and can be seen in Appendix II for an extensive overview.

4.7 DISCUSSION & CONCLUSION

There is an emerging need to evaluate PACS implementations as healthcare providers are facing both growing demand for improved care and higher expectations of service delivery [2]. Hospitals are pressured not only to spend money wisely, but also to demonstrate that it was wisely spent [181].

PACS is a system that is designed to streamline operations through the entire patient-care delivery system that is expected to make a significant difference in terms of throughput and clinical action as well. Earlier, Van de Wetering et al. [40] argued that theories on business/IT-alignment, organizational fit and adoption of IS/IT can help to understand why certain key elements in clinical practice have not been realized.

Through a systematic review of PACS literature on maturity, and the construction of a maturity model for PACS using a meta-analytic approach, a first step has been taken towards an integrated framework for PACS alignment and implementation. It enables hospitals to quantify PACS maturity and relate this to PACS deployment performances in the hospital enterprise. We used a qualitative meta-analysis approach for the review and analysis of 34 selected scientific papers on PACS. This meta-analytic approach allowed us to structure the PACS literature in a new way and hence provide a basis for new theorization, i.e. the proposed maturity model. In this chapter, it is actually demonstrated that PACS maturity levels can be extracted from scientific sources, and five maturity levels can be identified: 1) PACS Infrastructure 2) PACS Process 3) Clinical Process Capability 4) Integrated Managed Innovation and 5) Optimized PACS Enterprise Chain.

With the progression from one PACS maturity level to the highest level, the operational (workflow) efficiency, IT-integration, and effective and qualitative care using PACS technology expand so that process innovation and adoption within the wider ePR's and overall efficiencies in the continuum of the patient-care delivery process can be realized.

Although our definition of the five levels of PACS maturity is based on extensive literature study and analysis, in practice the five levels might not be fully exclusive or deterministic. Still, our five-level model is consistently based on a meta-analysis using a clustered process focus on communality, interrelationship and stage of maturity. Like in any type of modeling, we had to balance between recognizing the details of practice and complying the need for overview and limitation. Based on the existing body of knowledge and a rigor theoretical approach, we believe that the five levels defined for our PACS maturity model is optimal from both a scientific and practical perspective.

Several final comments can be made concerning our methodology. Although extensive, the literature search we performed concerns a single point of time (i.e. as of Winter 2007). Obviously, new literature results and insight are being published with a rapid pace. It would therefore be an interesting elaboration to perform this literature research in later years. A result might be that the model needs to be extended. Also, we did not take into account the variety in quality and impact of the queried publications. In theory, it would be possible to cluster publications into a group of influential and often referenced papers, and papers that have a low impact and reference rate. Doing so, it can explored whether weighting of the reviewed papers change the results of this study.

A third and final discussion point concerns the structuring and replication of our qualitative meta-analysis, including the literature review and maturity model construction. In order to formalize the analyses we executed during all steps, one can think of explicitly modeling these, and associated deliverables through – for instance – using a method engineering approach [182].

To the best of our knowledge, this study is the first of its kind to review the maturity and evolvability concepts of PACS within hospitals and turn these into a maturity model. The proposed model is valuable for researchers as well as consultants and medical practitioners. It can be applied as a valuable tool for organizational assessments, monitoring and benchmarking purposes. Hence, the proposed PACS maturity model (PMM) contributes to an integral alignment model for PACS technology. By assessment of hospitals with the PMM, the model can be empirically validated. This results in data that can be used for benchmarking purposes. It should be noted, however, that the PMM does not provide a roadmap or blueprint on how to evolve through the levels of maturity.

For this purpose, further research is required in order to explore what is needed to actually evolve through the different maturity levels. For each maturity level and the transformation from a certain level to the next one, a set of measurements can be defined. Although this is not elaborated in this study, we suggest to organize these measurements into projects that take into account the risks involved, investment costs, critical success factors and benefits. In addition, an alignment perspective [81] can be applied in managing similarities, overlap and synergy between the improvement projects.

As an example, our maturity model defines that improvements in operational efficiencies, IT-integration and effective and qualitative care can be achieved by integrating PACS within an ePR (see Figure 4-2, maturity level 4: integrated managed innovation). This can be organized accordingly by a multidisciplinary project team that take into account both technological and organizational implications of such an improvement step. A framework that elaborates such a practical and multidisciplinary alignment approach for PACS deployment is currently under investigation.

5

EVOLUTIONISTIC OR REVOLUTIONARY PATHS? A PACS MATURITY MODEL FOR STRATEGIC SITUATIONAL PLANNING

While many hospitals are re-evaluating their current PACS, few have a mature strategy for PACS deployment. Furthermore, strategies for implementation, strategic and situational planning methods for the evolution of PACS maturity are scarce in the scientific literature. Consequently, in this chapter we propose a strategic planning method for PACS deployment. This method builds upon a PACS Maturity Model (PMM), based on the elaboration of the strategic alignment concept and the maturity growth path concept previously developed in the PACS domain. First we review the literature on strategic planning for information systems and information technology and PACS maturity. Secondly, the PMM is extended by applying four different strategic perspectives of the Strategic Alignment Model whereupon two types of growth paths (evolutionistic and revolutionary) are applied that focus on a roadmap for PMM. This roadmap builds a path to get from one level of maturity and evolve to the next. An extended method for PACS strategic planning is developed. This method defines eight distinctive strategies for PACS strategic situational planning that allow decision-makers in hospitals to decide which approach best suits their hospitals' current situation and future ambition and what in principle is needed to evolve through the different maturity levels. The proposed method allows hospitals to strategically plan for PACS maturation. It is situational in that the required investments and activities depend on the alignment between the hospital strategy and the selected growth path. The inclusion of both strategic alignment and maturity growth path concepts make the planning method rigorous, and provide a framework for further empirical research and clinical practice.[1]

5.1 INTRODUCTION

The first PACS was introduced more than two decades ago to reduce reliance on film-based radiology departments [21]. PACS has since become an integrated component of today's healthcare delivery system [22]. The introduction of PACS within hospital practice has significantly changed the working practices of radiologist and end-users of the system [183, 184]. Achieving this type of filmless environment with PACS is a high-cost venture, however [32].

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[1] This work was originally published as: Van de Wetering, R., Batenburg, R., & Lederman, R. (2010). Evolutionistic or revolutionary paths? A PACS maturity model or strategic situational planning. *International Journal of Computer Assisted Radiology and Surgery*, 5(4), 401–409.

PACS is well matured and offers customized archiving solutions and reading stations that fulfill the needs of most users [14, 30-32]. More efficient, extensive, cost-effective, scalable and vendor independent infrastructure PACS solutions have been developed, to overcome the technical and practical limitations of current operational file systems (e.g. Unix) and PACS database design [29, 185]. However, the majority of commercial PACS vendors have developed PACS specifically for radiology and need to change the structure of current systems to extend PACS towards other specialties (e.g. cardiology, dermatology, ophthalmology, surgery, haematology, pathology, neurophysiology, digestive, orthopaedics, obstetrics, gynaecology, allergology, urology and pneumology) [30, 185].

Many hospitals attempting to extend PACS beyond radiology take this as an opportunity to re-evaluate their current systems and are looking to replace their original imaging networks with state-of-the-art equipment to improve overall system performance [16]. Moreover, many hospitals who have 5-7 years of experience with PACS, are planning for major upgrades or have already migrated to a new PACS vendor [28].

This upgrade development is driven by the current volume of imaging data produced by modalities like CTs and MRs that have major impact on the common architecture. The selection of a (new) PACS vendor should go beyond purely financial considerations [186] and be based on a deliberate consideration concerning project responsibility, compatibility, standardization, ease of upgrading and updating, as well as service and maintenance [187].

However, in the vendor selection and purchasing strategy process often important criteria such as detailed specification and descriptions of operational functionality, project documentation and adequate specificity in the contract are forgotten [188].

PACS directly affects patient care, (clinical) workflow and clinical effectiveness [23]. As the importance of imaging technology and the radiology practice grows and evolves, the importance of strategic direction and preparation for the future are becoming more significant [27].

In practice, we see that a strategic planning approach towards PACS and PACS (re)deployment is lacking, both in hospital board rooms and in the literature. There are case study examples about the implementation of PACS and the conversion to digital imaging [6, 127]. The Baltimore VA Medical Centre for instance, is such a well-documented PACS implementation case. It describes the implementation process over the years and the subsequent maturation and evolvability of the PACS into a larger healthcare imaging system and ePR from the beginning [20, 31, 189]. The strategic alignment between PACS and the hospital enterprise is not addressed, however, nor is the strategy process behind the PACS deployment and its critical conditions. Most contributions in the domain of strategic plans for PACS solely elaborate on the transition from a non-PACS environment towards a fully digital radiology and diagnostic imaging environment [31, 46, 47]. While the parts concerning the operational planning of a PACS are addressed, the strategic/situational investment and activity steps required to evolve from the current system implementation (as-is) towards a higher level of maturity are not.

Given the above, the main objective of this chapter is to develop a method for hospitals that enables the strategic planning of PACS deployment. The method put forward is based on the elaboration of the PACS Maturity Model (PMM) [43] through the strategic alignment concept and the maturity growth path concept. By combining both concepts we propose a framework and method for the alignment of PACS development and hospital strategy that is more likely to be achieved in practice. This framework can be used for both further empirical research and practical application.

5.2 THE PACS MATURITY MODEL

Several maturity models have been developed to measure, plan and monitor the evolution of IS/IT in organizations. Within this field Nolan and Gibson [54, 55] are considered the founders of the IS/IT stage-based maturity perspective, that has been further extended by others [57, 58]. Examples of maturity models are the Capability Maturity Model for software development [49], the Supply Chain Management Maturity Models [60], the Business Process Orientation Maturity Model [61], the Maturity model for interoperability in digital government and so on.

For PACS, Van de Wetering and Batenburg developed the PMM [43]. Based on a literature review of 34 scientific papers on PACS development and a subsequent meta-analysis, they found three general streams in PACS maturity and evolution: (1) radiological and hospital-wide process improvements, (2) integration optimization and innovation and (3) Enterprise PACS and the electronic Patient Record (ePR). From this, they defined five levels of PACS maturity that hospital enterprises can achieve:

- Level 1: PACS Infrastructure;
- Level 2: PACS Process;
- Level 3: Clinical Process Capability;
- Level 4: Integrated Managed Innovation;
- Level 5: Optimized Enterprise PACS Chain.

These PACS maturity levels are defined by their increasing process focus. With the progression towards maturity level 5, operational (workflow) efficiencies, IS/IT-integration and qualitative care using PACS technology expand. Additionally, the level of retrieving more timely and accurate information for clinicians, physicians and hospital management increase as well. At the highest levels, processes are effectively redesigned and underlying clinical processes and workflows are optimized, supported by the integration of PACS within a larger hospital enterprise (strategy) and the ePR. It is at the optimized enterprise PACS chain level where PACS is fully integrated into the ePR, that PACS can be maximized for efficiency purposes and clinical effectiveness.

The PMM is a descriptive, partly normative model that is, as of now, not explicitly developed as a guideline for strategic planning, nor is it made situational for different factors and conditions. Although the model can be interpreted as a straightforward (i.e. sequential) accumulation of PACS investments, it is not defined which steps need to be taken to cross-maturity levels. Also, the development through the maturity model might differ in pace, and in the ‘optimal’ cross-cutting route. Both shortcomings will be addressed in the next two sections.

5.2.1 EXTENDING THE PMM: STRATEGIC ALIGNMENT

Strategic alignment is a central element of strategic planning, the process by which organizations develop and deploy a competitive, long-term strategy in which internal resources are integrated into external opportunities. The process for strategic IS/IT planning has been first addressed by King and Cleland [78]. They suggest that the highest level of ‘sophistication for strategic planning for information systems’ should meet three criteria: (1) it should incorporate processes for relating IS strategy to the existing business strategy of the enterprise, such that a significant change in business strategy would require a significant change in IS strategy, (2) it should explicitly incorporate processes for assessing the existing and planned IS resources of the organization with the objectives of identifying potentially useful changes in the business strategy, tactics, or the processes that they may support, and (3) it should govern information and information systems as a strategic resource or competitive weapon, and explicitly involves processes for the identification of opportunities for the use of the information resource [190].

As of now, the common term for strategic alignment is business/IT-alignment, a broad and widely used concept that aims to optimize the organizational benefits from IS/IT at the strategic and operational level, as well as the mutual adaptation of the business and IT domain [52].

Undoubtedly the most cited concept in the field is the Strategic Alignment Model (SAM) by Henderson and Venkatraman [44], and extended by others [80]. The SAM was driven by the difficulty of many organizations during the nineties to create value from investments in IS/IT because of the lack of alignment between the business and IT strategy. The authors claim that a dynamic process is needed to ensure continuous alignment between the business and IS/IT domains, to achieve ‘strategic fit’ as well as ’functional integration’. This is illustrated in Figure 5-1, which shows the linkages between four quadrants that emerge from combining the business and IT domain on the one hand, and the external (i.e. strategic) and internal (i.e. operational) domain on the other.

The quadrants of the SAM can be connected in several ways, illustrated by four different strategic perspectives or paths. Each path describes a perspective that addresses the two linkages (strategic fit and functional integration) to realize business/IT-alignment. Plans and actions based on the four perspectives should envision strategic alignment by applying the ‘one that fits best’ of the four perspectives, each with its own starting point (anchor), mean (pivot) and effect domain (target) [191]. These perspectives differ by the path they define to ‘walk’ over the alignment model. Henderson and Venkatraman [44] stress that neither of these perspectives is superior to one another: “*If they were, it would not be strategic because all firms would adopt it*” (p. 482). The key in really creating a competitive advantage therefore lies in choosing the right perspective for the right situation.

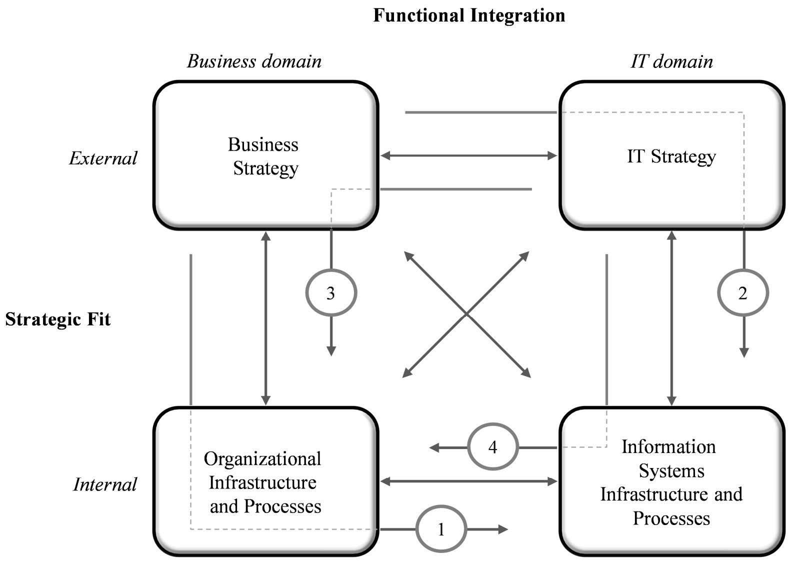

Fig. 5-1 The SAM

If we apply the SAM and the four distinct perspectives by Henderson and Venkatraman to the PMM as described above, the following can be derived:

1. The first perspective (path “1” in Figure 5-1) is labeled by the authors as the *Strategy Execution* perspective. Business strategy is the main driver for all organizational and IT infrastructural choices. This perspective defines the role of top management (business) as the strategy formulator and IT management’s role is that of strategy implementer. The IT function is primarily seen as a cost/-service center for the organizational processes and infrastructure. Applied to the PACS domain, this perspective implies that investments and innovation are restricted by budgets that are defined by the hospital board. The hospital board might develop strategic actions that touch the role of PACS within the organization, but most likely the maturation of PACS as such is not prioritized. In this perspective, PACS is a typical ‘supportive’ or ‘key operational application’ [52].

2. The second perspective (path “2” in Figure 5-1), is the *Technology Potential* perspective. Here the business strategy is explicitly aligned with the IT strategy in order to support the chosen business strategy with the accompanying specification of the required IS infrastructure, systems configuration and processes for system development and maintenance. An organization that follows this perspective seeks technology leadership to differentiate from its competitors. IT is seen as imperative to support the business, but the business is still leading on a strategic level. In this perspective, PACS can become part of strategic considerations if the hospital board aims to innovate and integrate the organization from a process perspective taking into account the scope of PACS within the hospital enterprise and system competences that better support existing business strategy.

3. *Competitive Potential* is the third perspective (path “3” in Figure 5-1). As in the previous approach, business and IT strategy are aligned, but now the top management views IT as the primary catalyst (driver) for changing the organization. This approach allows IT to change the business based on new technologies and opportunities, while the business still decides which technologies to implement. PACS can be such an IT-driver with ‘competitive potential’ (or: high potential) but this obviously requires top management support and explicit investments within the hospital enterprise. PACS needs to be internally positioned in such a way that it can actually drive chain optimization and thereby influencing the distinctive competences of the business strategy.

4. The fourth and last perspective (path “4” in Figure 5-1) is the *Service Level* perspective. Here the aim is to reach a world class IT service organization ensuring effective deployment and optimal use of IT resources and be optimally responsive to the demands of end-users. The IT strategy leads the internal design of the IT infrastructure and subsequently the organizational processes. In contrast with the other perspectives, the role of business strategy drive is indirect. In this approach, the maturation and deployment of PACS can be leading too. In contrast to the Competitive Potential perspective, alignment with the hospital strategy is less important. This implies that PACS can be deployed as a direct driver for operational processes and/or change.

In overview, the four perspectives describe four types of alignment between the business and IT domain. Two perspectives (Technology Potential and Competitive Potential) are based on a strategic fit between business and IT, meaning that it will depend crucially on the strategic agenda and support of senior management if PACS is to be matured to the highest levels. The other two perspectives (Strategy Execution and Service Level) are based on functional integration, meaning that PACS can either be leading or following within the hospital enterprise (i.e. high potential or bound to maturation).

5.2.2 EXTENDING THE PMM: GROWTH PATHS

In section “The PACS maturity model”, we referred to several stage-based maturity models, including the PMM. After extending this model with four different perspectives on strategic alignment (that actually condition the PMM), this section focuses on a roadmap for PMM, that is, how to get from one level of maturity and evolve to the next [57]. While organizations tend to evolve from one stage to the next, some organization take strategic leaps and evolve to higher levels of development [59]. Gluck et al. [65] indicate that formal strategic planning does indeed evolve along similar lines and phases among different organizations, with accompanying effectiveness of strategic decision making. This maturity process takes place at varying rates of progress and is different for each organization operating in a different market, see also [66].

As was shown in “The PACS maturity model”, the PMM assumes that levels have a sequential, accumulated, relationship with each other. The next question is obviously how hospitals actually realize this maturation and evolvability in terms of steps and accompanied actions, to reach a higher level of maturity. This requires detailed investment planning focused on realizing transitions in practice.

Growth paths can be considered as an extended method for the management of transitions that are needed to evolve through the PACS maturity levels. As outlined by the previous section, growth and evolvability requires strategic vision and planning. Synthesizing from literature on the underlying premises of PACS, case studies and practical experiences of hospitals with PACS deployment, we believe that two main growth paths can be gleaned:

A. *Evolutionistic growth paths*: evolutionistic growth paths (or: plateau planning) develop logically in stages. These stages follow one another based on predefined objectives and goals. Each of the PACS maturity levels is a precursor for the next level, so that the structures on which the current PACS rest undergo little change with movement to the next level. Thus, the evolutionistic growth path is defined as going from PACS maturity level 1 to Level 2, from 2 to level 3 and so on (as indicated in Figure 5-2 with small arrows). Such an evolutionistic growth path should not be interchanged with the evolutionary concept [67]. Evolutionary concepts focus more on mechanisms and processes by which changes occur and new characteristics of entities come into being, resulting in a new states of equilibrium [see also 192]. The evolutionistic approach follows the philosophy of total and continuous quality management in which incremental process improvement is achieved [193, 194].

B. *Revolutionary growth paths*: revolutionary growth paths take a more radical approach in that it takes strategic ‘leaps’ in order to evolve to higher levels of PACS maturity (see Figure 5-2). Such a path introduces a radical change and process focus for the hospital and does not follow the logic of monotonous sequential development, i.e. that stages follow one another by definition.

> Rather revolutionary paths take leaps to higher maturity levels skipping intermediary maturity levels [59]. It requires strategic deliberation to implement such radical process changes. These paths follow the ideology of Business Process Reengineering and Business Process Innovation that had high impacts in previous decades [194, 195]. Revolutionary does not mean however, that the intermediary levels (and their associated elements and deployment activities) are not addressed in a strategic plan. For instance, the transition from maturity level 2 to level 5 is revolutionary in that it ‘leaps’ over the intermediary maturity levels, but still requires that all the matured levels are addressed, either in aggregate or specifically.

Since hospital strategic planning processes are formed on the basis of internal, external, market-driven and non-market-driven components [118], they are thus situational. Activities for each growth path to realize a specified maturity transition are likewise conditional on given situations such as the given PACS’s state of maturity and the specified strategic alignment direction. In other words, specified growth paths depend on what is required to realize transition towards higher levels of PACS maturity. In our view, a desired maturity level cannot be achieved without conscientiously governing and addressing all process focused elements with inevitable investments and deployment activities at each of the intermediary maturity levels. This does not favor either an evolutionistic or revolutionary growth path (or a combination), it does, however, imply that careful consideration is required when choosing a strategic direction. Hence, growth paths capture an important dimension of strategic planning for PACS.

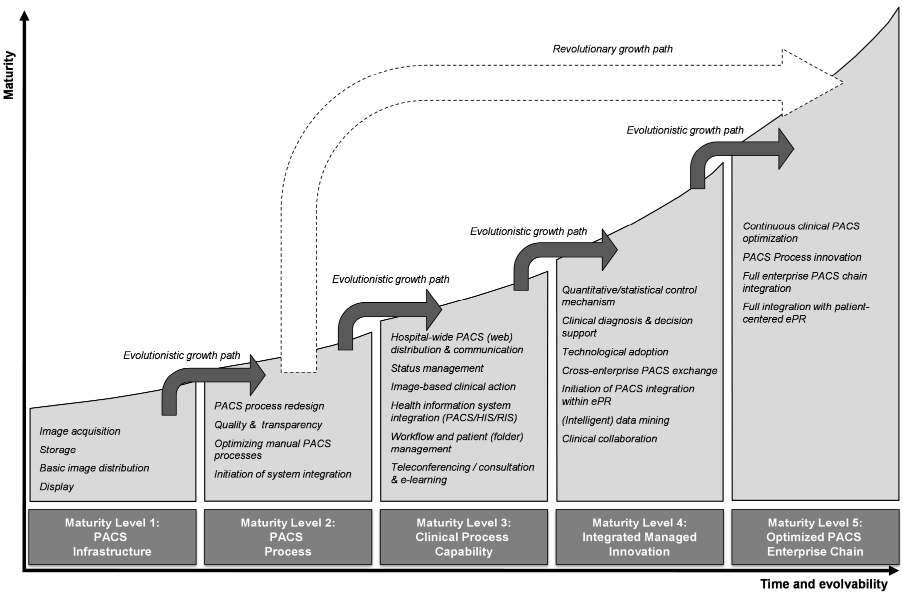

Fig. 5-2 Situational growth paths for PACS maturity

5.3 TOWARDS A SITUATIONAL AND STRATEGIC PLANNING METHOD FOR PACS

Now that we have described the concepts of strategic alignment and roadmaps as extensions of the PMM, the next step is to elucidate these into a strategic planning method for PACS.

We define eight strategies that are based on the combination of the ‘four’ original perspectives that envision strategic alignment (strategy execution, technology potential, competitive potential and service level) with two types of growth paths (evolutionistic and revolutionary). These eight strategies build the decision space: an extended method for PACS strategic planning.

The eight strategies are summarized in Table 5-1. The table serves as a decision framework for decision-makers in order to choose a strategic direction and deploy PACS towards a desired level of maturity.

The distinctive strategies defined by the framework incorporate the triangular construct of the strategic alignment model. It encompasses the three quadrants of the strategic alignment model, and addresses the principles of strategic fit and functional integration simultaneously. This first enables decision-makers to select a clear strategic direction, by taking the business or the IT domain as the anchor point. Secondly, decision makers are guided to decide how to travel in this direction (the growth path), given the hospital resources and competencies. This decision is more internally and operationally oriented.

In order to differentiate between the strategic perspectives and being able to select the growth path that best meets a hospitals’ current and future needs, we suggest the following 3 steps to be taken:

1. Assess the current maturity state of PACS and also a “to-be” situation should be determined using the PMM involving multiple stakeholders (e.g. radiologists, management, technologists, referring physicians, etc.).

2. Second is a fit-gap analysis that determines whether the current maturity level is either a precursor for the “to-be” situation, or the desired maturity level ‘leaps’ over intermediary stages. At this stage it needs to be decided whether the growth path follows an incremental improvement process (evolutionistic), radical changes (revolutionary) or a hybrid combination of the two. In terms of strategy, this decision implies if hospital structure and PACS process focus and/or persist on the previous chosen path by retaining current strategies and structures.

3. A third step is deciding which of the four strategic approaches best suits the current hospitals’ situation and future ambition in order to realize strategic alignment, and translate these in terms of steps and accompanied actions.

	Growth paths	
Strategic perspectives	A) Evolutionistic	B) Revolutionary
1. Strategy execution perspective: *In this perspective the hospital strategy is the main driver for organizational processes and PACS infrastructural choices.*	**Evolutionistic strategic planning focus**: *Dealing with incremental process improvement using PACS technology.* PACS is seen as operational IS/IT in support of improvements in the hospital infrastructure. The main orientation in this perspective is on integration and operational alignment of the PACS infrastructure meeting the demands of hospital organization.	**Revolutionary strategic planning focus**: *Becoming a lean and mean hospital utilizing PACS for process innovation.* The hospital board is the strategy formulator, while PACS implements that strategy in order to improve hospital infrastructure and processes. Processes are redesigned and extended beyond radiology and the hospital enterprise requiring new PACS infrastructure capabilities. This usually results in changes to the PACS architecture.
2. **Technology potential**: *This perspective focuses on how PACS technology can be included into the IT strategy and subsequently the IT infrastructure and processes.*	**Evolutionistic strategic planning focus**: *Extending current vision on optimal usage of PACS technology within the hospital.* Driven by hospital strategy, this method focuses on the added value of PACS aiming at a reliable PACS infrastructure as the impacted domain. Imperative is step-wise integration of PACS and other medical IS/IT.	**Revolutionary strategic planning focus**: *Revising current vision in terms of scale and functionality of PACS.* The PACS infrastructure is based on a top management technology vision on doing hospital operations. PACS competencies might come from (outside the usually chosen paths and focus on adapting new technologies (e.g. image post-processing programs).
3. **Competitive potential**: *This perspective has a focus on turning PACS technology into leading technology, that can directly drive*	**Evolutionistic strategic planning focus**: *Creating awareness and consolidating PACS as a catalyst in changing the hospital.*	**Revolutionary strategic planning focus**: *Changing strategy and operations using new technologies and developments.*

and enable new hospital strategies	The hospital board views PACS as a catalyst in changing hospital strategy. Within the evolutionistic growth path, focus is on hospital business deciding which PACS technologies and developments to implement on an operational level to support clinical processes and come competitive with PACS operations.	This focus concedes PACS to change the hospital strategy, i.e. to become the best-in-class PACS hospital. A revolutionary method enables new strategic directions focusing on expansion, new services (to other hospitals) and becoming more distinctive/competitive in terms of agile PACS and digital radiology operations.
4. **Service Level**: *The perspective focuses on how to achieve a new IT strategy for PACS improvements that can optimize in organizational processes as patient care, quality, and new services.*	**Evolutionistic strategic planning focus**: *Optimizing current PACS services to meet (end)user demands and needs.* From the evolutionistic perspective hospitals PACS is matured to meet (end)user demands and use technological advancements. The role of PACS is to support key areas of the hospital operations and balance short-term objectives with long-term investments. This is primarily achieved through building upon existing SLAs with PACS vendors to improve current service levels.	**Revolutionary strategic planning focus**: *Adopting new PACS technology to fulfill requirements in hospital operations.* By including PACS within the hospital IT strategy, it aims to change the PACS infrastructure and processes to be organized accordingly. This implies optimal fulfillment (e.g. everything on-line, imaging data always and everywhere available, simultaneous availability of old images, instant image retrieval). Hospitals go beyond current vendor contracts to achieve objectives and PACS strategy.

Table 5-1 Eight strategic planning methods for PACS Maturity[2]

[2] Note that the proposed planning strategies are situational applicable and that there are considerable variations of the entries possible.

Both the ‘Technology Potential’ and ‘Competitive Potential’ strategy (that are both based on a strategic fit between business and IT) depend on the strategic agenda and support of senior management. Pursuing the *Technology Potential* strategy (triangular construct) to reach a desired level of maturity fits best if the hospital – driven by hospital strategy – is aiming for a more reliable and extended PACS infrastructure as the primary impacted domain. Following the *Competitive Potential* strategy on the other hand, is more effective when the hospital board views PACS as a catalyst (i.e. leading technology) in changing hospital strategy. This fits with the ambition to become more efficient on operational levels within the hospital enterprise and beyond, e.g. by enabling cross-enterprise document sharing for medical images between chain partners.

Both the Strategy execution and Service level strategies are based on functional integration, meaning that PACS can either be ‘leading’ or ‘following’ within the maturing process. The *Strategy Execution* strategy is applicable if the hospital wants achieve operational alignment of the PACS infrastructure meeting the demands of hospital board as a strategy formulator. As a consequence hospital strategy is the main driver for optimizing organizational processes and associated PACS infrastructural choices. The *Service Level* strategy (triangular construct) is more appropriate in realizing strategic alignment when PACS is primarily deployed to meet (end)user demands and needs and support key areas of the hospital operations. This implies that new PACS technology is acquired in order to fulfill operational requirements in the hospital. For instance, if radiologists want long-term archived CT-studies to be retrieved within seconds, this yields that a new data storage solutions, configuration and infrastructure are required.

In practice, hospitals will define their own roadmap evolutionary, revolutionary or both as a hybrid strategy. Based on the above considerations each strategic roadmap defines improvement projects that can be executed according to the triangular construct within the SAM. Both the alignment and fit approach that build the model imply that multi-disciplinary teams are formed consisting of physicians, technologists and engineers, to deliver (tactical and operational level) the agreed objectives [15]. Consecutively, actions and results should be monitored using project management methods. Basically, evolving towards a higher level of PACS maturity includes critically reflecting on the chosen path while maintaining continuous alignment between the business and IS/IT domains.

5.4 DISCUSSION AND CONCLUSION

Achieving optimal usage of PACS in hospitals seems a long, complex and poorly examined process. Thus, a method for hospitals that enables the strategic planning of PACS is very valuable. In this chapter we propose a strategic planning method towards PACS deployment, based on the application of the strategic alignment concept, and the maturity growth path concept on the PACS domain. This extends the current PMM [43] and defines strategic planning from an integrated and situational perspective. The framework and method provides a practical application for decision-makers for setting goals, critically reflecting on the current PACS systems and evolving towards higher levels of PACS maturity.

Although the proposed framework currently includes five maturity levels of the PMM, this does not implicate that strategic developments will come to a standstill after hospitals have reached the optimized PACS enterprise chain level. On the contrary – as the medical imaging field matures and expands to include imaging throughout the enterprise chain, developments and disruptive innovations continue to emerge. Examples are the application of serial advanced technology attachment, data grid architecture development, cloud computing, scalable distributed server environment and service oriented architecture [196]. Considerable challenges in terms of integration, co-operation and collaboration are at stake for hospital enterprises in the development towards shared diagnostic data repositories on regional and national levels, containing longitudinal patient records with diagnostic images and reports [157].

One needs to take into account that hospital boards tend to define their strategy, growth paths and roadmaps based on their short and long-term needs. As a consequence, hospitals are driven in daily practice by external, market-driven and non-market-driven factors, leading to emerging and sometimes opportunistic strategic planning. In retrospect, the maturation of PACS might than be classified of evolutionary or revolutionary nature. In our view, applying the concept of strategic planning is valuable to any hospital that is willing to (re-)evaluate their PACS investments and the overall system performance. Through the use of the proposed framework, strategic planning by alignment is more likely to be achieved in practice.

Stage-based theories are often criticized for being over-simplistic with regard to the assumed set of consistent (i.e. sequential) stages [67, 68]. In this case, we extended the PMM by bringing in strategic alignment and situational growth paths. We demonstrate that both levels of maturity and growth paths are interrelated, avoiding the linearity pitfall of most stage-based models.

To the best of our knowledge, this study is the first in applying the concept of strategic planning for PACS maturity. It outlines what in principle is needed to evolve through the different maturity levels and what the considerations are at each level. It contributes to an integral alignment model for PACS technology by further specifying PMM with strategic planning methods.

Despite its attractiveness our developed framework has several limitations. Obviously, applying our strategic planning method to a number of hospital cases is needed to validate it and to allow for critical reflection. Furthermore, a specific validation opportunity concerns the application of certain growth paths and strategic perspectives and how this is related to clinical performance within the hospital. What also is not addressed in this study, is how hospitals can truly align PACS on a given maturity level and how to account for optimal diffusion within the organization. A suggested method may be validation by expert sessions, for instance. These matters are currently under investigation. We expect that our method can likewise be used to describe and reconstruct any hospital PACS case.

In this chapter, we argued that the framework is situational. It provides four different routes to achieve business/IT-alignment that are dependent on the strategic direction of the hospital. Next, the two ‘operational’ routes, expressed as both evolutionistic and revolutionary growth paths, are also to be aligned with the context of hospital strategies [118]. To conclude, we expect that the inclusion of both strategic alignment and maturity growth path concepts make strategic planning PACS planning in hospitals rigorous. The framework developed is therefore designed for further empirical research and clinical practice application.

Part III:

Complexity perspective for PACS maturity and multifactorial PACS performance implications

6

A SITUATIONAL ALIGNMENT FRAMEWORK FOR PACS

This chapter reports outcomes of a study on an integrated situational alignment framework for PACS labeled as: PISA. Following the design research cycle, complementary validation methods and pilot cases were used to assess the proposed framework and its operationalized survey. In this chapter, the authors outline (a) the process of the framework' development, (b) the validation process with its underlying iterative steps, (c) the outcomes of pilot cases, and (d) improvement opportunities to refine and further validate the PISA framework. Results of this study support empirical application of the framework to hospital enterprises in order to gain insights into their PACS maturity and alignment. We argue that the framework can be applied as a valuable tool for assessments, monitoring and benchmarking purposes and strategic PACS planning[1].

6.1 INTRODUCTION

As investments in healthcare are generally large and mission critical in case of medical imaging technology, the need for structured implementation, measurement approaches and holistic evaluation methods is expanding [14, 15, 40]. The fact that hospitals around the world are re-evaluating their PACS implementations reflects this demand [16]. PACS are workflow-integrated imaging systems that are designed to streamline operations throughout the entire patient-care delivery process and have become an integrated component of today's healthcare delivery system [22]. However, hospitals have often failed to achieve necessary productivity levels and operational efficiencies (e.g. reduction of costs, productivity increase, and optimization of patient episode throughput time) using PACS, even though pursuing a full filmless environment using PACS is a high-cost venture [32].

Currently, hospitals have a tendency toward re-evaluating implemented radiology systems to overcome technical and practical limitations of operational file systems and deployed PACS database design [29, 185]. More efficient, extensive, cost-effective, and vendor-independent infrastructure PACS solutions are available to hospitals. This re-evaluation process is also driven by the current volumes of imaging data produced by advanced modalities like CTs and MRs that have major impact on the common

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Information System and Information Technology (IS/IT) architecture. This poses serious challenges in terms of storing growing amounts of data, cross enterprise document sharing, protecting patient information [197] and general alignment with evolving technologies and disruptive innovations such as the application of serial advanced technology attachment, data grid architecture development, cloud computing, scalable distributed server environment, and service-oriented architectures [196]. In doing so, hospitals are planning for major updates and even large-scale replacements trajectories to other PACS vendors in overcoming technical, practical limitations and improve overall system performance [16, 29].

Due to the above developments and growth of the radiology practice, the importance of strategic and prospective directions is becoming more urgent [27]. In practice, strategic planning approaches towards imaging technology, PACS, and PACS (re)deployment are lacking, both in hospital board rooms as well as in scientific literature. This makes it difficult to harmonize or 'align' PACS goals, objectives, and improvement activities with the hospital's strategic agenda. Achieving optimal alignment of PACS and pursuing its intended goals and objectives within the hospital enterprise, seems an intricate and poorly examined process and lacks scientific grounds.

Digital radiology (management) systems are difficult to evaluate due its evolving nature, the high number of involved departments and professionals and hard to define patient outcomes [198]. Earlier, Van de Wetering et al. [40] argued that theories on business/IT-alignment, organizational fit and adoption of IS/IT can help to understand why certain key elements in clinical practice have not been realized. A method that supports the process of optimally aligning PACS and defines the synergetic effects within hospital operations will be very valuable. However, this method has not been developed, empirically applied, and validated yet.

In developing such a method, the current study combines an existing model on PACS maturity (i.e. continuous system evolvability process from immature stages of growth/maturity towards another level) [43], with the concept of business/IT-alignment (i.e. investments made in organizational domains related to PACS should be balanced out in the organization in order to obtain synergizing benefits) [44, 81]. From this, the first objective is to develop a framework and associated survey to empirically assess a hospital's current PACS maturity and alignment regarding different strategic directions. The second goal is to systematically examine the applicability of this framework and instrument and attentively explore its implications in terms of maturity and alignment on PACS performance at two different pilot hospitals in the Netherlands. Based on the responses from these pilot hospitals, improvements will be made to the PACS integrated situational alignment (PISA) framework and related survey.

The remainder of this chapter is outlined as follows: We will first review a synthesized model to measure levels of PACS maturity and subsequently address principles of business/IT-alignment, and review concepts of PACS performance. Subsequently, a first version of the PISA framework is proposed. 'Methods and Material' section discusses applied validation methods, after which results are presented. Several framework improvements are presented, after which the PISA framework is completed. Finally, the chapter concludes with a brief discussion on the implications of this study, identifies inherent limitations, sets out a research agenda and sets out main conclusions.

6.2 DEFINING FRAMEWORK CONSTRUCTS

6.2.1 PACS MATURITY CONCEPTS

Theories on IS/IT maturity and adoption are well established in business and IS/IT literature, going back to the early 1970's. The concept of the IS/IT maturity stage hypothesis was introduced by Nolan [55] in 1973. Later on, this model was extended, frequently discussed, and adapted [57]. In general, IS/IT maturity models provide insight into the structure of elements that represent process effectiveness of IS/IT in organizations. They also allow organizations to define roadmaps on how to get from one level of maturity and evolve to the next [57]. Recently, a specific PACS Maturity Model (PMM) [43] was developed that describes PACS maturity and evolvability in the hospital enterprise. Based on a literature review of 34 scientific papers on PACS development and a subsequent meta-analysis, the PMM was built upon three general streams in PACS maturity and evolution: (1) radiological and hospital-wide process improvements, (2) integration optimization and innovation, and (3) enterprise PACS and the electronic Patient Record (ePR). From this, the model defines five cumulative levels of PACS maturity that hospital enterprises can achieve:

- Level 1: PACS Infrastructure;
- Level 2: PACS Process;
- Level 3: Clinical Process Capability;
- Level 4: Integrated Managed Innovation;
- Level 5: Optimized Enterprise PACS Chain.

With the progress toward the top maturity level 5 operational (workflow) efficiency, IS/IT integration and qualitative care using PACS technology increases. Although the PMM model can be interpreted as a straightforward (i.e. sequential) accumulation of PACS investments, it does not explicitly define mechanisms on how hospitals can actually move from one maturity level to another. For developing a PACS alignment framework, however, the PMM serves as a foundation for its underlying body of knowledge and rigorous theoretical approach including the concept of business/IT-alignment.

6.2.2 CONCEPTS ON BUSINESS/IT-ALIGNMENT

The concept of 'strategic' alignment – also called 'fit' [76] – is a major concern for executives and IT practitioners for decades and refers to applying IS/IT in an appropriate and timely way, in harmony (i.e. complementarity between activities) with business strategies, goals, and needs [77]. It is a central element of strategic planning, the process by which organizations develop and deploy a competitive, long-term strategy in which internal resources are integrated into external opportunities [78].

The classic Strategic Alignment Model (SAM) of Henderson and Venkatraman [44] is undoubtedly the most cited concept in the field and extended by others [80]. Their model argues that a dynamic process is needed to ensure continuous alignment between business and IS/IT domains, to achieve ‘strategic fit’ as well as ’functional integration’. The model does, however, have its limitations. For instance, relations in the model are not operationalized, nor clearly defined [81]. Subsequently, Turban et al. [199] developed – and extended – the model for business/IT-alignment containing new mutual relations among business dimensions that are assumed to contribute to the successful implementation and adoption of IS/IT. Better known as the MIT90’s framework, a descendant of Leavitt’s diamond, another alignment model, was developed based on the idea of internal ‘fit’ as a dynamic equilibrium of five key organizational dimensions and external fit as strategy formulation based on environmental trends and changes in the market place using IT as an enabler.

Many studies since then have used concepts that are incorporated in the MIT90 framework and its model. Thus, it is not surprising that recent alignment models have strong similarities. A shortcoming of most alignment models, however, is that they do not explicate how the dimensions of the model interact with and depend on each other. This shortcoming was addressed by Scheper [81] among others. Scheper starts by defining five organizational dimensions:

I. *Strategy and policy (S&P)*: organization of strategy and policy procedures;
II. *Organization and processes (O&P)*: addresses processes as a basic principle for organizational development;
III. *Monitoring and control (M&C)*: financial and non-financial management control;
IV. *Information technology (IT)*; concerns IT management and development processes;
V. *People and culture (P&C)*: reflects value and significance of employees for an organization.

Different from most other alignment models, Scheper subsequently developed levels of maturity in measuring the development stage for each of the five dimensions, creating a multidimensional maturity matrix (cf. Sledgianowski et al. [84] for an equivalent approach). Next, he claims that alignment can be directly measured by comparing the maturity levels of all five dimensions at the same time. His alignment principle is based on the idea that organizations can mature each single dimension, but only equalization among all dimensions (i.e. alignment) will significantly improve organizations’ performances.

6.2.3 MULTIFACTORIAL PACS PERFORMANCE

Evaluation methods have proven valuable in the past in order to assess consequences of changing the traditional film-based practice to digital (radiological) workflow [34]. Since then, several scholars argue that enterprise-PACS benefits should be evaluated from different perspectives [15].

As there are many interrelated steps between PACS usage and eventual patient outcome, the imaging workflow chain and sub steps that affect the quality of imaging services and clinical outcomes are imperative to the evaluation of PACS [19]. Based on the wider adoption of technology acceptance models and levels of clinical efficacy [200, 201], we define PACS performance as the multifactorial impacts and benefits produced by the application of PACS. This is expressed in terms of hospital efficiency and clinical effectiveness with respect to PACS workflow and the patients' clinical journey. For the purpose of this study, we adopted the outcomes of a meta-analytic approach that has synthesized original PACS sources on PACS performance and balanced evaluation models [40, 48]. Based on a total of 37 papers published between 2000 and 2009 that were included for review purposes in this approach (after applying several inclusion criteria having retrieved 980 key publications and positioning papers), four performance constructs are defined. These constructs were subsequently translated into measurements that are representative elements for the maturity performance measurement of PACS.

Defined by its 'multifactorial' nature, these constructs includes measures that are available for the assessment of PACS in hospitals and can be applied to assess impacts of PACS, from (a) technical information systems perspective, (b) organizational efficiency, (c) service outcomes, and (d) clinical contribution. Appendix III includes all adopted PACS measures. These measures are adopted into our framework since they are valuable for empirical research and likewise relevant for radiology practice.

6.2.4 PISA FRAMEWORK

From the previous sections, our PISA framework combines the two pillars (1) *PACS maturity* (i.e. classifying PACS systems according to their stage of development and evolutionary plateau of process improvement) and (2) *alignment* (i.e. investments made in organizational dimension related to PACS should be balanced out in the organization in order to obtain synergizing benefits) and claims that both affect PACS performance of the hospital enterprise. Figure 6-1 provides a schematic sketch of our framework and depicts PACS maturity on the horizontal axis and organizational dimensions on the vertical axis. Of the two pillars, alignment is often the least defined one (if at all) and is often suggested as important without guidelines for practice. In our framework, we explicitly define alignment as the degree of leveling between five organizational dimensions described in section 6.2.2 [81]. I.e. alignment is measured as the degree to which the five dimensions are distinctive with regard to their maturity levels as previously defined by the PMM (see section 6.2.1). Hence, alignment can be expressed within Figure 6-1 as a line connecting all five (horizontal) organizational dimensions (the figure also displays two 'possible' scenarios of alignment among dimension on a low and high level of maturity for demonstrative purposes). Next, the framework claims that the degree of alignment and synergetic mechanisms between the several organizational dimensions (i.e. independent variable) is directly and positively related to PACS performance (i.e. dependent variable).

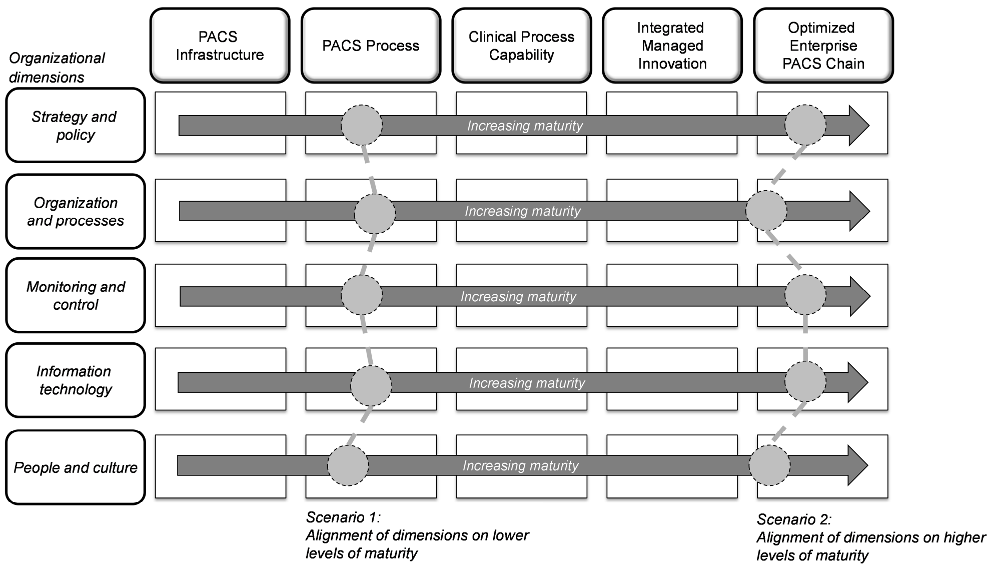

Fig. 6-1 PISA framework

6.3 METHODS AND MATERIAL

6.3.1 FRAMEWORK DEVELOPMENT PROCESS

A project team[2] applied an incremental development process that follows the design science methodology. In this approach, knowledge is produced by constructing and evaluating artifacts which are subsequently used as input for a better awareness of the problem [202]. To ensure quality and validity of the developed measurement instrument, we applied complementary validation methods. Guidelines were used when building the artifacts [202], securing their face and content validity, performing extensive pre-tests, and executing pilot cases at two different hospitals. Figure 6-2 provides an overview of the five interrelated process steps that were conducted, using a process delivery diagram [203].

[2] The project team consists of two professors and an associate professor of organization and information and business/IT-alignment and a PACS/medical informatics researcher.

During the *first step* the project team reviewed literature on PACS maturity and alignment and created common ground concerning the research topic. Based on this review and the project teams' own field experience, key concepts were developed. In *step 2* these key topics were critically reviewed by two recognized PACS experts (a professor of radiology and head of a radiology department). These experts provided the project team with feedback, input, and advice on key concepts in diagnostic imaging and general radiology practices. Taking these valuable suggestions into account, an initial survey was created – *step three* – which was subsequently discussed with industry consultants and a PACS R&D manager during a focus group meeting. A result of this focus group was a technical architecture of each of the PACS maturity stages of the framework that was helpful in redefining technical aspect in the survey (this architecture is available upon request). The initial survey contained 28 statements – four statements for each organizational dimension (i.e. independent variable) and eight for PACS performances (i.e. dependent variable).

Starting *step 4*, two PACS experts once again reviewed each item of this initial construct and commented on applied scales, significance and importance of each item for PACS maturity and alignment. Also, both experts evaluated the PACS maturity and alignment level of their own hospital. Outcomes suggested some extensions of the survey. All input was transformed into individual validation sessions ('Delphi method') with three radiologists, a neurologist, a technologist, and medical informatics researcher. These sessions were used to evaluate the structure of the constructed framework and comment on the specified PACS topics and features of the operationalized survey. Using the 'talk-aloud protocol' experts articulated their thoughts and considerations as they filled in the survey. These six experts (representing four hospitals and four different economical geographical areas in the Netherlands) were recruited using personal and professional networks. Outcomes were used to improve our survey statements on validity (i.e. do the incorporated survey items measure what they are supposed to measure), reliability (i.e. is each question posed correctly and can radiologist, technologists, and PACS administrators address them), and empirical application (e.g. size of survey and tooling). Results were discussed within the project team. The survey was extended to a total of 45 statements, covering most intersections of the five horizontal axes (i.e. organizational dimensions), and the five vertical axis (i.e. PACS maturity levels). Per organizational dimension, the items were formulated according to a cumulative order, i.e. that of 'increasing complexity' along the maturity scale.

The results of the two pilots are described in section 6.4.3 of this chapter (the piloted survey items are presented in Appendix IV). *Step 5* is the conclusion, i.e. the final questionnaire as a result of the complete validation of the framework.

6.3.2 PILOT SITES

In the spring of 2010, two Dutch hospitals with different characteristics were selected (see Table 6-1) to participate as a pilot case. The two hospitals were known within the field as actively involved in optimizing their PACS deployment. As such, the pilot could focus on applying the framework for the first time on two ‘advanced hospitals’. This provides good opportunities to improve the contents of the survey and improve the clarity of the statements, if necessary.

	Number of beds	Yearly exams	Capacity of radiologist (FTE)	PACS vendor	Experience with PACS (years)
Hospital A	360	78146	4.5	Care-stream	6
Hospital B	900	200000	12.5	Agfa	5.5

Table 6-1 Background characteristics of pilot sites

Per hospital two radiologists (including head of department), head of radiological technologists and a PACS administrator completed an online survey within a secured web-environment. These informants appear to be the most familiar with the subject of PACS maturity and performance, making intra-institutional validity likely.

Including multiple stakeholders from the radiology department also reduces common source variance associated with sampling from the same source [77, 204], excluding face validity issues. The respondents completed the survey separately, in order to avoid systematic bias and any peer pressure to give particular answers. It took the eight respondents approximately 20-25 minutes to complete the survey. Comparing the individual results within each hospital allowed us to measure levels of agreement between the respondents.

The applied 7-point Likert scale for each statement consisted of the classic values strongly disagree’, ‘disagree’, ‘somewhat disagree’, ‘neutral’, ‘somewhat agree’, ‘agree’ and ‘strongly agree’. This scale is typically used for subjective performance evaluation. It is applicable for balanced assessments rather than objective measurements. In general, outcomes of assessments in complex areas as medical processes are often qualitative and hence rely on subjective perceptions of clinicians rather than on quantitative statistics [172]. All statements were phrased in present tense, but respondents were asked to provide answers for both the current and future/preferred situation of their hospital.

Next to the items measuring PACS maturity as defined by our PISA framework, the survey also contained some general questions (e.g. name, function, years of experience using PACS, etc.). PACS performance finally was measured using 13 performance statements on how well PACS contributes to efficiency and effectiveness (see section 6.4.1).

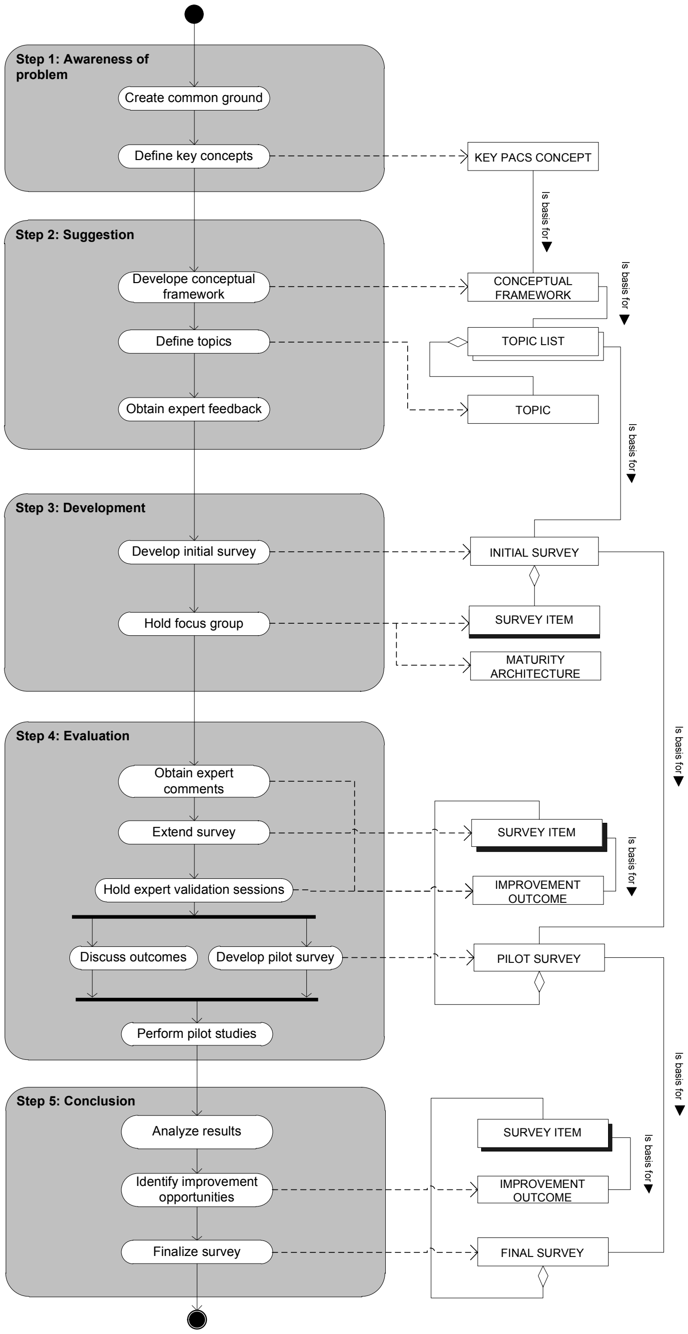

Fig. 6-2 Framework development process

6.4 RESULTS

6.4.1 DATA AND MEASUREMENT

Analysis of the data from the 8 completed pilot questionnaires was performed in two steps. First, the results were analyzed by comparing the descriptive statistics for both hospitals. The mean as well as standard deviation (SD) and median (*M*) of all maturity items were computed for the two hospitals. First, we assume that there is low variation in scores per maturity level and organization dimension, indicating that there is a level of agreement between the 4 respondents of each hospital. Secondly, we assume for both hospitals that there is a decreasing mean score for each next maturity level per organizational dimension, confirming the cumulative order (‘difficulty’) of the maturity items as defined by the PISA framework. Table 6-2 sets out the results for each question (*Q*), where *Q1* and *Q2* are the two statements per maturity level (ML).

Based on the descriptives in Table 6-2 several remarks can be made. Regarding the mean scores per hospital, most statements comply with the assumed cumulative order, i.e. mean scores decrease with higher maturity levels for each organizational dimension. There are a few exceptions, however; these items are in ‘bold’. For instance, item Q2 of maturity level 4 related to “strategy and policy” has an unexpected high mean score (6.38), deviating from the premise that the mean score at lower maturity levels would be higher as these items are less ‘difficult’ to agree with for hospitals.

Likewise, item Q2 of maturity level 3 related to “organization and processes” has a lower mean score than assumed, i.e. items at higher maturity levels of this dimension show higher instead of lower mean scores. These deviations are in fact violations of our accumulation assumption, but also provide essential improvement opportunities. In same vein, we analyzed the scores on the PACS performance items for both hospitals. PACS performance was measured through 13 questions that address the perceived benefits of PACS application in the respondents’ hospital. Table 6-3 shows the results. Based on comments of the respondents and the descriptive statistics, some remarks can be made.

It appears during the pilot that for hospital B, that questions *C1* and *C4* could only be answered by radiologists, making them apparent radiologist specific. Also, statement *C2* has a relatively ‘too high’ mean and median score accompanied by a low SD, suggesting that the scale of this item needed modification.

Organizational dimension 1: strategy and policy							
	Hospital A		Hospital B		All pilot respondents		
	Mean	SD	Mean	SD	Mean	SD	*M*
Maturity level 3 Q1	4.50	1.29	3.25	1.26	**3.88**	1.36	3.50
Maturity level 3 Q2	3.75	1.50	4.25	0.96	4.00	1.20	3.50
Maturity level 4 Q1	4.25	0.96	3.00	1.83	3.63	1.51	4.00
Maturity level 4 Q2	6.75	0.50	6.00	1.41	**6.38**	1.06	7.00
Maturity level 5 Q1	3.50	1.00	4.50	2.52	4.00	1.85	4.00
Maturity level 5 Q2	3.75	1.89	3.00	0.82	3.38	1.41	3.50
Organizational dimension 2: organization and processes							
	Hospital A		Hospital B		All pilot respondents		
	Mean	SD	Mean	SD	Mean	SD	*M*
Maturity level 3 Q1	4.50	2.38	3.50	1.73	4.00	2.00	4.50
Maturity level 3 Q2	2.00	0.82	1.25	0.50	**1.63**	0.74	1.50
Maturity level 4 Q1	1.50	0.58	3.75	0.50	2.63	1.30	2.50
Maturity level 4 Q2	5.25	1.50	5.50	0.58	**5.38**	1.06	5.50
Maturity level 5 Q1	1.25	0.50	1.00	0.00	1.13	0.35	1.00
Maturity level 5 Q2	4.75	1.71	4.50	1.73	**4.63**	1.60	5.00
Organizational dimension 3: monitoring and control							
	Hospital A		Hospital B		All pilot respondents		
	Mean	SD	Mean	SD	Mean	SD	*M*
Maturity level 3 Q1	4.00	0.82	3.75	1.71	3.88	1.25	4.00
Maturity level 3 Q2	3.50	1.00	3.25	0.96	3.38	0.92	4.00
Maturity level 4 Q1	4.67	1.15	2.25	1.26	3.29	1.70	4.00
Maturity level 4 Q2	2.75	1.50	3.75	1.26	3.25	1.39	4.00
Maturity level 5 Q1	4.75	0.96	3.25	2.22	4.00	1.77	4.00
Maturity level 5 Q2	3.75	1.26	4.00	1.83	3.88	1.46	4.00
Organizational dimension 4: information technology							
	Hospital A		Hospital B		All pilot respondents		
	Mean	SD	Mean	SD	Mean	SD	*M*
Maturity level 3 Q1	5.25	0.50	5.75	1.26	5.50	0.93	5.50
Maturity level 3 Q2	5.50	1.29	4.75	2.63	5.13	1.96	5.50
Maturity level 4 Q1	4.75	0.96	5.50	1.00	5.13	0.99	5.50
Maturity level 4 Q2	5.50	1.00	2.75	2.06	4.13	2.10	5.00
Maturity level 5 Q1	5.00	1.00	5.00	0.82	**5.00**	0.82	5.00
Maturity level 5 Q2	3.50	1.29	3.50	1.91	3.50	1.51	3.50
Organizational dimension 5: people and culture							
	Hospital A		Hospital B		All pilot respondents		
	Mean	SD	Mean	SD	Mean	SD	*M*
Maturity level 3 Q1	3.00	1.41	4.25	2.22	3.63	1.85	4.00
Maturity level 3 Q1	4.50	1.00	2.50	1.29	3.50	1.51	3.50
Maturity level 4 Q2	3.25	1.71	5.00	2.00	4.13	1.96	4.50
Maturity level 4 Q2	3.25	1.26	4.75	1.89	4.00	1.69	4.00
Maturity level 5 Q1	4.25	0.96	5.00	0.82	**4.63**	0.92	5.00
Maturity level 5 Q2	3.00	1.83	5.00	1.41	4.00	1.85	4.50

Table 6-2: Descriptive statistics

Besides evaluation by analysis of the hospital descriptive statistics, all eight respondents commented on the items and provided suggestions for their elaboration and modification. In general, the respondents of the pilot concluded that the survey was useful, easy to interpret, and a valuable tool for further PACS development in their hospital.

	Hospital A			Hospital B			All pilot respondents		
	Mean	S.D.	M.	Mean	S.D.	M.	Mean	S.D.	M.
Clinical contribution									
C1	5.50	1.29	5.50	4.50	0.00	4.50	5.17	1.17	5.00
C2	6.25	0.50	6.00	7.00	0.00	7.00	**6.63**	**0.52**	7.00
C3	4.33	2.08	5.00	5.25	1.71	5.50	4.86	1.77	5.00
C4	5.33	0.58	5.00	6.50	0.00	6.50	5.80	0.84	6.00
Organizational efficiency									
O1	4.75	0.96	4.50	5.00	0.00	5.00	4.86	0.69	5.00
O2	3.00	1.41	3.00	6.33	0.58	6.00	5.00	2.00	6.00
Service construct									
S1	4.50	1.00	5.00	6.00	0.00	6.00	5.25	1.04	5.50
S2	5.25	0.50	5.00	2.25	0.96	2.50	3.75	1.75	4.00
S3	5.25	0.50	5.00	5.75	0.50	6.00	5.50	0.53	5.50
S4	6.00	0.00	6.00	5.75	0.50	6.00	5.86	0.38	6.00
Technical Information System									
T1	4.50	1.91	4.00	5.25	2.87	6.50	4.88	2.30	5.50
T2	5.50	1.29	5.50	6.50	0.58	6.50	6.00	1.07	6.00
T3	5.50	1.29	5.50	5.00	0.82	5.00	5.25	1.04	5.00

Table 6-3: PACS performance descriptives[3]

6.4.2 INSTRUMENT REFINEMENT

By critically considering the results of the pilot statistics, including the comments and recommendations of the respondents, we modified several survey statements. Table 6-4 lists the modifications proposed after the pilot studies.

Number	Dimension	Type of modification	Impact on model
1	Strategy and policy	ML3Q1 was interchanged with ML4Q2 based on perceived complexity. In its new position ML4Q2 was reworded following recommendations of the respondents	Better fit of model and ordered complexity
2	Organization and processes	ML5Q2 was interchanged with ML3Q2 based on perceived complexity of the statement	Better fit of model and ordered complexity
3	Organization and processes	Statement ML4Q2 was reworded to fit the complexity of maturity level 4 based on comments of one of the respondents	Statement ML4Q2 better fits maturity level 4 and follows increased complexity
4	Information technology	Statement ML5Q1 was reworded to fit the complexity of maturity level 5	Statement ML5Q1 better fits maturity level 5 and follows increased complexity
5	People and culture	Statement ML5Q1 was reworded to fit the complexity of maturity level 5	Statement ML5Q1 better fits maturity level 5 and follows increased complexity
6	PACS performance	Answer categories of performance metric C2 (see Appendix IV) have been rescaled	Results in better distribution of scores

Table 6-4: Survey modifications

[3] Productivity was calculated using the total amount of exams (and specified per modality) divided by the total capacity (i.e. FTE radiologists).

From the mean 'modified' and 'old' scores of statements for each separate maturity level – see Figure 6-3 – it can be gleaned that the modified survey statements were successfully ordered by PACS maturity, i.e. hierarchical order.

6.4.3 MEASURING PACS MATURITY AND ALIGNMENT

After the maturity items and measurements are evaluated, the next step is to examine how PACS 'alignment' can be measured. As suggested earlier by our PISA framework, we recall that alignment can be indicated by the differences between the maturity scores on the five organizational dimensions. Hence, overall maturity scores for each of the five organizational dimensions were calculated. To adjust the survey design in which we defined subsequent maturity items, an algorithm was constructed in such a way that it captures this principle of accumulating maturity.

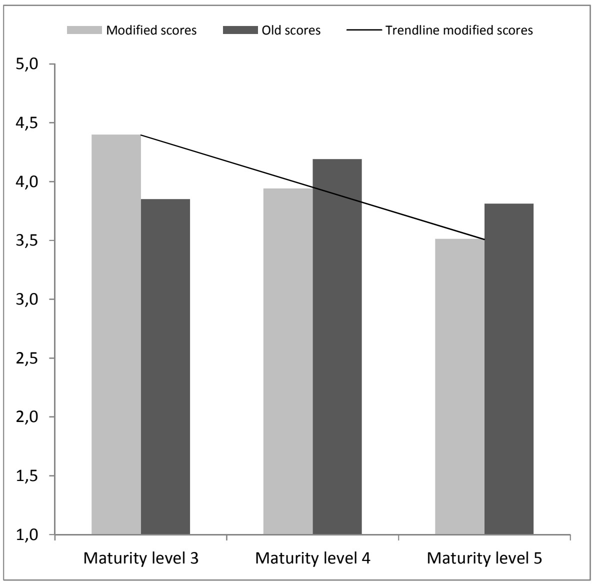

Fig. 6-3 Mean scores per PACS maturity level

This algorithm includes the following assumptions:

1. Mean scores (ranging from 1 to 7) were used in order to calculate scores for each organizational dimension (i) for maturity levels 3-5: $\mu_{i3\text{-}5}$.
2. PACS maturity levels (λ) were assigned points, λ_3=200, λ_4=300 and λ_5 =400. Thus, each λ has a total range of 100 points.
3. A mean score of 4 – on the applied Likert scale – was used as a threshold (T). A mean per statement of ≥4 confirms the specified λ to which the statement is assigned to. A mean of <4 confirms that the preceding λ is more applicable.

4. Because we defined a T at 4 on our Likert scale, the remaining score space for both scores ≥4 (i.e. $7 - T$) and <4 (i.e. $T - 1$) is applied in the calculation of maturity, represented by γ.

Using the above assumptions, the following three-step algorithm was applied to each organizational dimension:

I. **if** $\mu_{i3} \geq 4$; **then** $(\mu_{i3} - T) \times (100/\gamma) + \lambda_3$; **else** $((\mu_{i3} - 1)/\gamma) \times \lambda_3 \rightarrow \pi_{i3}$

II. **if** $\mu_{i4} \geq 4$; **then** $(\mu_4 - T) \times (100/\gamma) + \lambda_4$; **else** **{ if** $((\mu_{i4} - 1)/\gamma) \times \lambda_4 \leq \pi_{i3}$; **then** π_{i3}; **else** $((\mu_{i4} - 1)/\gamma) \times \lambda \rightarrow \pi_{i4}$ **}**

III. **if** $\mu_{i5} \geq 4$; **then** $(\mu_5 - T) \times (100/\gamma) + \lambda_5$; **else** **{ if** $((\mu_{i5} - 1)/\gamma) \times \lambda_5 \leq \pi_{i4}$; **then** $(\pi_{i3} + \pi_{i4})/2$; **else** $((\mu_{i5} - 1)/ \gamma) \times \lambda_5 \rightarrow \pi_{i5}$ **}**

The PACS maturity scores ($\pi_{i3\text{-}5}$) calculated following this algorithm were then normalized and summed, weighing their contribution to the overall PACS maturity (see Figure 6-4).

Now that we have created monotonous cumulating maturity scales for each organization dimensions, we next define the overall alignment measure (α). There are different methods possible to calculate the differences between the maturity scores of the five organizational dimensions. In this study, we applied the difference between the maximum and minimum maturity scores of the five dimensions as measure [85]. The ‘smaller’ this difference, the ‘better’ the alignment between the dimensions (see Table 6-5). An alternative for the alignment measurement is calculation of the standard deviation between the five dimensional maturity scores, or selecting the minimum score (as the ‘weakest link’). In practice, these alternative measurements for alignment strongly correlate with our initial ‘min–max’ measurement.

Table 6-5 shows the final and aggregated PACS maturity and alignment scores for both hospitals, including the mean score for PACS performance (β). Comparing these means allows us to explore the claim that high PACS alignment coincides with high PACS performance. Obviously this can only be done attentively, as we only have data on two hospitals.

Hospital	S&P	O&P	M&C	IT	P&C	α	β
A (as-is)	308	229	317	344	273	115	5.1
B (as-is)	294	270	266	333	349	83	5.5
A (to-be)	381	358	376	389	363	31	-
B (to-be)	399	406	393	409	386	23	-

Table 6-5: PACS maturity and alignment scores

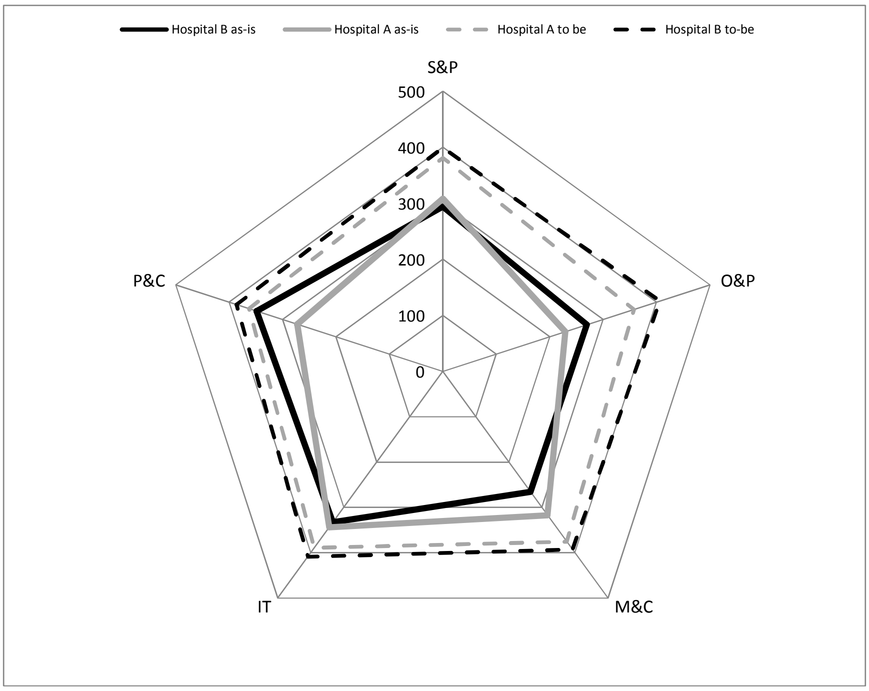

Fig.6-4: PACS maturity and alignment scores

From Table 6-5 can be concluded that hospital B has a relatively lower α-score than hospital A, which implies that its PACS alignment (i.e. degree of alignment and synergetic mechanisms between the several organizational dimensions) is better. Also hospital B has a higher β score than A implying better PACS performance. While hospital A especially has lower maturity scores on O&P and P&C, hospital B has deficiencies in the M&C dimension. Hence, for hospital A the gap between IT and O&P is to be closed to reach optimal alignment (represented by the solid gray line in Figure 6-4). Likewise, optimal alignment for hospital B is inhibited by the distance between the scores on the P&C and M&C dimensions. Items related to O&P have moderately low maturity scores, whereas the IT dimension demonstrates relative higher maturity in both hospitals. This seems to resemble a (current) strong technology focus that might hinder a balanced perspective also taking operational/organizational efficiencies into account.

In doing our pilot, we also collected qualitative information to evaluate our PISA framework and underlying concepts/expectations. From interviews, it became clear that both hospitals currently have a predominant ‘local’ (departmental) focus on PACS, rather than aiming at aligning PACS operations hospital-wide and beyond hospital boundaries. The following excerpt from a respondent from hospital B clarifies this view:

> *"Our hospital has a clear local orientation towards operations with respect to PACS. Strategy and policy on a regional, cross-enterprise level is currently missing...."*

Also, the outcomes of this pilot suggest that both hospitals have improvement opportunities on several organizational dimensions. Our PISA framework supports hospitals to define specified investments that will improve PACS maturity and alignment.

6.4.4 APPLICATION IN PRACTICE

Now that we have described basic concepts of PACS maturity and alignment, the next step is to glean some common and practical guidelines for PACS that will support hospital decision makers in deciding how to travel in a certain direction (i.e. mature PACS), given the hospital' specific resources and competencies and current system infrastructure.

Hospital strategic planning processes are formed on the basis of internal, external, market-driven and non-market-driven components [118] (i.e. they are thus situational). Improvement activities to realize a PACS maturity transition are likewise conditional on given situations such as the given PACS's state of maturity and the specified strategic alignment direction. Thus, PACS maturity and alignment improvement programs depend on what is required to realize transition toward higher levels of PACS maturity. As such, we believe that desired maturity levels cannot be achieved without conscientiously governing and addressing all process focused elements and deployment activities at each of the intermediary maturity levels. This implies that careful consideration is required when toward a certain maturity level.

In order to define specified improvement activities – with accompanying investments – that can be executed along the five organizational dimensions that best meets a hospitals' current and future needs, we suggest the following steps to be taken:

- As a first step, assess the maturity, alignment, and performance state of the current deployed PACS ("as-is") and also a "to-be" situation should be determined using the PACS maturity model – and survey – involving multiple stakeholders (e.g. radiologists, technologists and PACS administrator, etc.).

- A second step concerns performing a fit-gap analysis in determining if the current PACS maturity level is either a precursor for the to-be situation or the desired maturity level 'leaps' over intermediary stages. Hence, at this stage, decision makers need to be decided whether the improvement roadmap follows an incremental improvement process (stages follow one another by definition), radical changes (i.e. introducing radical changes to processes and not following the logic of monotonous sequential development), or a hybrid combination of the two. This decision implies - in terms of strategic direction - if the hospital structure and PACS process focus and/or persist on a previously chosen paths by retaining current strategies and structures.

- In the third and final step, we suggest to set out all improvement activities and make deliberate investments that are required in order to achieve the desired level of PACS maturity and alignment. For this purpose, a set of measurements can be defined which are organized into projects that take into account the risks involved, investment costs, critical success factors, and benefits. In the course of the execution of all (hospital-wide) activities, the level of alignment between the five organizational dimensions should monitored in managing similarities, overlap, and synergy between the improvement projects in order to realize strategic objectives and optimal deployment of PACS.

In practice, hospitals define their own improvement roadmaps incrementally, radical or both as a strategy. Based on the above steps and accompanying considerations, each optimization roadmap defines improvement projects that can be executed according to the five organizational dimensions. Both the alignment and fit approach that build the model imply that multi-disciplinary teams should be formed to deliver (on tactical and operational levels) the agreed objectives [15]. Consecutively, actions and results should be monitored using project management methods. Basically, evolving toward a higher level of PACS maturity includes critically reflecting on the chosen path (i.e. direction) while continuously maintaining alignment between the business and IS/IT dimensions and improve overall PACS performance.

6.5 DISCUSSION

Motivated by what appears to be an intricate process on which scientific sources seem scarce, this paper proposes an integrated situational framework that allows hospitals to empirically assess PACS maturity and alignment. By explicitly addressing a hierarchical order (‘increasing complexity’) of survey items along the maturity scale, communality, and interrelationship of stages of maturity, this study avoided common pitfalls in business/IT-alignment survey instruments and case research. Our study provided initial support for the basic claim that alignment and performance in the PACS domain coincide, thus enabling practical mechanisms for decision makers for setting goals, critically reflecting on current systems and strategically plan toward higher levels of PACS maturity and alignment.

In spite of its enticement, our framework has several limitations that suggest caution is required with the interpretation of the findings. First, this study was based on only two hospitals. This inhibits generalizability of key results. However, by restricting the scope of the study, we were able to get an in-depth view of both hospitals’ operations. Second, this study did not provide any “best-practices” that other hospitals can benefit from nor does it provide extensive handles for comprehensive strategic planning to obtain optimum PACS performance. Since both studied hospitals differ in their respective PACS maturity and alignment scores, this could imply that the PISA framework may elucidate best-practices. Finally, there is a need to develop a more robust measure of maturity and alignment. The applied calculation may have inherent biases since it was partly based on a rule-based algorithm.

The above limitations suggest avenues for further research. First, it is our ambition to validate the PISA framework in a representative group of Dutch hospitals. This allows the project team to examine extreme (high or low) scores and their respective impact on PACS performance by applying conventional analytical techniques, path analysis, and structural equation modeling to verify construct validity, factor reliability and overall goodness-of-fit of the model. Second, the underlying mechanisms through which PACS performance is achieved are by no means comprehensible. Therefore, additional research is required to identify interaction effects – co-alignment [76] – of (latent)variables connecting maturity and alignment to PACS performance.

6.6 CONCLUSIONS

We argue that better PACS performance can be achieved by explicitly aligning maturity scores on each of the five organizational dimensions, done simultaneously and hence by an integrated management perspective. The PISA framework demonstrates promising results and outcomes of this study support empirical application of the framework to hospital enterprises in order to gain insights into their PACS maturity and alignment. In practice, the PISA framework appears as a useful checklist to systematically identify the improvement areas for hospitals in the PACS domain and is designed for further empirical research and clinical practice application.

7

USING STRUCTURAL EQUATION MODELING TO ASSESS AN INTEGRATIVE PACS PERFORMANCE MODEL: COMPLEXITY IMPLICATIONS IN ACHIEVING MULTIFACTORIAL PACS PERFORMANCE

Owing to the large financial investments that go along with complex PACS deployments and the inconsistent outcomes of PACS performance evaluations, there is a pressing need for a better understanding of the implications of PACS deployment in hospitals. We claim that there is a gap in the research field, both theoretically and empirically, to describe and explain the success of PACS deployment and maturity in hospitals.

The first objective is to develop a holistic perspective on PACS performance by enriching the concept of IT maturity and business/IT-alignment with systems and complexity theory. From this perspective, an integral hypothesis is generated.

The second objective is to statistically test this hypothesis (and thereby our holistic perspective) by applying Structural Equation Modeling (SEM) using data collected from 64 hospitals. Third, the objective is to set out some general strategic guidelines to optimize PACS deployment and maturity. These three objectives all contribute to the scientific literature on strategic and situational planning and the practical evolution of PACS maturity in hospitals.

As a basis, theoretical principles relevant to PACS performance, maturity and alignment are reviewed from a system and complexity perspective. A conceptual model to explain PACS performance and a set of testable hypotheses are then developed. Then, SEM, i.e. causal modeling, is applied to validate the model and hypotheses based on a research sample of 64 hospitals that use PACS, i.e. 70% of all hospitals in the Netherlands. SEM is applied as a statistical method to simultaneously assess the validity of all measurement variables (i.e. manifest constructs) and all latent variables (i.e. higher-order constructs).

The outcomes of the SEM analyses substantiate that the measurements of all constructs are reliable and valid. PACS alignment – modeled as a higher-order construct of five complementary organizational dimensions and maturity levels – has a significant positive impact on PACS performance. This result is robust and stable for various sub-samples and segments.

This chapter presents a conceptual model that explains how alignment in deploying PACS in hospitals is positively related to the perceived performance of PACS. The model is based on the principles of complexity and system theory to gain deeper insights into the concepts of PACS maturity and alignment.

The conceptual model seems to be valid and, therefore, is extended with tools as checklists to systematically identify the improvement areas for hospitals in the PACS domain. The holistic approach towards PACS alignment and maturity provides a framework for clinical practice.

7.1 INTRODUCTION

After nearly 30 years of PACS technology development and evolution, the PACS has become an integrated component of today's healthcare delivery system, integrating many interrelated Information Systems and Information Technology (IS/IT) components into medical imaging practice [17]. PACS, as a solution for radiology practice and hospital operations, offers customized archiving solutions and reading stations that fulfill the needs of most users [14, 31, 32]. Nowadays, more extensive and efficient, cost-effective, scalable and vendor-independent infrastructure PACS solutions have been developed, overcoming the inherent technical and practical limitations of earlier PACS deployments [29]. At the same time, many hospitals are strategically planning and preparing for future radiology needs [27] by re-evaluating their radiology systems and looking to replace (or upgrade) their original imaging networks with state-of-the-art equipment to improve overall system performance [16, 28].

A trend towards system evaluation using appropriate models and techniques heightens the prospect of greater accountability and system success in hospitals [40]. As such, effective implementation and evolvability strategies are required for the successful adoption and maturation of PACS and that requires a broader scope than just an implementation strategy focused on technological considerations. Organizational and human factors and the involvement of key actors in the process are the principal factors for successful adoption [42].

In this respect, evaluation methods have proven valuable to assess the impacts of PACS on (radiological) workflow [34, 35, 38], although it has been argued that PACS benefits for hospitals should be evaluated from different angles and that the inclusion of clinical and not-for-profit goals make evaluations more relevant [40]. Since imaging workflow chains and the associated sub-steps that affect the quality of imaging services and clinical outcomes are imperative, as are the criteria to be applied to the evaluation of systems [19, 20], studies using different evaluation angles and stakeholders are becoming more common [14, 15, 41].

Still, little scientific knowledge is available about the mechanisms that govern PACS performance and deployment success in hospitals. Owing to the large financial expenses that go along with PACS, there is a pressing need for models or frameworks that are adequate to rigorously assess and evaluate the performance of PACS, so that future strategic plans and investments can be better informed. Finding the key determinants of PACS performance is essential to develop these types of models, but this has been a conundrum for many years. At the same time, there are many opportunities to use theories and perspectives from the field of information systems research, which has had a long and specific focus on exploring what is often called the 'critical success factors' of IS/IT in organizations.

One such opportunity is to apply complementarity and organizational alignment principles to PACS evaluation [43, 45]. The concept of complementarity factors and synergizing effects has gained considerable attention in recent years in IS/IT research

and other interdisciplinary fields [73, 74]. The key notion is that specific activities in organizations are complements if doing (more of) any one of them increases the returns to doing (more of) the others. This idea is already important in medical and diagnostic practice, and it might be of specific use in understanding and optimizing (enterprise-wide) PACS performance (e.g. productivity, workflow optimization, etc.).
Complexity theory and Complex Adaptive Systems (CAS) theory [88-90] both address co-evolutionary concepts, self-organized emergent behavior and the structure of systems. These theories can serve as another contribution to the analysis and understanding of PACS performance in hospitals. They contribute to a 'holistic' approach that fits with the complex nature of enterprise-wide PACS and the complexity of hospitals as complex organizational systems of medical practice.

We aim to build upon the existing research and related work in the field of PACS deployment. As such, we will use the PACS Maturity Model (PMM) [43, 45], which includes a number of ideas from the IS/IT field, as a starting point. This model includes a checklist for evolving onto the next level of maturity [49]. This model departs from the notion that PACS deployment is a stepwise process, from an immature stage of growth/maturity towards the next maturity level. From this, it is assumed that the deployment and adoption process of PACS is cumulative. As modeled by the PMM, a hospital sequentially and necessarily evolves through different levels of maturity before PACS is successfully implemented and optimum PACS performance can be achieved. As we will argue in this chapter, the PMM can be enriched with other theories into a conceptual model that is both extended *and* sparse enough to explain and understand PACS performance variations in hospitals.

The main goal of this study is to develop an integrative model to empirically assess, on the one hand, the maturity and organizational alignment of PACS, and, on the other hand, their impact on PACS performance. This implies that performance is defined as having multifactorial impacts and benefits, as produced by the application of PACS in terms of hospital efficiency (and service) and clinical effectiveness. With respect to workflow and patients' clinical journeys [48], PACS can be assessed as a system designed to improve and govern operations throughout the patient care delivery system, including significant contributions in terms of patient throughput and initiating earlier (image-based) clinical action. We depart from the notion that theories from the IS/IT field provide new perspectives to understand how key elements in clinical practice can be achieved using PACS [40].

The validation of the proposed conceptual model for PACS performance is essential given the intangible nature of PACS performance as the central *explanandum* at stake. In this chapter, we present how the theoretical concepts of maturity and alignment coincide with covariation (or co-alignment) [76] as an operationalized statistical scheme within Structural Equation Modeling (SEM). The empirical part of this chapter is dedicated to assessing the impact of PACS maturity and alignment on the multifactorial nature of PACS performance using primary data collected among 64 hospitals in the Netherlands. The main objective of this part of the chapter is to empirically validate the proposed integrative PACS performance model. Based on these analyses, the third and final step is to derive improvement guidelines for strategic planning and optimization plans of PACS maturity and performance within hospitals. The validated model will thereby provide a framework for clinical practice as well.

7.2 Theoretical Background

7.2.1 Starting Point: the PMM

Maturity models have been developed to measure, plan and monitor the evolution of IS/IT in various organizations and markets. Within this field, Nolan and Gibson [54] are considered the founders of the IS/IT stage-based maturity perspective, although it has been further extended by others [57, 58]. For digital radiology and PACS, Van de Wetering and Batenburg developed the PACS Maturity Model (PMM) [43]. In their study, they defined five levels of PACS maturity that hospitals can achieve:

Level 1: PACS Infrastructure;
Level 2: PACS Process;
Level 3: Clinical Process Capability;
Level 4: Integrated Managed Innovation;
Level 5: Optimized Enterprise PACS Chain.

The levels of maturity are defined by their increasing process and integration focus. With the progression towards maturity level 5, operational (workflow) efficiencies, IS/IT integration and qualitative care using PACS technology expand. At the highest levels, processes are effectively redesigned and underlying clinical processes and workflows optimized, supported by the integration of PACS within the wider hospital strategy using electronic Patient Record (ePR) and electronic Medical Record (eMR) documents.

The PMM is descriptive and partly normative and has been developed as a guideline for assessment and strategic planning. In principle, the model can be interpreted as a straightforward (i.e. sequential) accumulation of PACS investments, from which steps can be defined that are imperative to the task of crossing maturity levels. In that respect, the PMM can be used for strategic planning, incorporating growth paths towards achieving higher levels of PACS maturity [45]. An important omission of the model is, however, that the development through the maturity model might differ by organizational domains, and that maximizing maturity might not be effective or ‘optimal’ in all circumstances. In other words, the model assumes continuous growth, but it might differ in *how* this is achieved and how this contributes to PACS performance. For this reason, we involve another theoretical perspective, as shown in the next section.

7.2.2 COMPLEMENTARITY AND ALIGNMENT THEORIES

The theory of complementarity was introduced by Edgeworth, who defined activities as complements "*if doing (more of) any one of them increases the returns to doing (more of) the others"* [71]. Complementarity theory assumes that the individual elements of a strategic planning process (i.e. the variables) cannot be individually optimized to achieve a better performance [72, 73]. Consequently, the impact of a system of complementary practices will be greater than the sum of its parts because of the synergistic effects of bundling practices together. The theory's strong formal (mathematical) notion provides punctual and analytical appropriateness to frequently indefinable notions of 'fit' and 'synergy' (i.e. intuitive ideas of synergies and systems effects) among the components of organizational strategies and its operational structures [73], and it has gained considerable attention in recent years in IS/IT research and other interdisciplinary fields [73, 74].

In spite of its attractiveness, complementarity theory solely demonstrates the results of 'Edgeworth' complements (i.e. synergetic effects) and typically does not explain its synergistic effects and mechanisms beyond general descriptions of 2+2=5 [75].

In the business and strategic management literature, complementarity is often labeled as 'fit' [76] or strategic alignment. Strategic alignment refers to applying IS/IT in a structural and stable way, in harmony with business strategies, goals and needs [77]. The Strategic Alignment Model (SAM) of Henderson and Venkatraman [44] is the most cited concept within this field [77, 79, 80]. Their model implies that a systematic process is required to govern continuous alignment between business and IS/IT domains, i.e. to achieve 'strategic fit' as well as 'functional integration'. The SAM has been extended by theorists, industry and consulting [80], who have all defined 'fit' as the balance or equilibrium of different organizational dimensions and 'external fit' as strategy development that is based on environmental trends and changes.
However, the SAM is not able to monitor or measure maturity and/or performance. This was improved by Scheper [81], who extended the SAM by combining it with the MIT 90s model [82, 83] and defining five key organizational domains that are essential to be aligned: (1) Strategy and policy (S&P); (2) Organization and processes (O&P); (3) Monitoring and control (M&C); (4) Information technology (IT) and (5) People and culture (P&C). In contrast to the SAM, Scheper also defined levels of incremental maturity for each of the five domains. Hence, he claimed that alignment could be practically measured and assessed by the comparative levels of maturity on each of the five dimensions.

Important steps are set by complementarity theory, the SAM and maturity measurements for different organizational domains, which can all be used to extend the basic PMM as presented above with the concept of alignment. Still, another limitation remains because the evolving, adaptive and dynamic (i.e. emergent) nature of these domains are not addressed [89]. Probably for reasons of complexity, the co-evolutionary and emergent nature of alignment has rarely been taken into consideration in IS/IT alignment research [90]. In the same vein, the SAM and other IS/IT alignment approaches perceive and operationalize alignment as a linear (static) mechanism. This neglects the fact that mechanisms are multidirectional and that change in one organizational domain has multilevel effects on other domains. Organizational performance is, in fact, a non-linear, emergent and partly unintended outcome, which cannot be approximated by any linear form [89, 91]. Therefore, we seek another extension of the PMM and alignment concepts to overcome this omission. This is addressed in the next section.

7.2.3 Complexity and Systems Theory

The field of CAS [88-90] and complexity theory – including research on themes such as co-evolutionary concepts, self-organized emergent behavior and structure – has its roots in physics, mathematics and evolutionary biology. It is based on the fundamental logical properties of the behavior of non-linear and network feedback systems, no matter where they are found [91]. CAS are considered as collections of individual agents with the freedom to act in ways that are not always totally predictable (non-linear), and whose actions are interconnected so that one agent's actions changes the contexts for other agents. Complexity theory incorporates fundamental concepts such as phase changes, fitness landscapes, self-organization, emergence, attractors, symmetry and symmetry breaking, chaos, self-organized criticality, generative relationships and increasing returns to scale [92].

CAS theories presume that the adaptation of systems to their environments emerge from the adaptive efforts of individual agents that attempt to improve their own payoffs [93]. Commonly cited examples include financial markets, weather systems, human immune system, colonies of termites and organizations including hospitals and healthcare systems in general [88, 94-98]. CAS challenge traditional management assumptions and perspectives on organizational behavior, and the key principle of this perspective is the notion that "at any level of analysis, order within a system is an emergent property of individual interactions at a lower level of aggregation" [91]. According to Holland [95], CAS have no single governing equation or rule that controls the system, but rather many distributed interacting components and parts, with little or nothing in the way of a centralized control. Each of the parts is governed by its own rules and schemata. These rules may participate in influencing an outcome, and each may influence the actions of other parts.

Complexity theory builds upon open systems theory[1] [100, 101] and the theory of dissipative structures [102] and sets forward plausible underlying mechanisms for system change and (non-)equilibrium states. Open systems, or self-maintaining

[1] Complexity science and CAS thinking search for generative simple rules in nature that underpin complexity and do not embrace the radical holism of systems theory [105].

structures as Boulding [101] classifies them, can be characterized as systems that (in contrast to closed systems in an equilibrium state) can perform work, which is unachievable in a closed system in which no material enters or leaves for the preservation of its state nor can energy be obtained from the system [205]. For this classification of systems to work, it must not be in an equilibrium state. Fluctuations from its environment obliges an open system to preserve its equilibrium state, and negative feedback mechanisms moderate the effects of fluctuations [88]. Nonetheless, open systems have an instigation to attain such an equilibrium state [206, 207].

Boulding classified systems by arranging theoretical systems and constructs in a hierarchy of complexity [101]. Therefore, system properties at lower levels in the hierarchy are also found in those higher in the hierarchy because the latter are built on the former (i.e. heritage). As such, open systems possess all the qualities that belong to the system at a cybernetic (or self-regulated systems) level [205]. Based on the theory of dissipative structures, any open system requires energy (or entropy) from the external environment to achieve a higher-level state or to be transformed into a new form with higher complexity and more capabilities to react with increased environmental contingencies [205].

Open systems make an effort to avoid a transition into thermodynamic equilibrium (i.e. by not adapting to environmental fluctuations) by using a continuous exchange of materials and energy with the environment (i.e. maintaining a negative entropy condition). This follows Ashby's [206] key principle of systems complexity, namely that to remain viable, a system needs to generate the same degree of internal complexity as the external complexity it faces in its environment.

A number of authors have stated that complexity theory can be considered a valuable instrument to cope with organizational and IS/IT changes in non-linear turbulent environments, including healthcare [88, 91, 93, 94, 96, 98]. Both complexity science and CAS are significant to the field of information systems in that IS/IT act like CAS. Owing to the continuous processes of change and adaptation, non-linear network feedback systems and co-evolvement is at constant stake in modern organizations. As whole entities and with respect to their mutually interdependent parts, they go through a series of adaptation/re-adaptation cycles [89]. This idea applies particularly well to the organization of medical practice, including the deployment of PACS or other medical IS/IT.

Here, we use the idea of both CAS and complexity theory to provide new perspectives for dealing with the emergent nature of IS/IT in organizations [89], more specifically the dynamics of (PACS) maturity, alignment and performance in hospitals. The basic thought is that it feeds a 'holistic' or 'complex' theoretical framework that fits the diversity of organizational components and interactions among the many agents that are involved in clinical and IT practice using PACS.

We assume that, next to strategic planning, PACS deployment is also unplanned and an emergent process. Likewise, PACS maturity, alignment and performance are phenomena that evolve within the hospitals. From this perspective, PACS resembles the principle of CAS. Arguments for this assumption can also be found in several sources [92, 208]. To turn this perspective into a conceptual model, a systematic agenda is required, linking theory development with mathematical or computational model development that does not follow the concepts of equilibrium-based mathematical approaches (i.e. that rely on linearity, attractors, fixed points and the like [95, 208]).

7.3 An Integrative PACS Performance Model

Based on the previous theoretical analyses, we develop a model that combines three concepts: (1) PACS maturity as the concept to define PACS and its elements, (2) PACS alignment as the concept to complement the organizational dimensions of PACS and (3) PACS performance as the added value of PACS within hospitals.

Using the PMM as a starting point, we suggest measuring maturity and alignment (as independent variables) by the degree to which hospitals score *and* differ on five organizational dimensions (see section 7.2.2). For each of these five dimensions distinctive maturity levels have previously been defined by the PMM [81]. These accompanying maturity levels can be successively labeled for S&P3, S&P4 and S&P5; O&P3, O&P4 and O&P5; and so on. Maturity levels 1 and 2 – as defined by the PMM – are omitted for practical reasons, which will be elaborated upon in section 7.4. In addition, we define PACS performance as a multifactorial (dependent) variable to be measured in terms of hospital efficiency (i.e. organizational construct containing the I. *Patient service*, II. *End-user service* and III. *Organizational efficiency* perspectives) and clinical performance (i.e. subdivided into I. *Diagnostic efficacy* and II. *Communication efficacy*) [40, 48].

Conceptual models often do not acknowledge the importance of the rationale underlying the functional form of their constructs (dependent and independent variables) [209] and devote little attention to the nature and direction (i.e. reflective or formative) of the relationships between the constructs [210]. These specifications are of significant value, however, since they map theoretical constructs onto real-world phenomena [211]. Furthermore, applied statistical methods are not freely interchangeable without confounding underlying theoretical arguments and understanding their operationalization [76]. Blalock [212] even argues that without an auxiliary theory, the ‘mapping’ of theoretical constructs onto empirical phenomena is ambiguous, and theories cannot be meaningfully tested. It is, therefore, crucial to use theoretical grounds so that series of predictions can be developed that would not readily be suggested by common sense or alternative theories [213]. In addition, in the development of the theory – model relationship the ontological adequacy of the relationship between the model – empirical phenomena should also be accounted for [208].

Our conceptual model is of the above genre and contains higher-order (multidimensional) latent constructs within the context of simultaneous equation systems [209]. These ‘latent constructs’ cannot be observed directly because their meanings are obtained by measuring the manifest variables. In interconnecting the three key concepts of PACS maturity, PACS alignment and PACS performance, we propose a reflective construct model, through which the manifest variables are affected by the latent variables (in contrast to the formative constructs) [209, 210, 214-216]. Using both reflective and formative constructs would also potentially bias results [217]. This type of measurement underlies classical test theory, reliability estimation and factor analysis, each of which treats a measure as a function of a latent variable (i.e. construct) that is accompanied by an error term.

We apply a multistep approach using path modeling to hierarchically construct latent variables as the independent part (i.e. PACS alignment) of the conceptual model and latent variables as the dependent part (i.e. PACS performance) of the conceptual model. With regard to the independent part of the conceptual model, we define:

1. The first-order exogenous constructs as representing the different maturity levels (labeled SP3–SP5, OP3–OP5, MC3–MC5, IT3–IT5, PC3–PC5) and relate each of them to their respective manifest variables: SP3: MV_1 & MV_2; SP4: MV_3 & MV_4; SP5: MV_5 & MV_6; OP3: MV_7 & MV_8; IT4: MV_{21} & MV_{22}; etc.;
2. The second-order construct as the five organizational domains, constructed by relating the blocks of the underlying first-order latent constructs (i.e. step 1);
3. The third-order construct, labeled as PACS alignment, as related to the underlying second-order constructs (i.e. step 2).

With regard to the dependent part of the conceptual model, we define:

4. The first-order exogenous constructs (Patient service, End-user service, Organizational efficiency, Diagnostic efficacy and Communication efficacy) and relate them to their respective manifest variables as defined by [40, 48] (Patient Service: MV_{31} & MV_{32}; End-user service: MV_{33} & MV_{34}; Organizational efficiency: MV_{35}, MV_{36} & MV_{37}; Diagnostic efficacy: MV_{38}, MV_{39} & MV_{40} and Communication efficacy: MV_{41} & MV_{42});
5. The second-order constructs (Organizational construct and Clinical performance construct), as related to the block of the underlying first-order latent constructs (see step 4);
6. The third-order construct, labeled as PACS performance, as related to the underlying second-order constructs (i.e. step 5).

Based on the above, the core of the conceptual model is to investigate the relationship between PACS alignment and PACS performance given the dependent and independent variables that build both multifaceted constructs. Hence, the main hypothesis to be empirically tested by the conceptual model can be formulated as:

> *"The alignment of PACS, as represented by the multifactorial nature of five organizational domains and their related maturity levels, has a positive relationship on PACS performance, as represented by the multifactorial nature in terms of hospital efficiency and clinical effectiveness and their related items."*

As follows from step 3 above, the alignment of PACS is defined as the pattern of internal consistency among the two sets of underlying constructs. More specifically, PACS alignment is modeled as a third-order latent construct, whereas the second-order constructs represent the organizational domains to be co-aligned and the first-order constructs represent the maturity levels. This modeling of PACS alignment is statistically appropriately captured by a pattern of covariation, which coincides with the concept of (co-)alignment [76].

In conceptual model construction, the use of covariation (or co-alignment) principles is limited unless considerable attention is provided to link the articulation of the theoretical position with the appropriate operationalization schemes [76]. Our conceptual model follows the central concept of internal logic among the various dimensions, since it is in accordance with the theories of complexity and CAS outlined previously. Our conceptual model is a more parsimonious presentation of the underlying factors gleaning interdependency of complex constructs [218]. The co-alignment as covariation approach is, therefore, preferred over other common alignment schemes (e.g. leveling, gestalt, moderator, mediator, etc.) since the operationalization of their optimal profiles – with numerical scores along a set of underlying areas of resource allocations – is difficult [76, 219].

The operationalization of our conceptual model can be performed most accurately using SEM [220]. SEM (or ‘causal modeling’) is a second generation data analysis family of statistical models that seeks to explain complex relationships among multiple observable and latent constructs in models. SEM is typically used to simultaneously validate multifaceted phenomena in terms of tentative cause and effect variables, including causal effects. In doing so, it simultaneously examines the measurement model (factor model or outer model) and the structural model (inner model or path model) [221, 222].

Basically, the SEM family can be divided into covariance-based SEM (CBSEM; i.e. hard modeling with heavy data distribution assumptions) [220] and partial least squares (PLS) SEM, which is introduced as NIPALS (Non-linear iterative PLS) modeling [223], i.e. soft modeling (or component-based SEM) with fewer data distribution assumptions [224]. PLS is a member of the class of generalized inverse approaches to regression. Unlike CBSEM, which emphasizes and reproduces the observed covariance matrix using a maximum likelihood function and overall model fit [225], PLS does not work with latent variables, but rather with block variables or components, and estimates model parameters to maximize the variance explained for all endogenous constructs in the model through a series of ordinary least squares (OLS) regressions, depending on the model specification based on theory [215, 222, 224, 226]. PLS algorithms allow each indicator to vary in how much it contributes to the composite score of the latent variable (i.e. no equal weights for all indicators) [224]. Furthermore, the mathematical principles of OLS estimation imply that PLS SEM even works with small sample sizes, whereas maximum likelihood or general least squares estimates usually require over 200 observations to avoid non-convergence and improper solutions [227]. Another difference between PLS and CBSEM is that PLS can work with both reflective (molecular, mode A or principal factor) and formative (molar, mode B or composite variables) measures [209-211, 216, 228] in a model, although this is not applicable in the present context [216]. Furthermore, because all block variables are assumed to be linear combinations of their indicators, PLS does not suffer from improper solutions and factor indeterminacy, as sometimes occurs in the context of CBSEM [229, 230]. Thus, PLS offers various additional advantages including not requiring (a) normally distributed data, (b) observation independence or (c) variable metric uniformity. It also has less need to explain the covariances of all items, a predictive focus and greater flexibility in modeling higher-order constructs [226, 231]. However, several features of PLS have often been criticized [232], and caution needs to be taken when applying PLS [233] with fewer data distribution assumptions and fewer required cases [224].

SEM techniques are specifically suited for the modeling of complex processes to serve both theory and practice. Therefore, SEM is the appropriate method to validate our conceptual model to capture the complex entanglement of PACS deployment and performance in hospitals. The application of SEM (and latent variable modeling) fits a mode of integrative thinking about theory construction, measurement problems and data analysis. It enables stating the theory more exactly, testing the theory more precisely and yielding a more thorough modeling/understanding of empirical data about complex phenomena and relationships [234].

Figure 7-1 displays the SEM notation of our conceptual model, capturing the theorized relationships between PACS maturity levels (i.e. first-order construct), organizational domains (i.e. second-order construct) and PACS alignment (i.e. third-order construct), on the one hand, and its impact on PACS performance (i.e. third-order construct), on the other.

7.4 METHODS

7.4.1 INSTRUMENT DEVELOPMENT PROCESS

We applied an incremental development process to the framework's questionnaire. To ensure the quality and validity of the developed measurement instrument, we applied complementary validation methods and guidelines to build the framework, securing their face and content validity, performing extensive pre-tests and executing pilot cases.

An initial survey was developed based on the literature, field experience and valuable suggestions by two PACS experts (a professor of radiology and the head of a radiology department) who provided the project team with feedback, input and advice on key concepts in diagnostic imaging and general radiology practices. This initial survey was then discussed with industry consultants and a PACS R&D manager during a focus group meeting, thereby redefining some technical aspects in the survey.

The topics in the survey were subsequently validated in several individual validation sessions (using the 'Delphi method') with PACS experts (three radiologists, a neurologist, a technologist and medical informatics researcher) representing four hospitals in four different geographical areas in the Netherlands. These sessions were used to evaluate the structure of the constructed framework and comment on the specified PACS topics and features of the operationalized survey for each of the proposed maturity levels and organizational dimensions. The outcomes were used to improve our survey statements on validity, reliability and empirical application (e.g. the size of the survey and tooling).

The questionnaire contained four major sections including a section for the respondent's basic (background) data and another for responses to our research constructs (i.e. maturity, alignment and PACS performance). Taking considerable comments into account, this initial survey was extended and applied in a pilot with two hospitals of different sizes and operating regions that were actively involved in optimizing their PACS deployments. At each hospital, two radiologists (including heads of department), the head of radiological technologists and a PACS administrator completed an online survey within a secure web environment. These informants were most familiar with the subject of PACS maturity and performance, making intra-institutional validity likely. Including multiple stakeholders from the radiology department also reduces common source variance associated with sampling from the same source [77, 204], excluding face validity issues. Respondents completed the survey separately to avoid systematic bias and any peer pressure to give particular answers.

After critically considering the results of the pilot studies, including the comments and recommendations of the respondents, we modified several survey statements. The pilot offered good opportunities to improve the contents of the survey and improve the clarity of the statements. The final questionnaire was extended to 43 statements[2], covering most intersections of the five business domains and the five PACS maturity levels.

For each organizational dimension, the items were formulated according to a cumulative order. Our questionnaire explicitly addressed a hierarchical order (i.e. increasing complexity') of survey items along the maturity scale, communality and interrelationship of stages of maturity, so that we avoided common pitfalls in survey instruments and case research. All questions were assessed using a seven-point Likert scale for each statement from Strongly Disagree to Strongly Agree. Such a scale is typically used for subjective performance evaluation and is applicable for balanced and holistic assessments rather than objective measurements. In general, the outcomes of assessments in complex areas such as medical processes are often qualitative and thereby rely on the subjective perceptions of clinicians rather than on quantitative

[2] Statements for maturity levels 1 and 2 were omitted for practical reasons and because all Dutch hospital have implemented the initial maturity level. Level 2 could be deducted from the assigned scores to level 3 statements.

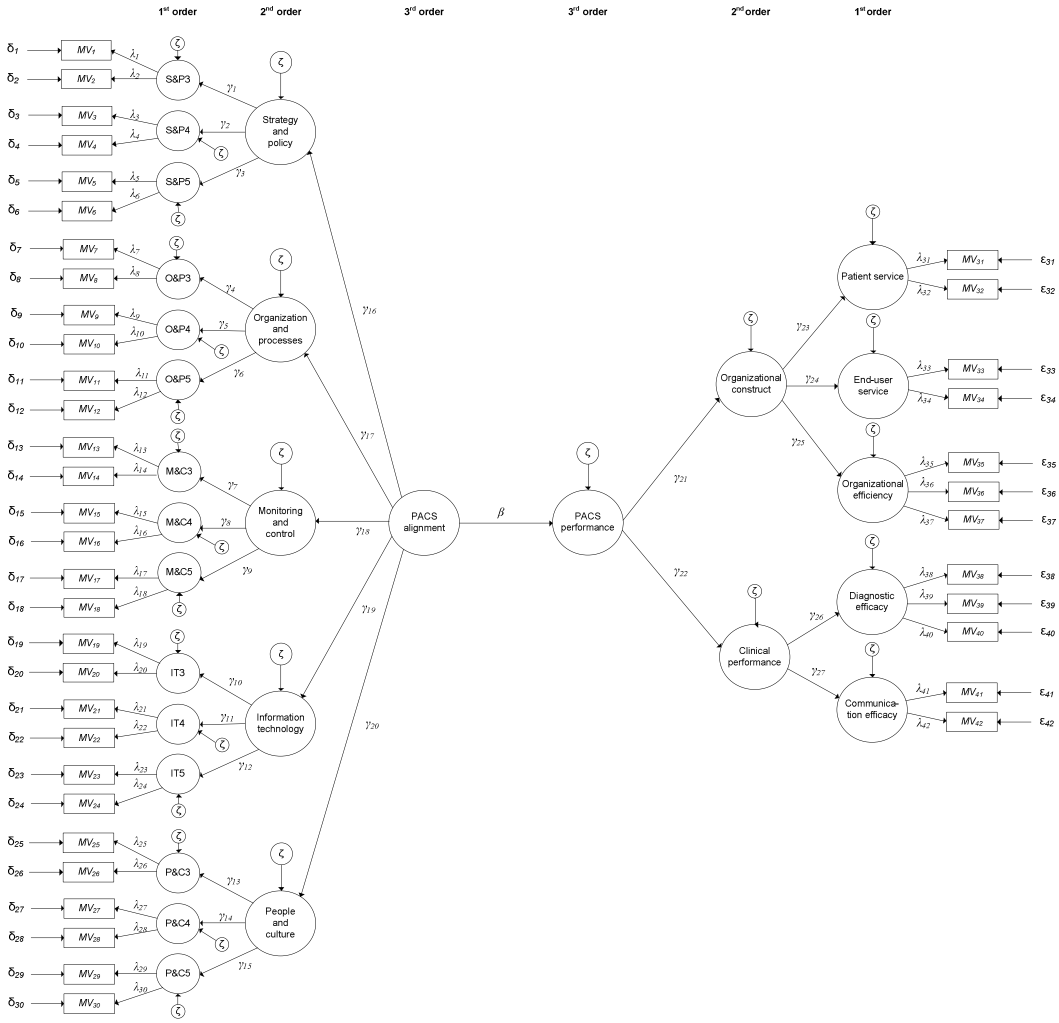

Fig. 7-1 Theoretical SEM notation for the PACS alignment model (δ_i/ε_i = measurement errors, ζ = disturbance terms for higher-order constructs, λ_i = first-order factor loadings, γ_i = factor loading coefficients for higher-order constructs, β = estimated value for the path relationship in the structural model)

1st order construct	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1. IT3	**0.86**																			
2. IT4	0.38	**0.81**																		
3. IT5	0.24	0.32	**0.72**																	
4. MC3	0.13	0.34	0.21	**0.79**																
5. MC4	0.14	0.30	0.27	0.50	**0.77**															
6. MC5	0.31	0.28	0.25	0.43	0.59	**0.81**														
7. OP3	0.17	0.19	0.38	0.40	0.32	0.39	**0.81**													
8. OP4	0.06	0.21	0.13	0.23	0.52	0.52	0.24	**0.79**												
9. OP5	0.19	0.06	0.24	0.07	0.27	0.19	0.03	0.42	**0.81**											
10. PC3	0.42	0.46	0.22	0.40	0.23	0.37	0.23	0.17	0.19	**0.78**										
11. PC4	0.28	0.10	–0.04	0.29	0.15	0.28	0.05	–0.05	0.14	0.51	**0.90**									
12. PC5	0.23	0.42	0.21	0.38	0.45	0.31	0.24	0.21	0.33	0.33	0.28	**0.82**								
13. SP3	0.07	–0.03	–0.02	–0.20	0.15	0.30	–0.11	0.19	0.04	0.09	0.05	–0.07	**0.73**							
14. SP4	0.17	0.23	0.47	0.31	0.32	0.35	0.22	0.24	0.36	0.23	–0.11	0.18	0.25	**0.77**						
15. SP5	0.03	0.20	0.26	0.39	0.32	0.42	0.44	0.18	0.21	0.27	0.23	0.23	0.19	0.43	**0.83**					
16. Patient service	0.27	0.15	0.31	0.11	0.09	0.34	0.19	0.16	–0.08	0.14	0.23	0.00	0.20	–0.01	0.14	**0.74**				
17. End-user service	0.44	0.36	0.34	0.46	0.45	0.53	0.40	0.20	0.07	0.39	0.16	0.39	–0.02	0.27	0.10	0.20	**0.76**			
18. Organizational efficiency	–0.13	–0.21	–0.08	0.02	–0.05	–0.02	0.23	–0.18	–0.28	–0.10	–0.18	0.09	–0.18	0.00	–0.04	0.04	0.20	**0.79**		
19. Diagnostic efficacy	0.08	0.13	0.28	0.19	0.32	0.30	0.23	0.21	0.08	0.01	0.07	0.17	0.01	0.08	0.17	0.12	0.30	–0.02	**0.81**	
20. Communication efficacy	0.49	0.31	0.22	0.30	0.10	0.18	0.20	0.06	0.30	0.38	0.24	0.36	–0.09	0.08	0.20	0.26	0.28	-0.12	0.09	**0.79**

Table 7-1 Inter-correlations of first order constructs ($N = 64$)

Sample descriptives							
	Total	% of total	AVG beds	fte radiologist	AVG Exams		Total
Hospital type						*Respondents*	
General hospital	37 (56)	66%	353	6.4	95900	Radiologist	29 (35%)
Top clinical	21 (27)	78%	657	10	160000	Head technologists / manager	26 (32%)
Academic	6 (8)	75%	944	27.2	193500	PACS administrator	27 (33%)

Table 7-2 Sample demographics (AVG = average, fte = full-time equivalent)

statistics [172]. Furthermore, the statements were phrased in the present tense, but respondents were asked to provide answers for both the current and future/preferred situations of their hospitals. Next to the items measuring PACS maturity as defined by our framework, the survey also contained some general questions (e.g. name, function, years of experience using PACS, etc.). Finally, PACS performance was measured using 12 performance statements on how well the system contributes to efficiency and effectiveness [40, 48, 235]. The results of the pilot supported the empirical application of the framework to gain insights into their PACS maturity and alignment and systematically identify improvement areas.

7.4.2 Data and Sample Collection Procedure

A survey was conducted targeting all general and top clinical hospitals (i.e. non-university teaching hospitals) and University Medical Centers in the Netherlands (N = 91). The questionnaire was sent to (1) the heads of the radiology departments (and radiologists), (2) the heads of technologists and/or department managers and (3) the PACS/RIS administrators of all radiology departments. In addition to an invitation to participate, a recent article on PACS maturity [43] was attached to introduce the concept of the study. Contact details were obtained from the secretaries of each individual radiology department.

Respondents were asked to fill out the survey either online or by returning the provided printed version to the university. In parallel, invitations to participate were sent via mail (and a reminder mail after five weeks) to all heads of radiology in the Netherlands by a radiologist whose expertise and PACS knowledge is widely recognized in the field.
Five weeks after, follow-up phone calls were made to all radiology departments that had not yet returned a single questionnaire. The main reasons for not participating were: internal policies not to participate in surveys, PACS replacement trajectories, time constraints, too many research participation requests and privacy concerns. Non-response in the current study was most likely to arise because of time restrictions rather than the nature of the questionnaire and the subject matter under study.

In total, 82 questionnaires were either filled in online or returned in the post. Representatives from twelve hospitals filled in at least one questionnaire, resulting in an overall response from 64 participating hospitals. This percentage is remarkably high in comparison to common survey response rates. All questionnaires were included into the analysis subject to quality criteria (e.g. no missing answers). Table 7-2 provides the demographics of our obtained sample. Participating hospitals – which all had their own radiology departments – could be divided into three categories: general hospitals, top clinical – large educational hospitals providing highly specialized medical care – and academic medical centers.

As can be seen from Table 7-2, our sample contains 75% of the academic hospitals, 78% of the top clinical hospitals and 66% of the general hospitals in the Netherlands.

This is a total response rate of 70% of the targeted hospitals. Therefore, the obtained sample is representative of hospitals in the Netherlands in terms of type and size.

7.4.3 INSTRUMENT VALIDATION

The application of SEM (mainly covariance-based), its misspecification in the literature and its reporting guidelines have been extensively reported [210, 229, 236]. Since the interpretation of parameter outcomes in PLS is not straightforward [230], we adopted the validation procedures outlined by Marcoulides and Saunders [233] and Chin [231] to assess the models 'outer' (measurement) and 'inner' model (structural). This was to:

1. Propose a model that is consistent with all currently available theoretical knowledge and collect data to test that theory (see section 7.2);
2. Perform data screening (including the accuracy of inputs, outliers, etc.);
3. Examine the psychometric properties (i.e. measurement model) of all variables in the proposed model;
4. Examine the magnitude of the relationships (i.e. structural model) and effects between the variables being considered in the proposed model;
5. Examine the magnitude of the standard errors of the estimates considered in the proposed model and construct confidence intervals for the population parameters of interest;
6. Assess and report the power of the study.

Following the above steps, we first performed tests on the data normality distribution of all manifest variables (MV_{1}–MV_{42}) using SPSS v 18.0. As a general rule of thumb, the absolute values of the ratio of skewness to its standard error (S.E.) and of kurtosis to its S.E. should be between $-2 \leq x \leq 2$; higher values indicate greater asymmetry and deviation from normality [237]. The outcomes suggested that our data slightly deviate from normality (AVG skew = |2,2| ; AVG kurtosis = |1,4|). Additional support for non-normal distribution came from a Kolmogorov–Smirnov test (KS Lilliefors test) for normality. All variables demonstrated significant values, thereby we rejected the null hypotheses that our data were not significantly different from normal distributions.

To perform this multistep approach and estimate the parameters in the inner and outer models, we used SmartPLS version 2.0M3 [238], which is a SEM application using PLS. We applied the path weighing scheme available within SmartPLS in addition to centroid and factor schemes with the knowledge that the choice among each scheme has a minor impact on the final result [224]. In addition, we applied a non-parametric bootstrapping [224, 226], as implemented into the SmartPLS application, to compute the level of the significance of the regression coefficients, with 500 replications to interpret their significance and to obtain stable results.

The current study has a sample size of $N = 64$. Given the rationale above (and in section 7.3) and the fact that our data are not normally distributed, we chose a PLS approach – which is robust for moderate sample sizes – over the use of covariance-based structures to validate our model. Hence, our main focus was on explaining (and predicting) the endogenous construct 'PACS performance' in which R^2 and the significant relationships among constructs indicated how well our model performed. Therefore, variance-based methods were preferred.

7.5 RESULTS

7.5.1 ASSESSMENT OF THE MEASUREMENT MODEL (THE 'OUTER' MODEL)

To demonstrate that the psychometric properties of the proposed integrated performance framework had satisfactory levels of validity and reliability, the measurement model was assessed for first-order constructs. To assess the convergent validity and reliability assessment of the indicators (i.e. manifest variables), composite reliabilities[3] (CR; [224, 239]) and average variance extracted (AVE; [221, 224, 239]) – i.e. the average variance of measures accounted by the latent construct – were computed. As a general rule of thumb, variables with a loading less than 0.6 should be removed from the sample [228, 240]. Low loading in models may be the result of (1) a poorly worded item, (2) an inappropriate item or (3) an improper transfer of an item from one context to another [241].

Table 7-3 includes loadings (λ) for all the items (MV_i) of each organizational domain (*D*) and maturity levels (*M*). λ can best be understood in terms of factor loadings (e.g. as a result of factor analysis) [226]. All loadings exceeded 0.7 except MV_1, MV_{16}, MV_{24} and MV_{25}. Considering that these values were close to the threshold, these items were retained in the original model. As can be seen from Table 7-3, all CR values were well above 0.7. Likewise, all AVE values exceeded the cut-off value of 0.5 proposed by Fornell and Larcker [239], indicating sufficient convergent validity. Table 7-4 includes five performance dimensions (D), measurements and indicators and the psychometric properties (i.e. AVE, CR, λ) of the dependent construct (i.e. endogenous construct). All the loadings of the dependent construct exceeded acceptable thresholds. Manifest variables MV_{37} and MV_{38} both had negative loadings and had to be removed from the PLS program to obtain reliable outcomes. Since MV_{33} and MV_{40} had loadings close to the threshold, these items were retained in the original model. Once again, all measures indicated that the dependent constructs were well defined and unidimensional.

[3] Composite reliability is similar to Cronbach's alpha without the assumption of the equal weighting of variables. Its mathematical formula (with the assumption that the factor variance = 1; standardized indicators) is $\rho = (\Sigma\lambda_i)^2 / ((\Sigma\lambda_i)^2 + \Sigma 1\text{-}(\lambda_i)^2)$.

PACS alignment construct					
D	*M*	Indicators	*λ*	AVE	CR
Strategy and policy	3	Primary interpretation by radiologists using uncompressed images *[mv1]*	0.67	0.54	0.70
		Emphasis is on the direct display of images from the archive *[mv2]*	0.79		
	4	PACS integration with the ePR is an important strategic objective *[mv3]*	0.76	0.59	0.77
		Alignment of investment plans between radiology and other departments/wards *[mv4]*	0.77		
	5	Inquiry of the external environment for new developments and products to optimize PACS functionality *[mv5]*	0.84	0.69	0.83
		Strategic and operational (multiyear) plans contain impact and opportunities for chain partners *[mv6]*	0.82		
Organization and processes	3	Active improvement of service levels using quality standards and measures for digital PACS workflow *[mv7]*	0.86	0.66	0.79
		Every image is instantly available on any workstation in the hospital for every user at any time *[mv8]*	0.76		
	4	All diagnostic images from other departments are stored into one central PACS archive *[mv9]*	0.81	0.62	0.77
		Dedicated workspace has all required patient information and integrated 2D/3D reconstruction tools *[mv10]*	0.77		
	5	PACS real-time data with chain partners using standard exchange protocols (XDS-i) if necessary *[mv11]*	0.80	0.66	0.80
		Hospital-wide requests and planning radiology exams using an electronic order-entry system *[mv12]*	0.83		
Monitoring and control	3	Recurrent prognosis concerning the amount of radiology exams and required storage capacity *[mv13]*	0.84	0.62	0.77
		Measurement and monitoring of financial and non-financial PACS data *[mv14]*	0.73		
	4	Service level agreements with PACS vendors are periodically evaluated *[mv15]*	0.90	0.60	0.74
		PACS generates comprehensive management information that is always on time *[mv16]*	0.61		
	5	The hospital confronts PACS vendors if Service level agreements are not (or partially) achieved *[mv17]*	0.86	0.64	0.78
		An accurate overview of the contribution of PACS to overall cost prices per radiology exam *[mv18]*	0.73		
Information technology	3	PACS is compatible with current international standards and classifications (HL7 and DICOM) *[mv19]*	0.85	0.73	0.85
		PACS exchanges information with the RIS and HIS without any complications *[mv20]*	0.86		
	4	Adoption of standard ‘off-the-shelf’ – vendor-independent – hardware and software *[mv21]*	0.78	0.66	0.79
		Impact prognosis on storage capacity because of modality upgrades or newly acquired devices *[mv22]*	0.83		
	5	Application of reagent (security) protocols in preserving the privacy of patient data, PACS data security and back-up *[mv23]*	0.77	0.52	0.70
		PACS is an integral part the hospitals’ ePRs *[mv24]*	0.67		
People and culture	3	The hospital actively involves the users of PACS in the development of customizable user interfaces *[mv25]*	0.64	0.60	0.75
		PACS process and procedure knowledge is extensively applied by clinicians and technologists *[mv26]*	0.89		
	4	End-users of PACS affect the decision-making process in selecting a specific PACS vendor *[mv27]*	0.90	0.81	0.89
		End-users affect digital PACS workflow and functionality improvements *[mv28]*	0.90		
	5	Radiologist awareness of PACS potential to influence the competitive position of the hospital and service delivery *[mv29]*	0.77	0.67	0.80
		Innovative solutions with PACS are discussed during clinico-radiological meetings *[mv30]*	0.87		

Table 7-3 Estimates for the psychometric properties of the first-order constructs for PACS alignment

As outlined in section 7.3, we used higher-order (multidimensional) latent constructs within the context of simultaneous equation systems. Within PLS, higher-order constructs can be constructed using repeated indicators (i.e. the hierarchical component model) [215, 223]. That is, all indicators of the first-order constructs are reassigned to the second-order construct, as second-order models are a special type of PLS path modeling that use manifest variables twice for model estimation. The same patterns are applicable to subsequent higher-order constructs. A prerequisite for this model approach is that all manifest variables of the first-order and higher-order constructs should be reflective [210]. As such, indicators share a common theme and are manifestations of the key constructs. In addition, any changes in constructs cause changes in the indicators. Hence, variance in each measure is explained by a construct common to all measures and error unique to each measure, and covariance among the measures is attributed to their common causes [242]. Thus, all constructs within our model were configured as reflective indicators and are considered exogenous variables.

It has been suggested that this procedure works best with the same amount of indicators per construct [231]. Therefore, all constructs in our PLS model were configured like this. Next to the assessment of first-order constructs, the higher-order constructs exceeded the average threshold values for composite reliability (i.e. CR $\geq$ 0.7). Table 7-5 includes loadings (i.e. factor loading coefficients, γ_i) for both second-order and third-order endogenous and exogenous reflective constructs. All higher-order 'factor' loadings of the independent part of the model provided a satisfactory fit to the data, meeting stipulated thresholds [243] and thereby supported the third-order hierarchical model of PACS alignment and its measurement model. In analogy to the exogenous constructs, the loadings for the endogenous higher-order constructs (i.e. PACS performance) had a significant meaning, indicating a strong goodness of fit and supporting the reflective PACS performance construct and its manifests.

Discriminant validity was assessed by verifying (1) whether indicators loaded more strongly on their corresponding (first-order) constructs than they did on other constructs and (2) that the square root of the AVEs should be larger than the inter-construct correlations [214] (see entries in bold in Table 7-1 along the matrix diagonal). The off-diagonal elements are correlations between latent variables as calculated by the PLS algorithm. As can be seen from Table 7-1, all square root scores of the AVEs are higher than the shared variances of the constructs with other constructs in the model. Thus, evidence of adequate convergent and discriminant validity was found for all constructs in the proposed conceptual framework. Further evidence of discriminant validity was obtained using cross-loadings as quality criteria [215, 239]. These findings indicate that the loadings for each indicator were greater than the cross-loading on other latent variables in the model.

In summary, the outcomes of the measurement model suggest that the PLS model is construct valid and reliable and that the estimates of the structural model (i.e. inner path model estimates) can thereby be evaluated.

PACS performance construct				
Measurement construct	Indicator	λ	AVE	CR
1) Patient service				
Patient waiting time	Elapsed time between a patients' arrival at radiology (on appointment) and subsequent exam *[mv31]*	0.71	0,55	0,71
Patient satisfaction	Satisfaction of patients on service delivery *[mv32]*	0.77		
2) End-user service				
Physician satisfaction	Satisfaction of referring clinicians on availability of imaging data and associated reports *[mv33]*	0.62	0,58	0,73
User satisfaction	User satisfaction on the current user interface and functionality of PACS *[mv34]*	0.88		
3) Organizational efficiency				
Report-turnaround-time	Sum of time after execution, reporting and the availability of imaging exams' finalized report of CT exams *[mv35]*	0.81	0,62	0,77
Radiologist productivity	The amount of yearly radiology exams per fte *[mv36]*	0.77		
Budget ratio	Percentage (over)expenditures of allocated PACS budgets *[mv37]*	-0.62		
4) Diagnostic efficacy				
Interpretation time	Time to process a series of CT exams *[mv38]*	-0.14		
Diagnostic accuracy	Sufficiency rate of current radiology workspaces for image interpretation *[mv39]*	0.93	0,65	0,79
Clinical capability	Workstations capability of displaying uncompressed CT studies (avg. 1500–2000 images) without delay *[mv40]*	0.67		
5) Communication efficacy				
Patient management	Contribution of PACS towards decision-making in diagnostic processes or treatment plans of patients *[mv41]*	0.82	0,62	0,76
Communication efficacy	PACS contribution towards the communication of critical findings and interdepartmental collaboration *[mv42]*	0.76		

Table 7-4 Estimates for the psychometric properties of the first-order constructs for PACS performance

Second-order construct							
Factor loading coefficients (γ_i)							
	Exogenous					Endogenous	
	S&P	O&P	M&C	IT	P&C	OC	CP
Maturity level 3	0.48	0.55	0.80	0.78	0.79		
Maturity level 4	0.80	0.83	0.82	0.85	0.80		
Maturity level 5	0.84	0.71	0.67	0.83	0.61		
Patient service						0.62	
End-user service						0.82	
Organizational efficiency						0.50	
Diagnostic efficacy							0.73
Communication efficacy							0.74
Third-order construct							
Factor loading coefficients (γi)							
	Exogenous constructs					Endogenous	
	S&P	O&P	M&C	IT	P&C	OC	CP
PACS alignment	0.64	0.70	0.70	0.85	0.70		
PACS performance						0.84	0.85

Table 7-5 Factor loadings for higher-order constructs

7.5.2 ASSESSMENT OF THE STRUCTURAL MODEL (THE 'INNER' MODEL)

While validating the outer model (i.e. measurement model), PLS also calculated the estimates of the structural model and its relationship among latent constructs. We found support for our integral hypothesis. There was a significant positive impact of PACS alignment on PACS performance (β = .62; t = 4.01; p < .0001).

Besides the direct effects of our model, we also accounted for the possible moderating effects (i.e. interaction effects) within our data through a multisample/group approach [244, 245]. In doing so, we equally divided our research sample into two groups based on the amount of beds of each hospital. Hence, group 1 (≤ 450 beds) was assigned 30 hospitals and the second group (> 450 beds) 34 hospitals. The model's path coefficients were subsequently estimated separately for each group using the standard errors obtained from bootstrapping [244, 246] – and no significant difference between the structural models could be detected (t = 0.36, p < .72). Likewise, we divided our sample of questionnaires into three disjoint groups, based on respondent category (i.e. radiologist, PACS administrator, head technologists/manager). The radiology group contains 29 cases (i.e. the 29 questionnaires that were completed by them), the PACS administrator group 27 cases, and the head technologist/manager group 26 cases. The model and its path coefficients were subsequently estimated for each of the three groups separately. No significant difference between the structural models for each of the group comparisons was found (radiology-administrator group: t = 0.01, p< .99; head technologist-administrator group: t = 0.55, p< .60; head technologist-radiology group: t = 0.46, p< .61).These outcomes imply that the impact of PACS alignment on the PACS performance construct (i.e. the hypothesized relationship) is stable for subsamples, i.e. the different respondent groups.

PLS path modeling – in contrast to CBSEM (e.g. using LISREL) – does not optimize any global scalar function so it naturally lacks an index that can provide the user with a global measure of fit (e.g. χ^2 statistic and various indices based on CBSEM) [224]. Although PLS modeling does not include a proper single goodness-of-fit measure, the variance explained by the model (R^2) – the coefficient of determination – values of the endogenous constructs can be used to assess this model fit. R^2 accounted for by PACS performance was 0.37. In accordance with R^2 effect size categorizations (i.e. 0.02; 0.13; 0.26 [247]), we concluded that the explanatory power was large. Thus, our expectation that the alignment of components related to PACS had a significant impact on the multifactorial performance of PACS in terms of efficiency and effectiveness was confirmed.

Next to the explained variance of our model (R^2), we also calculated the Q^2 of our endogenous constructs (i.e. using Stone–Geisser's test [224]) to assess the quality of each structural equation measured by the cross-validated redundancy and communality index (using the blindfolding procedure in SmartPLS) and to evaluate the predictive relevance for the model constructs. Q^2 measures how well the observed values are reproduced by the model and its parameter estimates by using cross-validation [224]. As such, Q^2 values larger than 0 imply the model's predictive relevance; values less than 0 suggest the model's lack of predictive relevance. In this study, all Q^2 values were above the threshold value of zero, thereby indicating the overall model's predictive relevance.

A global measure of fit (i.e. goodness-of-fit index, GoF) has also recently been suggested [224, 248]. The GoF, defined as the geometric mean of the average communality of all constructs with multiple indicators and the average R^2 (for endogenous constructs), represents an operational solution for an index validating the PLS model globally. Since communality equals AVE in PLS [215], the cut-off is set to 0.5 [239]. Subsequently, taking small, medium and large effect sizes for R^2 (i.e. 0.02; 0.13; 0.26) into account [247], GoF criteria for small, medium and large effect sizes can be obtained: 0.10, 0.25 and 0.36 [215]. For our model a GoF value of 0.45 was obtained, thereby exceeding the cut-off value for large effects (GoF = 0.36) [247], which directs towards the conclusion that our model performs well compared with the base values and was a good fit of the model to the data.

As a final step in our multistep approach, we conducted a power analysis for all global model parameters. We used G*Power [249] – a general standalone program – for statistical tests, which is commonly used in social and behavioral research. Power ($1 - \beta$) of statistical tests can be defined as the probability of falsely retaining an incorrect H_0 [247]. Power calculations indicated that the power for all the parameters in our model exceeded 0.96. This level of power indicates a high probability that the analytical tests will yield statistically significant results if the phenomena truly exist, and thereby a high probability of successfully rejecting H_0 [247].

7.6 DISCUSSION AND CONCLUSION

7.6.1 PRINCIPAL FINDINGS AND CONCLUSIONS

Evaluation methods, techniques and measures to assess the impacts of PACS have proven valuable in the past. However, more holistic and integral perspectives have been advocated including maturity concepts, organizational alignment and complementarity (or synergizing) effects in finding the key determinants of PACS performance within hospitals.

This study proposed an integrative PACS performance model, adopting theories and perspectives from the field of information systems research, complexity theory and CAS thinking. Although CAS approaches have been criticized for their lack of recommendations about how managers should behave [250], this study provides new perspectives for dealing with the emergent nature and dynamics of PACS maturity, alignment and performance in hospitals.

Based on the results of this study, several conclusions can be drawn. A key conclusion of this study is that our main hypothesis was empirically tested and found to be true. Based on the validated 'inner' and 'outer' structures of our multifaceted model, we conclude that our model – validated through data from 64 hospitals within the Netherlands – shows a significant positive impact for the PACS alignment construct on perceived PACS performance. This confirms that the situational alignment (i.e. being dependent on hospital-specific resources, capabilities and the use of PACS) of components related to PACS, either intended or unintended (i.e. spontaneous self-organization, emergence**)**, has a significant impact on the multifactorial performance of PACS in terms of efficiency and effectiveness.

The modeled relationships among PACS constructs (and their measures) within our framework also explain the rules and mechanisms that govern interactions between lower-order (first and second) elements at an aggregate level (i.e. PACS alignment – third-order construct) create dynamic, evolving and emergent properties.

The empirical findings of this study support that our conceptual model can be seen as a more parsimonious presentation of underlying factors, namely latent constructs. That is, PACS alignment can be represented as the interdependency of five underlying organizational domains (complex constructs [218]), each containing maturity levels that in their turn can be represented by manifest variables. Likewise, PACS performance (i.e. explanandum) follows this parsimonious concept and can be represented by a higher-order construct.

Although complexity theory posits simple causes for complex effects, we argue that our model has the potential to explain PACS performance within hospital operations and offers a sense-making tool that guides a decision-making process concerning PACS advancements and strategic planning.

This study demonstrated that providing theoretical arguments and foundations is imperative for understanding the outcomes of any study. This includes linking methods to an operationalized computational scheme, i.e. the application of SEM in our study reflected the massive entanglement of complex PACS systems in hospitals. We incorporated a systematic agenda linking theory development with a computational model, thereby overcoming the acknowledged limitations of existing approaches and focusing more on synergizing and complementarity effects [75], resource-based configurations and gestalts [251]. Moreover, the adoption and application of complexity theory – and specifically CAS – opens up a whole new vista of perspectives, approaches and techniques because its underlying assumptions differ from those of classical science [252].

Complexity theory introduces new ways to investigate regularities that differ from those of traditional science, which tend to focus on *ad hoc* cause–effect relationships [99]. In essence, PACS are CAS in the field of medical imaging that are continuously changing, adapting (non-linearly) to environmental requirements and unplanned changes and co-evolving as whole entities with respect to their mutually interdependent parts (including ePR, computerized physician order-entry and other medical IS/IT). To the best of our knowledge, this study is the first that empirically applies the concept of alignment, maturity and complexity science and theory to the research domain of PACS and medical informatics. We hope that the outcomes of this study will support hospital decision-makers.

7.6.2 COMPLEXITY PERSPECTIVE FOR SITUATIONAL STRATEGIC PACS PLANNING

The conclusions drawn from the current study form the basis for a different PACS strategic planning agenda that places long-term PACS planning and strategic alignment into context and complements previous PACS planning studies [43, 45, 188]. PACS – as a complex adaptive system – cannot be deployed as a ‘static’ system within hospitals. Expected and unexpected changes need to be made because of continuous adaptation to environmental turbulence. From this, we argue that, next to ‘traditional’ strategic planning, PACS deployment is also unplanned and an ‘emergent’ process. This means that it should be recognized that in the strategic planning of PACS deployment, ‘the unplanned’ should also be included. Although this seems a paradoxical task, we believe that synthesizing from the main outcomes of this chapter some guidelines can be derived to aim for this. To do so, we suggest that hospitals who want to take their PACS systems to the next (maturity) level and advance PACS performance should follow two ‘routes’:

‘Route 1’:

Mature and align PACS by explicitly identifying and executing improvement activities on each of the five organizational dimensions of the PMM. The basic goal of this route is to realize these improvements simultaneously, i.e. from an integrated perspective. While evolving PACS towards higher levels on all maturity dimensions, managers should critically reflect on the chosen improvement paths by governing the alignment between the dimensions, in particular between those within the business and IS/IT domains. Hence, route 1 follows the logic of an ‘*intended*’ PACS strategy and thereby a *deliberate* (i.e. conscious) planning process.

‘Route 2’:

To be simultaneously ‘adaptive’ in the course of executing PACS deployment (as illustrated by route 1), it is actually required to truly specify a depiction of future PACS and its maturity stages. As hospitals are mainly driven in daily practice by external, market-driven and non-market-driven factors, this is a major challenge. Instead of following *ad hoc* or opportunistic ways of strategic planning, hospitals need to plan PACS maturity, alignment and performance as goals that co-evolve within hospitals. This complex task can only be achieved by mobilizing the diversity of interactions among all organizational agents involved in the deployment of PACS in clinical and IT practice. Route 2 follows the logic of an ‘*emergent*’ PACS strategy that forms gradually and perhaps unintentionally.

In summary, we believe hospitals should follow a *dual* strategic PACS maturity planning perspective that drives a continuous process of change and adaptation as well as the co-evolvement and alignment of PACS. Adaptability and changeability should be integral properties, next to traditional and deliberate PACS strategic planning. Within hospitals, decision-makers need to cope with organizational and IS/IT changes that occur in non-linear turbulent healthcare environments.

As outlined above, the dual strategic planning of PACS maturity can be defined as a pattern of decisions [253] that are the result of (*I*) a deliberate PACS maturity strategy *and* (*II*) an emergent PACS maturity strategy that is effectuated in time and with conceivable changes. If these two strategic routes do not coincide, an intended PACS strategy (and associated operationalized 'plans') does not get realized in the course of execution. As a result, impractical and unrealistic expectations are set and poor decisions are made in uncertain environments, leading to an unrealized PACS strategy [253].

Following the general principles for practice – grounded in the alignment and complexity principles – we believe strategic planning for PACS maturity can be interpreted as a combination of intended, unintended and unrealized strategic routes. This reminds of the classic, but still highly cited, vision of Henry Mintzberg on strategic planning [253].

7.6.3 LIMITATIONS AND AVENUES FOR FUTURE RESEARCH

Despite its attractiveness, our study and integrative framework has several limitations. These limitations are largely related because of our research sample. First, although sufficiently large to achieve acceptable levels of statistical significance given all quality criteria for the inner model and outer model, our sample is limited to hospitals in the Netherlands, thereby limiting generalizability.

Although we believe that our framework provides an assessment frame for hospitals worldwide to evaluate the triangular construct of PACS maturity, alignment and performance, we expect that our model can also be used to describe and reconstruct any hospital PACS case. It is our ambition to extend this research (also longitudinal) and the application of the proposed model to other countries within Europe, and then onto the United States and so on. The model can then be reassessed and evaluated for its robustness, and the established higher-order constructs of our model can be validated through larger sample sizes. Comparing results across countries and groups might well contribute to the generalizability of our findings.

Second, our obtained data included various demographic variables (e.g. type, size, region), but our empirical analysis did not consider in-depth the possible differences among group segments. PLS SEM studies rarely report critical heterogeneity issues concerning their data, relating the presentation and interpretation of results based on the unrealistic assumption that data stem from a homogeneous population; this can be misleading [254]. Traditional (sequential) clustering techniques (e.g. K-means, tree clustering) on manifest variables are ineffective to account for heterogeneity in path model estimates, and often fail to provide useful results for segment-specific PLS analysis. Thus, they do not allow us to perform response-based segmentation on the basis of hypothesized model structures [255].

Using finite mixture (FIMIX) PLS procedures, segmentation can be applied to empirical data. This approach allows model parameters to be estimated and observations' affiliations to be simultaneously segmented [256]. This has the advantage compared with an *a priori* segmentation scheme in that derived segments are homogeneous in terms of model (structural) relationships based on fully available information for both manifest and latent variable scores [254, 257]. The results indicate that by segmenting data – using an extended *ex post* analysis – higher levels of explained variance can be achieved for various homogeneous sub-groups. However, we did not provide a comprehensive *ex post* FIMIX-PLS analysis [258]. Future research could elaborate on these segments by analyzing the principal mechanisms that contribute to higher explained variance (R^2) and include detailed multiple group comparisons into its analysis. These findings provide a platform for acquiring further differentiated PLS path modeling conclusions given segment-specific estimations.

Third, the primary focus of our study was on PACS within hospitals. In that respect, it would be a logical step to extend our concepts on alignment, maturity and complexity theory to medical IS/IT in general (e.g. including ePR, clinical decision support and computerized provider order-entry).

A final remark is that in our study we might have encountered common method variance (CMV) (a subset of method bias)[4], which is a common phenomenon in survey research and can cause problems (e.g. with construct validity). This can specifically occur when respondents rate survey items at the same point in time and both exogenous and endogenous constructs are self-perceived by the same respondents. There still is little consensus about the extent of common method biases and variances or the seriousness of these effects.

In summary, the current study validated a theorized PACS performance framework. We argue that the adopted complexity perspectives are crucial for explaining PACS performance and systematically identifying improvement areas within hospital operations as well as being aligned with the situational context of hospital strategies. In practice, the validated PACS performance framework is a useful checklist to systematically identify improvement areas for hospitals in the PACS domain.

[4] Principle component analysis (using SPSS v18) among all manifest variables of the model showed that multiple components/factors were present, making CMV unlikely.

8

SUMMARY AND DISCUSSION

Throughout this dissertation we have addressed an important omission in the current PACS literature, and medical informatics in general, by elaborating on the concepts of maturity, organizational alignment (i.e. fit) and complexity science (and complex adaptive systems) to understand how key benefits and PACS performance in clinical practice can be achieved.

Among the various research objectives it was our main aim to understand how hospitals can evolve and mature their PACS from an immature stage of growth/maturity towards the next maturity level to advance their respective PACS performances. Therefore, the main research question of this dissertation as explained in chapter 1 was:

'how can hospitals mature their PACS?'

The following sections will address the main findings of our research. The implications of our findings for science and practice and a reflection and discussion on key decisions throughout this thesis will also be elaborated upon. Finally, this chapter discusses the limitations and sets out avenues for further research.

8.1 MAIN FINDINGS

This PhD thesis consists of three interrelated sections with related sub-research questions that address the main research question.

8.1.1 PART I: EVALUATION PERSPECTIVES ON PACS WORKFLOW

Part I answers RQ1: *"How can the impact of PACS on hospital workflow be evaluated?"*

The mainstream focus on single PACS implementation and evaluation issues within scientific studies has made it difficult to gain a clear understanding of the overall impacts on the PACS workflow. In particular, the literature does not explain the intangible value created for patients by the patient care benefits of PACS. This is an important component of the hospital's strategy overall because it relates to IS strategy and clinical excellence in particular.

The multiple goals of hospitals require a context-specific concept of strategy and appropriate evaluation techniques for IS/IT, and PACS in particular. Therefore, a richer understanding of PACS workflow outcomes is required to enable a more diverse understanding of outcomes from the staff's various perspectives.

Conventional business models and evaluation methods do not adequately capture the complexity of public hospitals' multiple goals. This suggests that business system evaluation models may be able to be modified meaningfully and valuably for health; valid outcomes require a radical review of models in terms of their purposes, concepts and structures. The associated research questions were:

1a) How can a holistic approach be applied to the evaluation of PACS?

This question was addressed by the development of an adapted balanced scorecard (BSC): the PACS-BSC. The application of the BSC framework and theories of strategy to PACS within the hospital environment enabled both a richer understanding of the workflow outcomes and a refinement of the BSC.

The BSC adapts to the specific needs of hospitals to evaluate organizational performance and IS/IT implementation. While retaining Kaplan and Norton's intention to evaluate outcomes from the perspective of the organization's strategy and to be flexible to whatever those outcomes and strategy may be, the PACS-BSC can be used to evaluate the impacts of PACS on workflow within hospitals. Thus, the PACS-BSC is a holistic method to evaluate PACS impact on workflow that is relevant to hospital's not-for-profit and clinical strategies. The model has enabled a more diverse understanding of outcomes from the staff's various perspectives.

1b) What are the impacts of PACS deployment on a hospital's workflow?

We investigated the impacts of PACS on the workflow of a hospital and applied the PACS-BSC model to evaluate the deployed PACS system. Following the four evaluation perspectives of our applied model (i.e. *Clinical Business Processes, Quality & transparency, Patient and Information Systems*), the results showed that all aspects improved through the PACS implementation (see chapter three for an extensive elaboration on workflow impacts).

In short, the diagnosis process within the hospital changed considerably in terms of efficiency and value for money. Images are all in a digital, browser-based format and PACS allows imaging reports to be rendered in real time, which has a positive impact on both the quality of patient care and the perception of radiology services by referring clinicians.

Analysis also demonstrated that multiple steps have been eliminated, making the workflow 'as simple as possible' and simultaneously making it easier to manage all the different activities of a department. Workflow has become simpler and transparent as a result of PACS implementation. Nearly all steps that were associated with hard copies

and film bags have been eliminated. In addition, improvements in the 'quality of the workflow' were noticed because fewer retakes of images were required.
From a technical point of view, PACS affects the overall contribution of IS/IT to workflow by making images 'accessible' and 'instantly available.' The integration of PACS with other IS/IT, such as the radiology, hospital and clinical information systems, further enhanced the process of accessing images, requests and pathology reports at the same time. Thus, PACS provides the means for better communication, diagnosis and clinical treatment.

Time Savings & Image-based Clinical Action (as an evaluation element of the Clinical Business Process perspective) and Patient Throughput & Flow (as an evaluation element of the Patient perspective) showed relatively small improvements. A common view held by respondents was that PACS made the patient flow more patient-centered in the continuum of clinical care and that various improvements in patient throughput also occurred because of improvements in different modalities and throughout the hospital.

The outcomes indicated that several factors, such as the busyness of a department, the availability of doctors and operating rooms and patient flows, had detrimental impact on aspects such as total clinical treatment and patient throughput, and that the organizational alignment of PACS in hospitals was an important critical success factor. Since its early development and publication, the PACS-BSC model has been acknowledged by many researchers around the world for providing a holistic frame of reference for workflow impacts [14, 15, 41, 259, 260]).

8.1.2 PART II: PACS MATURITY AND STRATEGIC SITUATIONAL PLANNING

Part II answers RQ2: *"How can a model be developed for the strategic situational planning of PACS technology in hospitals?"*

RQ2 is addressed through the systematic development of a PACS Maturity Model (PMM) and its subsequent extensions into the strategic alignment concept and the maturity growth path concept. This model enables hospitals to gain insights into their (strategic) objectives for growth and maturity with regard to PACS, the electronic Patient Record (ePR) and other health information systems. Moreover, the proposed model can be applied as a valuable tool for organizational assessments, monitoring and benchmarking purposes. Hence, the PMM contributes to an integral alignment model for PACS technology. The associated research questions were:

2a) How can the maturity stages of the PACS domain be defined and modeled?

In our research, we applied a qualitative meta-analysis of 34 selected scientific papers on PACS by using three distinct analytical phases: (1) meta theory, (2) meta method and (3) metadata analysis. This process enabled us to gain a comprehensive understanding of the PACS literature from a maturity and evolvability perspective. These various phases and steps of this meta-analytic approach allowed us to analyze original sources, define stages of maturity with the associated PACS process focus and subsequently construct a model containing relationships among the distinct levels of maturity based on the reviewed sources. The defined PACS maturity stages that hospitals can achieve are:

- *Level 1: PACS Infrastructure*; this initial maturity level concerns the basic and unstructured implementation and usage of image acquisition, storage, distribution and display.

- *Level 2: PACS Process*; at the PACS Process level most initial pitfalls have been covered by so-called ‘second’ generation – more advanced – PACS deployments. The general focus of this level is on effective process redesign/reengineering, optimizing manual workflow in radiology and initiating transparent PACS processes outside radiology.

- *Level 3: Clinical Process Capability*; this third level is represented by the evolution of PACS towards a system that can cope with operational workflow and patient management, hospital-wide PACS distribution, communication and image-based clinical action. Evolution to this level requires important alterations in terms of processes, extending the scope beyond imaging data and the level of integration of health information systems.

- *Level 4: Integrated Managed Innovation*; the Integrated Managed Innovation level can be characterized by the initial integration of PACS into the ePR and cross-enterprise exchange of digital imaging data (XDS-i) and supporting material. This level goes beyond the previous level with the adoption of emerging technologies such as computer-assisted readings and computer-aided diagnosis, resulting in decision support for clinical PACS usage.

- *Level 5: Optimized Enterprise PACS Chain*; finally, level five is the Optimized Enterprise PACS Chain. At this level, and with PACS fully integrated into the wider ePR, PACS can be maximized for efficiency purposes and clinical effectiveness. The adoption within the wider ePR and healthcare facility integration is continually optimized and the operational improvements yield process innovations and overall efficiencies in the continuum of the patient care delivery process.

With the progression from one PACS maturity level to the highest level, operational (workflow) efficiency, IT integration and effective and qualitative care using PACS technology expand so that process innovation and adoption within the wider ePRs and overall efficiencies in the continuum of the patient care delivery process can be realized.

If we summarize the PACS maturity levels, together with the associated process focus and the relationship among the distinct levels of maturity, the following maturity model appears (Figure 8-1).

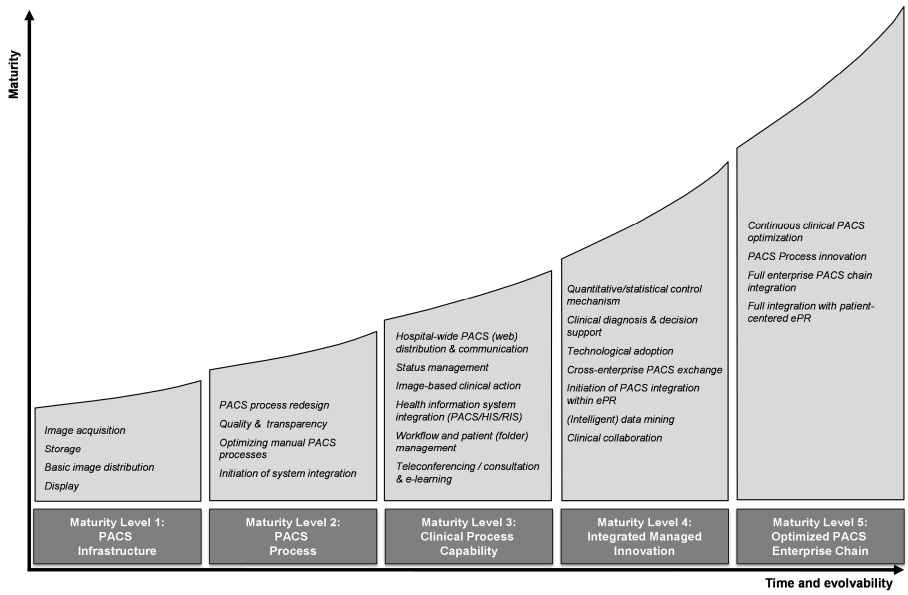

Fig. 8-1 The PMM

2b) What integrated strategies enable the strategic planning of PACS deployment within a hospital?

As elaborated on in chapter five, in essence the PMM is not developed as a guideline for strategic planning, so it does not explicitly define which paths can be taken in order to cross maturity levels. Therefore, an extended framework for PACS strategic planning was developed with the PMM at its core. This framework defines eight distinctive strategies for PACS strategic situational planning based on the combination of the 'four' original perspectives of the strategic alignment model that envision strategic alignment (strategy execution, technology potential, competitive potential and service level) with two types of growth paths: '*evolutionistic'* that develop logically in stages based on predefined objectives and goals and '*revolutionary'* that take a more radical approach in that such a path introduces a radical change and process focus for the hospital and does not follow the logic of monotonous sequential development (see Figure 8-2).

The incorporated eight strategies build the decision space: an extended method for PACS strategic planning. This framework allows decision-makers in hospitals to decide which approach best suits their hospital's current situation and future ambition and what in principle is needed to evolve through the different maturity levels. We argue that the framework is situational in that the required investments and activities depend on the alignment between the hospital strategy and a selected growth path.

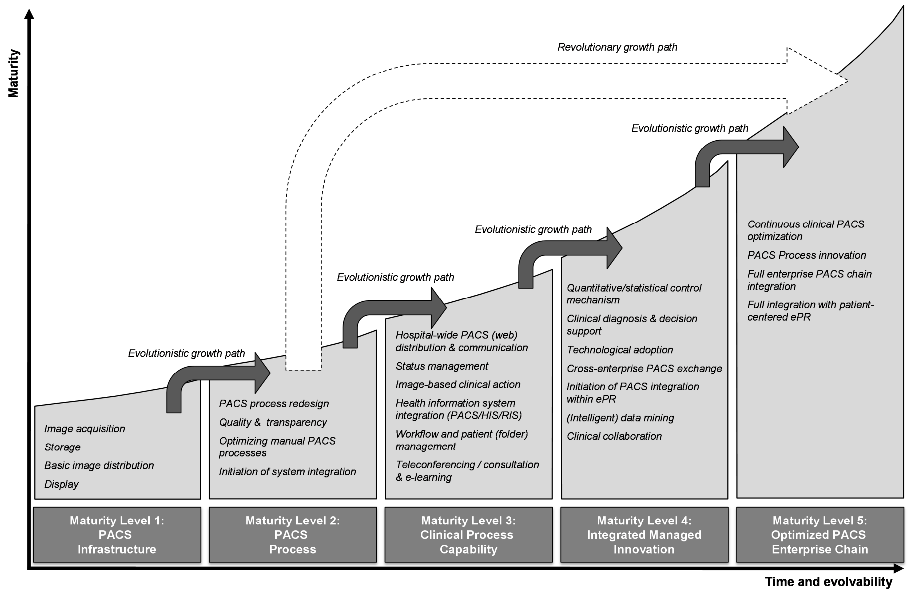

Fig. 8-2 Situational growth paths for PACS maturity

8.1.3 PART III: COMPLEXITY PERSPECTIVES FOR PACS MATURITY AND MULTIFACTORIAL PACS PERFORMANCE IMPLICATIONS

Part III answers RQ3: *"How can the relationship between maturity and the organizational alignment of PACS within hospitals and the multifactorial performance of PACS be understood from a complexity perspective?"*

We answered this third research question through the empirical application and validation of an integrative PACS performance model that conceptually includes maturity concepts, organizational alignment (and complementarity) effects to find the key determinants of PACS performance within hospitals. The associated research questions were:

3a) What defines the multifactorial nature of PACS performance?

Based on technology acceptance models for diagnostic imaging technology and the levels of (clinical) efficacy, as well as balanced evaluation models, PACS performance is defined by a synthesized review as "*the multifactorial impacts and benefits produced* *by the application of PACS in terms of hospital efficiency and clinical effectiveness with respect to PACS workflow and patients' clinical journeys*." In this dissertation, we adopted the outcomes of a meta-analytic approach that synthesized original PACS sources on PACS performance and balanced evaluation models. Based on 37 papers published between 2000 and 2009 that were included for review purposes (after applying several inclusion criteria having retrieved 980 key publications and positioning papers), descriptive performance constructs were defined.

These constructs were subsequently translated into representative elements for the maturity performance measurement of PACS. As such, these constructs include measures that are available for the assessment of PACS, from both organizational and clinical perspectives, addressing its organizational efficacy, service outcomes and clinical impact. This multifactorial perspective is further expanded in chapter 7 where PACS performance is classified within a hierarchical latent (i.e. factorial) construct including:

1. The first-order exogenous constructs (*Patient service*, *End-user service*, *Organizational efficiency*, *Diagnostic efficacy* and *Communication efficacy*) and their respective manifest (i.e. measurable) variables;

2. The second-order constructs (*Organizational construct* and *Clinical performance construct*) related to the block of the underlying first-order latent constructs; and

3. A third-order construct, labeled *PACS performance*, related to the underlying second-order constructs, as a representative construct for the multifactorial nature of PACS performances in terms of hospital efficiency and clinical effectiveness.

Hence, this perspective provides an infrastructure to operationalize the relationships between a performance construct of PACS and its (maturity and alignment) measurement.

3b) Which mechanisms govern situational effective maturity by the organizational dimensions related to PACS in hospitals?

The levels of maturity – as presented by the PMM – are defined by their increasing process and integration focus. The development through maturity stages might differ by organizational domains related to PACS, and maximizing maturity might not be effective or 'optimal' in all circumstances (i.e. situationally dependent). In our studies, we applied complementarity and organizational alignment principles to PACS evaluation to fill this void.

The concept of complementarity factors and synergizing effects has gained considerable attention in IS/IT research and other interdisciplinary fields in recent years. The key notion is that specific activities in organizations are complements "if doing (more of) any one of them increases the returns to doing (more of) the others." In our work, we explicitly define ‘alignment’ as the degree of leveling between five organizational dimensions (see chapter 6). Following this definition, alignment is represented by the degree to which the organizational dimensions are distinctive with regard to their maturity levels as previously defined by the PMM. Hence, alignment can be expressed within Figure 8-3 as a line connecting all five (horizontal) organizational dimensions.

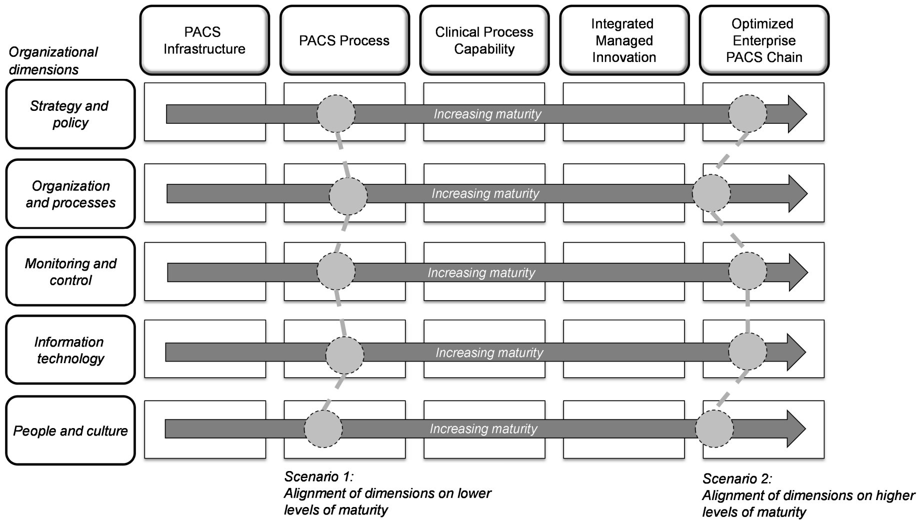

Fig 8-3 PISA framework

3c) Which theory complements systems maturity and organizational alignment?

Complementarity theory and alignment measurements for different organizational domains are valuable contributions that can be used to extend the basic PMM. In spite of their attractiveness, these theories solely demonstrate results of 'Edgeworth' complements (i.e. synergetic effects) and typically do not explain its synergistic effects and mechanisms beyond general descriptions of 2+2=5. In addition, they do not address the evolving, adaptive and dynamic (i.e. emergent) nature of these domains. They neglect the fact that mechanisms are multidirectional and that change in one organizational domain has multilevel effects on other domains.

Therefore, we adopted the idea that both complex adaptive systems and complexity theory provide new perspectives for dealing with the emergent nature of IS/IT in organizations, more specifically the dynamics of (PACS) maturity, alignment and performance in hospitals.

The basic thought is that this feeds a ‘holistic’ or ‘complex’ theoretical framework that fits the diversity of organizational components and interactions among the many agents involved in clinical and IT practice using PACS. We assume that, next to strategic planning, PACS deployment is also unplanned and an emergent process.

Likewise, PACS maturity, alignment and performance are phenomena that evolve within hospitals. From this perspective, PACS resembles the principle of CAS.

3d) How can the hypothesized relationships among (PACS) maturity, alignment and performance be holistically modeled and empirically validated?

Based on extensive theoretical analyses, a conceptual model was developed combining three central concepts: (1) PACS maturity as the concept to define PACS and its elements, (2) PACS alignment as the concept to complement the organizational dimensions of PACS and (3) PACS performance as the added value of PACS within hospitals.

For modeling purposes, the alignment of PACS is defined as the pattern of internal consistency among underlying constructs and is statistically appropriately captured by a pattern of covariation, which coincides with the concept of (co-)alignment. In doing so, our conceptual model follows the central concept of internal logic among the various dimensions because it is in accordance with the theories of complexity and CAS.

Interconnecting the three key concepts of PACS maturity, alignment and performance, we used reflective higher-order (multidimensional) latent constructs within the context of simultaneous equation systems (see Figure 8-4 for an abstract display of this conceptual model). In this figure, γ_i represents third-order loadings (i.e. factor loading coefficients) between the second-order and third–order exogenous reflective constructs and β the estimated value for the path relationship in the structural model.

These ‘latent constructs’ cannot be observed directly because their meanings are obtained through the measurement of manifest variables (i.e. indicators). PACS alignment, given this type of modeling, is represented as a third-order latent construct, whereas the second-order constructs represent the organizational domains to be co-aligned and the first-order constructs represent maturity levels (see chapter 7, section 2.4). Testing and validating our conceptual model was accurately performed using Structural Equation Modeling (SEM or ‘causal modeling’).

SEM is a second generation data analysis family of statistical models that seeks to explain complex relationships among multiple observable and latent constructs in models. SEM is typically used to simultaneously validate multifaceted phenomena in terms of tentative cause and effect variables.

3e) What is the relationship between (PACS) maturity and organizational alignment in terms of performance?

Based on a systematic validation procedure of the ‘inner’ (i.e. the magnitude of the relationships and effects between the latent variables being considered) and ‘outer’ (i.e. the reliability and validity of all reflective constructs in the model) structures of our multifaceted model using SEM, we conclude that our integrative model – validated through data from 64 hospitals within the Netherlands – shows a significant positive impact of PACS alignment on PACS performance with a high coefficient of determination (i.e. explained variance) accounted for by PACS performance.

This confirms that the situational alignment (i.e. being dependent on hospital-specific resources, capabilities and the use of PACS) of components related to PACS, either intended or unintended (i.e. spontaneous self-organization, emergence), has a significant impact on the multifactorial performance of PACS in terms of efficiency and effectiveness. Furthermore, the hypothesized relationships among PACS higher-order constructs (and their measures) within our framework explain the rules and mechanisms that govern interactions between lower-order (first and second) elements at an aggregate level (i.e. PACS alignment – third-order construct).

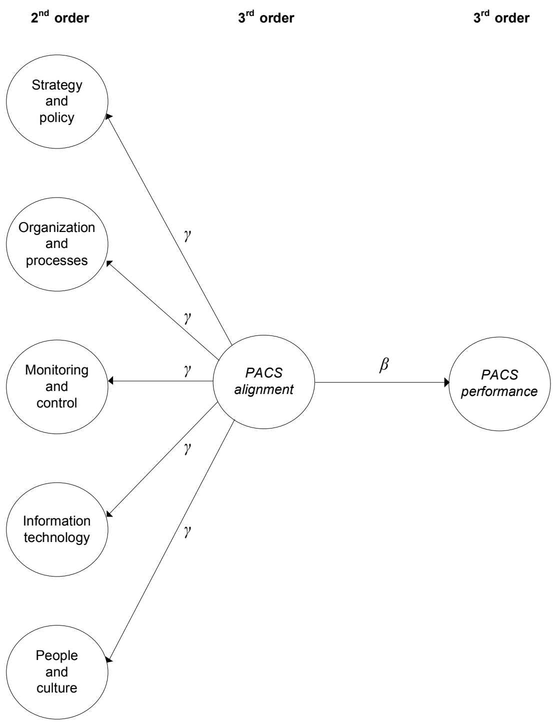

Fig 8-4 Hypothesized relationships among underlying constructs (only second- and third-order latent constructs are displayed).

3f) Which guidelines for strategic PACS maturity planning can be gleaned from hospitals and radiology departments in particular, by applying the complexity perspective as a foundation of our integrative framework?

PACS – as outlined in chapter 7 – is a complex system of IS/IT and radiology workflow design. As such, PACS cannot be deployed as a ‘static’ system within hospitals.

Expected and unexpected changes need to be made because of continuous adaptation to environmental turbulence. From this, we argue that, next to 'traditional' strategic planning, PACS deployment is also unplanned and an 'emergent' process. This means that it should be recognized that in the strategic planning of PACS deployment, '*the unplanned*' should also be included. Although this seems a paradoxical task, we believe that synthesizing from the main outcomes of this dissertation some guidelines can be derived to aim for this.

We believe hospitals should follow a '*dual'* strategic maturity planning perspective of PACS throughout the hospital. The dual strategic planning of PACS maturity can be defined as a pattern of decisions [253] that are the result of:

- *(I)* A deliberate PACS maturity strategy (while critically reflecting on the chosen improvement in the course of execution); and
- *(II)* An emergent PACS maturity strategy that is effectuated in time and with conceivable changes.

Therefore, adaptability and changeability should be integral properties of PACS as a system, next to traditional and deliberate PACS strategic planning. Within hospitals, decision-makers need to cope with organizational and IS/IT changes that occur in non-linear turbulent healthcare environments. If these two strategic routes do not coincide, the intended PACS strategy (and associated operationalized 'plans') does not get realized in the course of execution. As a result, impractical and unrealistic expectations are set and poor decisions are made in uncertain environments, leading to an unrealized PACS strategy [253].

We elaborate on this 'dual' strategic maturity planning process in the next section.

8.1.4 DUAL STRATEGIC PACS MATURITY PLANNING

Based on the outcomes of the various studies included in this dissertation, we suggest that hospitals who want to take their PACS systems to the next (maturity) level and advance PACS performance should follow two 'routes':

'Route 1':

Mature and align the adopted PACS by explicitly identifying and executing improvement activities on each of the five organizational dimensions – as outlined in chapter 6 – and the PACS maturity levels (see chapters 4 and 5). The basic goal of this route is to realize these improvements simultaneously, i.e. from an integrated perspective. While evolving PACS towards higher levels on all maturity dimensions, managers and decision-makers should critically reflect on the chosen improvement paths by governing the alignment between the dimensions, in particular between those within the business and IS/IT domains. Hence, this 'route' follows the logic of an '*intended*' PACS strategy and thereby a *deliberate* (i.e. conscious) planning process.

'Route 2':

To be simultaneously 'adaptive' in the course of executing PACS deployment (as illustrated by route 1), it is actually required to truly specify a depiction of future PACS and its maturity stages. As hospitals are mainly driven in daily practice by external, market-driven and non-market-driven factors, this is a major challenge. Instead of following *ad hoc* or opportunistic ways of strategic planning, hospitals need to plan PACS maturity, alignment and performance as goals that 'co-evolve' within hospitals. This complex task can only be achieved by mobilizing the diversity of interactions among all organizational agents that are involved in the deployment of PACS in clinical and IT practice. This 'route' follows the logic of an '*emergent*' PACS strategy that forms gradually and perhaps unintentionally.

In summary, hospitals should follow a *dual* strategic maturity planning perspective that drives a continuous process of change (which is non-linear) and adaptation as well as the co-evolvement and alignment of PACS. In doing so, adaptability and changeability become integral properties of PACS as a system within the hospital operations, next to more traditional (i.e. deliberate) PACS strategic planning.

Following the general principles for practice – grounded in the alignment and complexity principles – we believe strategic planning for PACS maturity can be interpreted as a combination of intended, unintended and unrealized strategic routes. This reminds of the classic, but still highly cited, vision of Henry Mintzberg on strategic planning [253]. In his work, Mintzberg argues that normative techniques and methods of analysis for strategic planning seem unable to address the complex reality of strategy formation. As such, he argues, that a 'strategy' is not a fixed plan nor does it change systematically at pre-arranged times solely at the will of management. Our *dual* strategic maturity planning perspective can be visualized in the figure below.

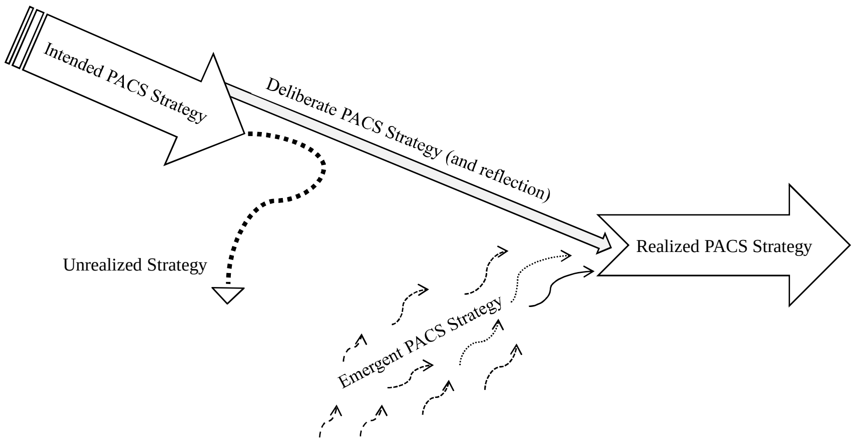

Fig 8-5 Dual strategic PACS maturity planning. Adopted from [261]

8.2 IMPLICATIONS OF OUR RESEARCH

Finding the *key determinants* of PACS performance has been a conundrum for many decades. Throughout this dissertation, we have advocated the importance of 'holistic' evaluation methods and perspectives in finding such determinants. Based on the various case studies, conceptual analyses, meta-analyses and empirical validations, we argue that our developed evaluation and maturity concepts and methods have the potential to holistically reflect on PACS performances of adopted systems and to explain PACS performance within hospitals operations. Moreover, they offer sense-making tools that guide decision-making processes concerning maturity of PACS and strategic situational planning. In doing so, this research extends the *body of knowledge concerning PACS maturity and evaluation perspectives* considerably.

With this knowledge, hospitals can formulate strategies and roadmaps to further enhance the performance of the adopted PACS system. Research in the PACS domain will not come to a standstill. On the contrary, we acknowledge that the research field is still evolving and expanding to include imaging throughout the enterprise chain, and developments and disruptive innovations continue to emerge. Therefore, research and development is now vital. We have seen a gradual uptake of our balanced evaluation perspectives and maturity concepts by the scientific community and hope to inspire others to use these empirically validated constructs as a frame of reference in their research and hospital practices.

With its subsequent (growth path, alignment and complexity science perspectives) extensions the PMM enables hospitals to quantify PACS maturity and relate this to PACS deployment performances. This model, as a foundation for its underlying body of knowledge and rigorous theoretical approach, allows hospitals *to systematically mature and align PACS in hospitals*. Applying these fundamental concepts to strategic PACS planning is valuable to any hospital that is willing to (re-)evaluate their PACS investments and overall system performances. Although hospital boards tend to define their strategies, growth paths and roadmaps based on their short- and long-term needs, we hope that decision-makers within hospitals will specify their strategic plans for PACS optimization while taking into account the outlined PACS maturation principles. Through the use of the proposed framework, strategic planning by alignment in hospitals is more likely to be achieved in practice.

In our work, we adopted *complexity theory and complex adaptive systems theory* to address co-evolutionary concepts, self-organized emergent behavior and the structure of systems and to serve as a contribution to the analysis and understanding of PACS performance in hospitals. These theories 'fit' with the complex nature of enterprise-wide PACS and the complexity of hospitals as complex organizational systems of medical practice. As addressed in chapter 7, the adoption and application of *these theories open up a whole new vista of evaluation perspectives, approaches and methods for PACS*, healthcare and the medical informatics research field. This is because the underlying assumptions differ from those of classical science and management practice that mainly focus on *ad hoc* cause–effect relationships. PACS are, in essence, complex adaptive systems that are continuously changing, adapting (non-linearly) to environmental requirements and unplanned changes and co-evolving as whole entities with respect to their mutually interdependent parts (including ePR, computerized physician order-entry and other medical IS/IT).

It has been argued that without auxiliary theories, the ‘mapping’ of theoretical constructs onto empirical phenomena is ambiguous, and theories cannot be meaningfully tested. For the empirical validation of our integrative framework, we acknowledged the importance of the rationale underlying the functional form of our model’s constructs. We presented how the three theoretical concepts of maturity, alignment and performance coincide with covariation (or co-alignment) using higher-order latent structures as an operationalized statistical scheme within SEM. This approach serves both theory and practice by capturing the complex entanglement of PACS within hospitals. It fits a mode of integrative thinking about theory building, measurement problems and data analysis and this allowed us to state the theory more exactly, test the theory more precisely and yield a more thorough understanding of our empirical data. We have the conviction that *our concepts and approach are fundamentally suited to be applied to medical IS/IT in general and other fields*, although the contents – at a manifest/indicator level – should be modified meaningfully to suit the principal concepts of other research fields. This provides researchers in the domain of IS/IT alignment and strategic alignment with valuable opportunities and challenges.

8.3 REFLECTION AND DISCUSSION

In this section, we will reflect on the 'key' decisions made across different chapters, to address the issues of consistency between them.

8.3.1 "The BSC is a valuable but limited performance instrument for PACS"

In chapters two and three, we applied the balanced scorecard (BSC) to evaluate holistically the PACS impacts on workflow. In essence, the BSC is a performance management model providing executives with a comprehensive framework to translate strategic objectives into a coherent set of measures. As such, the BSC can be considered a management process rather than a well-defined assessment method for complex IS/IT in hospitals (i.e. PACS). Therefore, its relevance and applicability to such an evaluation – although adaptive by design – can be questioned. We acknowledged the importance of these fundamental questions and argued that valid outcomes of evaluations of IS/IT require a radical review of models in terms of purpose, concepts and structure. Moreover, our primary objective was to frame and examine holistically (i.e. from various angles) the PACS impacts on workflow and therefore common technical PACS evaluations – which tended to focus on specific parts of the workflow implications – were not qualified for such an evaluation. Following this, our refined BSC (i.e. PACS-BSC) enabled a clear multi-perspective view on reality while reality simultaneously refined the theory.

In the light of these results, important issues remain unanswered. For instance, we did not devote a great deal of energy to the explicit linkage and interrelationship among measures between the perspectives and did not discuss whether the proposed method is fully exclusive and deterministic. In the same vain, we did not discuss how outcomes of this study relate to large amounts of published assessment and evaluation studies on health-care IS/IT and medical care [6, 262-264]. Since health IS/IT assessment methods are subject to constant review, research concerning the applicability of the PACS-BSC and general workflow methods still seem very relevant, so that potential deficiencies may be found and modified accordingly.

As a method, the PACS-BSC has proven valuable by providing a richer (qualitative) perspective on PACS impacts from various angles based on semi-structured interviews. However, it does not provide key uniform metrics for organizational assessments, monitoring and benchmarking purposes that are likewise relevant for validating hypothesized performance models using survey research. Therefore, in chapters six and seven – in which the main goal was to develop an integrative model to assess empirically, on the one hand, the maturity and organizational alignment of PACS and, on the other hand, their impact on PACS performance – we systematically defined PACS performance based on the wider adoption of technology acceptance models and levels of clinical efficacy [200, 201]. For its operationalization, however, we adopted outcomes of a meta-analytic approach synthesizing original PACS sources on PACS performance and balanced evaluation models, including the PACS-BSC [40, 48].

Consequently, performance constructs – with associated measures of maturity performance measurement of PACS – complement the evaluation perspectives of the PACS-BSC. Thus, the two approaches have, in essence, different meanings and purposes. In fact, the PACS-BSC incorporates qualitative themes rather than quantitative performance measures and in chapter six we adopt a quantitative approach towards PACS performance, defining it in chapter seven as a dependent construct that is classified within a hierarchical latent (i.e. factorial) construct.

8.3.2 "Concepts of organizational alignment are complementary to PACS maturity"

In chapter four, we systematically reviewed the PACS literature on maturity for the construction of a maturity model for PACS using a meta-analytic approach as the first step towards an integrated framework for PACS alignment and implementation. The developed model, the PACS maturity model (PMM), is a descriptive, partly normative model that is not explicitly developed as a guideline for strategic planning, nor is it made situational for different factors and conditions (see chapter five). The model was therefore extended using strategic alignment perspectives of the Strategic Alignment Model and growth paths (evolutionistic and revolutionary), as a first step towards addressing 'optimal' cross-cutting routes. The inclusion of both strategic alignment and maturity growth path concepts made this planning method rigorous; however, the model does have its apparent limitations. Specific validation issues arise concerning the application of the incorporated perspectives and how this is related to clinical PACS performance. Also, in chapter five we did not address how hospitals can truly 'align' PACS on a given maturity level and how we can account for 'optimal' diffusion within organizations.

Therefore, we concluded that the PMM served as a foundation for its underlying body of knowledge and rigorous theoretical approach, including the concept of business–IT alignment. To identify those complementarity and organizational alignment principles that are required to align PACS, we turned to an empirically validated business–IT alignment model of Scheper [81].

The decision to incorporate this model into our studies might seem arbitrary due to the availability of various other alignment models, although Scheper's concept of alignment is fundamentally different. His 'alignment principle' is based on the idea that organizations can mature each relevant single organizational dimension, but only through equalization among all the dimensions in order to enhance further an organization's performance. As such, it incorporates the triangular construct of maturity, alignment and performance that best fits our research objectives. Thus, we adopted Scheper's concept of five organizational dimensions as a complement to the established PACS maturity levels in defining an alignment model. Nevertheless, the integration process of this alignment concept perspective with our PMM gives rise to various questions that are not explicitly articulated in this dissertation.

First, one could argue that the organizational dimensions (i.e. strategy and policy, organization and processes, monitoring and control, information technology, people and culture) are not exclusively related to Scheper's model and definition of alignment. In the literature, various other models and theories are available, incorporating similar domains [80, 81, 199]. An interesting extension would be to investigate whether or not adapting or recombining existing dimensions into others would have a significant impact on the overall model fit (using structural equation modeling) and coefficients of determination. This could demonstrate the uniqueness of the chosen model's dimensions and further support our empirically validated basic building blocks.

Second, the underlying mechanisms through which PACS performance is achieved by alignment and maturity scores are by no means comprehensible or made explicit for individual hospitals in chapters six and seven. This touches upon a highly relevant scholarly discussion on what maturity and alignment actually are and how they should be measured accordingly. It is necessary to recognize that there are roughly those maturity models that perceive alignment (or fit) as an explanatory variable for maturity and those that see maturity as an explanatory variable in the alignment equation. We defined alignment as the degree of leveling between five organizational dimensions described in section 6.2.2., i.e. alignment is accordingly measured as the degree to which the five dimensions are distinctive with regard to their maturity levels as defined by the PMM. Hence, to measure the level of alignment, we applied the difference between the maximum and the minimum maturity scores of the five dimensions as measure [85], although various well-known alternatives are available (e.g. the standard deviation between the five dimensional maturity scores, or selecting the minimum score as the 'weakest link'). In spite of its attractiveness, our approach reveals several limitations and is not without fault. In order to calculate an overall maturity score (which is required to calculate the max.–min. difference) – to explore attentively the basic claim that high PACS alignment coincides with high PACS performance – we constructed a heuristic (i.e. algorithm) that captured the principle of accumulating maturity.

As previously highlighted, there is a need to develop a more robust measure of maturity and alignment since its calculation may have inherent biases since it was partly based on a rule-based algorithm. In addition, calculating hospitals' level of maturity and alignment (and fit-gap analysis between current maturity levels and 'to-be' situations) should not become an 'objective' itself. These concepts are meant to identify systematically situational (i.e. dependent on hospital-specific resources, capabilities and the use of PACS) factors for harmonizing or 'aligning' the intended goals, objectives and enhancement activities of PACS with the hospital's strategic agenda and operational workflow.

8.3.3 "Multifaceted models imply interaction effects"

We stressed, in chapter six, that additional research would be required to identify the interaction effects – co-alignment [76] – of (latent) variables connecting maturity and alignment to PACS performance. Doing so overcomes any scholarly discussions (although highly valuable for further research) on whether higher 'overall' maturity levels (combined with relatively low alignment between organizational domains) are better than lower overall maturity levels with a moderately better alignment score.

Therefore, our empirically validated conceptual model (in chapter 7) is of the above nature, interconnecting the three key concepts of PACS maturity, PACS alignment and PACS performance. The model follows the central concept of internal logic among the various dimensions, since it is in accordance with the theories of complexity and CAS. The model is a more parsimonious presentation of the underlying factors gleaning interdependency of complex constructs [218] while simultaneously explaining the emergent nature and dynamics of PACS maturity, alignment and performance in hospitals. It allowed us to state the theory more exactly, test the theory more precisely and yield a more thorough understanding of the empirical data about the complex phenomena and relationships that alignment and maturity embrace.

Based on the empirically tested main hypothesis and 'inner' and 'outer' structures of our multifaceted model, we confirmed that the situational alignment of the components related to PACS, either intended or unintended (i.e. spontaneous self-organization, emergence) has a significant impact on the multifactorial performance of PACS. Therefore, PACS cannot be deployed as a 'static' system within hospitals' meaning, that next to 'traditional' strategic planning, PACS deployment is also an unplanned, 'emergent' process. We suggested (in section 7.6.2.) that hospitals should follow a dual strategic PACS maturity planning perspective that drives a continuous process of change and adaptation as well as the co-evolvement and alignment of PACS. Hence, route 1 follows the logic of an 'intended' PACS strategy and thereby a deliberate (i.e. conscious) planning process. Route 2, on the other hand, follows the logic of an 'emergent' PACS strategy that forms gradually and perhaps unintentionally.

Conscientious readers could now be confused since we have already defined 'two' maturity growth path concepts (evolutionistic and revolutionary) in section 5.2.2, although this is a somewhat more semantic discussion. Growth paths can be considered as an extended method for the management of transitions that are needed to evolve through PACS maturity levels. By definition, these growth paths are – initially[1] – part of an 'intended' PACS strategy and thereby a deliberate (i.e. conscious) planning process. That is to say, these growth paths are of a different order and can be part of 'route 1' of our dual strategic PACS maturity planning perspective.

8.3.4 "Multiple stakeholders have a common ground concerning PACS maturity"

We addressed, in chapter six, the importance of a multiple-stakeholder perspective reducing the common source variance associated with sampling from the same source [77, 204], while simultaneously excluding face validity. In addition, we explicitly assumed that low variation (i.e. low standard deviation) between scores per maturity level (and organization dimensions) indicates that there is a level of agreement between

[1] One should take into account that hospital boards tend to define their growth paths and roadmaps based on their specific short- and long-term needs. Consequently, hospitals could be driven in daily practice by external, market-driven and non-market-driven factors, leading to 'emerging' and sometimes 'opportunistic' strategic planning. In retrospect, the maturation of PACS might then be classified as being of an evolutionary or revolutionary nature.

the respondents of each specific hospital. In addition, we assumed that there would be a decreasing mean score for each next maturity level per organizational dimension, confirming the cumulative order of the maturity items as defined by our integrative framework. We explicitly addressed the latter assumption, while the former issue is not articulated and is lacking in-depth attention in our study that initially accentuated an incremental development method of a framework and survey. During our evaluation of the pilot survey outcomes, it appeared that several PACS performance questions were initially radiology-specific, suggesting modification was needed so that other informants would be able to address the subject matter.

In chapter seven, we adopted the above multiple-stakeholder perspective in the assessment of our proposed higher-order conceptual model. We obtained a response rate of over 70% with follow-up actions and obtained a representative data sample of hospitals in the Netherlands in terms of type and size. Also, the sample characteristics showed comparable amounts of respondent categories (i.e. heads of the radiology departments, heads of technologists and PACS/RIS administrators). It should be noted that we were able to persuade twelve hospitals to fill in more than one questionnaire. This allowed us to check for inter-respondent validity/agreement. Besides agreement between the appraisals of multiple stakeholders of those twelve hospitals, the main argument for using a single survey was, in most cases, that the submitted questionnaire was representative of the other respondents. This strengthened our belief that the scores per hospital could be combined under the assumption that the various stakeholders have a common ground concerning the subject matter of PACS maturity and performance.

For future research, although we accounted for the possible moderating effects (i.e. interaction effects) within our data through the multisample/group approach [244, 245], it would be interesting to consider the in-depth differences among group segments for heterogeneity issues.

8.3.5 Summary

In this section, we have endeavored to provide readers with insight concerning the ‘key’ decisions (i.e. *A*: the BSC is a valuable but limited performance instrument for PACS, *B*: concepts of organizational alignment are complementary to PACS maturity, *C*: multifaceted models imply interaction effects and *D*: multiple stakeholders give representative answers) made during the research. Obviously, additional studies need to be conducted to address all the identified topics of interest and the (measurement) challenges encountered thus far. These reflections, among others, will be consolidated into topics for future research in the next section.

8.4 LIMITATIONS AND AVENUES FOR FURTHER RESEARCH

Despite the attractiveness of our findings, our work is subject to several limitations that suggest caution is required with the interpretation of the findings. These limitations suggest avenues for further research, which will be subsequently addressed.

8.4.1 EMPIRICAL SCOPE

Our work empirical work – although sufficiently large for our study purposes – is limited to hospitals in the Netherlands. We believe that our framework is applicable to hospitals worldwide but it is our ambition to *extend this research to other countries* within Europe, and then onto the United States and so on. Comparing results across countries and groups might well contribute to the generalizability of our findings. This simultaneously provides various opportunities to *reassess the model* and evaluate individual and overall model fit measures for its robustness.

Likewise, using larger research samples, *a priori* and *ex post* structured data segmentation and group analysis, for instance based on demographic variables (e.g. type, size, region) could be applied to the empirical data. Future research could elaborate on the analysis of the principal mechanisms that contribute to the higher explained variances of our model and include *multiple group comparison* in their analysis. Another interesting extension would be to investigate whether or not adapting or recombining the existing organizational dimension (of our conceptual model) into others would have a significant impact on the overall model fit and coefficients of determination. Such findings provide a platform for acquiring further differentiated conclusions given the segment-specific parameter estimations.

We obtained our data at a single point in time. However, to gain a clear understanding of the incremental development (i.e. evolution and maturity) of PACS within hospitals, longitudinal analysis could be beneficial. We argued that PACS resembles the principle of a complex adaptive system that is continuously changing, adapting (non-linearly) to environmental requirements and unplanned changes and co-evolving as whole entities with respect to their mutually interdependent parts. Therefore, current strategic plans and the alignment patterns of hospitals might not be effective over an extended period of time. Such *a longitudinal approach* offers various opportunities for future research concerning strategic planning, the alignment of PACS and advancing PACS performance.

8.4.2 PRACTICAL SCOPE

Medical imaging developments continue to emerge, and new literature results and insights are being published at a rapid pace. Currently, five levels of maturity have been identified (within our stage-based PMM), but this does not imply that developments will come to a standstill after hospitals have reached the 'optimized PACS enterprise chain' level. The field is becoming multidisciplinary, maturing and expanding to include imaging throughout the entire enterprise (imaging) chain. Developments and disruptive innovations also continue to emerge. Therefore, it would be an interesting elaboration to perform a *systematic meta-analysis on PACS maturity and evolvability literature in later years*. A result might be that the PMM needs to be extended or revised.

Furthermore, the primary focus of our study is on PACS, although this is closely related to other medical IS/IT within the hospital such as RIS, HIS, ePR, computerized provider order-entry and so on. In that respect, it would be a logical step to explore possibilities to extend our concepts on alignment, maturity and complexity theory towards *medical IS/IT in general*. Likewise, it would be interesting to investigate whether seemingly distinct and not closely related medical IS/IT within hospitals (from for instance pathology, the laboratory, pharmacy and other important medical disciplines) could be matured and interfaced with each other, via for instance standard exchange protocols. Then, we could explore whether this has any relevant and significant impacts upon workflow efficiencies, decision support, interdisciplinary processes, accurate information for clinicians, physicians and hospital management and effective and qualitative care. It goes without saying that this is not an easy task to achieve. However, this would be a valuable extension to our PACS maturity perspective and could provide the much-needed insight to make justified trade-offs in developing hospital-wide ePR's – and to decide which specific medical IS/IT to integrate – and even nationwide clinical depositories and medical/health records.

Finally, in essence, PACS is a *complex adaptive system* that evolves, adapts and embraces a dynamic (i.e. emergent) nature within hospitals. The outcomes of this dissertation suggest that this perspective is a valuable contribution to the analysis and understanding of PACS maturity, strategic planning and performance implications in hospitals. However, the implications of complexity sciences and complex adaptive systems for strategic management practice and decision-making processes within hospitals are by no means well defined and comprehensible. This offers many opportunities for future research because the underlying assumptions differ from those of classical science and management practice.

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PACS maturity levels

PACS maturity level	PACS process focus	Used references
1) *PACS Infrastructure* ❑	Basic and unstructured usage of the following processes: ➢ Image acquisition process ➢ Storage process ➢ Image distribution process ➢ Display process	✓ [168] ✓ [21] ✓ [167]
2) *PACS Process* ❑❑	The process focus of the "PACS Process" maturity level is on: ➢ PACS process redesign ➢ Quality & transparency ➢ Optimizing manual PACS processes ➢ Initiation of system integration ➢ Qualitative measurements	✓ [173] ✓ [20, 47, 113, 132, 170, 171, 265] ✓ [167] ✓ [153] ✓ [136]
3) *Clinical Process Capability* ❑❑❑	The process focus of the "Clinical Process Capability" maturity level is on: ➢ Hospital-wide PACS (web) distribution & communication ➢ Control/status management ➢ Patient (folder) management ➢ Image-based clinical action ➢ HIS/RIS/PACS (multimedia) integration ➢ Workflow management ➢ Teleconferencing/consultation & e-learning	✓ [130] ✓ [173] ✓ [22] ✓ [174] ✓ [172] ✓ [167] ✓ [12] ✓ [266] ✓ [166] ✓ [152] ✓ [175] ✓ [22]

4) *Integrated Managed Innovation* ❑❑❑❑	The process focus of the “Integrated Managed Innovation” maturity level is on: ➢ Quantitative/statistical control mechanism ➢ Clinical diagnosis and decision support ➢ Technological adoption (e.g. CAD, IASS, FFDM, bone age assessment) ➢ Cross-enterprise PACS Exchange ➢ Initiation of PACS integration within ePR ➢ (Intelligent) data-mining ➢ Clinical collaboration	✓ [173] ✓ [174] ✓ [172] ✓ [178] ✓ [174, 175] ✓ [135, 267] ✓ [32, 140, 166, 179, 180] ✓ [23, 157] ✓ [31] ✓ [152] ✓ [12] ✓ [267] ✓ [177] ✓ [176]
5) *Optimized Enterprise PACS Chain* ❑❑❑❑❑	The process focus of the “Optimized Enterprise PACS Chain” maturity level is on: ➢ Continuous clinical PACS optimization ➢ PACS Process innovation ➢ Full enterprise PACS chain integration ➢ Full integration with patient-centered ePR	✓ [31, 140] ✓ [179, 180] ✓ [176] ✓ [23, 157] ✓ [31] ✓ [32] ✓ [166] ✓ [157]

Multifactorial PACS performance[1]

Performance constructs	Measurements	Definition of performance measurement
Clinical contribution		
• Interpretation agility	Interpretation time per modality examination	Time to process a series of exams (dictation usually overlaps this process) after quality control
• Efficacy of PACS	Diagnostic accuracy	Sufficiency rate of current radiology workspaces and viewing monitors for image interpretation
• Contributions to clinical communication and collaboration	Communication efficacy	PACS contribution towards the communication of critical findings and interdepartmental collaboration
• Therapeutic intervention	Patient management contribution	Contribution of PACS towards decision-making in diagnostic processes or treatment plans of patients
Organisational efficiency		
• Timeliness of radiology report	Report-turnaround-time	Sum of time after execution, reporting and the availability of imaging exams' finalized report (includes dictation turnaround time)
• Productivity	Number of examinations	The amount of yearly radiology exams per full time equivalent radiologist
• Cost-effectiveness	Budget ratio or cost prise	Percentage (over)expenditures of the allocated PACS budget or a cost prise per modality exam
Service outcomes		
• Perceived service to patients	Patient satisfaction	Satisfaction of patients on service delivery
• Service delivery to referring physicians	Referring physician satisfaction	Satisfaction of referring clinicians on availability of imaging data and associated reports
• Service delivery to users	User satisfaction	User satisfaction on the current user interface and functionality of the PACS
• Patient flow & throughput	Patient waiting time	Elapsed time between a patients' arrival at radiology (on appointment) and the subsequent exam
Technical information system perspective		
• Instantaneous image display of newly acquired images	Average time-to-display	Average time-to-display of newly acquired images (with full data set of screen)
• Old images availability	Average time-to-display	Average time-to-display of old images (with full data set of screen) from the digital archive

[1] We adopted the outcomes of a meta-analytic approach that synthesized original PACS sources. Based on 37 papers published between 2000 and 2009 that were included for review purposes (after applying several inclusion criteria having retrieved 980 key publications and positioning papers), descriptive performance constructs were defined.

Pilot survey statements

This appendix[1] contains all statements and measures of our piloted survey. It includes the five organizational dimensions – including maturity levels (ML) – and all PACS performance items. For each organizational dimension statement, a typical seven-point Likert scale was applied (see section 6.3.1). For PACS performance, the scale is included in the table. For each ML, two questions (Q1, Q2) were included. Based on our rigorous approach, we believe that two questions are optimal from both a scientific and practical perspective. In addition, the experts were convinced this would cover sufficient amounts of detail.

Organizational dimension 1: strategy and policy	
ML 3	(Q1) Short and long term (investment) plans concerning PACS are aligned between radiology and other departments/wards
	(Q2) Within the hospital emphasis is on direct display of images from the archive instead of required storage capacity
ML 4	(Q1) Integration of PACS with the Electronic Patient Record (ePR) is an important strategic objective of the hospital
	(Q2) The basic principal with the usage of PACS is primary interpretation by radiologists using uncompressed (highest resolution) images from all modalities
ML 5	(Q1) The external environment is consciously inquired for new developments and products to optimize PACS functionality
	(Q2) Strategic and operational (multiyear) plans contain impact and opportunities for chain partners with respect to PACS
Organizational dimension 2: organization and processes	
ML 3	(Q1) The hospital actively improves its service level using quality standards and measures for digital PACS workflow
	(Q2) All departments of the hospital enterprise can request and plan radiology exams using an electronic order-entry system (that is integrated with PACS/RIS)
ML 4	(Q1) All diagnostic images from other departments (including cardiology, nuclear medicine, endoscopy, gynaecology, pathology) are stored into one central PACS archive
	(Q2) At each dedicated workspace radiologists have all required patient information (e.g. lab results, reports, previous studies, etc.) and integrated 2D/3D reconstruction tools
ML 5	(Q1) The hospital exchanges PACS-data real-time with chain partners using standard exchange protocols (cross-enterprise document sharing/XDS-i) if necessary
	(Q2) Every image (including old images for comparison) is instantly available on any workstation in the hospital for every user at any time
Organizational dimension 3: monitoring and control	
	(Q1) Prognosis concerning the amount of radiology exams and required PACS

[1] Statements for maturity level 1 and 2 for each organizational domain are omitted for practical reasons and due to the fact that all Dutch hospitals have a PACS implemented (initial maturity level). Level 2 can be deducted from assigned scores to level 3 statements.

ML 3	storage capacity are performed on a recurrent basis
	(Q2) The hospital measures and monitors both financial and non-financial PACS data (e.g. amount of exams, quality, patient satisfaction, productivity, etc.)
ML 4	(Q1) Service level agreements (SLA) with PACS-vendors (for instance concerning maintenance, functionality, costs and storage capacity) are periodically evaluated
	(Q2) PACS generates comprehensive management information that is always on time
ML 5	(Q1) The hospital confronts PACS vendors if SLA's are not (or partially) achieved
	(Q2) The hospital has an accurate overview of the contribution of PACS to overall cost prices per radiology exam (for al modalities)
Organizational dimension 4: information technology	
ML 3	(Q1) PACS is compatible with current international standards and classifications (Health Level 7 and Digital Imaging and Communication in Medicine - DICOM)
	(Q2) PACS exchanges information with the radiology information systems (RIS) and hospital information system (HIS) without any complications
ML 4	(Q1) The hospital adopts standard 'off-the-shelve' - vendor independent - hardware (for archiving solutions) and software for PACS
	(Q2) The impact on PACS storage capacity and requirements are prognosed due to upgrades with respect to modalities or newly acquired devices.
ML 5	(Q1) The hospital applies reagent (security) protocols throughout the hospital enterprise in preserving privacy of patient data, PACS data security and back-up (incl. preventing a 'single point of failure')
	(Q2) PACS is integral part the hospitals' ePR
Organizational dimension 5: people and culture	
ML 3	(Q1) The hospital actively involves users of PACS with the development of customizable user-interfaces
	(Q2) PACS process and procedure knowledge are extensively applied within the hospital by clinicians and technologists
ML 4	(Q1) End-users of PACS affect the decision making process in selecting a specific PACS vendor
	(Q2) End-users affect digital PACS-workflow and functionality improvements
ML 5	(Q1) Radiologist are aware of the fact that PACS has the potential to influence the competitive position of the hospital and service delivery to chain partners
	(Q2) Innovative solutions (e.g. integration of new tools and applications) with PACS are discussed during clinico-radiological meetings

PACS performances (and ID)	*Applied answer scale*
Clinical contribution	
Interpretation time (C1): time to process a series of CT exams (defined as the time interval between availability of full data set on screen and finalization)	*Likert 1-7* (< 5 min, 5-8, 8-11, 11-14, 14,17, 17-20, > 20 min)
Diagnostic accuracy (C2): sufficiency rate of current radiology workspaces (including viewing monitors) for image interpretation	*Likert 1-7* (0-20%, 20-40, 40-60, 60-70, 70-80, 80-90, 90-100%)
Communication efficacy (C3): PACS contribution towards communication of critical findings and interdepartmental collaboration	*Likert 1-7* (no contribution at all - profound contribution)
Patient management contribution (C4**)**: contribution of	*Likert 1-7* (no contribution

PACS towards decision-making in diagnostic process or treatment(plan) of patient	at all - profound contribution)
Organizational efficiency	
Report-turnaround-time (O1): sum of time after execution, reporting and availability of imaging exams' finalized report of CT-exams	*Likert 1-7* (< 2 hours, 2-4, 4-6, 6-8, 8-10, 10-12, >12 hours)
Budget ratio (O2): percentage (over)expenditures of allocated PACS budgets	*Likert 1-7* (no over expenditure, 0-10%, 10-20, 20-30, 30-40, > 40%)
Service outcomes	
Patient waiting time (S1): elapsed time between a patients' arrival at radiology (on appointment) and subsequent exam	*Likert 1-7* (< 5min, 5-10, 10-15, 15-20, 20-25, 25-30, > 30 min)
Referring physician satisfaction (S2): satisfaction of referring clinicians on availability of imaging data and associated reports	*Likert 1-7* (totally not satisfied - totally satisfied)
Patient satisfaction (S3): satisfaction of patients on service delivery	*Likert 1-7* (totally not satisfied - totally satisfied)
User satisfaction (S4): user satisfaction on the current user interface and functionality of PACS	*Likert 1-7* (totally not satisfied - totally satisfied)
Technical information system perspective	
Average time-to-display (T1): average time-to-display of old CT-studies (with approximately 400 images) from PACS (with full data loaded on screen)	*Likert 1-7 (<10 sec, 10-20, 20-30, 30-60, 60- 5 min., > 5 min., sometimes no retrieval)*
Average time-to-display (T2): Average time-to-display of newly acquired CT-studies (with approximately 400 images) from PACS (with full data set of screen)	*Likert 1-7 (<5 sec, 5-10, 10-20, 20-30, 30-60, 60- 5 min., > 5 min.)*
Display time (T3): each dedicated workstation is capable of displaying uncompressed CT-studies - averaging 1500-2000 images - without any delay	*Likert 1-7 (totally agree - totally not agree)*

Publication list

Main international refereed publications

[1] Van de Wetering, R., Batenburg, R., Oudkerk, M., Van Ooijen, P.M.A., Brinkkemper, S., and Scheper, W., *A situational alignment framework for PACS.* Accepted for publication in the Journal of Digital Imaging, 2010.

[2] Van de Wetering, R., Batenburg, R., and Lederman, R., *Evolutionistic or revolutionary paths? A PACS maturity model for strategic situational planning.* International Journal of Computer Assisted Radiology and Surgery, 2010. **5**(4): p. 401–409.

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International refereed publications and abstracts

[6] Van de Wetering, R. and Batenburg, R., *Defining and formalizing: a synthesized review on the multifactorial nature of PACS performance.* International Journal of Computer Assisted Radiology and Surgery, 2010. **5**(Suppl. 1): p. 170.

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Other publications

[9] Van de Wetering, R. and Batenburg, R., *PACS integrated situational alignment framework: a quantitative approach for successful PACS alignment and performance assessment in hospitals*, in *3rd SIKS/BENAIS Conference on Enterprise Information Systems*. 2008: Tilburg.

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Summary

Worldwide health-care systems today face strong pressure to improve clinical quality, enhance and improve service efficiency, expand access and reduce costs. As investments in health care are generally large and process critical in the case of medical imaging technology, the need for structured implementation, measurement approaches and holistic evaluation methods is expanding [14, 15]. The fact that hospitals around the world are strategically planning and preparing for future radiology needs and re-evaluating their current Picture Archiving and Communication Systems (PACS) implementations – to enhance overall system performance – reflects this demand [16].

In essence, PACS acquires medical images digitally from several modalities in the radiology department (e.g. computed tomography, magnetic resonance imaging, ultrasound, plain X-ray), stores them in central data repositories, enables (post-) processing, analysis and image interpretation and makes imaging data available on display upon request by, for instance, referring clinicians. This foundation for the all-digital practice of radiology [18] touches upon every single part of the imaging workflow chain and associated sub-steps that affects the quality of imaging services and clinical outcomes [19, 20].

This dissertation addresses an important omission in the PACS literature and medical informatics in general by elaborating the concepts of maturity (i.e. classifying systems according to their stage of development and evolutionary plateau of process improvement), organizational alignment (i.e. investments made in organizational domains related to PACS should be balanced out in the organization to obtain synergizing benefits) and complex adaptive systems and complexity theory (i.e. interdisciplinary theories that study the behavior of interacting components of dynamic, non-linear systems) to understand how key benefits and PACS performance in clinical practice can be achieved [40]. PACS directly affects patient care, clinical workflow and clinical effectiveness [23], and achieving the strategic alignment of PACS and pursuing its intended goals and objectives within hospitals seem to be an intricate and poorly examined process. We highlight the value of a PACS evaluation and maturity framework that enables hospitals to reflect holistically on their PACS performance of adopted systems and supports the process of maturing PACS into hospital operations. Elucidating from previous scientific work, our main research question is ‘how can hospitals mature their PACS?’

This dissertation consists of three interrelated parts. The first part explores the impacts of PACS on hospital workflow using a holistic approach that provides fundamental features for assessing PACS from various perspectives. An expanded model is developed, as a much more appropriate tool for examining PACS. In doing so, a classical Balanced Scorecard (BSC) is modified to reflect the nature of the clinical values of hospital strategy. This model is then subsequently applied to a major public hospital that implemented a hospital-wide PACS to improve its workflow and patient care.

The second part of this dissertation synthesizes the PACS literature on maturity and evolvability in hospitals and defines the PACS Maturity Model (PMM); see Figure 9-1. The PMM describes five levels of PACS maturity and the corresponding process focus. This is subsequently extended as a strategic planning method for PACS deployment, based on the elaboration of the strategic alignment concept and the maturity growth path concepts for the PACS domain. The PMM enables hospitals to quantify PACS maturity and relate this to PACS deployment performances. This model, as a foundation for its underlying body of knowledge and rigorous theoretical approach, allows hospitals to mature PACS systematically in hospitals.

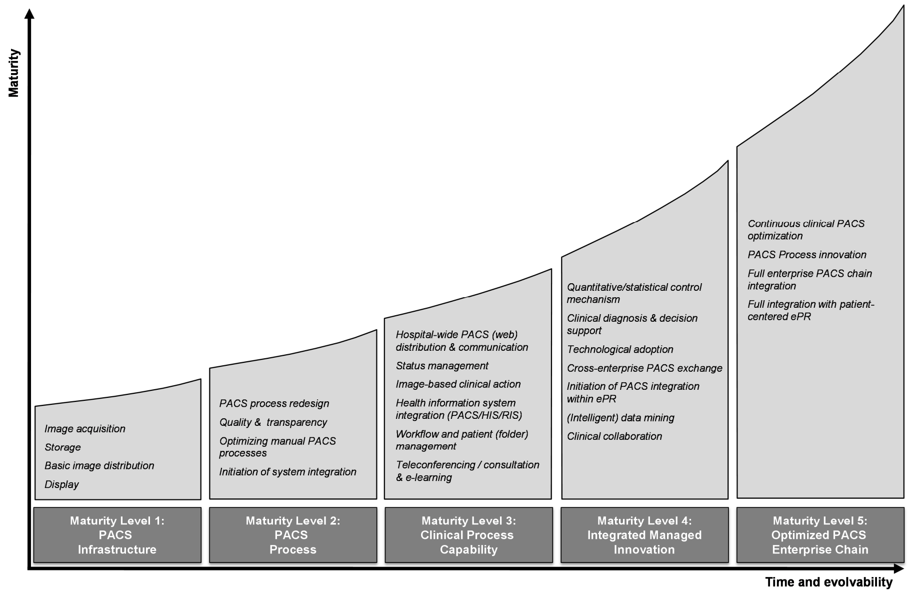

Fig. 9-1 The PACS maturity model

Finally, the third part develops a rigorous perspective and method that supports the process of situationally aligning PACS (i.e. being dependent on hospital-specific resources, capabilities and the use of PACS) in hospitals. We develop such an integral (i.e. holistic) model to assess empirically the maturity and organizational alignment of PACS and its impact upon PACS performances – defined as the multifactorial impacts and benefits produced by the application of PACS in terms of hospital efficiency and clinical effectiveness with respect to PACS workflow and patients' clinical journeys [48] – in hospitals. From this conceptual model an integral hypothesis is generated. We statistically test this hypothesis (and thereby our perspective) using Structural Equation Modeling (SEM) with data from 64 hospitals within the Netherlands. In addition, we provide some general strategic guidelines for optimization concerning PACS deployment and maturity. This holistic model enriches the concept of IT maturity and business/IT-alignment with systems and complexity theory. These theories contribute to a holistic approach that fits with the complex nature of enterprise-wide PACS and the complexity of hospitals as complex organizational systems of medical practice.

A key conclusion of this dissertation is that our main hypothesis was empirically tested and found to be true. Based on the validated ‘inner’ and ‘outer’ structures of our operationalized higher-order (multidimensional) SEM model, we conclude that our conceptual model – validated through data from 64 hospitals within the Netherlands – shows a significant positive impact for the PACS alignment construct on perceived PACS performance. Thus, our expectation that the alignment of components related to PACS had a significant impact on the multifactorial performance of PACS in terms of efficiency and effectiveness was confirmed. Based on various sources (case studies, conceptual design, meta-analyses and survey research) a PACS evaluation and maturity framework is developed that enables hospitals to reflect holistically on their PACS performance of adopted systems and likewise has predictive power to explain PACS performance within hospitals’ operations. The framework supports a strategic and systematic deployment of PACS to enhance subsequent evolvability and reduce maturity complications.

Based on the outcomes of the various studies included in this dissertation, we believe that hospitals should follow a strategic PACS maturity planning perspective that drives a continuous process of change and adaptation as well as the co-evolvement and alignment of PACS. Adaptability and changeability should be integral properties, next to traditional and deliberate PACS strategic planning. Within hospitals, decision makers need to cope with organizational and information system changes that occur in non-linear turbulent health-care environments, otherwise impractical and unrealistic expectations are set and poor decisions are made in uncertain environments, leading to an unrealized PACS strategy [253]. This offers many opportunities for future research because the underlying assumptions differ from those of classical science and management practice.

The relevance of this research is therefore of a scientific as well as of a practical and societal nature. It extends the body of knowledge concerning PACS maturity and its evaluation from a business informatics perspective. This is important since the filmless facilities of PACS can be exploited much further, to achieve higher productivity levels and operational efficiency gains in hospitals.

Research in the PACS domain will not come to a standstill. On the contrary, we acknowledge that the research field is still evolving and expanding to include imaging throughout the enterprise chain, and developments and disruptive innovations are continuing to emerge. Therefore, research and development are now vital.

Nederlandse samenvatting

Wereldwijd staan hedendaagse zorgstelsels onder grote druk om de kwaliteit van zorg en de efficiency van dienstverlening te verbeteren, toegang tot zorg uit te breiden en toenemende zorgkosten te reduceren. Benodigde investeringen in de gezondheidszorg zijn doorgaans groot en van essentieel belang als het medische beeldvormingstechnologie betreft. Daarmee groeit tevens de behoefte aan effectieve implementatie- en meettoepassingen en holistische evaluatie technieken [14, 15]. Deze behoefte wordt bevestigd door het feit dat ziekenhuizen over de gehele wereld strategische plannen maken, zich voorbereiden op toekomstige behoeften, en hun huidige Picture Archiving and Communication System (PACS) implementaties opnieuw evalueren om de algehele systeemprestaties te verbeteren [16].

In essentie verkrijgt PACS diagnostische beelden digitaal van verschillende modaliteiten (bijvoorbeeld computertomografie, magnetische resonantie, echografie, gewone X-straling) binnen de radiologieafdeling, slaat deze beelden op in centrale databases, maakt nabewerking, analyse en interpretatie mogelijk en stelt beeldgegevens op verzoek beschikbaar aan bijvoorbeeld doorverwijzend artsen. Dit fundament voor de geheel gedigitaliseerde radiologiepraktijk [18] raakt elk onderdeel van de imaging werkprocesketen en de daarbij horende (vervolg)activiteiten en beïnvloedt daarmee de kwaliteit van imaging service en klinische resultaten [19, 20].

Dit proefschrift vult een belangrijk hiaat op in de bestaande PACS literatuur en medische informatica in het algemeen. Door in detail concepten van maturity (i.c. systemen classificeren aan de hand van hun ontwikkelniveau en evolutionair plateau van procesverbetering), organisatorische alignment (i.c. investeringen in organisatiecomponenten gerelateerd aan PACS dienen op elkaar te zijn afgestemd om synergetische effecten te bewerkstelligen) en complex adaptieve systemen en complexiteitstheorie (i.c. interdisciplinaire theorieën die het gedrag van interacterende componenten van dynamische, niet-lineaire systemen bestuderen) te bestuderen, wordt in kaart gebracht hoe belangrijke efficiencywinsten en PACS prestaties in de praktijk gerealiseerd kunnen worden [40].

PACS heeft een directe invloed op de patiëntenzorg, diagnostische processen en effectiviteit van artsen [23]. Echter, het realiseren van optimale (strategische) afstemming van PACS op (diagnostische)processen en het nastreven van de beoogde doelen/doelstellingen binnen ziekenhuizen, lijkt een ingewikkeld en onvoldoende geadresseerd onderwerp in de wetenschappelijke literatuur. Daarom benadrukken wij de toegevoegde waarde van een PACS evaluatie en maturity raamwerk, dat ziekenhuizen in staat stelt om op een holistische wijze te reflecteren op de huidige PACS prestaties en tevens het ontwikkelproces van PACS in ziekenhuizen ondersteunt. Gebaseerd op reeds uitgevoerd wetenschappelijk onderzoek, is onze centrale onderzoeksvraag ‘hoe kunnen ziekenhuizen hun PACS ontwikkelniveau verbeteren?’

Dit proefschrift bestaat uit drie aaneengesloten delen. Het eerste deel verkent de impact van PACS op de werkprocessen van een ziekenhuis middels een holistische benadering die de fundamentele eigenschappen biedt voor het beoordelen van PACS vanuit verschillende perspectieven. Een uitgebreid model wordt ontwikkeld, als een geschikt instrument voor het onderzoeken van PACS. Hierbij wordt een klassieke Balanced Scorecard (BSC) aangepast om de klinische waarden van ziekenhuisstrategieën te reflecteren. Dit model wordt vervolgens toegepast bij een groot openbaar ziekenhuis dat een ziekenhuisbreed PACS heeft geïmplementeerd om de werkprocessen en patiëntenzorg te verbeteren.

Het tweede deel van deze dissertatie doorgrondt de PACS literatuur over maturity en evolutiemogelijkheden in ziekenhuizen en definieert het PACS Maturity Model (PMM), zie Figuur 9-2. Het PMM beschrijft vijf verschillende PACS ontwikkelstadia met de daarbij horende procesfocus. Dit model wordt vervolgens uitgebreid als een strategische planningsmethodiek ten behoeve van PACS implementaties, gebaseerd op de uitwerking van strategisch alignment- en maturity groeipad concepten voor het PACS domein. Het PMM stelt ziekenhuizen in staat om PACS maturity te kwantificeren en te relateren aan implementatieprestaties. Dit model, als fundament vanwege haar uitgebreide kennisdomein en rigoureuze theoretische benadering, ondersteunt ziekenhuizen om PACS stelselmatig in ziekenhuizen te evolueren.

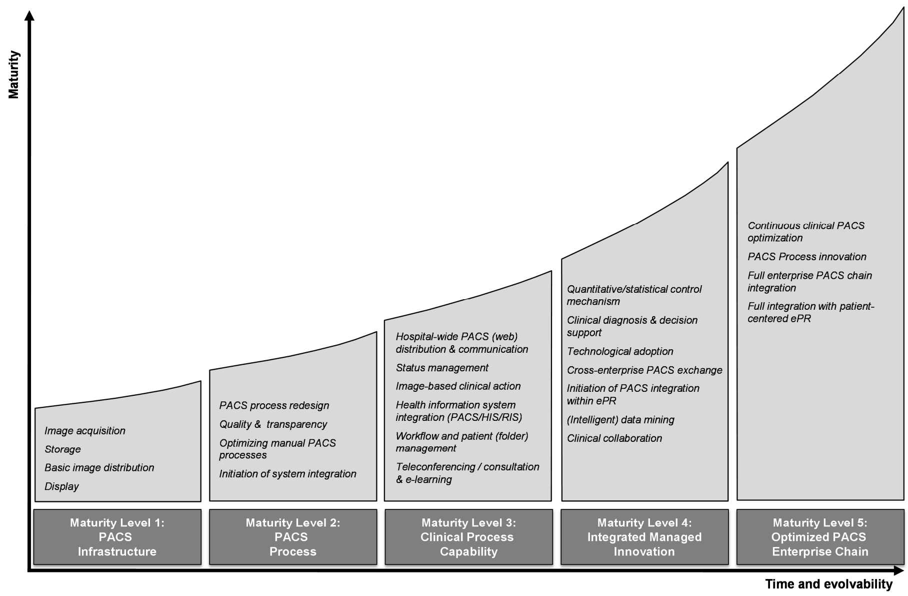

Fig. 9-2 Het PACS maturity model

Ten slotte, het derde deel ontwikkelt een rigoureus perspectief en methodiek die het proces van situationeel PACS alignment (i.c. afhankelijk van ziekenhuis specifieke resources, competenties en het gebruik van PACS) binnen ziekenhuizen ondersteunen. We ontwikkelen een dergelijk integraal model om de mate van maturity en organisatorisch alignment van PACS en de impact hiervan op PACS prestaties – gedefinieerd als de multifactoriële effecten en opbrengsten als gevolg van het gebruik van PACS in termen van ziekenhuisefficiëntie en klinische doeltreffendheid met betrekking tot PACS workflow en de klinische patiënttrajecten [48] – in ziekenhuizen empirisch te toetsen. Op basis van dit conceptueel model wordt een integrale hypothese opgesteld. We toetsen deze statistisch (en daarmee tevens ons nieuwe perspectief) met behulp van structurele vergelijkingsmodellen (Structural Equation Modeling, SEM) aan de hand van gegevens van 64 ziekenhuizen in Nederland. Tevens worden algemene strategische richtsnoeren uiteengezet met betrekking tot PACS implementaties en maturity optimalisatie. Dit integrale model verrijkt de concepten van IT-ontwikkelingsniveaus en business/IT-alignment met systeem- en complexiteitstheorie. Deze laatste theorieën dragen bij aan een holistische benadering die past bij de complexe aard van ziekenhuisbrede PACS implementaties en de complexiteit van de ziekenhuizen zijnde complexe organisatorische systemen van de geneeskundepraktijk.

Een belangrijke conclusie van dit proefschrift is dat onze integrale hypothese empirisch is getoetst en bleek te kloppen. Gebaseerd op het ‘meetmodel’ en ‘structureel model’ van ons geoperationaliseerde hogere-orde (multidimensionale) SEM model, concluderen we dat ons conceptuele model – gevalideerd middels gegevens van 64 ziekenhuizen in Nederland – een significant positief effect laat zien tussen het gedefinieerde PACS alignment construct en de gepercipieerde PACS prestaties. De verwachting, dat het alignment van componenten gerelateerd aan PACS een significante invloed heeft op de multifactoriële PACS prestaties in termen van efficiency en effectiviteit, is daarmee bevestigd. Gebaseerd op verschillende bronnen (case studies, conceptueel ontwerp, meta-analyses en survey-onderzoek) is dus een PACS evaluatie- en maturity raamwerk ontwikkeld dat ziekenhuizen in staat stelt om kritisch te reflecteren op de huidige PACS prestaties, dat eveneens het niveau van functioneren van een geïmplementeerd PACS systeem kan verklaren. Het raamwerk ondersteunt de strategische en systematische inzet van PACS om ontwikkel- en evolueerprocessen te verbeteren en maturity complicaties te verminderen.

Gebaseerd op resultaten van diverse studies in dit proefschrift, geloven wij dat ziekenhuizen baat hebben bij een strategisch PACS maturity planningsperspectief, dat een continu proces van verandering en aanpassing stimuleert, alsmede de integrale ontwikkeling en alignment van PACS. Aanpassingsvermogen en de veranderbaarheid dienen hiervan integraal onderdelen te zijn, naast het traditionele en doelbewuste strategisch PACS plannen. Ziekenhuismanagers en beleidsmakers, dienen in te spelen op organisatie- en informatiesysteemveranderingen, die zich continu voordoen in de niet-lineaire turbulente gezondheidszorg, ten einde onpraktische en onrealistische verwachtingen en foute beslissingen, welke leiden tot het niet realiseren van geformuleerde PACS strategieën te voorkomen [253]. Het bovenstaande biedt veel mogelijkheden voor toekomstig onderzoek, omdat de onderliggende aannames afwijken van die van de klassieke wetenschap en managementpraktijk.

De relevantie van dit onderzoek is dan ook van een wetenschappelijk alsook van een praktische en maatschappelijke aard. Het breidt de kennis uit over PACS maturity- en evaluatiemethoden vanuit een bedrijfskundig informaticaperspectief. Dit is belangrijk aangezien de filmloze faciliteiten van PACS verder kunnen worden benut, zodat hogere productiviteitniveaus en verbeterde operationele efficiënties binnen ziekenhuizen kunnen worden behaald.

Onderzoek in de PACS domein zal niet stil komen te staan. Integendeel, wij constateren dat dit onderzoeksveld nog steeds in ontwikkeling is en zich uitbreidt naar imaging over de gehele enterprise (zorg)keten. Daarnaast zullen nieuwe ontwikkelingen en baanbrekende innovaties onverminderd blijven verschijnen. Daarom zijn onderzoek en ontwikkeling nu van cruciaal belang.

About the author

Rogier van de Wetering was born on June 10, 1981, in Rotterdam, the Netherlands. After grammar school, he started studying information sciences at Utrecht University in 2000. After obtaining his propaedeutics, he continued his ‘doctoraal’ (i.e. Bachelor-Master programme) studies at Utrecht University and completed his Masters research in Business Informatics at the Department of Information Systems at Melbourne University, Australia, as a visiting researcher.

He graduated in 2005, after which he started work as a business/IT consultant for Deloitte Consulting in health care and the public sector. In September 2007 he started his PhD – part-time (i.e. one day a week) – at the Center for Organization and Information, Department of Information and Computer Sciences, Utrecht University.

In the summer of 2010, Rogier took a five-month sabbatical leave to dedicate himself fully to his research and dissertation. During these months he presented at various international conferences and was also co-organizer and lecturer of the Medical Informatics Seminar at the Faculty of Sciences. In 2011, within three and a half years from the official start, he successfully finished his PhD research.

Rogier currently works as a senior management consultant at Deloitte and as a researcher at Utrecht University. In addition, he is a lecturer in medical informatics and a supervisor of various students on their theses. He has written many papers and published in highly regarded international journals. He has research interests in many related fields, having made contributions to the foundation of PACS maturity, evolutionistic and revolutionary growth paths for PACS, the application of structural equation modeling, IS/IT balanced evaluation perspectives, business/IT-alignment measurement and the complex adaptive systems perspective for PACS.

His main research program is to develop a general theory of the ‘adaptive’ and ‘emergent’ nature of IS/IT and complex multi-entangled systems: more specifically, the triangular construct of non-linear dynamics of a system’s maturity states, organizational alignment and system performances.