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A Waterfall Three-Stage Multi-Criteria Decision Making Framework for Value Analysis of e-Health Business Models

Faramak Zandi
University of Houston - Clear Lake
Email: Zandi@uhcl.edu

Andy Borchers
Lipscomb University
Email: andy.borchers@lipscomb.edu

ABSTRACT

This paper develops a waterfall three-stage multi-criteria decision making (MCDM) framework which evaluates different e-business models throughout sequential stages of a value stream. This waterfall framework integrates three MCDM stages as follows (1) At the upstream stage of the framework, we prioritize e-business models based on their capabilities to capture the optimal value; (2) At the midstream stage of the framework, we rank the e-business models with respect to their abilities to create the best value; and (3) At the downstream stage of the framework, we identify the best-practice e-health business model which can deliver the highest value to patients.

KEYWORDS: Waterfall Methodology, Three-Stage Multi-Criteria Decision Making, Value Analysis, e-Health Business Model, and Value-Based e-Health Care

INTRODUCTION

Nowadays e-healthcare organizations evaluate their performance through value flows, while they measured success through traditional financial flows in past decades. The e-healthcare organizations put patients first to achieve their sustainable success and grow their market share instead of focus on short-term financial performance. Indeed, e-healthcare services are shifting from volume-based to value-based e-health care (Kaiser & Lee, 2015; Porter & Thomas, 2013). The e-business models are the key first step to value-based success. Therefore, there is a necessity to identify the best practice e-business model which adds the highest value throughout three sequential stages of the value stream: value capture, creation, and delivery. This paper aims to address this issue.

LITERATURE REVIEW

In current literature, little attention has been paid to selecting the best practice e-health business model. Several papers have suggested value-based leadership and management (Amit, & Zott, 2001; Buchko, 2007; Porter, 2009; Ulaga,2003; Viinamäki,2009; and Williams, 2002). Further studies have established a link between value-based management and health care(Feeley et al, 2010; Godbold & Lees, 2013; Graber & Osborne, 2008; Kaplan et al, 2015; Oluwadamilola et al, 2016; Parvinen et al, 2010; Porter & Guth, 2012; Porter et al, 2013; Porter, 2010; Pruzan, 1998; Ulaga, 2003).
Several academic researchers have studied e-business models (Afuah & Tucci, 2000; Applegate, 2001; Barnes & Hunt, 2001; Betz, 2002; Eriksson & Penker, 2000; Gordijn et al,

2000; Hedman & Kalling, 2003; Horsti, 2016; Johnson, 2010; Johnson, 2008; Linder & Cantrell, 2000; Lytras et al, 2009; Magretta, 2002; Osterwalder & Pigneur, 2009; Osterwalder et al, 2005; Pateli & Giaglis, 2004; Rappa, 2004; Rappa, 2004; Rolón et al, 2015; Teece, 2009; Toro-Jarrín el al, 2016; Vasilecas, 2016; Weill, P., and, 2001), but just few studies have focused on value-based business models (Chesbrough & Rosenbloom, 2002; Gordijn & Akkermans, 2001; Kaiser & Lee, 2015; Wirtz et al , 2010; Yang et al , 2016; Ye & Wang, 2013).
To our best knowledge, there is no decision making framework in the existing literature to identify and select the best-practice e-business model in value-based e-healthcare systems. For this purpose, we develop a novel decision making framework for identification of the e-health business model which delivers the highest value to patients.
There are three key challenges to evaluate the e-health business models throughout the three sequential stages of the value stream. The first difficulty originates from the presence of three decision making stages and more than one criterion at each stage. In the current literature, it is very common to use the MCDM methods. However, these methods do not consider more than one stage. The second challenge is related to the fulfillment of each stage before proceeding to the next stage. In order to overcome the first and second challenges, we propose a waterfall three-stage MCDM framework.
The last challenge is corresponding with the integrity of decision makers' (DMs) preference information flow throughout the three sequential stages of the value stream. In order to address the last challenge, the waterfall framework represents the dependency of the three stages using the DMs' preference information flow. In this framework, DMs' preferences are incorporated before, during or after each stage of the waterfall framework as a priori, interactive and a posteriori preference information. First, the optimal order of the e-business models at each stage is considered as the a priori information for the next stage. Then, the orders of the e-business models are adjusted based on the DMs' preferences as the interactive information during each stage. Finally, a minimum level of the DMs' preferences as the a posteriori information is used to eliminate less favorable e-business models after each stage.
Value stream management is a discipline for Lean implementation. Lean techniques allow the e-healthcare organizations to move toward a patient-centered system. The patient-centric healthcare organizations place patient value at the first stage of their business decisions. Indeed, their main goal is to maximize outcomes; since the outcomes are measured based on value capture, we evaluate the e-business models with regard to their capabilities to capture value at the first stage in the waterfall framework. Then, we prioritize the business models with respect to their capabilities to create and deliver the highest value to patients at the next stages of the waterfall framework.
As most measures in the value analysis of the e-business models are based on judgments under uncertainty, they are expressed using imprecise information. Therefore, we develop a fuzzy value analysis to evaluate the three sequential stages of the value stream in the e-business models.
The main contributions of the proposed waterfall three-stage decision making framework are threefold: (1) it integrated three MCDM stages of the value stream for the selection of the best-practice e-business model; (2) it links the DMs' preference information flow through the stages of the value stream; and (3) it develops the crisp value analysis to the fuzzy value analysis.
This paper is organized into five sections. In Section 2, we illustrate the details of the proposed framework. In Section 3, we present a case study to demonstrate the applicability of the waterfall framework. In Section 4, we exhibit a dimensional comparison of the waterfall framework with the existing single-stage MCDM matrices. The paper presents conclusions in Section 5.

THE PROPOSED WATERFALL THREE-STAGE DECISION MAKING FRAMEWORK

The waterfall three-stage decision making framework depicted in Figure 1 along with the mathematical notations and definitions presented in Appendix are used to choose the best practice e- health business model. This Figure represents the structured waterfall methodology to evaluate the e-business models through the three sequential stages including value capture analysis, value creation analysis, and value delivery analysis of the e-business models. It analyzes the e-business models from the upstream stage to the downstream stage just like a waterfall. The first stage uses the linear assignment method to prioritize the e-business models based on their capabilities to capture the optimal value. The second stage utilizes the Linear Programming technique for Multidimensional Analysis of Preference (LINMAP) method to rank e- business model with respect to their abilities to create the best value. The third stage uses the Interactive Simple Average Weighting (SAW) method to identify the best-practice e-business model which delivers the highest value to their patients.

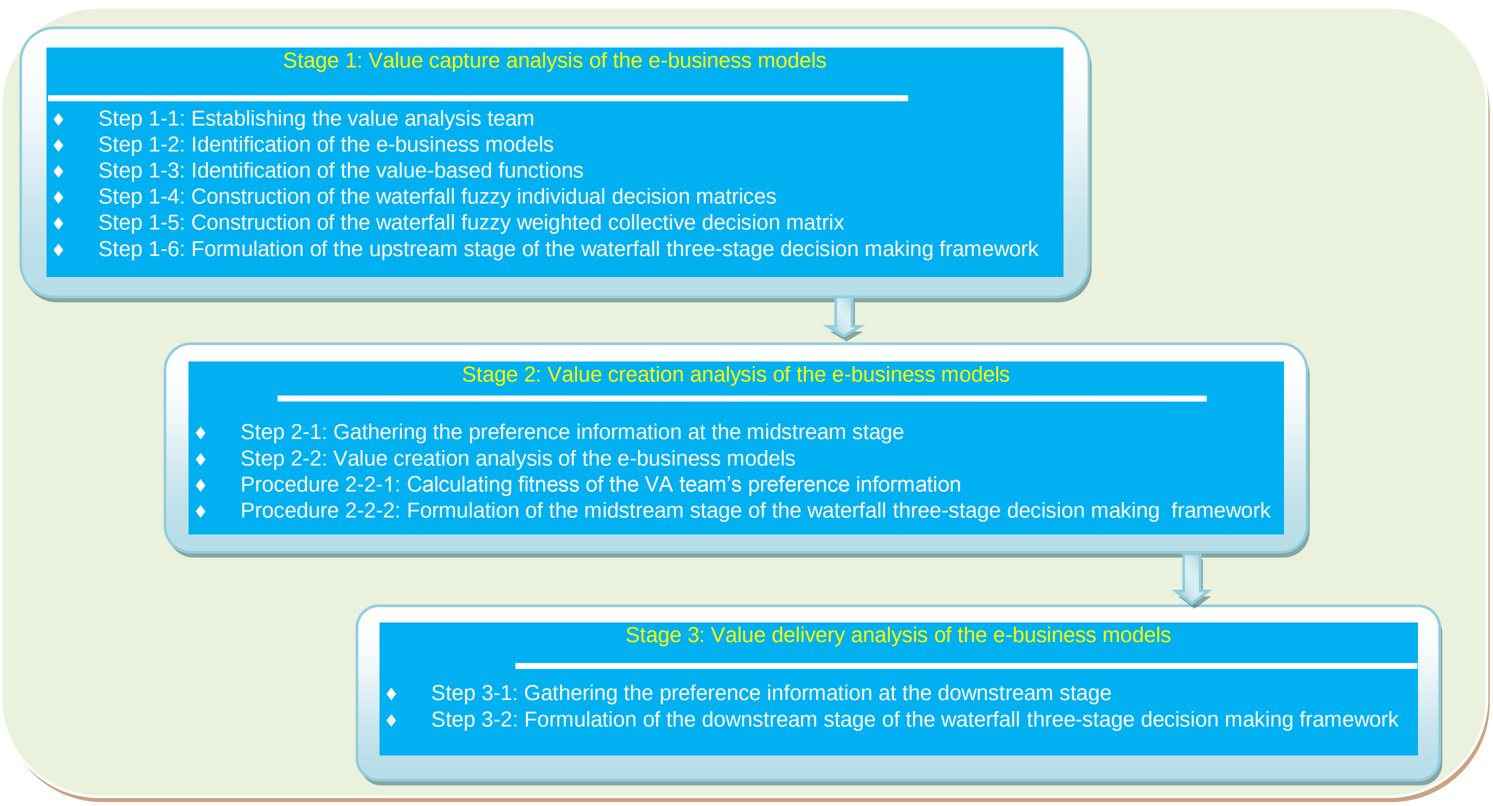


Figure 1: The proposed waterfall three-stage multi-criteria decision making framework for value analysis of the e-health business models

The proposed waterfall framework is as follows:

Stage 1: Value Capture Analysis of the e-Business Models
At this stage, we analyze the abilities of the e-business models to capture the best value. This stage is divided into the following six steps:
Step 1-1: Establishing the value analysis team

In this step, we establish a value Analysis (VA) team as follows:

$$\underline{T(vc)} = [m_1, m_2, ..., m_k, \ldots, m_t] \tag{1}$$

Next, voting power weights of the team members are determined as follows:

$$\underline{D} = [d_1, d_2, ..., d_k, \ldots, d_t] \tag{2}$$

Step 1-2: Identification of the e-business models

In this step, a list of the e-business models is identified. Let us assume that the e-business models have been identified as follows:

$$\underline{B} = [B_1, B_2, \ldots, B_{n_1}] \tag{3}$$

Step 1-3: Identification of the value-based functions

In this step, the VA team identifies a list of value-based functions as decision criteria at each stage of the waterfall framework. Let us assume that we have the following functions:

$$\underline{F(q)} = \left[\, f_1(q),\, f_2(q), \ldots,\, f_{m_1}(q) \right] \;\; q = 1,2,3 \tag{4}$$

Next, the team determines the importance weights of the functions as follows:

$$\underline{W[F(q)]} = \left[w[f_1(q)], w[f_2(q)], \ldots, w[f_{m_1}(q)] \right] \;\; q = 1,2,3 \tag{5}$$

Step 1-4: Construction of the waterfall fuzzy individual decision matrices

In this step, the VA team members construct waterfall fuzzy individual decision matrices which evaluate the e-business models with respect to the value-based functions as shown in Table 1.

Step 1-5: Construction of the waterfall fuzzy weighted collective decision matrix

In this step, the waterfall fuzzy weighted collective decision matrix is constructed using the voting power weights of the VA team members as shown in Table 2. Where the elements of the fuzzy weighted collective decision matrix at each stage of the waterfall matrix are calculated as follows:

$$\tilde{v}(f_{ij}(q)) = \frac{\sum_{k=1}^{t} d_k.[\tilde{v}^k(f_{ij}(q))]}{\sum_{k=1}^{t} d_k} \;\; i = 1,2,\ldots,m_1;\, j = 1,2,\ldots,n; q = 1,2,3 \tag{6}$$

Table 1: The waterfall fuzzy individual decision matrix

		e-business models		
		B_1	…	B_{n_1}
value capture functions	$f_1(1)$	$\tilde{v}^k[f_{11}(1)]$	…	$\tilde{v}^k[f_{1n_1}(1)]$
	⋮	⋮	…	⋮
	$f_{m_1}(1)$	$\tilde{v}^k[f_{m_1 1}(1)]$	…	$\tilde{v}^k[f_{m_1 n_1}(1)]$

		e-business models		
		B_1	…	B_{n_2}
value creation functions	$f_1(2)$	$\tilde{v}^k[f_{11}(2)]$	…	$\tilde{v}^k[f_{1n_2}(2)]$
	⋮	⋮	…	⋮
	$f_{m_2}(2)$	$\tilde{v}^k[f_{m_2 1}(2)]$	…	$\tilde{v}^k[f_{m_2 n_2}(2)]$

		e-business models		
		B_1	…	B_{n_3}
value delivery functions	$f_1(3)$	$\tilde{v}^k[f_{11}(3)]$	…	$\tilde{v}^k[f_{1n_3}(3)]$
	⋮	⋮	…	⋮
	$f_{m_3}(3)$	$\tilde{v}^k[f_{m_3 1}(3)]$	…	$\tilde{v}^k[f_{m_3 n_3}(3)]$

Table 2: The waterfall fuzzy weighted collective decision matrix

		e-business models		
		B_1	…	B_{n_1}
value capture functions	$f_1(1)$	$\tilde{v}\ [f_{11}(1)]$	…	$\tilde{v}\ [f_{1n_1}(1)]$
	⋮	⋮	…	⋮
	$f_{m_1}(1)$	$\tilde{v}\ [f_{m_1 1}(1)]$	…	$\tilde{v}\ [f_{m_1 n_1}(1)]$

		e-business models		
		B_1	…	B_{n_2}
Value creation functions	$f_1(2)$	$\tilde{v}\ [f_{11}(2)]$	…	$\tilde{v}\ [f_{1n_2}(2)]$
	⋮	⋮	…	⋮
	$f_{m_2}(2)$	$\tilde{v}\ [f_{m_2 1}(2)]$	…	$\tilde{v}\ [f_{m_2 n_2}(2)]$

		e-business models		
		B_1	…	B_{n_3}
value delivery functions	$f_1(3)$	$\tilde{v}\ [f_{11}(3)]$	…	$\tilde{v}\ [f_{1n_3}(3)]$
	⋮	⋮	…	⋮
	$f_{m_3}(3)$	$\tilde{v}\ [f_{m_3 1}(3)]$	…	$\tilde{v}\ [f_{m_3 n_3}(3)]$

Step 1-6: Formulation of the upstream stage of the waterfall three-stage decision making framework

In this step, evaluates the abilities of the e-business models to capture value, the VA team uses the linear assignment method to construct the upstream stage of the waterfall framework as shown in Figure 2.

Stage 2: Value creation analysis of the e-business models

At this stage, the team evaluates the abilities of the e-business models to create the best value. This stage is divided into the following two steps:

Step 2-1: Gathering the preference information at the midstream stage

In this step, the VA team uses the optimal solution at the upstream-stage of the waterfall framework as the a priori information for the midstream stage of the waterfall framework. Then, it eliminates the less favorable e-business models based on the minimum preference level.

Step 2-2: Value creation analysis of the e-business models

In this step, the team uses the LINMAP method to evaluate the abilities of the e-business models to create the best value.
This step is divided into the following two procedures:

Procedure 2-2-1: Calculating fitness of the VA team's preference information

In this procedure, supposing that the team's preference information has stated e-business model B_k is better than e-business model B_l, fitness of the preference information is calculated as follows:

$$poorness\,of\;\;fit = \sum_{(k,l)\in D} Max\left\{0,\left[\tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2)\right]\right\} \tag{7}$$

$$goodness\,of\;\;fit = \sum_{(k,l)\in D} Max\left\{0,\left[\tilde{d}_{B_l}(2) - \tilde{d}_{B_k}(2)\right]\right\} \tag{8}$$

where:

$$\tilde{d}_{B_i}(2) = -\sum_{j_2=1}^{m_2} w(f_{j_2}(2)).\tilde{v}(f_{i_2.j_2}(2)) \qquad i_2 = 1, 2, \ldots, n_2 \tag{9}$$

$D = \left\{\left(k,l\right)\right\}$ denotes the team's preference judgments as a set of e-business model pairs $\left(k,l\right)$ so that the e-business model B_k is preferred to the e-business model B_l.

Procedure 2-2-2: Formulation of the midstream stage of the waterfall three-stage decision making framework

In this procedure, formulation of the midstream stage of the waterfall framework is defined as follows:

$$\begin{gathered} Min\ \ poorness\, of\ \ fit \\ \text{St:} \\ goodness\, of\ \ fit - poorness\, of\ \ fit = 1 \end{gathered} \tag{10}$$

or:

$$\begin{gathered} Min \sum_{(k,l)\in D} Max\left\{0, \left[\tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2)\right]\right\} \\ \text{St:} \\ \sum_{(k,l)\in D} Max\left\{0, \left[\tilde{d}_{B_l}(2) - \tilde{d}_{B_k}(2)\right]\right\} - \sum_{(k,l)\in D} Max\left\{0, \left[\tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2)\right]\right\} = \tilde{1} \end{gathered} \tag{11}$$

Assume:

$$Max\left\{0, \left[\tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2)\right]\right\} = \tilde{z}_{kl}(2) \tag{12}$$

Consequently:

$$\tilde{z}_{kl}(2) \geq 0 \, and \; \tilde{z}_{kl}(2) \geq \tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2) \tag{13}$$

Therefore, equations (11) can be rewritten as:

$$\begin{gathered} \text{Min} \sum_{(k,l)\in D} \tilde{z}_{kl}(2) \\ \text{St:} \\ \sum_{(k,l)\in D} \left[\tilde{d}^2_{B_k}(2) - \tilde{d}^2_{B_l}(2)\right] = \tilde{1} \\ \tilde{z}_{kl}(2) \geq \tilde{d}_{B_k}(2) - \tilde{d}_{B_l}(2) \\ \tilde{z}_{kl}(2) \geq 0 \end{gathered} \tag{14}$$

After substituting equation (9) into equations (14), the team uses the obtained LINMAP model at the midstream stage of the waterfall framework, as shown in Figure 2.

The upstream stage of the waterfall decision making framework

$$Max \sum_{j_1=1}^{n_1}\sum_{i_1=1}^{m_1}[w(f_{i_1}(1))[\tilde{v}(f_{i_1 j_1}(1))].x_{i_1 j_1}(1)]$$

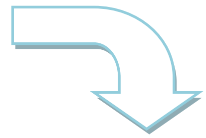
$St:$

$$\sum_{i_1=1}^{m_1} x_{i_1 j_1}(1)=1 \quad j_1=1,2,\ldots,n_1$$

$$\sum_{j_1=1}^{n_1} x_{i_1 j_1}(1)=1 \quad i_1=1,2,\ldots,m_1$$

$$x_{i_1 j_1}(1)=0,1 \quad i_1=1,2,\ldots,m_1;\ j_1=1,2,\ldots,n_1$$

The preference information flow from the upstream stage to the midstream stage of the waterfall sequential MCDM framework



The midstream stage of the waterfall decision making framework

$$Max \sum_{(k_2,l_2)\in D_2(h)} \tilde{z}_{k_2 l_2}(2)$$

$St:$

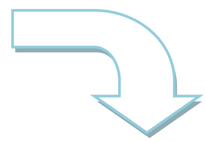
$$\sum_{i_2=1}^{m_2} w(f_{i_2}(2))\left[\tilde{v}(f_{i_2 k_2}(2))]-\tilde{v}(f_{i_2 l_2}(2))]\right]+\tilde{z}_{k_2 l_2}(2)\geq 0$$

$$\sum_{(k_2,l_2)\in D_2(h)} \sum_{i_2=1}^{m_2} w(f_{i_2}(2))\left[\tilde{v}(f_{i_2 k_2}(2))]-\tilde{v}(f_{i_2 l_2}(2))]\right]=\tilde{1}$$

$$\tilde{z}_{k_2 l_2}(2)\geq 0 \qquad (k_2,l_2)\in D_2$$

$$w(f_{j_2}(2))\geq 0 \qquad j_2=1,2,\ldots,n_2$$

The preference information flow from the midstream stage to the downstream stage of the waterfall sequential MCDM framework



The downstream stage of the waterfall decision making framework

$$Max\, z(3)$$

St:

$$\left[[\tilde{v}(f_{[11]}(3))]-[\tilde{v}(f_{[12]}(3))]\right].x_1(3)+\left[[\tilde{v}(f_{[12]}(3))]-[\tilde{v}(f_{[13]}(3))]\right].x_2(3)+\cdots+$$

$$\left[[\tilde{v}(f_{[1(n_3-1)]}(3))]-[\tilde{v}(_{[1n_3]}(3))]\right].x_{n_3-1}(3)+z(3)\leq[\tilde{v}(f_{[11]}(3))]-[\tilde{v}(f_{[12]}(3))]$$

$$\vdots$$

$$\left[[\tilde{v}(f_{[m_3 1]}(3))]-[\tilde{v}(f_{[m_3 2]}(3))]\right].x_1(3)+\left[[\tilde{v}(f_{[m_3 2]}(3))]-[\tilde{v}(f_{[m_3 3]}(3))]\right].x_2(3)+\cdots+$$

$$\left[[\tilde{v}(f_{[m_3(n_3-1)]}(3))]-[\tilde{v}(_{[m_3 n_3]}(3))]\right].x_{n_3-1}(3)+z(3)\leq[\tilde{v}(f_{[m_3 1]}(3))]-[\tilde{v}(f_{[m_3 2]}(3))]]$$

$$x_1(3),x_2(3),\ldots,x_{n_3-1}(3)\geq 0$$

$$z(3):\text{Unconstrained}$$

Figure 2: The proposed waterfall three-stage decision making framework

Stage 3: Value delivery analysis of the e-business models

At this stage, the team analyzes the abilities of the e-business models to deliver the highest value. This stage is divided into the following two steps:

Step 3-1: Gathering the preference information at the downstream stage

In this step, the team uses the optimal decision at the midstream-stage as the a priori information for the downstream stage of the waterfall framework. Then, it eliminates the less favorable e-business models based on the minimum preference level. The adjusted preference information is used as an initial feasible order of e-business models at this stage.

Step 3-2: Formulation of the downstream stage of the waterfall three-stage decision making framework

In this step, the best practice e-business model is identified using the interactive SAW method, as shown in Figure 2.
If the team accepts the optimal solution of this stage, it will be the most preferred order of e-business models. Otherwise, team will present the interactive preference information to improve the current order of the e-business models. This interactive process at the downstream stage continues until the VA team accepts the optimal decision of the downstream-stage.
The following case study demonstrates the applicability of the waterfall framework to identify the best practice e-health business model.

CASE STUDY

An American hospital has been constructed in December 2001. Today the hospital covers a population of around 250,000 people, providing 350 beds and having 1,300 employees, and 200 physicians.
With regard to requirements of the shift from volume-based to value-based e-health care, one of hospital strategic objectives is to perform the best practice e-health business model. For this purpose, the hospital's chief information officer (CIO) considered the implementation of an e-health business model as a separate, core project and offered the proposed waterfall three-stage decision making framework in this study to choose the best practice e-health business model as follows:

Stage 1: Value capture analysis of the e-business models

In the Step 1-1, the hospital's CIO established the VA team including e-healthcare manager, value analyst, e-business analyst, and IT manager as policy makers to support the project.
Next, the voting power weights of the members of the cross-functional team were determined as follows:

$$\underline{D} = [d(1) = 0.25, d(2) = 0.25, d(3) = 0.2, d(4) = 0.3]$$

In the Step 1-2, the team offered the following four e-business models:

b_1: Business Model Canvas (Osterwalder & Pigneur)

b_2: Business Model (Gordijn)

b_3: Business Model (Johnson)

b_4: Business Model (Hedman & Kalling)

Although the waterfall framework proposed in this paper can be used for a wide range of value-based functions, the VA team identified some functions for the evaluation of the four e-business models in the case study. In the Step 1-3, the team identified the following four value capture functions at the upstream stage: (1) Patient Survival: it represents decreased mortality rates; (2) Time to Recovery: it is the expected timeframe for recovery; (3) Sustainability of Recovery or Health over Time: it indicates maintained functional level, acuity of chronic conditions, and medical complications;(4) Degree of Recovery: it determines degree of recovery after critical illness and return to former functional status of patients. Then, the VA team identified the following six creation functions at the midstream stage: (1) Diagnostic and Treatment Accuracy: it defines diagnostic errors and failure in the and treatment; (2) The Ability to Measure Outcomes: it measures the ability of provision of meaningful reports to patients; (3) Reduce Cycle Times across the Care Cycle: it specifies timeframes from diagnosis to treatment; (4) Standardizing Care: it determines patient safety; (5) Integrated Practice Units (IPUs): it represents redundancy of care services and delayed diagnosis; (6) Multidisciplinary Care: it considers a multidisciplinary team consists of different medical professionals to deliver patient-centered, coordinated and comprehensive care to patients. Finally, the VA team identified the following eight delivery functions at the downstream stage: (1) Security of Clinical Information: it points to risks of sharing electronic medical records(EMR); (2) Flexibility to Adapt to Patients' Changing Needs: it measures patients' changing needs and expectations; (3) Operational Efficiency: it determines the operational efficiency of the e-business models to deliver the highest value; (4) Integrated Care Delivery Systems: it demonstrates the accessibility of the medical record online using automated service delivery; (5) Expand Geographic Reach: it shows expanding e-healthcare providers’ coverage;(6) Response Time: it indicates the speed of value delivery;(7) Move to Bundled Payments: it determines payments based on pain reduction instead of fees for discrete services;(8) Elimination of Non–Value-Adding Services: it demonstrate a remarkable value delivery, as shown in Table 3.

In the Step 1-5, the fuzzy weighted collective decision matrix was constructed as shown in Table 4.

In Step 1-6, the team prioritized the e-business models to create the best value stream using the first stage of the waterfall framework as shown in Figure 3.

The optimal solution of this stage was as follows: $\{b_2, b_1, b_3, b_4\}$

Table 3: The value-based functions in the case study

	value-based functions	***References***
The upstream stage	*Patient Survival*	*(Porter,2010)*
	Time to Recovery	*(Porter,2010)*
	Sustainability of Recovery or Health over Time	*(Porter,2010)*
	Degree of Recovery	*(Porter,2010)*
The midstream stage	*Diagnostic and Treatment Accuracy*	*(Akhmetov & Bubnov,2015)*
	The Ability to Measure Outcomes	*(Stowell & Akerman , 2015)*
	Reduce Cycle Times across the Care Cycle	*(Porter & Guth, 2012; Porter ,2008)*
	Standardizing Care	*(Porter & Kaplan ,2016)*
	Integrated Practice Units (IPUs)	*(Porter & Thomas ,2013)*
	Multidisciplinary Care	*(Fayanju et al, 2016; Chang et al, 2001; Porter & Thomas ,2013))*
The downstream stage	*Security of Clinical Information*	*(McClelland & Thomas,2002)*
	Flexibility to Adapt to Patients' Changing Needs	*(Gentry & Badrinath , 2017; Stowell &Akerman , 2015)*
	Operational Efficiency	*(Brea-Solis, 2010)*
	Integrated Care Delivery Systems	*(Porter & Thomas ,2013)*
	Expand Geographic Reach	*(Porter & Thomas ,2013)*
	Response Time	*(Lillrank et al, 2010)*
	Move to Bundled Payments for Care Cycles	*(Porter & Thomas ,2013; Porter ,2008)*
	Elimination of Non–Value-Adding Services	*(Porter, 2010)*

Table 4: The waterfall fuzzy weighted collective decision matrix in the case study

	B_1	B_2	B_3	B_4
$f_1(1)$	(6.25,7.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(2.25,3.75,0.75,0.75)
$f_2(1)$	(2.25,3.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
$f_3(1)$	(8.25,9.75,0.75,0.75)	(8.25,9.75,0.75,0.75)	(4.25,5.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_4(1)$	(4.25,5.75,0.75,0.75)	(2.25,3.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(2.25,3.75,0.75,0.75)

	B_1	B_2	B_3
$f_1(2)$	(6.25,7.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
$f_2(2)$	(4.25,5.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
$f_3(2)$	(8.25,9.75,0.75,0.75)	(8.25,9.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_4(2)$	(6.25,7.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(8.25,9.75,0.75,0.75)
$f_5(2)$	(6.25,7.75,0.75,0.75)	(8.25,9.75,0.75,0.75)	(8.25,9.75,0.75,0.75)
$f_6(2)$	(4.25,5.75,0.75,0.75)	(6.25,7.75,0.75,0.75)	(6.25,7.75,0.75,0.75)

	B_1	B_2
$f_1(3)$	(6.25,7.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_2(3)$	(4.25,5.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_3(3)$	(4.25,5.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_4(3)$	(8.25,9.75,0.75,0.75)	(8.25,9.75,0.75,0.75)
$f_5(3)$	(8.25,9.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_6(3)$	(6.25,7.75,0.75,0.75)	(4.25,5.75,0.75,0.75)
$f_7(3)$	(6.25,7.75,0.75,0.75)	(6.25,7.75,0.75,0.75)
$f_8(3)$	(8.25,9.75,0.75,0.75)	(6.25,7.75,0.75,0.75)

The upstream stage of the waterfall decision making framework

$Max\ Z(1)=0.63x_{12}(1)+0.27x_{13}(1)+0.11x_{14}(1)+0.73x_{21}(1)+0.27x_{23}(1)+0.07x_{24}(1)+0.17x_{31}(1)+$

$0.27x_{32}(1)+0.46x_{33}(1)+0.23x_{34}(1)+0.12x_{41}(1)+0.14x_{42}(1)+0.19x_{43}(1)+0.35x_{44}(1)$

St:

$x_{11}(1)+x_{12}(1)+x_{13}(1)+x_{14}(1)=1$

$x_{21}(1)+x_{22}(1)+x_{23}(1)+x_{24}(1)=1$

$x_{31}(1)+x_{32}(1)+x_{33}(1)+x_{34}(1)=1$

$x_{41}(1)+x_{42}(1)+x_{43}(1)+x_{44}(1)=1$

$x_{11}(1)+x_{21}(1)+x_{31}(1)+x_{41}(1)=1$

$x_{12}(1)+x_{22}(1)+x_{32}(1)+x_{42}(1)=1$

$x_{13}(1)+x_{23}(1)+x_{33}(1)+x_{44}(1)=1$

$x_{14}(1)+x_{24}(1)+x_{34}(1)+x_{44}(1)=1$

$x_{11}(1),x_{12}(1),x_{13}(1),x_{14}(1),x_{21}(1),$

$x_{22}(1),x_{23}(1),x_{24}(1),x_{31}(1),x_{32}(1),$

$x_{33}(1),x_{34}(1),x_{41}(1),x_{42}(1),x_{43}(1),$

$x_{44}(1)=0,1$

Preference information flow:

$D=\{(b_2,b_1),(b_2,b_3)\}$

The midstream stage of the waterfall decision making framework

$Min\ Z(2) = z_{21}(2) + z_{23}(2)$

St:

$w(f_2(2)).(1.25,2.75,0.75,0.75)+w(f_3(2)).(-2.75,-1.25,0.75,0.75)+w(f_5(2)).(1.25,2.75,0.75,0.75)+$

$w(f_6(2)).(1.25,2.75,0.75,0.75)+z_{21}(2)\geq 0$

$w(f_1(2)).(3.25,4.75,0.75,0.75)+w(f_2(2)).(3.25,4.75,0.75,0.75)+w(f_3(2)).(1.25,2.75,0.75,0.75)+$

$w(f_4(2)).(-2.75,-1.25,0.75,0.75)+w(f_6(2)).(-2.75,-1.25,0.75,0.75)+z_{32}(2)\geq 0$

$w(f_1(2)).(3.25,4.75,0.75,0.75)+w(f_2(2)).(5.25,6.75,0.75,0.75)+w(f_4(2)).(-2.75,-1.25,0.75,0.75)+$

$w(f_5(2)).(1.25,2.75,0.75,0.75)+w(f_6(2)).(-2.75,-1.25,0.75,0.75)=1$

$w(f_1(2)),w(f_2(2)),w(f_3(2)),w(f_4(2)),w(f_5(2)),w(f_6(2)),z_{21}(2),z_{32}(2)\geq 0$

Preference information flow:

$\{b_2,b_1\}$

The downstream stage of the waterfall decision making framework

$Max\ z(3)$

St:

$(1.25,2.75,0.75,0.75).x_1(3)+z(3)\leq(-0.25,0.75,0.75,0.75)$

$x_1(3)\geq 0$

$z(3)$: Unconstrained

Figure 3: The waterfall three-stage decision making framework in the case study

Stage 2: Value creation analysis of the e-business models

In Step 2-1, the team eliminated the e-business model b_4 as the less favorable e-business model. Using the above optimal order, the team defined the a priori ordinal preferences as follows: $\{(b_2, b_1), (b_2, b_3)\}$.

In Step 2-2, the team ranked the e-business models to create the best value stream using the second stage of the waterfall framework, as shown in Figure 3. The optimal solution of this stage was as follows: $\{b_2, b_1, b_3\}$

Stage 3: Value delivery analysis of the e-business models

In Step 3-1, the team eliminated the e-business model b_3 as the less favorable e-business model. Then, the team defined the following order as the a priori preferences: $\{b_2, b_1\}$
In Step 3-2, team ranked the e-business models to deliver the best value stream using the downstream stage of the waterfall framework, as shown in Figure 3. The optimal solution at this stage was b_1. Therefore, the Canvas business model was selected as the best practice e-health business model. Figure 4 illustrated the stages of the value stream through Canvas e-health business model.

DIMENSIONAL COMPARISON OF THE EXISTING SINGLE-STAGE METHODS AND THE PROPOSED WATERFALL FRAMEWORK

Let us assume that we have n_1 e-business models, m_1 value capture functions, m_2 value creation functions, and m_3 value delivery functions. Therefore, the number of rows and columns of the single-stage decision matrix would be n_1 and $m_1 + m_2 + m_3$, respectively. In the other word, the dimension of the single-stage decision matrix will be $n_1 \times (m_1 + m_2 + m_3)$. But, because of elimination of the dominated e-business models at the three stages of the waterfall framework, the dimension of the waterfall decision matrix will be $n_1 \times m_1 + n_2 \times m_2 + n_3 \times m_3$ where $n_2 \le n_1, n_3 \le n_2$. As shown in Figure 5, it is clear that the size of waterfall decision matrix is smaller than the single-stage decision matrix.

In the case study, with regard to having 4 e-business models, 4 value capture functions, 6 value creation functions, and 8 value delivery functions, the number of rows and columns of the single-stage decision matrix were 4 and 18, respectively. Therefore, the numbers of the elements in the single-stage fuzzy individual decision matrices were 288 while this number in the waterfall was 200. It is obvious that the number of the elements in the waterfall decision matrix was much less than the number of the single-stage decision matrix elements.

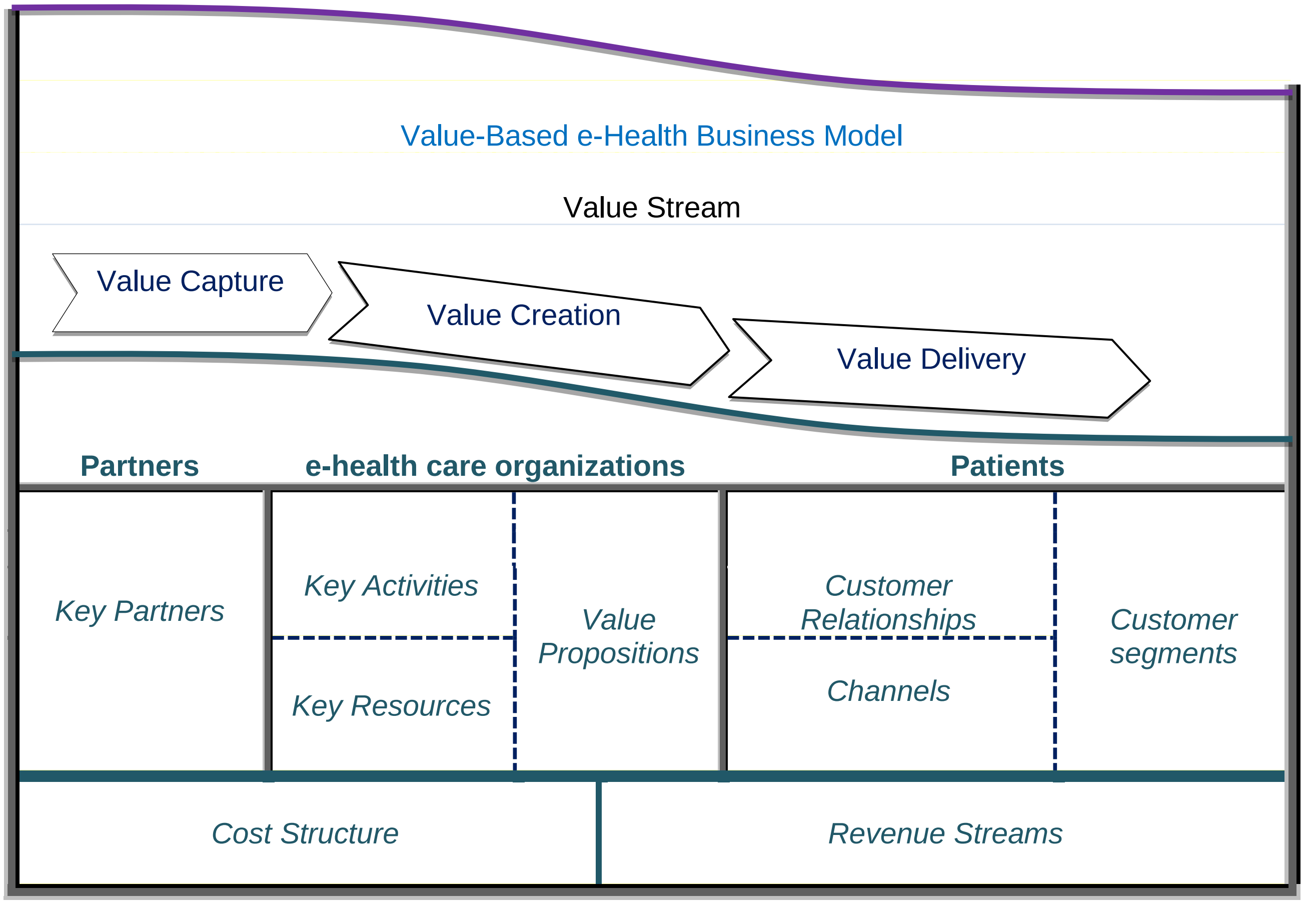


Figure 4: Canvas e-business model along with the value stream

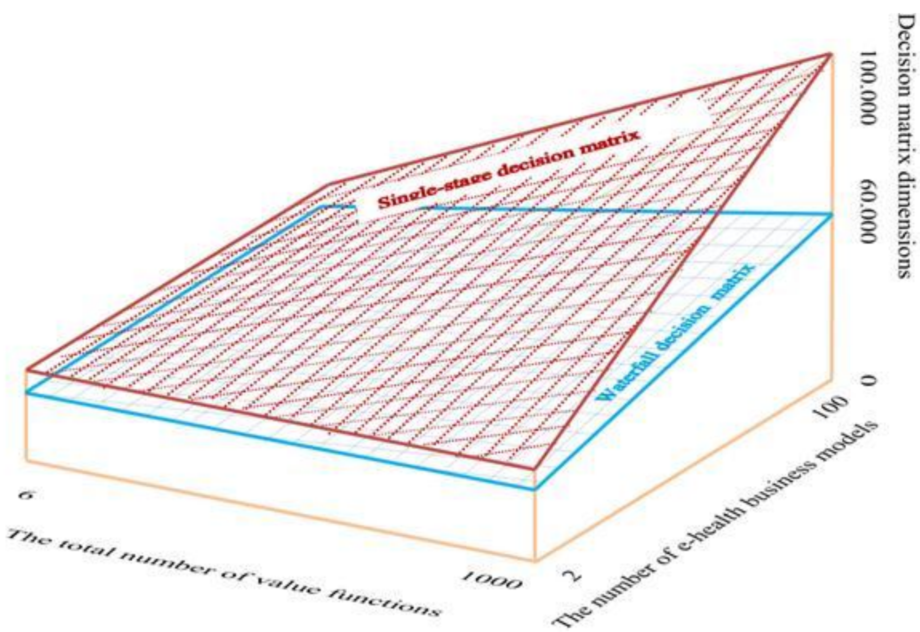


Figure 5: The dimensional comparison of the sequential decision matrices in the waterfall MCDM framework and the existing single-stage MCDM matrices

CONCLUSIONS

We developed the waterfall three-stage MCDM framework to select the best practice e-health business model. This proposed waterfall framework integrated three different MCDM methods to identify the best-practice e-business model which can deliver the highest value to their patients. It required the fulfillment of the each decision making stage of the waterfall framework, before proceeding to the next. Therefore, the DMs' preference information flow, including a priori, interactive and a posteriori preferences, was used to link the three MCDM stages. We developed the fuzzy three-stage value analyses to evaluate the three sequential stages of the value stream in the e-business models. We presented the case study to demonstrate the applicability of the proposed of the waterfall framework and exhibited the dimensional analysis of the waterfall three-stage decision making framework.

APPENDIX: MATHEMATICAL NOTATIONS AND DEFINITIONS

m_1	The number of value capture functions at the upstream stage of the waterfall three-stage MCDM framework
m_2	The number of value creation functions at the midstream stage of the waterfall three-stage MCDM framework
m_3	The number of value delivery functions at the downstream stage of the waterfall three-stage MCDM framework
n_1	The number of the e-business models
t	The number of the VA team members
$f_{m_1}(1)$	The value capture function m_1 at the upstream stage of the waterfall three-stage MCDM framework
$f_{m_2}(2)$	The value creation function m_2 at the midstream stage of the waterfall three-stage MCDM framework
$f_{m_3}(3)$	The value delivery function m_3 at the downstream stage of the waterfall three-stage MCDM framework
B_{n_1}	The e-business model n_1
m_k	The VA team member k
d_k	The voting power of the VA team member k
$w[f_{m_1}(1)]$	The importance weight of the value capture function m_1 at the upstream stage of the waterfall three-stage MCDM framework
$w[f_{m_1}(2)]$	The importance weight of the value creation function m_1 at the midstream stage of the waterfall three-stage MCDM framework
$w[f_{m_1}(3)]$	The importance weight of the value delivery function m_1 at the downstream stage of the waterfall three-stage MCDM framework
$\tilde{v}[f_{i_1 j_1}(1)]$	The fuzzy weighted collective ordinal rank of the e-business model j_1 with respect to the value capture function i_1 in the upstream matrix of the waterfall fuzzy weighted collective matrix

$\tilde{v}[f_{i_2 j_2}(2)]$ The fuzzy weighted collective ordinal rank of the e-business model j_2 with respect to the value creation function i_2 in the midstream matrix of the waterfall fuzzy weighted collective matrix

$\tilde{v}[f_{i_3 j_3}(3)]$ The fuzzy weighted collective ordinal rank of the e-business model j_3 with respect to the value delivery function i_3 in the downstream matrix of the waterfall fuzzy weighted collective matrix

$\tilde{v}^k[f_{i_1 j_1}(1)]$ The fuzzy individual ordinal rank of the e-business model j_1 with respect to the value capture function i_1 evaluated by the VA team member k in the upstream matrices of the waterfall fuzzy individual matrices

$\tilde{v}^k[f_{i_2 j_2}(2)]$ The fuzzy individual ordinal rank of the e-business model j_2 with respect to the value creation function i_2 evaluated by the VA team member k in the midstream matrices of the waterfall fuzzy individual matrices

$\tilde{v}^k[f_{i_3 j_3}(3)]$ The fuzzy individual ordinal rank of the e-business model j_3 with respect to the value delivery function i_3 evaluated by the VA team member k in the downstream matrices of the waterfall fuzzy individual matrices

REFERENCES

[1] Afuah, A. and Tucci, C. L. (2000). *Internet business models and strategies: text and cases*, McGraw-Hill, USA.

[2] Akhmetov I., Bubnov RV. (2015). Assessing value of innovative molecular diagnostic tests in the concept of predictive, preventive, and personalized medicine. EPMA J,6: 19. http://dx.doi.org/10.1186/s13167-015-0041-3.

[3] Amit, R. and Zott, C. (2001). Value creation in e-business, *Strategic Management Journal*, 22(6/7), 493-520

[4] Applegate, L. M. (2001). Emerging e-business models, *Harvard Business Review*, 79(1), 79-87

[5] Barnes, S. and Hunt, B. (2001). *E-commerce and v-business: business models for global success*, Butterworth-Heinemann, Oxford, Great Britain.

[6] Betz, F. (2002). Strategic business models, *Engineering Management Journal*, 14(1), 21-27.

[7] Brea-Solis H, Ramon Casadesus-Masanell and Emili Grifell-Tatje (2010). 'Business Model Evaluation: Quantifying Walmart's Sources of Advantage', Harvard University

[8] Buchko, A.A. (2007). The effect of leadership on values-based management, *Leadership and Organization Development Journal,* 28, 36-50

[9] Chang, J.H., Vines, E., Bertsch, H., Fraker, D.L., Czernieck, B.J., Rosato, E.F., et al. (2001). The impact of a multidisciplinary breast cancer center on recommendations for patient management. Cancer, 91(7), 1231–1237.

[10] Chesbrough, H., and Rosenbloom, R. S. (2002). The role of the business model in capturing value from innovation: evidence from Xerox Corporation's technology spin-off companies. *Industrial and Corporate Change*, 11(3), 529-555.

[11] Eriksson, H. and Penker, M. (2000). *Business modeling with UML – business patterns at work*, John-Wiley & Sons, New York.

[12] Fayanju OM., Mayo TL., Spinks TE., et al. (2016). Value-based breast cancer care: a multidisciplinary approach for defining patient-centered outcomes. Ann Surg Oncol. 23, 2385–90

[13] Feeley, T. W., Albright, H., Walters, R. and Burke, T. W. (2010). A method for defining value in healthcare using cancer care as a model, *Journal of Healthcare Management* 55(6), 399–412

[14] Gentry S, Badrinath P. (2017). Defining Health in the Era of Value-based Care: Lessons from England of Relevance to Other Health Systems. Cureus 9: e1079. PMID 28405529 DOI: 10.7759/cureus.1079

[15] Godbold, R., Lees, A.(2013). Ethics education for health professionals: A values based approach, *Nurse Education in Practice*, 13(6), 553-560.

[16] Gordijn, J., and Akkermans, H. (2001). E^3-value: Design and evaluation of e-business models. *IEEE Intelligent Systems*, 16 (4), 11-17.

[17] Gordijn, J., Akkermans, J., and van Vliet, J. (2000). What's in an electronic business model? Knowledge engineering and knowledge management - methods, models, and tools, *LNAI* 1937, 257-273

[18] Graber, D.R. and Osborne Kilpatrick, A. (2008). Establishing values-based leadership and value systems in healthcare organizations, *Journal of Health and Human Services Administration*, 31(2), 179-197

[19] Hedman, J. and Kalling, T. (2003). The business model concept: Theoretical underpinnings and empirical illustrations. *European Journal of Information Systems*, 12(1), 49-59.

[20] Horsti, A. (2016). Revolution of e-business models, VDM Verlag

[21] Hwang, C.L., and Lin, M.J., (1987). *Group decision making under multiple criteria (Lecture notes in economics and mathematical systems),* Berlin: Springer.

[22] Johnson, M. W. (2010). *Seizing the white space: Business model innovation for growth and renewal.* Boston, MA: Harvard Business Press.

[23] Johnson, M. W., Christensen, C. M., & Kagermann, H. (2008). Reinventing your business model. *Harvard Business Review*, 86(12), 50-59.

[24] Kaiser, L. S. and Lee, T. H. (2015). Turning value-based health care into a real business model, *Harvard Business Review*

[25] Kaplan, R. S., MacLean, C. H., Dresner, A., Haas, D. A. and Feeley, T. W. (2015). Health care providers need a value management office. *Harvard Business Review*.

[26] Kaplan, R. S., Haas, D. A., Helmers, R. A., Rucci, and Brady, M. (2015). The Mayo clinic model for running a value-improvement program, *Harvard Business Review*

[27] Kaplan, R. S., Witkowski, M. L., Abbott, M., Guzman, A., Higgins, L., Meara, J., Padden, E., Shah, A., Waters, P., Weidemeier, M., Wertheimer, S. and Feeley, T. W. (2014). Using time-driven activity-based costing to identify value-improvement opportunities in healthcare, *Journal of Healthcare Management* 59(6), 399–413

[28] Kaplan, R. S., Blackstone, R. P., Haas, D. A., and Thaker, N. G. (2015). Measuring and communicating health care value with charts, *Harvard Business Review*.

[29] Kim, Jim Yong, Joseph Rhatigan, Sachin H. Jain, and Michael E. Porter. (2009). From a declaration of values to the creation of value in global health, Global Public Health.

[30] Lillrank, P., Groop, J. and Malmstro¨m, T. (2010), “Demand and supply-based operating modes – a framework for analyzing health care service production”, Milbank Quarterly, Vol. 88 No. 4, pp. 595-615.

[31] Linder, J. C. and Cantrell S. (2000). *Changing business models: surveying the Landscape*, Accenture Institute for Strategic Change.

[32] Lytras, M. D., Damiani, E. and Ordonez De Pablos, P. (2009). Web 2.0: *The business model*, New York, Springer Science and Business Media, LLC

[33] Magretta, J. (2002). Why business models matter? *Harvard Business Review*, 80(5), 86-92.

[34] Oluwadamilola, F. M., Mayo, T. L., Spinks, T. E., Lee, S., Barcenas, C. H., Smith, B. D., Giordano, S. H., Hwang, R. F., Ehlers, R. A., Selber, J. C., Walters, R., Tripathy, D., Hunt, K. K., Buchholz, T. A., Feeley, T. W., and Kuerer., H. M. (2016). Value-based breast cancer care: a multidisciplinary approach for defining patient-centered outcomes, *Annals of Surgical Oncology*, 23(8).

[35] McClelland, R., & Thomas, V. (2002). Confidentiality and security of clinical information in mental health practice. Advances in Psychiatric Treatment, 8, 291–296.

[36] Osterwalder A., and Pigneur, Y. (2009). *Business model generation*, Self-Published

[37] Osterwalder A., Pigneur, Y., and Tucci, C. L. (2005). Clarifying business models: origins, present, and future of the concept, *Communications of the Association for Information Systems*, 16, 1-25

[38] Parvinen, L. A., Windischhofer, R., Gustafsson, M. (2010). Competitive advantage through value-based health care: The case of Metso Corporation, *European Management Journal*, 28(3), 195-207.

[39] Pateli, A. C., and Giaglis, G. M. (2004). A research framework for analyzing e-business models, *European Journal of Information Systems,* 34(2), 23-38

[40] Porter, M. E., and Guth, C. (2012). Redefining German health care: Moving to a value-based system. Heidelberg: Springer.

[41] Porter, Michael E., Erika A. Pabo, and Thomas H. Lee. (2013). Redesigning primary care: A strategic vision to improve value by organizing around patients' needs, *Health Affairs* 32(3), 516–525.

[42] Porter, Michael E., and Thomas H. Lee. (2013). The strategy that will fix health care, *Harvard Business Review*, 91(10), 50–70.

[43] Porter, Michael E. (2010). What is value in health care? *New England Journal of Medicine* 363(26), 2477–2481.

[44] Porter, Michael E. (2009). A strategy for health care reform—toward a value-based system, *New England Journal of Medicine* 361(2), 109–112

[45] Porter, Michael E. (2009). The Finnish health care system: a value based perspective, *Sitra Reports*.

[46] Porter, Michael E. (2008). Value-based health care delivery, *Annals of Surgery,* 248(4)

[47] Porter ME and Kaplan RS (2016). How to pay for health care. Harvard Business Review. Vol. July- August, 88-100.

[48] Pruzan, P. (1998). From control to values-based management and accountability, *Journal of Business Ethics,* 17, 1379-1394

[49] Rappa, M. (2004). The utility business models and future of computing services, *IBM Systems Journal*, 43(1), 32-42

[50] Rolón, E., Chavira, G., Orozco, J., Soto, J. P. (2015). Towards a framework for evaluating usability of business process models with BPMN in health sector, *Procedia Manufacturing*, 3, 5603-5610.

[51] Stowell, C, Akerman C. (2015). Better Value in Health Care Requires Focusing on Outcomes. Harvard Business Review. https://hbr.org/2015/09/better-value-in-health-care-requires-focusing-on-outcomes.

[52] Teece, D. J. (2009). Business models, business strategy and innovation. *Long Range Planning*

[53] Toro-Jarrín, M. A., Ponce-Jaramillo, I. E., Güemes-Castorena, D. (2016). Methodology for building process integration of business model canvas and technological roadmap, *Technological Forecasting and Social Change*, 110, 213-225

[54] Ulaga, W. (2003). Capturing value creation in business relationships: a customer perspective, Industrial Marketing Management, 32 (8), 677-693.

[55] Vasilecas, O., Kalibatiene, D., Lavbič, D. (2016). Rule- and context-based dynamic business process modeling and simulation, *Journal of Systems and Software*, 122, 1-15
[56] Viinamäki, O-P. (2009). Intra-organizational challenges of values-based leadership, *Electronic Journal of Business Ethics and Organizational Studies*, 14, 6-13
[57] Williams, S.L. (2002). Strategic planning and organizational values: Links to alignment. *Human Resource Development International*, 5, 217-233.
[58] Weill, P., and Vitale, M. (2001). *Place to space: Migrating to e-business models*, McGraw-Hill, Irwine.
[59] Wirtz, B. W., Schilke, O. and Ullrich, S. (2010). Strategic development of business models: Implications of the web 2.0 for creating value on the internet. *Long Range Planning*, 43, 272-290.
[60] Yang, M., Evans, S., Vladimirova, D., Rana, P. (2016). Value uncaptured perspective for sustainable business model innovation, *Journal of Cleaner Production*.
[61] Ye, Q., Wang, H. (2013). The study of re-construction method of EV business model based on value chain analysis, Proceedings of the FISITA 2012 World Automotive Congress, 192, 899-907.
[62] Zadeh, L.A. (1965). Fuzzy sets. Information and Control, 8, 338-353.
[63] Zimmermann, H.J. (1991). *Fuzzy set theory and its applications*. 2nd Edition, Boston: Kluwer Academic Publishers.