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Factors impacting technology adoption in hospital bed logistics

Purpose: This study aims to refine and expand technology adoption theory for a healthcare logistics setting by combining the technology-organization-environment (TOE) framework with a business process management (BPM) perspective. The paper identifies and ranks factors impacting the decision to implement instances of technologies in healthcare logistics processes.

Research design: A multiple case study is carried out at five Danish hospitals to investigate the bed logistics process. A combined technology adoption and BPM lens is applied to gain an understanding of the reasoning behind technology adoption.

Findings: A set of seventeen factors impacting the adoption of technologies within healthcare logistics were identified. The impact factors perceived as most important to the adoption of technologies in healthcare logistics processes relate to quality, employee work conditions and employee engagement.

Research limitations/implications: This paper seeks to understand how managers can use knowledge about impact factors to improve processes through technology adoption. The findings of this study provide insights about the factors impacting the adoption of technologies in healthcare logistics processes. Differences in perceived importance of factors enable 1) ranking of impact factors, and 2) prioritization of changes to be implemented. The study is limited to five hospitals, but is expected to be representative of public hospitals in developed countries and applicable to similar processes.

Originality/value: The study contributes to the empirical research within the field of BPM and technology adoption in healthcare. Furthermore, the findings of this study enable managers to make an informed decision about technology adoption within a healthcare logistics setting.

Keywords: healthcare logistics; business process management; technology adoption; technology-organization-environment framework

Introduction

Healthcare systems around the world face the challenge of rising healthcare costs.

Expectations of high quality care together with an ageing population and more sophisticated treatments have led to more expensive healthcare provision (OECD, 2015; WHO, 2010). Thus, there is an increasing pressure to provide high quality care at lower costs. One opportunity for reducing healthcare costs is by addressing logistics expenditure in hospitals. Logistics activities account for more than 30% of hospital costs, half of which could be eliminated by applying best practices (Aptel et al., 2009; McKone-Sweet et al., 2005; Poulin, 2003). Main and supporting logistical flows in

1
2
3 hospitals therefore hold great potential for cost reductions.

4
5 Hospitals are turning to manufacturing based supply chain management (SCM)
6
7 best practices and business process management (BPM) concepts such as just-in-time
8
9 (JIT) (Aptel and Pourjalali, 2001; Kumar, Ozdamar, et al., 2008; Kumar, DeGroot, et
10
11 al., 2008), lean (Hicks et al., 2015; Joosten et al., 2009; Kollberg et al., 2007), total
12
13 quality management (TQM) (Chen et al., 2004; Chow-Chua and Goh, 2000), business
14
15 process reengineering (BPR) (Bertolini et al., 2011; Elkhuizen et al., 2006; van Lent et
16
17 al., 2012) and automation (Granlund and Wiktorsson, 2013; Markin, 1994) in an effort
18
19 to become more efficient and effective. However, hospitals are often left to their own
20
21 experience to decide on a process design that suits their needs (van Lent et al., 2012).
22
23 Similarly, whether to implement a technology is up to each hospital to decide and may
24
25 differ depending on the focus areas of the hospital (Xie et al., 2016).
26
27

28
29 Introducing a new technology can significantly impact hospital costs and quality
30
31 performance (Li and Benton, 2006) and can free up time for caretakers to perform other
32
33 tasks (Bloss, 2011; Li and Benton, 2006). Technology adoption theory aims to predict
34
35 under which circumstances a technology is adopted. The technology-organization-
36
37 environment (TOE) framework identifies three contexts relevant to technology
38
39 adoption, namely the technological, organizational and environmental contexts (Baker,
40
41 2012; Tornatzky and Fleischer, 1990). Applied in a healthcare logistics setting, the TOE
42
43 framework may elucidate factors influencing the decision to adopt technologies to
44
45 improve healthcare logistics processes.
46
47

48
49 A new technology will invariably affect the process in which the technology is
50
51 implemented and the process design (Attaran, 2003; Karimi et al., 2007). Thus,
52
53 technologies can greatly improve the efficiency of processes (Voss, 1988). Conversely,
54
55 processes need to be aligned with the introduction of new technologies (Hung, 2006;
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1
2
3 Trkman, 2010). The TOE framework enables the assessment of potential technologies
4
5 to be adopted. However, the main constructs of the TOE framework have not changed
6
7 since it was developed in 1990 by Tornatzky and Fleischer (Baker, 2012), whereas the
8
9 development in technologies has increased significantly over the past almost 30 years.
10
11 Combining different theoretical models could contribute to a better understanding of
12
13 technology adoption in organizations (Oliveira and Martins, 2011).
14

15
16 The TOE framework is somewhat static and fails to consider how the
17
18 introduction of a new technology ties in with and affects the process in which the
19
20 technology will operate, i.e. the dynamics of introducing a new technology.
21
22 Consequently, the TOE framework does not consider how the introduction of a
23
24 technology will improve or deteriorate the process and operations of a hospital.
25
26 Supplementing the TOE framework with a process construct adds a dynamic
27
28 perspective for predicting technology adoption in a constantly changing environment
29
30 with fast paced technological advancements.
31

32
33 This paper seeks to identify the factors impacting the design of healthcare
34
35 logistics processes by investigating why instances of technologies have been
36
37 implemented in a hospital bed logistics process. The first research question is
38
39 formulated as follows:
40

41 ***RQ1:*** Which factors impact the decision to implement instances of
42
43 technologies in healthcare logistics processes?
44

45
46 Differences in process design provide different points of departure for
47
48 introducing a new technology, both in terms of the extent of changes and the level of
49
50 improvement increments. Failure to consider the current state of a process would
51
52 therefore be to neglect the process improvement dimension and the benefits gained from
53
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1
2
3 a technology. To identify the impact factors in RQ1, a conceptual framework is
4
5 developed based on the TOE framework combined with a BPM perspective.
6

7 Organizations operate under different circumstances and the benefits reaped
8
9 from a technology therefore differ (Chan et al., 2001). Hence, organizations must select
10
11 a technology that best fits their specific needs depending on the context in which the
12
13 hospital operates. The factors impacting the decision to adopt a technology may
14
15 therefore differ in importance depending on the context, e.g. industry, market segment
16
17 and corporate strategy. A second research question is therefore investigated:
18

19
20 **RQ2:** How do the identified impact factors differ in terms of importance for the
21
22 decision to adopt a technology within healthcare logistics processes?
23

24 This study aims to refine and expand technology adoption theory for a
25
26 healthcare logistics setting by applying a combined technology adoption and BPM lens
27
28 to a multiple case study of the bed logistics process in five Danish hospitals. The study
29
30 therefore contributes to technology adoption literature and healthcare logistics literature
31
32 by providing a set of factors impacting the decision to adopt technological innovations
33
34 in a healthcare setting. Furthermore, the study illustrates how the process perspective
35
36 enriches the TOE framework and in turn how the TOE framework enhances BPM
37
38 theory.
39

40
41 This paper is organized as follows. A literature review is provided linking
42
43 technology adoption to BPM for a healthcare logistics setting. The research method is
44
45 then described, following a presentation of the results. Finally, the paper discusses and
46
47 concludes on the results of the study.
48

49 50 51 **Literature review**

52
53
54 The following literature review covers four areas: 1) logistics processes in healthcare, 2)
55
56 technologies in healthcare logistics, 3) technology adoption and TOE, and 4) BPM in
57
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59
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1
2
3 healthcare. The literature review follows a sequence that logically links technology
4 adoption to BPM for a healthcare logistics setting. By providing this trail of evidence
5 from literature, the key elements of the study aims, research questions and objectives
6 are covered and the link between them established. In relation to the RQs, the first
7 section of the literature review provides the contextual background of the investigated
8 processes. The second and third section relate to the technological aspect of the RQs,
9 and the fourth section underpins and further justifies the importance of the BPM
10 dimension in explaining the adoption of technologies in a healthcare logistics setting.
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21 *Logistics processes in healthcare*

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24 Logistics relates to the movement and transmittal of goods, services and information
25 (Lummus et al., 2001) and is closely related to SCM, which is reflected in the definition
26 of logistics management provided by the Council of Supply Chain Management
27 Professionals (Council of Supply Chain Management Professionals, 2016):
28
29
30
31

32
33
34 Logistics management is that part of supply chain management that plans,
35 implements, and controls the efficient, effective forward and reverses flow and
36 storage of goods, services and related information between the point of origin and
37 the point of consumption in order to meet customers' requirements.
38
39
40

41
42 There has been a growing interest in the field of healthcare operations and SCM
43 (Volland et al., 2016), including the selection and design of the service delivery system
44 (Dobrzykowski et al., 2014). E.g. Spens and Bask (2002) expand a SCM framework by
45 applying the framework to a blood transfusion supply chain and Narayana et al. (2014)
46 investigate the factors impacting the reverse pharmaceutical supply chain.
47
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50

51
52 A process oriented approach to SCM can improve supply chain performance
53 (Aronsson et al., 2011; Kumar, Ozdamar, et al., 2008). Principles such as six sigma (Jin
54 et al., 2008), lean (Souza, 2009), JIT (Jarrett, 1998; Kumar, Ozdamar, et al., 2008; Pan
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3 and Pokharel, 2007), TQM (Heinbuch, 1995), BPR (Chow-Chua and Goh, 2000;
4
5 Elkhuisen et al., 2006; Ho et al., 1999), and cellular operations (Parnaby and Towill,
6
7 2009) have therefore been applied to healthcare logistics processes. However, the extent
8
9 of the field continues to be limited.

10
11 The process investigated in this paper is the bed logistics process, which
12
13 includes the flow of beds and the flow of patients. A survey of Dutch hospitals revealed
14
15 that the most prevalent process management approaches in patient logistics are care
16
17 pathways and benchmarking, followed by BPR and lean management. However, half of
18
19 the survey hospitals had not achieved their goals (van Lent et al., 2012). This suggests a
20
21 need for more research on how to successfully improve patient and bed logistics from a
22
23 process perspective.

24
25
26 Beds are a scarce resource and hospitals are faced with both poor bed utilization
27
28 and bed shortages (Bekker and Koeleman, 2011; Holm et al., 2013; Schmidt et al.,
29
30 2013). At the same time, the growing demand for healthcare resources increases the
31
32 pressure for better utilization of bed capacity (Bekker and Koeleman, 2011). A number
33
34 of constraints in the bed logistics process contribute to the complexity of managing the
35
36 process; e.g. single rooms, no mixed-sex rooms, incompatibility between pathologies,
37
38 and contagiousness. Bed management units must solve these issues in a context of high
39
40 uncertainty as treatment outcomes are not fully predictable and as emergency patients
41
42 need immediate treatment (Schmidt et al., 2013). Consequently, changes are repeatedly
43
44 made due to acute patients and inaccuracy in expected length of stay (Bachouch et al.,
45
46 2012). Computer aided decision support can help overcome the challenges in the bed
47
48 logistics process and improve bed utilization by taking different constraints into account
49
50 (Schmidt et al., 2013). Operations research approaches such as simulation studies (Kim
51
52 et al., 2000; Schmidt et al., 2013), scheduling (Bekker and Koeleman, 2011) and
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1
2
3 mathematical modelling (Bachouch et al., 2012; Utley et al., 2003) have been used to
4
5 solve these optimization problems. Others have taken a more process oriented approach
6
7 (Banerjee et al., 2008; Parnaby and Towill, 2009; Villa et al., 2009, 2014), but research
8
9 in this area is more limited.

10
11 The provided literature study suggests a need for research on bed logistics,
12
13 particularly on selecting the appropriate process design. This paper applies the less used
14
15 process management approach to bed logistics and provides a framework that supports
16
17 the assessment of process designs in terms of technology adoption and investigates the
18
19 factors determining the adoption of technologies as part of the process design.

22 23 *Technologies in healthcare logistics*

24
25
26 Nurses spend as much as 30% of their time on logistics tasks such as tracking down
27
28 medication and other supplies. Technologies can help care staff spend more time on
29
30 patient care (Bloss, 2011; Granlund and Wiktorsson, 2013). Hence, technologies can
31
32 improve process efficiency (Pokharel, 2005; Voss, 1988), provide cost savings, reduce
33
34 data entry errors, and increase customer service levels (Pan and Pokharel, 2007). IT in
35
36 particular can significantly influence an organization's overall logistics competence
37
38 (Closs et al., 2006). The types of technologies applied in healthcare logistics processes
39
40 undertake one of two types of tasks: information management or materials transport.
41
42 Each of these types of technologies is described in the following.

43
44
45 *Information management.* IT can dramatically improve the accuracy, reliability,
46
47 speed and productivity of logistics processes in hospitals (Su et al., 2011). Wamba and
48
49 colleagues provide an extensive literature review on the application of RFID in
50
51 healthcare and identify three overall applications: 1) patient management, 2) asset
52
53 management, and 3) staff management. Benefits include efficiency, quality and
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1
2
3 management gains (Wamba et al., 2013), increased productivity, and reduced inventory
4
5 loss (Kumar and Rahman, 2014).

6
7 Barcodes and RFIDs can serve the same purpose. RFIDs can provide more
8
9 benefits, albeit at a higher cost. A study by Romero and Lefebvre found that combining
10
11 the use of barcodes and RFIDs resulted in better inventory management and less
12
13 inventory loss, decreasing the amount of manual labor, length of procurement cycles
14
15 and number of recall activities (Romero and Lefebvre, 2015).

16
17 *Materials transport.* Automated guided vehicles (AGVs) are mobile robots that
18
19 can autonomously navigate and transport items such as medicine, lab results, food,
20
21 linen, equipment and other supplies, allowing nurses to spend more time with patients
22
23 (Bloss, 2011; Granlund and Wiktorsson, 2013; Kumar and Rahman, 2014; Landry and
24
25 Philippe, 2004). Another technology used for transporting items in hospitals is
26
27 pneumatic tubes where items are transported in canisters by using compressed air.
28
29 Pneumatic tube systems have been widely used in laboratory practices to transport items
30
31 such as blood samples (Al-Riyami et al., 2014; Granlund and Wiktorsson, 2013;
32
33 Jørgensen et al., 2013).

34
35
36
37 The described technologies perform different types of activities but can serve the
38
39 same purpose, i.e. to free up time for care personnel. To decide on which technologies
40
41 to implement, different assessment and justification methods can be applied.

42 43 44 45 *Technology adoption and TOE*

46
47 There are several ways to assess and justify the implementation of a new technology.
48
49 Technology assessment methods tend to focus on informing policy makers of the
50
51 general impact of a new type of technology. E.g. health technology assessment informs
52
53 policy makers about the efficacy, safety, and cost-effectiveness of technologies that
54
55 solve a health problem and improve the quality of life (Ritrovato et al., 2015; WHO,
56
57
58
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1
2
3 2015). However, this paper is not concerned with solving a health problem as such or
4
5 with designing a new technology, but rather the justification of technologies.

6
7 Meredith and Suresh distinguish between three methods for technology
8
9 justification: strategic, economic and analytic (Meredith and Suresh, 1986). Strategic
10
11 justification relates to considerations such as business objectives and competitive
12
13 advantage. An example of an economic method is the calculation of payback time, e.g.
14
15 (Granlund and Wiktorsson, 2013; Landry and Philippe, 2004; Reyes et al., 2012). The
16
17 analytic approach includes techniques such as the weighted factor model and the
18
19 Analytic Hierarchy Process (AHP).

20
21
22 Whether a technology is adopted not only depends on an assessment of a given
23
24 technology, but also on individual users' attitude toward the technology. The field of
25
26 psychology thereby lends itself to explaining the adoption of technologies. Fishbein and
27
28 Ajzen (1975) proposed the theory of reasoned action, suggesting that actual behavior
29
30 depends on behavioral intention, which in turn is determined by an individual's attitude
31
32 towards a given behavior and the subjective norm associated with that behavior. The
33
34 theory of planned behavior is an extension of the theory of reasoned action with the
35
36 addition of perceived behavioral control as a factor influencing the intention to use a
37
38 technology (Ajzen, 1985).

39
40
41 Building on the theory of reasoned action paradigm, Davis (1985) proposed the
42
43 technology acceptance model (TAM) to explain the user motivation and intent to accept
44
45 or reject information systems. Over time, TAM has evolved from introducing the
46
47 model, through model validation, model extension and model elaboration. In the final
48
49 1996 version of TAM, external variables were added as antecedents of user motivation
50
51 (Venkatesh and Davis, 1996). Since then, several authors have identified different
52
53 external variables of TAM (Lee et al., 2003); e.g. variables explaining the perceived
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1
2
3 usefulness of a system (Venkatesh and Davis, 2000) and variables determining
4
5 perceived ease of use (Venkatesh, 2000).
6

7 Bagozzi (2007) critiques TAM for its simplicity and for the development in
8
9 technology acceptance literature becoming fragmented, incoherent and chaotic due to
10
11 the excessive number of variables identified for predicting user behavior. He argues that
12
13 researchers should instead aim to deepen TAM by explaining the relationships between
14
15 the motivational variables and between the intention to use a technology and actual
16
17 behavior.
18
19

20 The technology adoption theories presented thus far relate to technology
21
22 adoption for individuals. Oliveira and Martins (2011) review technology adoption
23
24 literature at the firm level and argue that most models are derived from the diffusion of
25
26 innovation (DOI) theory and the technology-organization-environment (TOE)
27
28 framework. The TOE framework has been used in conjunction with other theories such
29
30 as DOI and institutional theory. Tornatzky and Fleischer (1990) developed the TOE
31
32 framework, which explains how a firm's context influences the adoption and
33
34 implementation of technological innovations. The framework consists of the following
35
36 three contexts: 1) technological context, 2) organizational context and 3) environmental
37
38 context. The technological context refers to relevant technologies, i.e. those in use and
39
40 those available in the market. Organizational context refers to organizational aspects
41
42 such as scope, size, and managerial structure. Finally, environmental context refers to
43
44 the setting in which the firm operates, i.e. the industry, competitors and government.
45
46 Several studies have since validated the TOE framework and additionally identified
47
48 underlying factors for particular technologies or contexts (Baker, 2012).
49
50
51

52 In DOI theory, Rogers identified characteristics for three contexts to better
53
54 understand technology adoption: individual (leader) characteristics, internal
55
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1
2
3 organizational structure characteristics, and external organizational characteristics
4
5 (Rogers, 1995). Looking at the DOI and TOE contexts, the similarities are evident.
6
7 First, individual leader characteristics and internal characteristics of organizational
8
9 structure of DOI are comparable to the organizational context in TOE. Second, the
10
11 external characteristics of the organization in DOI correspond to the environmental
12
13 context of TOE. Finally, the implicit emphasis of technological attributes in the DOI is
14
15 similar to the technological context of the TOE (Baker, 2012).
16

17
18 TOE is applicable for a healthcare environment and factors influencing the
19
20 adoption of technologies in healthcare have been investigated, e.g. for RFID adoption
21
22 (Cao et al., 2014), the adoption of telemedicine (Hu et al., 2000) and electronic
23
24 signature (Chang et al., 2007). Furthermore, TOE has been applied in logistics and
25
26 supply chain management settings, e.g. for patient tracking (Cao et al., 2014) and
27
28 electronic supply chain systems (Lin, 2014).
29

30
31 The TOE framework was chosen as part of the theoretical lens of this study for a
32
33 number of reasons. First, TOE was chosen because of its proven applicability for
34
35 healthcare and logistics settings, e.g. (Cao et al., 2014; Lin, 2014). Second, the TOE
36
37 framework was chosen because of its parsimonious attributes and broad applicability for
38
39 different types of innovations (Baker, 2012). Third, as firms become more
40
41 interconnected, the understanding of the environmental context becomes increasingly
42
43 important and may differ across firms. Taking such different views of the environment
44
45 into account would provide actionable insights for practitioners (Baker, 2012). This
46
47 study focuses on the hospital bed logistics process and identifies technology adoption
48
49 factors to be considered for practitioners within a healthcare logistics setting. The study
50
51 thereby provides actionable insights for practitioners in this setting.
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1
2
3 The TOE framework has scarcely evolved since its initial development in 1990
4
5 and contributions mainly relate to identifying context specific factors rather than
6
7 extending the framework with additional constructs (Baker, 2012). However,
8
9 technological advancements mean that organizations are now faced with a wider array
10
11 of technologies that are faster in terms of computing power. Oliveira and Martins
12
13 (2011) argue that for future research in technology adoption, it is necessary to combine
14
15 different theoretical models to better explain IT adoption. This study advances the TOE
16
17 framework both in terms of context specific factors and in terms of adding a construct,
18
19 i.e. the *process* construct. The process construct adds a time element as processes are
20
21 carried out over a certain timespan. The increasing effect of technologies on time
22
23 compression makes the enhanced framework more dynamic and sensitive to
24
25 technological advancements. The TOE framework aims to explain the adoption of
26
27 technologies as determined by the context (Tornatzky and Fleischer, 1990). However,
28
29 the framework fails to consider the effects of introducing the technology, e.g. in terms
30
31 of efficiency. Most organizations would hesitate to invest in new technologies without
32
33 expecting operational gains ultimately reflected in the financial bottom line. Moreover,
34
35 the benefits realized from introducing a technology differs between organizations
36
37 depending on the specific circumstances of the organization (Chan et al., 2001). Thus,
38
39 combining the TOE framework with the BPM perspective allows for taking into
40
41 account both the *effects on* and *effects of* a technology to better explain technology
42
43 adoption.
44
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46
47
48

49 *Business process management in healthcare*

50
51 Similar to the introduction of technologies, companies can utilize BPM to improve a
52
53 company's performance and provide a competitive advantage (Ho et al., 1999; Hung,
54
55 2006; Liu et al., 2011). BPM is a structured approach to analyzing and continually
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1
2
3 improving fundamental activities in a company's operations (Zairi, 1997). There are two
4
5 distinct approaches to creating change in BPM: a radically oriented BPR approach and
6
7 the incrementally oriented TQM approach (Hung, 2006). Moreover, BPM approaches
8
9 can address different needs depending on variability in demand patterns. Thus, a lean
10
11 approach to designing business processes can eliminate waste in a process and improve
12
13 process efficiency for processes with low demand variability (Guimarães et al., 2013;
14
15 Pilkington and Fitzgerald, 2006). In contrast, agility allows for responsiveness to
16
17 changes in demand (Holweg, 2005). Lean and agility are often compared and can be
18
19 combined in a leagile approach, e.g. (Aronsson et al., 2011).
20
21

22 To ensure the success of BPM efforts, Trkman identified a set of critical success
23
24 factors, which relate to three constructs: 1) process design, 2) organizational structure,
25
26 and 3) technologies. First, business processes should be standardized and aligned with
27
28 strategic objectives and a focus on continuous improvement should be ensured
29
30 (Armistead et al., 1999; Davenport and Short, 1990; Hung, 2006; Trkman, 2010; Zairi,
31
32 1997). Second, organizational structure and business processes should be aligned.
33
34 Hence, training, employee empowerment and employee engagement are vital at the
35
36 employee level, and management commitment is essential at the managerial level to
37
38 sustain changes (Armistead et al., 1999; Ho et al., 1999; Hung, 2006; Trkman, 2010).
39
40 Finally, continued alignment of technologies is imperative to the success of BPM
41
42 (Hung, 2006). Thus, together with human resources and organizational change,
43
44 technologies are enablers of process redesign.
45
46

47
48 Introducing BPM tools and methods in a healthcare context may not be
49
50 straightforward due to the idiosyncratic nature of healthcare. As such, hospitals are
51
52 complex systems consisting of unique and interrelated processes coordinated across
53
54 several organizational units (Aronsson et al., 2011; Kannampallil et al., 2011; Lillrank
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1
2
3 et al., 2011). Problems are often specific to a healthcare context, making it difficult to
4
5 standardize these processes (Helfert, 2009). Furthermore, healthcare processes are
6
7 viewed as unpredictable, non-routine processes that make it hard to schedule production
8
9 and to apply a process approach (Aronsson et al., 2011; Jarrett, 1998; Lillrank et al.,
10
11 2011). The particular circumstances of a healthcare environment could therefore
12
13 complicate the applicability of BPM approaches in healthcare.
14

15
16 Despite the specific challenges in healthcare operations, hospitals have managed
17
18 to apply BPM tools and methods such as lean (Hicks et al., 2015; Joosten et al., 2009;
19
20 Kollberg et al., 2007), JIT (Aptel and Pourjalali, 2001; Kumar, Ozdamar, et al., 2008;
21
22 Kumar, DeGroot, et al., 2008), TQM (Chen et al., 2004; Chow-Chua and Goh, 2000)
23
24 and BPR (Bertolini et al., 2011; Elkhuisen et al., 2006; van Lent et al., 2012) to reduce
25
26 costs and improve quality of care. However, these managerial tools have not been
27
28 systematically implemented in healthcare settings (Towill and Christopher, 2005; Yasin
29
30 et al., 2002) and managers are often left to their own experience to decide which process
31
32 management approach best fits their hospital (van Lent et al., 2012). The ability to
33
34 assess a supply chain solution is therefore vital to identifying the best option for a
35
36 particular hospital. However, there are certain challenges related to assessing
37
38 performance of healthcare supply chains (Böhme et al., 2013), making it difficult to
39
40 assess the value and success of a change (McKone-Sweet et al., 2005). Lega et al.
41
42 (2012) argue for measuring five quality dimensions: 1) delivery performance, 2) time to
43
44 deliver, 3) flexibility, 4) distribution of workloads, and 5) information accuracy and
45
46 timeliness. The study by Lega and colleagues is limited to these five quality dimensions,
47
48 but more research is needed to fully understand the performance dimensions of health
49
50 supply chains to enable the assessment of possible supply chain solutions.
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3 In terms of demand patterns and uncertainty in healthcare, unpredictability is a
4 product of both artificial variation introduced by the system itself and natural variation
5 inherent to a healthcare system (Litvak et al., 2005; Litvak and Long, 2000; Noon et al.,
6 2003; Walley et al., 2006). Artificial variation can be reduced by eliminating poor
7 hospital practices (Litvak et al., 2005; Walley et al., 2006), thereby reducing waste and
8 improving quality of care (Litvak and Long, 2000). To achieve better utilization of
9 resources in a healthcare supply chain, Kumar et al. (2008) therefore propose a more
10 process oriented system for redesigning healthcare supply chains. Thus, unpredictability
11 should not inhibit the adoption of BPM in healthcare.
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22 The application of lean and agile approaches is often associated with
23 predictability and subsequently the level of certainty in demand patterns. Whereas lean
24 responds poorly to variability and seeks to smooth out demand variability, an agile
25 process strategy responds well to variability (Naylor et al., 1999). Aronsson et al.
26 investigate the applicability of lean and agile processes in a healthcare supply chain.
27 Agile processes are responsive and flexible while lean processes focus on eliminating
28 waste in the process (Aronsson et al., 2011). Several examples of lean applications in
29 healthcare exist, e.g. as reported by Souza (2009). Still, the application of lean remains
30 narrow and tool focused rather than a system-wide philosophy (Radnor et al., 2012). As
31 an example, Jarrett (1998) argues that JIT, i.e. a lean tool, is applicable in a healthcare
32 setting and could reduce costs but that contingency plans should be in place in cases of
33 disruption.
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48 To accommodate both the need for a rapid response to variability and the
49 increasing pressure for efficiency, several authors suggest a leagile process strategy for
50 healthcare delivery systems (Aronsson et al., 2011; Rahimnia and Moghadasian, 2010;
51 Towill and Christopher, 2005). A leagile process is a process which combines agile and
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1
2 lean concepts (Aronsson et al., 2011). Aronsson et al. (2011) argue that healthcare
3 processes should be divided into sub-processes according to organizational boundaries.
4
5 Furthermore, each sub-process should be standardized and be subject to either a lean or
6 agile design depending on the characteristics of the sub-process, e.g. variability and
7 volume.
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13 In addition to the impact of predictability on selecting a suitable BPM approach,
14 hospitals must decide whether to adopt a radical or incremental change approach for
15 introducing BPM interventions. In terms of continuous improvement, studies have
16 demonstrated that approaches such as lean, JIT and TQM are applicable in a healthcare
17 setting due to high volumes and repetitive tasks, e.g. (Chen et al., 2004; Jarrett, 1998;
18 Persona et al., 2008; Souza, 2009). Similarly, Kumar et al. argue that the more radical
19 BPR approach is suitable for a healthcare setting due to the tangibility of items, high
20 volumes and task repetition (Kumar, Ozdamar, et al., 2008). Thus, the same arguments
21 seem to apply for both incremental and radical change approaches. Furthermore,
22 implementing quality management through both continuous improvement and BPR can
23 lead to reduced operating costs and waiting time and an improved organizational
24 structure in hospitals (Chow-Chua and Goh, 2000).
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39 This literature review shows that although an agile approach is better at
40 managing process variability, most literature focuses on lean rather than agility
41 (Rahimnia and Moghadasian, 2010). Furthermore, introducing a leagile approach in
42 hospitals could support hospitals in achieving both responsive and efficient processes
43 (Aronsson et al., 2011), although literature on this topic too is scarce. However,
44 practitioners need guidelines for how to select a suitable BPM intervention and ensure
45 successful implementation (van Lent et al., 2012). Thus, it seems that literature does not
46 necessarily treat the topics needed to address the specific challenges of a healthcare
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3 setting. Furthermore, literature should aim to close the gap between research needs and
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5 the needs of practitioners by providing guidelines for selecting a suitable BPM
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7 approach. More research is therefore needed on the application of BPM in healthcare,
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9 particularly when and how it should be applied. This paper proposes a set of impact
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11 factors that supports decision makers in designing logistics processes which
12
13 accommodate the needs of a hospital.
14

15
16 Pan and Pokharel (2007) argue that to understand logistics activities in hospitals,
17
18 it is necessary to determine the use of information and communication technologies
19
20 (ICTs) and barriers to ICT adoption. This study identifies factors determining
21
22 technology adoption specifically for a healthcare logistics setting. The study combines
23
24 the TOE framework with BPM theory, thus adding a *process* construct to the TOE
25
26 framework. The TOE framework ensures that necessary technology adoption aspects
27
28 are considered. BPM theory, in turn, ensures the success of the process in which the
29
30 technology is adopted.
31

32
33 The difference between the BPM aspect and the TOE framework lies in the
34
35 *environment* of the TOE framework and the *process* dimension of the BPM perspective.
36
37 This paper has argued that to assess a technology, the *process flow* aspect needs to be
38
39 considered. Conversely, from a BPM perspective, the *environment* needs to be
40
41 considered because of the need to understand under which conditions the flow operates.
42
43 E.g. there may be governmental requirements in terms of tracking items in the
44
45 healthcare supply chain to reduce counterfeiting (Bendavid et al., 2012; Chircu et al.,
46
47 2014). Furthermore, external pressure to ensure patient safety can lead to safety
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49 mechanisms in the form of RFID and barcodes in the process (Anand and Wamba,
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51 2013; Bendavid et al., 2012). Finally, improved lead times and treatments may
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53 encourage patients to seek treatment in particular hospitals, and governments can apply
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3 pressure to measure and benchmark performance. As an example, in the UK, hospital
4 benchmarking allowed for nationwide comparisons of hospitals, although it has been
5 seriously contested whether this type of benchmarking actually encourages best practice
6
7 (Northcott and Llewellyn, 2005).
8
9

10 11 12 **Method**

13 Research objectives, research design, data collection and data analysis are presented in
14
15 the following.
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17

18 19 20 *Research objectives*

21
22 The research objectives detail how the research questions are answered. To answer
23 RQ1, challenges in healthcare logistics and reasons behind implementing changes in
24 healthcare logistics were identified. The identified challenges and reasons for
25 implementing technological instances were synthesized to encapsulate the factors
26 impacting the decision to implement these technological instances. Thus, using the
27 impact factors in a decision process will reflect factors already used in a decision
28 process and additionally address challenges to improve process performance and reach
29 organizational goals (Locke and Latham, 2002; VandeWalle et al., 2001). To answer
30 RQ2, differences in perceived importance of the identified impact factors were
31 established and compared to differences in process design, i.e. a cross-case analysis
32 (Benbasat et al., 1987; Eisenhardt, 1989; Yin, 1994).
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47 48 *Research design*

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50 A case study research design was chosen because it provides rich data and enables a
51 deep understanding of a phenomenon (Meredith, 1998; Yin, 2014). The investigated
52 phenomenon is the improvement of healthcare logistics processes and the unit of
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3 analysis is the bed logistics process. Both quantitative and qualitative methods can be
4
5 applied in case study research to understand a phenomenon (Meredith, 1998). In this
6
7 study, both qualitative and quantitative data is collected and analyzed.
8

9 The investigated multiple case study consists of five hospitals located in the
10
11 capital region of Denmark. The number of case studies is consistent with Eisenhardt,
12
13 who suggests investigating four to ten cases (Eisenhardt, 1989). The case hospitals were
14
15 chosen because they are located within the same hospital region and represent different
16
17 hospital sizes and levels of technology adoption.
18

19
20 Although the rigor of case study research has been contested, case research can
21
22 produce valid findings in itself without the need for further testing through alternative
23
24 methods (Ketokivi and Choi, 2014). There is a need for case study research to advance
25
26 the field of operations management (McCutcheon and Meredith, 1993) and an increase
27
28 in such studies has been observed in recent years (Barratt et al., 2011). The rigor of case
29
30 study research has been demonstrated for building supply chain management and
31
32 logistics theory, e.g. (Ellram, 1996; Stuart et al., 2002). However, the quality aspects of
33
34 case research within logistics and supply chain management are often poorly described.
35
36 To properly assess the quality of case research, Pedrosa et al. (2012) propose the use of
37
38 three quality criteria: transferability, truth-value and traceability. Each of these quality
39
40 aspects is described later in the Method section.
41
42

43
44 Ketokivi and Choi (2014) emphasize the importance of a theoretical orientation
45
46 in case research. They argue that case research can generate, test or elaborate theory.
47
48 Theory elaboration focuses on contextualizing a general theory. Thus, case studies can
49
50 enable theory refinement and extension (Voss et al., 2016). This study elaborates and
51
52 refines the TOE framework by identifying underlying factors relating to the TOE
53
54 constructs and extends the TOE framework in terms of the added BPM aspect.
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Data collection

Data was collected over a seven month period. The case study hospitals were chosen because they differ in size and specialization whilst being located within the same region. Hospital 1 served as a pilot for data gathering in the other hospitals (see hospital overview in Table 1). Both qualitative and quantitative data was collected. Data was collected mainly through interviews and observations and was carried out in three stages: 1) a preliminary stage, 2) a round of semi-structured interviews, and 3) a round of structured interviews to validate the results. The interviewees were chosen based on their knowledge of the bed logistics process and their involvement in a technology adoption and process improvement decision. In addition, different types of documents were gathered as background information from Hospital 1.

(1) The preliminary stage. The preliminary stage was carried out in Hospital 1, serving as a pilot study, with twelve open interviews and four process observation sessions. Interviews were conducted with managers in the logistics department involved in the bed logistics process. Furthermore, clinical staff and employees with knowledge of data, technologies and improvement initiatives in the bed logistics process were interviewed. In eight of the interviews, managers were interviewed and in four of the interviews employees were interviewed. The observations were direct observations of each step of the bed logistics process with some interaction with the people involved. Furthermore, documents were collected that provided an overview of beds in the outpatient clinic, a standard operating procedure for handling beds, data on the number of dirty beds collected and cleaned, and admission and discharge data. The purpose of data collection in the preliminary stage was to learn about the bed logistics process, the challenges in the process, and any improvement potential. Although the nature of data gathering in Hospital 1 resembled a pilot, data gathering was extensive enough to match

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2
3 the quality of data gathered in the other hospitals and was therefore included in the final
4
5 study.

6
7 (2) *Semi-structured interviews.* A round of semi-structured interviews was then
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9 carried out with a manager at each of the other four hospitals. These managers were
10
11 responsible for the cleaning of beds. Furthermore, the bed logistics process at each of
12
13 these four hospitals was observed, focusing on the part of the process for cleaning and
14
15 for transporting beds. The data collected at this stage was then analyzed and a list of
16
17 impact factors identified.

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19
20 (3) *Structured interview validation.* A round of structured interviews followed
21
22 with a manager from each of the five case study hospitals. The impact factors identified
23
24 in the first two data collection stages were presented in the structured interviews.
25
26 Respondents were then asked to rank the identified impact factors on a scale from 0-10
27
28 according to importance for improving healthcare logistics processes. Interview guides
29
30 were used for the interviews with questions related to the research questions and
31
32 objectives. Additional guidelines were used to guide the observations. The interviews
33
34 lasted between ½-1½ hours and the observations lasted 1-2 hours. The interview guide
35
36 for the structured interviews can be found in appendix.
37
38
39

40 41 *Analysis*

42
43 Based on the reviewed literature, a conceptual framework for data analysis is developed
44
45 combining technology adoption theory with BPM theory. Specifically, the conceptual
46
47 framework combines the TOE framework with the dimensions of success criteria for
48
49 BPM. Figure 1 illustrates the developed conceptual framework. The framework is used
50
51 to code the qualitative data collected in the case study hospitals. By coding data
52
53 according to the four constructs, i.e. healthcare environment, technology, organizational
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2
3 structure and process flow, factors impacting the decision to adopt technologies in the
4
5 bed logistics process were identified.
6

7
8 [FIGURE 1 NEAR HERE]
9

10
11 The analysis follows the sequence of the research objectives. Challenges,
12
13 implemented technologies, and reasons for implementation were identified through
14
15 coding of interview and observational data (Corbin and Strauss, 2015; Miles et al.,
16
17 2014). Data was coded to identify factors impacting the decision to implement changes
18
19 in a process. Each identified factor was ranked according to importance for improving
20
21 healthcare logistics processes. In the structured interviews, the impact factors were
22
23 ranked by letting respondents assign values on a 0-10 scale; 0 being of no importance
24
25 and 10 being of extreme importance to the improvement of processes.
26
27
28

29 30 *Data validity and reliability* 31

32 To improve the validity of the results, a multiple case study was chosen as research
33
34 design (Eisenhardt, 1989; Eisenhardt and Graebner, 2007; Yin, 2014). The three quality
35
36 criteria proposed by Pedrosa et al. (2012) to assess the quality of case research are
37
38 described in the following. First, transferability refers to the extent to which the findings
39
40 of a study apply to other contexts. Transferability is ensured by stating the theoretical
41
42 aim in the Introduction, describing the unit of analysis, i.e. the bed logistics process, and
43
44 justifying the case selection as done in the Research design section of the Method.
45
46 Second, truth-value refers to the conformance between the reality of the informants'
47
48 context and the reality presented by the researcher. Truth-value is ensured through a
49
50 careful description of the data analysis process in the Results, including the coding
51
52 process. Third, traceability refers to documenting data and the research process. To
53
54 increase reliability, a case study protocol was used to guide data collection (Yin, 1994).
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3 Interview guides, observation guides, and purpose of data collection were included in
4
5 the protocol. Respondent validation was used to further improve the validity of the
6
7 study (Yin, 2014). Furthermore, a description and overview of informant selection is
8
9 provided. Transparency of the reasoning in the conducted research is vital for the rigor
10
11 of case research (Ketokivi and Choi, 2014). Thus, the chain of evidence linking data,
12
13 analysis and results is found in the Results section and is displayed in table form (Table
14
15 2) as promoted by several authors (Eisenhardt and Graebner, 2007; Miles et al., 2014;
16
17 Voss et al., 2002).

18
19
20 Multiple data sources were used to enable triangulation of data, hence increasing
21
22 reliability and providing stronger evidence to substantiate the identified constructs
23
24 (Benbasat et al., 1987; Eisenhardt, 1989; Voss et al., 2002), i.e. impact factors.
25
26 Examples of data triangulation were found where different data sources support the
27
28 same argument. Conversely, some statements were found to contradict other sources of
29
30 evidence; e.g. compared to what had been observed or what had been stated in another
31
32 interview.

33
34
35 Case study research is situationally grounded whilst seeking a sense of
36
37 generalizability. This ensures methodologically rigorous and practically relevant
38
39 research (Ketokivi and Choi, 2014). This study is situationally grounded in bed
40
41 logistics, but seeks generalizability for hospital logistics processes. The study targets
42
43 practitioners in healthcare management, particularly managers in healthcare logistics.
44
45

46 47 **Results**

48
49
50 Impact factors are identified based on case study data and ranked. In this section, case
51
52 study data is analyzed using the conceptual framework developed for this study. Factors
53
54 influencing the decision to adopt technological innovations are identified for each of the
55
56 constructs in the framework. The impact factors are then ranked according to the
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1
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3 importance in a technology adoption decision.
4
5

6 *Identifying impact factors related to the healthcare environment*
7

8
9 Three of the five case hospitals have a 24 hour emergency department whereas the other
10 two hospitals provide an emergency clinic with limited opening hours. Table 1 provides
11 an overview of the hospitals.
12
13

14 [TABLE 1 NEAR HERE]
15
16
17

18 The environmental context of the TOE framework relates to the industry,
19 competitors and government. The Danish healthcare system is mainly government
20 funded and the administration of hospitals is divided into five regions. The five case
21 hospitals are all located within the capital region and differ in size and specialization.
22 Because the hospitals are publicly funded and offer different specializations, the
23 hospitals do not compete in the same way as in the private sector. In terms of
24 governmental influence, the hospitals are subject to a yearly 2 per cent productivity goal
25 (Astman et al., 2016). The productivity requirement has increased the pressure on
26 hospitals to become more efficient and effective. Factors related to increasing the
27 efficiency of hospitals have been categorized as process flow indicators because of a
28 better thematic match, although the motivation relates to the environmental context.
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42 As public entities, the hospitals must follow certain laws and guidelines. In
43 terms of bed cleanliness, i.e. *output quality*, all of the hospitals had encountered quality
44 issues with the cleanliness of hospital beds. Some hospitals had therefore added process
45 steps to ensure cleanliness. Hospital 4 claimed not to have quality issues anymore due to
46 major quality improvement efforts:
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52
53 Compared to the other hospitals, we don't really have any quality issues, but it's
54 something that is very important to us. The wards used to fail hygiene checks, so
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3 we introduced check lists for the beds before cleaning. If the bed fails the check, it
4 is sent to repairs. Also, every bed has an ID and we manually register whether the
5 bed has been cleaned manually or in a machine.
6
7

8 Furthermore, environmental goals, i.e. *environmental consideration* and laws regarding
9 employment, e.g. *employee work conditions* must be considered. The importance of
10 *environmental considerations* is supported by the following statement of a manager
11 from Hospital 2:
12
13
14
15

16
17
18 The bed washing machine we chose is very environmentally friendly and only uses
19 10-12 liters of water per wash. By comparison, one of the other hospitals uses 200
20 liters of water per wash... some even say 800 liters per wash!
21
22
23

24 The importance of *employee work conditions* is exemplified by a quote from a Hospital
25 3 manager:
26
27
28

29 This year we are establishing a new area for cleaning and making beds, which will
30 run on tracks, have improved indoor climate, cranes will be used for heavy lifting
31 and there will be more natural light in the room. Currently, the employees must
32 walk outside every hour due to no natural light and poor indoor climate. The new
33 facility will greatly improve the work conditions for the employees.
34
35
36
37

38 Factors relating to efficiency and employee work conditions better suit the
39 process flow and organizational structure contexts. Thus, from a bed logistics
40 perspective, it may be necessary to view the environmental context somewhat
41 differently. In this study, the environment is therefore viewed from a systems point of
42 view as anything that enters, exits or somehow influences the system, i.e. the bed
43 logistics process, from the outside. Thus, in addition to *output quality*, *future proofing*,
44 *security of supply* and *impact on related processes* were identified as impact factors
45 relating to the healthcare environment. In terms of *future proofing*, this was imperative
46 for the choice of bed washing machine at Hospital 2:
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3 There were several possible solutions in play, but one of the most important
4 reasons for choosing this solution was that it is simple for the employees to operate
5 and the machine is easy to repair, it is not necessary to split the whole thing apart.
6
7

8 The challenges of *security of supply* was corroborated by several statements, e.g.
9
10 Hospital 3: “It is a challenge that there are not always enough pillows and blankets”,
11
12 and Hospital 4: “It can be a challenge that there are sometimes not enough beds
13 available for the patients”. Finally, *impact on related processes* can be either of a
14
15 positive or negative nature; e.g. a negative impact of increased workloads for other
16
17 processes, or a positive impact of using washing machines for other items such as
18
19 assistive aids. As a manager from Hospital 5 notes:
20
21
22

23
24 We have started to use the washing machines to clean other things than beds, for
25
26 example assistive aids. We have even had a cart developed especially for the
27
28 assistive aids to be able to wash them in the machines.
29

30 *Identifying impact factors related to process flow*

31
32 The bed logistics process starts with the patient being admitted to the hospital and
33
34 placed in a bed. During hospitalization, the patient is transported in a bed by
35
36 transporters to and from treatments. Furthermore, the bed is cleaned in the ward by the
37
38 cleaning department during their daily cleaning routine. When the patient is discharged,
39
40 the dirty bed is transported to a central bed cleaning area by a transporter and cleaned
41
42 by a central bed cleaning team. In some hospitals, beds are cleaned manually, in others
43
44 they are cleaned automatically using special washing machines. One of the hospitals
45
46 distinguishes between ‘slightly dirty’ and ‘dirty’ beds; slightly dirty beds are cleaned
47
48 manually using disinfectant wipes and dirty beds are cleaned in a washing machine.
49

50
51 This study is delimited to the part of the bed logistics process from the bed being
52
53 delivered to the patient until the bed is delivered to a new patient. However, patient
54
55 transport is not part of this study.
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2
3 The identified impact factors relating to the efficiency and effectiveness of the
4 process flow are *lead time*, *risk of mistakes*, *consistency*, *value-added time* and
5 *unnecessary process*. Furthermore, *risk of mistakes* and *consistency* both imply a quality
6
7 aspect. In terms of *lead time*, a manager from Hospital 5 had the following remark:
8
9

10
11
12 We invested in a crane to improve the work conditions of our employees. The
13 challenge is that the crane takes too long and so the employees don't want to use it
14 because it's too slow.
15
16

17
18 *Risk of mistakes* was an issue due to a lack of process knowledge and perhaps even
19
20 disregard among certain employee groups as pointed out in Hospital 1:
21
22

23
24 Beds for pick-up should be handed over in a certain way, but the nurses don't
25 always follow procedure. Sometimes we're in doubt about whether the bed is
26 actually supposed to be picked up or not. And if oxygen bottles and other things
27 are left in the bed, it can cause technical problems at the conveyor belt and stop it.
28
29

30
31 Further quotes supporting the identified impact factors can be found in Table 2.
32
33

34 *Identifying impact factors related to organizational structure*

35

36
37 The organizational structure relates to aspects such as scope, size, and managerial
38 structure. The bed logistics process involves several different organizational units: bed
39 cleaning staff, general cleaning staff, transporters and nurses. The large number of
40 organizational units involved in the bed logistics process makes the process fragmented
41 and requires collaboration between several staff groups. This fragmentation increases
42 the *risk of mistakes* in the process, i.e. a process related factor, and emphasizes the
43 significance of *competence shifts*, i.e. handovers, and *competence match*, i.e. ensuring
44 the right skills and behavior. E.g. as noted by a transporter at Hospital 1:
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3 Each floor leaves the beds for pick-up differently, so you have to learn how they do
4 it in each floor so you don't make a mistake.
5

6
7 The *work conditions* for employees have improved greatly over the years. The
8
9 centralized bed cleaning provides better ergonomic work conditions and some hospitals
10
11 have introduced equipment for loading and unloading mattresses. One hospital
12
13 implemented a monorail to ease transport to a separate bed cleaning facility and to
14
15 improve the ergonomic position for bed cleaning staff. Another hospital introduced
16
17 cranes for lifting mattresses:
18

19
20
21 We invested in a crane to improve the work conditions of our employees. The
22
23 challenge is that the crane takes too long and so the employees don't want to use it
24
25 because it's too slow.
26

27 A main challenge in the bed logistics process is *employee engagement*,
28
29 particularly employee absenteeism. Cleaning tasks and patient transport are considered
30
31 dull, repetitive tasks that are physically demanding, leading to high rates of
32
33 absenteeism. Another challenge relating to *employee engagement* is low staff retention
34
35 rates:
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39 There are over 80 ways of cleaning a room and the employees need to learn the
40
41 right way under for circumstance. We pay for extensive training of the employees
42
43 and then they go off to a better paid job in the private sector.
44

45 This lack of continuity in the staff base poses challenges for the quality of cleaning as
46
47 mentioned by the head of the cleaning department at Hospital 1:
48

49
50 The quality of cleaning depends greatly on the person doing it...especially for
51
52 weekend staff and the use of temps during vacation season, but we are trying to
53
54 solve the issue through training.
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Identifying impact factors related to technology

The technology context refers to relevant technologies which are in use and available in the market. The hospitals differ in the extent of technology adoption in the bed logistics process. The *degree of automation* therefore differs greatly for the hospitals and influences the process, e.g. in terms of *output quality*, the elimination of *unnecessary processes* and *employee work conditions*. The identified technologies include washing machines for bed washing, equipment to load and unload mattresses when washing beds, a monorail for bed transport, and barcodes and RFIDs for tagging beds. The parentheses in Table 1 indicate that the technology had been installed but was not used in everyday operations. This was due to either 1) the implementation had failed, 2) the technology had only been tested, or 3) further investments were needed to fully operate. The attempted implementation of a crane in hospital 3 failed because the crane could not endure water, and the crane in hospital 5 failed because employees refused to use it due to prolonged processing times. Hospital 1 had barcodes attached to all of the beds for repair purposes but lacked the software to enable bed management. RFID was tested at hospital 1 and 4, but had not been implemented due to political reasons. One important difference between barcodes and RFID is the *degree of automation*, i.e. RFID technology can automatically capture data whereas barcodes need manual intervention.

Data availability in the bed logistics processes is scarce. However, technologies such as RFID can increase data availability and consequently enable *traceability* and *information management* to improve process flows. Two managers at Hospital 1 elaborate on these two factors:

Not a lot of data exists around bed logistics... we have started to count the number of beds cleaned using an electronic device, but it does not register the progression during the day, it just gives us a total...so we write down three times a day what

1
2
3 the count is. And this is only for normal beds, children's beds we still count
4 manually.
5

6
7 Seventeen impact factors were identified. Table 2 provides transparency on how the
8 impact factors were derived from data.
9

10
11 [TABLE 2 NEAR HERE]
12
13

14
15 Table 3 summarizes the identified impact factors and how they relate to the
16 constructs Healthcare environment, Technology, Process flow and Organizational
17 structure.
18
19

20
21 [Table 3 near here]
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24
25

26 *Ranking the identified impact factors*

27

28
29 Table 4 provides an overview of how the hospitals have weighted each of the identified
30 impact factors. The table is sorted in descending order according to the average weight
31 (μ) and includes the standard deviation (σ) for each impact factor. The association of
32 impact factors to the constructs Healthcare environment (H), Technology (T), Process
33 flow (P) and Organizational structure (O) is indicated in the table.
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35
36
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38

39
40 [TABLE 4 NEAR HERE]
41

42 A few comments on the validity of the results in Table 4 are necessary. First, Hospital 1
43 weighted the decision parameters more nuanced and lower than the other hospitals. This
44 could reflect either a different interpretation of the scale or simply a lower perceived
45 importance of the decision criteria. Furthermore, all hospitals seem to agree that *output*
46 *quality* is of high importance. Hospital 4 had diligently addressed their quality issues
47 through different initiatives, thus did not assign a high weight to *output quality*.
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54 However, the fact that the hospital had invested substantial efforts to reach the current
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3 level of quality indicates that output quality is indeed important and that the weighting
4
5 does not reflect the manager's actual view. The discrepancy is evident in the following
6
7 statement from the manager responsible for bed logistics at the hospital:
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10 Compared to the other hospitals, we don't really have any quality issues, but it's
11 something that is very important to us. The wards used to fail hygiene checks, so
12 we introduced check lists for the beds before cleaning. If the bed fails the check, it
13 is sent to repairs. Also, every bed has an ID and we manually register whether the
14 bed has been cleaned manually or in a machine.
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19 The case study hospitals have different levels of technology adoption in the bed
20 logistics process (see Table 1). To ensure that the weighted importance of impact
21 factors is not merely a product of technology adoption levels in the organization, the
22 hospitals were grouped in Table 4 according to their level of technology adoption in the
23 bed logistics process. Hospital 3 uses no technologies in daily operations whereas
24 Hospital 2 has adopted three types of technologies. The use of technology in the bed
25 logistics process at Hospital 1, 4 and 5 is somewhere in the middle. Table 4 shows that
26 the *degree of automation* is the only impact factor that shows a consistent pattern in
27 relation to technology adoption. For the hospitals with either high or low technology
28 adoption, the degree of automation is considered of high importance. For the hospitals
29 with medium technology adoption, the importance was considered slightly lower.
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43 In summary, most hospitals agreed that the impact factors identified in the
44 interviews are important for improving healthcare logistics processes as none of them
45 have received low average scores. Furthermore, apart from *degree of automation*, the
46 importance of the impact factors did not seem to depend on the level of technology
47 adoption.
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High ranking impact factors

The highest ranking impact factors are also the factors that exhibit the most agreement amongst respondents, i.e. low standard deviation (σ). The highest ranking impact factors relate to *quality*, *employee work conditions* and *employee engagement*. The identified factors *risk of mistakes*, *consistency* and *output quality* relate to quality. *Output quality* is included here, as the ranking does not reflect actual perceived importance, particularly regarding Hospital 4 which had introduced additional steps to ensure the cleanliness of beds upon patient discharge. Although hospitals have introduced several measures to address the challenges related to *quality*, *employee work conditions* and *employee engagement*, *employee engagement* in particular continues to be a significant challenge.

Impact factors with low consensus

The impact factors with low consensus, i.e. high standard deviations, are incidentally also the lowest ranking impact factors (see Table 4). The lowest ranking factors are *competence match*, *competence shifts*, *traceability* and *unnecessary process*. Hospital 1, 2 and 3 do not see *competence match* as an important impact factor. Interestingly, Hospital 2 is the same hospital that stressed the importance of a simple washing machine solution that is easy for the employees to use. Furthermore, the Hospital 1 case study provides supporting evidence that *competence match* is imperative in ensuring correct handovers, i.e. *competence shifts*. Hospital 1 and 2 consider *competence shifts* of low importance. However, Hospital 1 has experienced several challenges when it comes to handovers as items are erroneously left in beds, disrupting the automated transport and causing downtime and a need for maintenance as noted by a transporter:

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3 Beds for pick-up should be handed over in a certain way, but the nurses don't
4 always follow procedure. Sometimes we're in doubt about whether the bed is
5 actually supposed to be picked up or not. And if oxygen bottles and other things
6 are left in the bed, it can cause technical problems at the conveyor belt and stop it.
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10 It would seem that the manager is either not aware of this challenge or simply does not
11 view it as an important issue.
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14 Technologies can be used to register handovers in the process and ensure
15 traceability. Hospital 2 is the only hospital that does not view *traceability* as an
16 important decision criterion. However, Hospital 2 is one of the hospitals that have
17 actually invested in barcode technology for traceability in the process. Thus, there
18 seems to be some inconsistency between the use of barcodes to ensure traceability and
19 the statement that traceability is not important.
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27 All hospitals stated that the financial aspect of investing in a potential
28 technology should be considered. There seems to be a discrepancy between the
29 perceived low importance of an *unnecessary process* and a strong emphasis on the
30 financial aspect. This indicates that some of the managers may not want to admit to
31 cutting resources. Conversely, as one of the bed cleaning managers pointed out:
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39 Automation is important for improving efficiency. However, we must also think of
40 the people working in these jobs – it will be difficult for them to find other jobs. I
41 believe in future solutions that include both automation and people.
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45 Thus, there seems to be a sense of responsibility from management to ensure jobs for
46 these employees. Another manager raised this point and referred to their social
47 responsibility.
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51 In summary, for the impact factors with low consensus, the perceived low
52 importance of an impact factor often did not match with other statements or past
53 behavior and should have been assigned higher values.
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Discussion

The benefits realized from a technology differ between companies (Xie et al., 2016); what is right for one company may not be right for others. The state of a process and the improvement potential of a process affect the benefits that can be realized from introducing a new technology. Moreover, depending on whether a radical or incremental process approach is applied may limit the possibilities of introducing a technology that would cause radically different processes. Thus, most investments in a company require a business case to justify the investment, including financial and operational effects. To better understand and predict technology adoption, a technology adoption framework should reflect this reality of organizations and include the BPM dimension to consider the operational effects of a technology. Conversely, BPM benefits from a technological perspective as technologies can affect both process design (Hung, 2006; Trkman, 2010) and process efficiency (Voss, 1988).

RQ1 implies a relationship between processes and technologies. A conceptual framework was developed based on the TOE framework and the success factors of BPM to analyze the case study data. The framework consists of four constructs: healthcare environment, technology, organizational structure and process flow. Combining the TOE and BPM framework suggests a relationship between the four constructs.

Examining the TOE framework, the technological and environmental aspects of the TOE framework constitute external factors, whereas the organizational aspect is internal to the organization. Adding a BPM perspective provides an additional internal dimension to the framework and creates a framework that is even more pertinent to a specific company or hospital, also providing a balance between external and internal constructs.

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3 A set of 17 impact factors was identified. Apart from the *degree of automation*,
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5 the study shows that the impact factors as decision criteria do not depend on the existing
6
7 level of technology adoption. The identified impact factors each relate to one of the
8
9 constructs healthcare environment, technology, process flow and organizational
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11 structure. Other studies have in a similar fashion identified factors inherent to the TOE
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13 framework for the adoption of certain technologies within a healthcare setting. E.g.
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15 performance gap, market uncertainty, perceived benefits, technology knowledge and
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17 vendor pressure influence RFID adoption in healthcare (Lee and Shim, 2007).
18
19 Furthermore, factors relating to perceived benefits, costs, IT readiness,
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21 action/interaction in the RFID adoption process and reactions to the RFID application
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23 affect RFID adoption in healthcare (Cao et al., 2014). Moreover, hospital size, adequate
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25 resources, vendor support and government policy have been identified as significant
26
27 factors determining e-signature adoption in healthcare (Chang et al., 2007). Hu et al.
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29 (2000) identify collective attitude of medical staff, perceived service risks and perceived
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31 ease of use as significant factors influencing technology adoption.
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35 This study suggests a number of new factors underlying the TOE framework for
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37 a healthcare logistics setting. For the technology construct, *impact on related processes*
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39 and *future proofing* had not been identified in other studies as impact factors. For the
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41 organizational structure construct, others have described the importance of human
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43 factors, e.g. attitudes and perceptions (Chang et al., 2007; Hu et al., 2000). The novelty
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45 of the factors identified in this study lies in the importance of *competence shifts*, i.e.
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47 handovers, *competence match*, *employee engagement* and *work conditions*. For the
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49 healthcare environment construct, *environmental considerations* and *degree of*
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51 *automation* constitute new constructs identified in this study. Finally, the additional
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53 process flow construct consists of five factors: *lead time*, *value-added time*, *risk of*
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3 *mistakes, consistency* and *unnecessary process*. I.e. these factors have not been
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5 identified previously in TOE literature as they do not fit the original TOE constructs.

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7 However, the factors share similarities with two of the healthcare supply chain
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9 performance dimensions suggested by Lega et al. (2012), namely delivery performance
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11 and time to deliver. Furthermore, the importance of flexibility to assess healthcare
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13 supply chain performance as proposed by Lega et al. (2012) suggests that a process
14
15 perspective is relevant in assessing supply chain solutions. Given that demand
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17 variability calls for the application of agile process strategies in healthcare as noted in
18
19 the literature review (Aronsson et al., 2011), flexibility can help achieve agile processes
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21 and supply chains to cope with demand variability.

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24 Compared to the factors identified by other researchers, the factors identified in
25
26 this study focus more on the operational and quality impact of a technology in addition
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28 to the interdependence between factors. Furthermore, this study provides a more
29
30 nuanced framework for explaining technology adoption in healthcare logistics by
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32 suggesting additional factors relating to each of the four constructs.

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35 To answer RQ2, the impact factors were ranked. The factors perceived as most
36
37 important for adopting technologies in healthcare logistics processes relate to *quality*,
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39 *employee work conditions* and *employee engagement*. Improvement of these aspects
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41 should therefore be incorporated in the process design. Relating to extant literature, the
42
43 *quality* concept is inherent to BPM, which is rooted in TQM (Hung, 2006; Zairi and
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45 Sinclair, 1995). On the point of *employee work conditions*, poor ergonomics can lead to
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47 worker injuries and has lately received more attention in literature, e.g. (Andriolo et al.,
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49 2016; Grosse et al., 2015; Keller and Ozment, 2009). Both poor *employee work*
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51 *conditions* and low *employee engagement* can lead to injuries, high absenteeism and
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53 high turnover rates, which in turn can be costly to the employer. However,
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3 incorporating human factors in an operating model, e.g. by involving workers in the
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5 process design, can improve the outcome for both employees and production (Grosse et
6
7 al., 2015; Guimarães et al., 2015). Furthermore, employee involvement is vital to the
8
9 success of BPM efforts (Hung, 2006). Thus, the findings of this study align with other
10
11 streams of literature. The consistency between the identified impact factors across the
12
13 five case studies and literature strengthens the validity and generalizability of the
14
15 results, suggesting that the impact factors apply to other hospital settings and potentially
16
17 other industries.
18

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20 The impact factors with least consensus regarding the importance to the redesign
21
22 of healthcare logistics processes through technology adoption are *competence shifts*,
23
24 *competence match*, *traceability* and *unnecessary processes*. *Competence shifts* and
25
26 *competence match* in particular are viewed differently and do not seem to receive the
27
28 attention they deserve. Similarly, a study by Keller and Ozment shows that logistics
29
30 managers often do not focus on building employee knowledge and driving employee
31
32 success (Keller and Ozment, 2009). Moreover, too many *competence shifts* or handoffs
33
34 lead to inefficiencies and inevitable errors and misunderstandings in a process (Parnaby
35
36 and Towill, 2009). However, training of both clinical and support staff to achieve the
37
38 right *competence match* can reduce errors and ensure correct handoffs, i.e. improve
39
40 quality. Training is therefore an important enabler of the successful redesign of
41
42 processes (Ho et al., 1999; Hung, 2006; Trkman, 2010).
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46 *Traceability* can support *competence shifts* and *competence match* by ensuring
47
48 visibility in a process and accountability for each process step and handover. Closely
49
50 related to *traceability* is the *degree of automation*, which can support *traceability*.
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52 Finally, *unnecessary processes* in an organization correspond to waste in a BPM context
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54 and should be eliminated (Hammer, 1990; Hammer and Champy, 1993; Womack and
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3 Jones, 2003). Except for *competence shifts* and *competence match*, the case study
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5 hospitals seem to consider the low consensus impact factors more than they let on.
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7 However, hospitals could benefit from paying more attention to *competence shifts* and
8
9 *competence match* both within and outside of the logistics organization. The lack of
10
11 respect and recognition of the importance of logistics activities found in the case study
12
13 is an example of how logistics and the benefit of logistics need to be marketed to the
14
15 rest of the organization to fully reap the potential of logistics services (Ralston et al.,
16
17 2013).
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20 In addition to identifying and ranking the impact factors, relations between the
21
22 impact factors have been identified. First, combining the TOE framework and BPM
23
24 perspective indicates a relationship between the four constructs technology,
25
26 environment, organizational structure and process flow. The novelty lies in the
27
28 combination of all four constructs and in the new relation between the environment and
29
30 the process flow. Thus, the environment affects how the process is designed, e.g. if a
31
32 sterile environment is needed. Conversely, the process affects the environment, e.g. in
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34 terms of customers or patients and competitors. Second, the identified impact factors
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36 underlying each construct are inadvertently linked according to the links between the
37
38 constructs. Third, antecedents of quality were identified from the impact factors relating
39
40 to organizational structure; *competence shifts* increases risk of mistakes, *competence*
41
42 *match* decreases *risk of mistakes* and increases *output quality*, and *employee*
43
44 *engagement* increases *output quality*. Furthermore, *degree of automation* was found to
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46 increase *output quality*, eliminate *unnecessary processes*, improve *employee work*
47
48 *conditions*, and enable *traceability* and *information management*.
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52 Each of the four main constructs in the developed framework should be
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54 considered and balanced when making changes to a logistics process, much like
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balancing the four perspectives of the Balanced Scorecard (Kaplan and Norton, 1992). The ranking of the impact factors indicates the weight each impact factor and subsequently each construct holds in a technology adoption decision. The impact factors could therefore be used as part of a quantitative assessment, e.g. by applying the AHP method or through a more descriptive and strategic analysis (Meredith and Suresh, 1986). AHP has been used for similar purposes such as determining process performance for different process designs (Frei and Harker, 1999), health technology assessment (Ritrovato et al., 2015), technology justification (Meredith and Suresh, 1986), and benchmarking logistics performance (Korpela and Tuominen, 1996). The decision factors could also provide areas for benchmarking process performance and ultimately identifying best practices. Thus, the prioritization of the decision factors brings attention to areas that should be improved first.

To summarize the discussion, the contribution of this study lies in the following. First, the study extends the TOE framework by combining the TOE and BPM perspectives. Second, impact factors pertinent to technology adoption in healthcare logistics are identified. Third, the level of technology adoption within a given organization does not seem to affect the importance of impact factors other than *degree of automation*. Fourth, differences in importance of impact factors are determined to better assess and predict technology adoption. Fifth, relations between impact factors were identified. Sixth, the impact factors provide a framework to which quantitative assessment methods can be applied to assess technologies.

Conclusion

This paper adds to the limited empirical research on technology adoption within the field of healthcare logistics. A multiple case study was conducted at five Danish hospitals and 17 factors influencing the decision to adopt technologies in a healthcare

1
2
3 logistics context were identified. Furthermore, the impact factors were ranked and the
4
5 most important factors identified as those relating to *quality*, *employee work conditions*
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7 and *employee engagement*. In the following, the scientific contribution and practical
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9 implications are explicated.
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12 In terms of scientific contributions, the study focuses on bed logistics processes
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14 in hospitals and combines a technology adoption and BPM theoretical lens to enhance
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16 the TOE framework. A conceptual framework for technology adoption was developed
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18 consisting of the three TOE constructs and an added process flow construct from the
19
20 BPM perspective. This study thereby contributes to technology adoption theory by
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22 extending and refining/elaborating the TOE framework; extension in terms of the added
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24 process flow construct and refinement/elaboration in terms of the impact factors
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26 identified for each of the four constructs in the developed conceptual framework. Thus,
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28 the conceptual framework was tested for the bed logistics process and refined through
29
30 the identified impact factors. The results show that the proposed conceptual framework
31
32 is applicable as a technology adoption framework and for a healthcare logistics setting.
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34 Although other studies have combined different theories with TOE, the framework
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36 developed in this study distinguishes itself from existing research by adding the process
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38 perspective. The process perspective ensures that the process in which a new technology
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40 is adopted is taken into consideration as the technology will function as an integrated
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42 part of that process. Furthermore, the developed framework has been tested for a
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44 healthcare logistics setting and for different types of technologies rather than focusing
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46 on a single technology, e.g. telemedicine (Hu et al., 2000), RFID (Cao et al., 2014) or
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48 electronic signatures (Chang et al., 2007).
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54 In addition to identifying the impact factors for an enhanced technology
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56 adoption framework, the impact factors were ranked according to the importance in a
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3 technology adoption decision. Although the results show that all the identified impact
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5 factors are important to a technology adoption decision, some are more important than
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7 others. From a practical perspective, it may not be feasible to assess all the 17 impact
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9 factors. Ranking the impact factors therefore enables decision makers to focus their
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11 attention for improvement initiatives. The most important impact factors identified in
12
13 this study relate to *quality*, *employee work conditions*, and *employee engagement*. These
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15 factors mainly relate to the process flow and organizational structure constructs of the
16
17 developed framework, but also the healthcare environment construct in terms of *output*
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19 *quality*. Thus, the results of the study stress the importance of incorporating human
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21 factors in the design of healthcare logistics processes and found that human factors have
22
23 implications for correct handovers and quality in the process. Furthermore, the results
24
25 suggest that decision makers should focus more attention on *competence match* and
26
27 *competence shifts*, i.e. handovers, as these factors have implications for the efficiency
28
29 and effectiveness of the processes.
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33 The practical implications of this study are multiple. First, the conceptual
34
35 framework provides a framework for decision makers to make an informed decision
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37 concerning technology adoption in a healthcare logistics process. Second, the
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39 framework enables a quantitative assessment which can be combined with a qualitative
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41 assessment based on the impact factors. Third, the process perspective and the effects
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43 on processes of introducing a technology should be considered in adopting a potential
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45 technology. E.g. if the introduction of a technology causes extra work for other
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47 organizational units, the technology might not be worth implementing. Fourth, the
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49 identified and ranked impact factors focus the attention of decision makers to the most
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51 important aspects of a technology adoption decision specific to a healthcare logistics
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53 context, i.e. *quality*, *employee work conditions* and *employee engagement*. Fifth, the
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3 impact factors indicate where managers should focus their attention in terms of new
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5 improvement initiatives for a healthcare logistics process. E.g. antecedents of improved
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7 quality were identified, suggesting that decision makers should pay more attention to
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9 reducing *competence shifts* or handovers, increasing *competence match* to fit the task,
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11 ensure *employee engagement*, and increase the *degree of automation*. Thus, to improve
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13 *quality*, these antecedents should be incorporated in the process design. Sixth,
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15 understanding the factors influencing the decision to adopt a technology in a healthcare
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17 logistics setting may induce technology providers to rethink the value proposition and
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19 product design that their products will offer in the future. Consequently, the framework
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21 may support the prediction of technology adoption.
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25 This study is subject to some limitations. First, the findings are limited to a
26
27 Danish setting. Second, the findings are specific to a healthcare context. Third, the
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29 findings are limited to hospitals sized up to 700 beds and would need to be validated for
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31 larger hospitals. The findings of this study are expected to be true for hospitals that
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33 operate under similar conditions, i.e. small to large public hospitals located in developed
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35 countries. However, further studies are needed to validate this. Other areas for future
36
37 research include the organizational aspect; human factors in particular are sparsely
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39 researched for healthcare logistics.
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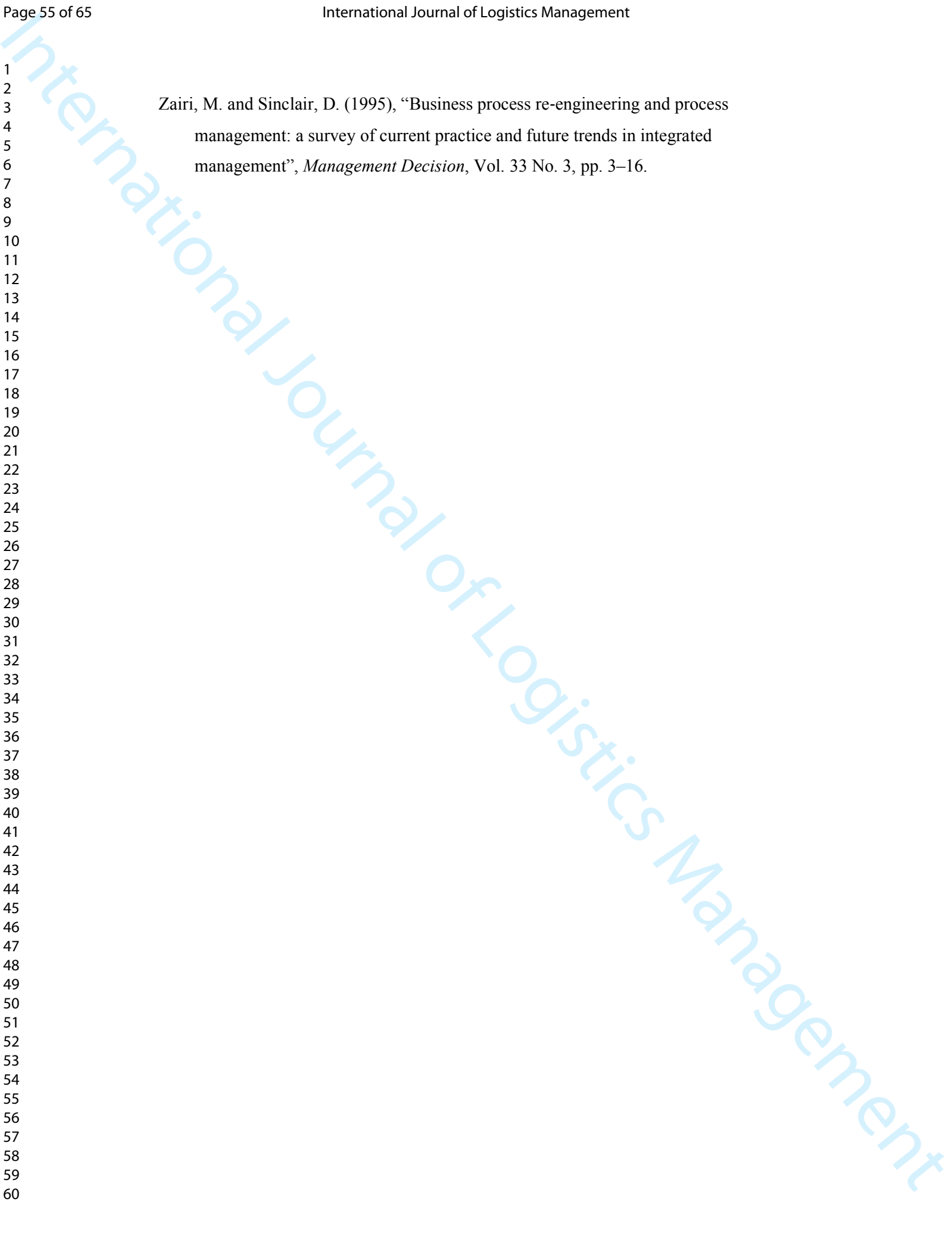
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Appendix

Table A1 provides an overview of the identified factors that the bed logistics responsible at each hospital was asked to rank on a 0-10 scale. The factors were identified based on the first round of interviews.

Table 1

Decision criterion	Description	Weight (0-10)
<i>Lead time</i>	Time from order to delivery.	
<i>Value-added time</i>	% of lead time adding value.	
<i>Security of supply</i>	Ensuring the right amount at the right time.	
<i>Traceability</i>	Enabling track and trace.	
<i>Degree of automation</i>	How automated is the process?	
<i>Information management</i>	The ability to collect, analyze and communicate data.	
<i>Environmental considerations</i>	Sustainable use of energy, chemicals, renewable materials etc.	
<i>Risk of mistakes</i>	Likelihood of mistakes occurring.	
<i>Consistency</i>	Standardization of the process and process output.	
<i>Future proofing</i>	Will the solution sustain in five years? Is it flexible?	
<i>Impact on related processes</i>	Negative and positive impact on other processes. E.g. other use for technology or increased workload for others.	
<i>Output quality</i>	Quality of product/service delivered.	
<i>Competence shift (handovers)</i>	Number of handovers in the process.	
<i>Competence match</i>	Do the competencies of the employees match the needs of the new process or is training needed?	
<i>Unnecessary process</i>	Can the process be avoided?	
<i>Employee engagement</i>	Is the employee motivated to perform the job? Is an incentive provided?	
<i>Employee work conditions</i>	Employee safety, work load, strenuous work, ergonomics, physical and psychological work environment.	

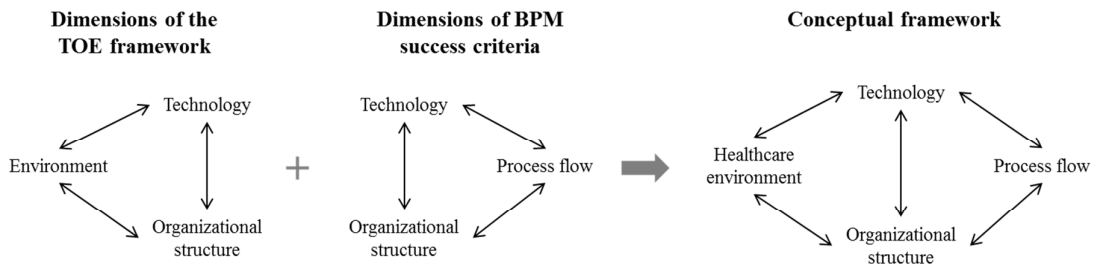


Figure 1. Developed conceptual framework for data analysis

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Table 1. Overview of case study hospitals, beds and implemented technologies

Hospital	# beds occupied	# actual beds	# beds cleaned/day	24h ED?	Implemented technologies				
					Washing machine	Equipment to (un)load mattress	Monorail	Barcodes	RFID
Hospital 1	700	1,200	235	Yes			X	(X)	(X)
Hospital 2	600	800	250	Yes	X	X		X	
Hospital 3	500	1,200	175	Yes		(X)			
Hospital 4	300	560	110	No	X	X			(X)
Hospital 5	250	500	120	No	X	(X)		X	

Table 2. Derived impact factors for the healthcare environment construct

Impact factor	Description of impact factor	Challenges identified in case studies	Case study data examples (quotes)	Technology					Reasons for implementing technology identified in case studies
				Washing machine	Equipment to (un)load mattresses	Monorail	Barcodes	RFID	
<i>Future proofing</i>	Ensuring that a solution is viable in the long run in relation to the overall strategy, future capacity needs, and future technology investments.	The placement of the bed cleaning area increases transporting time for beds. The monorail transports beds to the bed cleaning area, but the tact of the monorail leads to inefficiencies. This system is not easily replaced.	H2: "There were several possible solutions in play, but one of the most important reasons for choosing this solution was that it is simple for the employees to operate and the machine is easy to repair, it is not necessary to split the whole thing apart."	N/A					N/A
<i>Security of supply</i>	Ensuring that the right bed and mattress is available at the right time.	Difficulties exist for ensuring enough clean beds and the right bed/mattress for the right patient. It is not known whether or not the available resources will match the need of resources, making it difficult to plan activities.	H3: "It is a challenge that there are not always enough pillows and blankets." H4: "It can be a challenge that there are sometimes not enough beds available for the patients."	N/A					N/A
<i>Impact on related processes</i>	Other processes could be affected negatively due to increased work load.	Increased work has incurred for related processes as a consequence of changes made to the bed cleaning process, e.g. by centralizing bed washing.	H5: "We have started to use the washing machines to clean other things than beds, for example assistive aids. We have even had a cart developed especially for the assistive aids to be able to wash them in the machines."	X					To possibly use the washing machines for other tasks.
<i>Output quality</i>	Quality of output, i.e. the cleanliness of beds. Differs from risk of mistakes as output quality would also depend on tools/machinery.	Hospitals have experienced difficulties in living up to cleaning requirements due to lack of qualified resources and a lack of quality standards. Furthermore, measuring quality is difficult and quality controls are insufficient.	H4: "Compared to the other hospitals, we don't really have any quality issues, but it's something that is very important to us. The wards used to fail hygiene checks, so we introduced check lists for the beds before cleaning. If the bed fails the check, it is sent to repairs. Also, every bed has an ID and we manually register whether the bed has been cleaned manually or in a machine."	X					To ensure consistent output quality, i.e. the cleanliness of all cleaned beds.
<i>Environmental considerations</i>	Considering the use of water, chemicals, electricity etc.	Excessive use of water occurs either through manual or automated washing, leading to environmental waste.	H2: "The bed washing machine we chose is very environmentally friendly and only uses 10-12 l of water per wash. By comparison, one of the other hospitals uses 200 l of water per wash... some even say 800 l per wash!"	X					To reduce the use and waste of water for washing bed.

Table 2 (continued). Derived impact factors for the technology construct

Impact factor	Description of impact factor	Challenges identified in case studies	Case study data examples (quotes)	Technology				Reasons for implementing technology identified in case studies	
				Washing machine	Equipment to (un)load mattresses	Monorail	Barcodes		RFID
<i>Degree of automation</i>	Enabling coordination and planning of activities through data availability.	Lack of data availability is an issue, e.g. regarding bed and mattress needs. In addition, a lot of the data is manually registered. This lack of data makes it difficult to plan resources.	<p>H5: "Automation is important for improving efficiency. However, we must also think of the people working in these jobs – it will be difficult for them to find other jobs. I believe in future solutions that include both automation and people."</p> <p>H1: "We have started to count the number of beds cleaned using an electronic device, but it does not register the progression during the day, it just gives us a total...so we write down three times a day what the count is. And this is only for normal beds, children's beds we still count manually."</p>			X			<p>Use staff when human attention is required.</p> <p>RFID more automated than barcodes to capture data.</p>
<i>Information management</i>	N/A	N/A	<p>H1: "Not a lot of data exists around bed logistics...we have started to count the number of beds cleaned using an electronic device, but it does not register the progression during the day, it just gives us a total...so we write down three times a day what the count is. And this is only for normal beds, children's beds we still count manually."</p>				X	X	Capturing data enables planning and studies to improve bed flow.
<i>Traceability</i>	Enabling traceability and localization of items in the process.	The whereabouts of the beds is unknown and data on the history of the bed is not available, making it time consuming and difficult to analyze how to improve the utilization of beds.	<p>H4: "Every bed has a unique ID, and we register what is washed in the machine and what is washed manually."</p>				X	X	Enables traceability of beds, data capturing and planning.

Table 2 (continued). Derived impact factors for the process flow construct

Impact factor	Description of impact factor	Challenges identified in case studies	Case study data examples (quotes)	Technology					Reasons for implementing technology identified in case studies
				Washing machine equipment to (un)load mattresses	Monorail	Barcodes	RFID		
<i>Lead time</i>	Time elapsed from a significant point in time until a significant end time.	Washing machines take longer but provide cleaner beds, which many hospitals were willing to trade off. However, loading equipment for mattresses failed due to employees not willing to wait for equipment to finish.	H5: "We invested in a crane to improve the work conditions of our employees. The challenge is that the crane takes too long and so the employees don't want to use it because it's too slow." H2: "It only takes 6 minutes for the machine to wash three beds at a time."	X					One of the washing machines was chosen because it can wash several beds at a time.
<i>Value-added time</i>	Time spent on process steps that do not add value to the patient or departments.	Non value-added time was experienced in terms of excessive transport times to other building, waiting time due to bottlenecks, and over processing/cleaning.	H1 observation: It took approximately 16 minutes for a bed to be transported from the main hospital building to the service building where the beds were cleaned and another 16 minutes back to the hospital building.	N/A					N/A
<i>Risk of mistakes</i>	The risk of making mistakes in the process. Risk mitigating mechanisms in place.	Mistakes mainly occur due to a lack of process knowledge, e.g. nurses do not leave the beds for the bed transporters in the correct condition for cleaning. Furthermore, there is a lack of systems knowledge to perform tasks correctly. Finally, incentives to perform process correctly are lacking.	H1: "Each floor leaves the beds for pick-up differently, so you have to learn how they do it in each floor so you don't make a mistake." H1: "Beds for pick-up should be handed over in a certain way, but the nurses don't always follow procedure. Sometimes we're in doubt about whether the bed is actually supposed to be picked up or not. And if oxygen bottles and other things are left in the bed, it can cause technical problems at the conveyor belt and stop it."	X					To avoid mistakes in the process. A simple solution ensures ease of use for the employees and makes it easier to match the right competencies
<i>Consistency</i>	The extent to which the process is performed the same.	Processes are often not performed in the same way because each employee has their own way of doing things and there are no standard operating procedures.	H1: "Each floor leaves the beds for pick-up differently, so you have to learn how they do it in each floor so you don't make a mistake." H1: "The quality of cleaning depends greatly on the person doing it...especially for weekend staff and the use of temps during vacation season, but we are trying to solve the issue through training."	X					To ensure consistent output quality, i.e. the cleanliness of all cleaned bed
<i>Unnecessary process</i>	Tasks that are unnecessary and could be avoided.	Use of unnecessary resources and unnecessary process steps.	H5: "Beds that have only been used momentarily and with no contamination risk, we clean with disinfectant wipes."	X		X			To reduce the use of employee resources.

Table 2 (continued). Derived impact factors for the organizational structure construct

Impact factor	Description of impact factor	Challenges identified in case studies	Case study data examples (quotes)	Technology						Reasons for implementing technology identified in case studies
				Washing machine	Equipment to (un)load mattresses	Monorail	Barcodes	RFID		
<i>Competence shifts</i>	Handovers that happen between resources in the process.	Handovers should be done by a different personnel group to avoid mistakes and rework. In the current setup, mistakes occur at handovers because employees do not know how to hand over correctly.	H1: "Each floor leaves the beds for pick-up differently, so you have to learn how they do it in each floor so you don't make a mistake." H1: "Beds for pick-up should be handed over in a certain way, but the nurses don't always follow procedure. Sometimes we're in doubt about whether the bed is actually supposed to be picked up or not. And if oxygen bottles and other things are left in the bed, it can cause technical problems at the conveyor belt and stop it."	X						Simple solutions ensure ease of use and makes it easier to match the right competencies.
<i>Competence match</i>	The extent to which employees have the necessary competencies to perform a task.	There is a general lack of systems knowledge in the hospitals. Wrongful handovers between departments means that beds are not handed over correctly.	H1: "The quality of cleaning depends greatly on the person doing it...especially for weekend staff and the use of temps during vacation season, but we are trying to solve the issue through training."	N/A						N/A
<i>Employee engagement</i>	The extent to which the employees feel motivated to perform a task and incentives for performing tasks.	Issues with low productivity experienced, mainly due to lack of incentives and motivation to perform tasks and use technologies. Another example is lack of feeling responsibility and pride due to transporter centralization.	H1: "There are over 80 ways of cleaning a room and the employees need to learn the right way under for circumstance. We pay for extensive training of the employees and then they go off to a better paid job in the private sector." H1: "The quality of cleaning depends greatly on the person doing it...especially for weekend staff and the use of temps during vacation season, but we are trying to solve the issue through training."	N/A						N/A
<i>Employee work conditions</i>	The conditions under which employees work. E.g. access to sunlight, ergonomics etc.	Working conditions for employees cleaning beds have historically been poor, although recently improved, and tasks are often physically strenuous, e.g. pushing beds.	H3: "We are establishing a new area for cleaning and making beds, which will run on tracks, have improved indoor climate, cranes will be used for heavy lifting and there will be more natural light in the room. Currently, the employees must walk outside every hour due to no natural light and poor		X	X				To alleviate employees from strenuous work.

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			indoor climate. The new facility will greatly improve the work conditions for the employees.”						
			H5: “We invested in a crane to improve the work conditions of our employees. The challenge is that the crane takes too long and so the employees don’t want to use it because it’s too slow.”						

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Table 3. List of impact factors serving as decision criteria

Healthcare environment	Technology	Process flow	Organizational structure
<ul style="list-style-type: none">• Future proofing• Security of supply• Impact on related processes• Output quality• Environmental considerations	<ul style="list-style-type: none">• Degree of automation• Information management• Traceability	<ul style="list-style-type: none">• Lead time• Value-added time• Risk of mistakes• Consistency• Unnecessary process	<ul style="list-style-type: none">• Competence shifts• Competence match• Employee engagement• Employee work conditions

Table 4. Impact factors with assigned weights of importance

Impact factors	Low techn. adoption	Medium technology adoption			High techn. adoption	All hospitals	
	Hospital 3	Hospital 1	Hospital 4	Hospital 5	Hospital 2	μ	σ
<i>Risk of mistakes (P)</i>	10	10	10	10	10	10.0	-
<i>Employee work conditions (O)</i>	10	8	10	10	10	9.6	0.8
<i>Consistency (P)</i>	10	7	10	10	10	9.4	1.2
<i>Employee engagement (O)</i>	10	7	10	10	10	9.4	1.2
<i>Security of supply (H)</i>	10	7	10	10	10	9.4	1.2
<i>Environmental considerations (H)</i>	10	7	10	8	10	9.0	1.3
<i>Value-added time (P)</i>	9	5	10	8	10	8.5	1.9
<i>Lead time (P)</i>	10	4	10	8	10	8.4	2.3
<i>Information management (T)</i>	10	5	10	9	8	8.4	1.7
<i>Impact on related processes (H)</i>	10	5	8	9	10	8.3	1.8
<i>Future proofing (H)</i>	9	4	8	10	10	8.0	2.1
<i>Output quality (H)</i>	10	9	-	10	10	7.8	3.9
<i>Degree of automation (T)</i>	9	6	7	7	10	7.8	1.5
<i>Traceability (T)</i>	8	7	10	10	2	7.4	2.9
<i>Competence shift (O)</i>	10	2	8	7	1	5.6	3.5
<i>Competence match (O)</i>	4	3	10	10	1	5.6	3.7
<i>Unnecessary process (P)</i>	9	3	8	-	5	5.0	3.3