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Relations between decision indicators for implementing technology in healthcare logistics – a bed logistics case study

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Abstract
The cost of healthcare is rising and reforms have been introduced across Europe to address the cost issue in healthcare. There is potential to improve logistical processes within healthcare to save costs and at the same time provide services that support high quality patient care. Re-designing processes and implementing technology can improve the efficiency of processes and reduce costs. A relations diagram has been developed that identifies the effects between the constructs *Logistics, Technology, Procedure* and *Structure*. Knowledge about how these constructs affect each other is important when deciding how to re-design processes and which technologies to implement.

Keywords: Healthcare logistics, technology assessment, process management

Introduction
The cost of providing healthcare is rising and the pressure for providing high quality services at lower costs in healthcare is increasing (OECD, 2013). Reforms have been introduced across Europe to address the healthcare cost issue. Currently, hospitals are being built across Denmark to create highly specialized hospitals in order to improve healthcare quality and lower costs (Andersen and Jensen, 2010).

Logistical processes are essential for a hospital to function and in providing services for the patients. According to Poulin (Poulin, 2003), over 30% of hospital costs are related to logistical activities and almost half of the logistical costs could be eliminated through the use of best practice. Improving the efficiency and effectiveness of healthcare processes not only economizes on resources but also improves the quality of services. Process improvements can be achieved through the use of different tools such as Business Process Reengineering (Hammer, 1990) or Lean (Womack et al., 1991) by eliminating process steps that do not create value for the patient. One way of improving process efficiency is to take advantage of technological solutions (Hammer, 1990; Jimenez et al., 2012; Voss, 1988).

Bed logistics is vital for the patient flow. This paper builds on a multiple case study investigating the bed logistics process at five Danish hospitals. Based on this multiple case study, a framework was developed to assess which technology to implement in a logistical healthcare process. The case studies identified 19 decision indicators for assessing a technology. These indicators each relate to one of the following constructs: *Logistics*, *Technology*, *Procedure* and *Structure (LTPS)*. *Logistics* refers to managing the flow of goods in a process, *Technology* refers to machinery, electronic devices and information systems, *Procedure* refers to the logistical process steps, e.g. as described in standard operating procedures, and *Structure* refers to the organizational structure. It is important for management within logistics to understand how these constructs interrelate when implementing technology and improving processes. Research exists on the individual construct relations (e.g. *Technology* and *Structure* (Leonard-barton, 1988; Mital and Pennathur, 2004; Neumann and Dul, 2010)) and to some extent on more than two constructs (Hammer and Champy, 1993; Jørgensen, 2013; Leavitt, 2013). However, there is a need to understand all the indicators' interrelations in a healthcare logistics context. This paper aims to develop a relations diagram that elucidates how the four *LTPS* constructs relate to each other in a healthcare logistics setting.

Methodology

In this section, the research objectives, research design, data collection, analysis of data, and data validation are described for the study.

Objectives

This paper investigates the following research question through a multiple case study conducted at five Danish hospitals:

- *How do the constructs Logistics, Technology, Procedure and Structure relate to each other in terms of effects in a healthcare logistics setting?*

The research question is answered through the following sub questions (SQs):

1) What does case study data suggest about the relationship between identified indicators relating to *Logistics*, *Technology*, *Procedure* and *Structure*?
2) What would the effects be on *Logistics*, *Technology*, *Procedure* and *Structure* if the technologies suggested and discussed in the case studies were implemented?
3) What does literature suggest about the relationships between identified indicators relating to *Logistics*, *Technology*, *Procedure* and *Structure*?

The aim is to develop a relations diagram that provides an overview of the effects of re-designing logistical healthcare processes by implementing technologies. The research question is answered by performing different analyses to identify relations between indicators. Relations between the LTPS constructs are elucidated through the identification of relations between the underlying indicators. These indicators were identified as the decision indicators that are important when deciding on how to re-design logistical healthcare processes by implementing technologies. By only focusing on relations between the identified indicators, the scope is narrowed down to relations between those indicators that have been identified as the most important for re-designing processes by implementing technologies. Therefore, only the relations that are of consequence to the decision process are considered in this study.

The first sub question is answered by identifying relations between indicators through case study data. To answer the second sub question, the effects on indicators by implementing technologies in the bed logistics process are analyzed. Lastly, effects between indicators have been identified in literature.

Case study as research design

Case study research can enrich the theoretical field of operations management (McCutcheon and Meredith, 1993; Voss et al., 2002). This study is based on qualitative research and is a multiple case study within the theoretical field of operations management. The unit of analysis is the bed logistics process and data was gathered at five Danish public hospitals. The overall research question is a "how" question and is of an explanatory nature, which makes the research suitable for a case study (Yin, 1994).

The five hospitals were selected because they are located within the same hospital district, which means they are subject to the same requirements and financial constraints. Hospitals of different sizes were chosen to include two small hospitals (250 and 300 beds capacity), a medium sized hospital (500 beds capacity) and two large hospitals (600 and 700 beds capacity). Furthermore, the hospitals had different levels of technology maturity, i.e. some had implemented technologies that others had not.

Data collection

Data was collected over a seven month period from February to August 2014 at five Danish hospitals. One hospital served as a primary collaborating hospital. Qualitative data was collected mainly through interviews and observations and was done in three stages: 1) a preliminary stage, 2) a round of semi-structured interviews and 3) a round of structured interviews validating the results. In the preliminary data collection stage, interviews and observations were carried out at the primary collaborating hospital. Here, 12 open interviews were conducted with managers of the bed cleaning departments. Furthermore, observations of processes were made on eight occasions while at the same time interviewing employees carrying out the processes. The observations are best described as direct observations but with some interaction with the people involved in the process. A round of semi-structured interviews and observations were then carried out with managers at each of the other four hospitals. These managers were responsible for the cleaning of the beds. This was followed by a round of structured interviews with the managers from each of the five hospitals to validate their response.

The purpose of data collection in the preliminary stage was to learn about the process, the challenges in the process and any improvement potential. Based on these interviews and observations at the primary hospital, an interview guide was developed to guide the round of semi-structured interviews and observations at each of the other four hospitals. The purpose of the semi-structured interviews and observations was to determine the decision constructs to evaluate technologies to implement in a logistical process. Furthermore, the preliminary stage as well as the round of semi-structured interviews provided in-depth knowledge about the indicators that were used to identify relations between them. Data collected from the semi-structured interviews and observations at each hospital was then consolidated to make a full list of decision criteria. The full list was presented to the managers from each of the five hospitals for respondent validation.

Analysis

Figure 1 depicts a framework developed during the study. The framework is a decision tool for re-designing logistical healthcare processes by implementing technology. The framework consists of the four LTPS constructs and 19 underlying decision indicators that reflect overall process performance. The indicators have been divided into efficiency and effectiveness as performance measures should reflect both. Efficiency refers to how well resources are utilized and effectiveness refers to the extent to which goals are accomplished (Mentzer and Konrad, 1991).

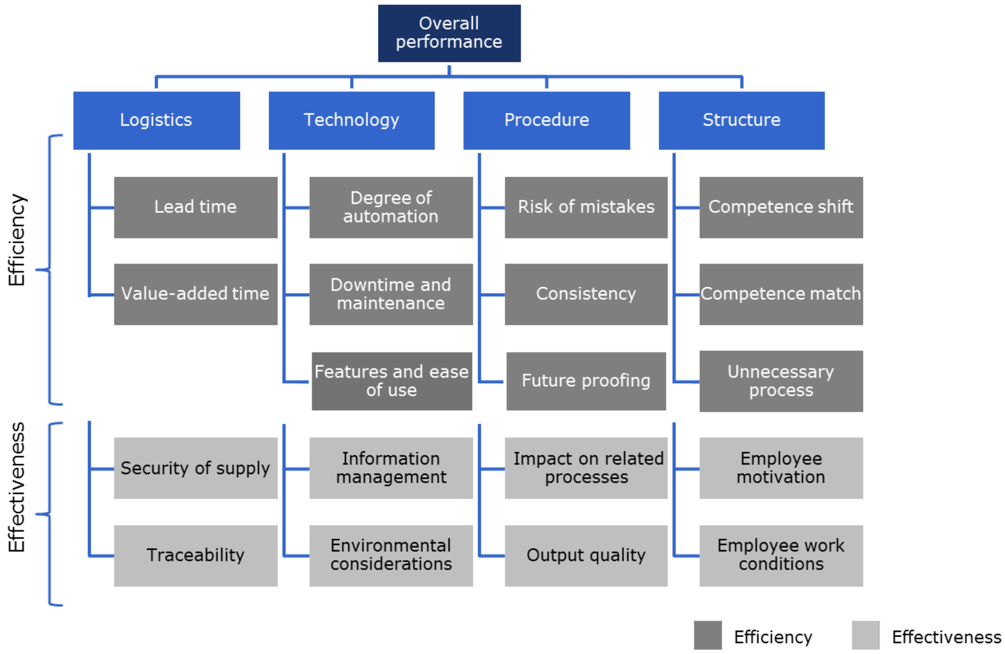

Figure 1 - Decision indicators identified for technology implementation in healthcare logistics

The three SQs will be answered for each relational pair between the four constructs (i.e. six pairs of relations). Qualitative data gathered from the five hospitals was coded in the qualitative data analysis tool NVivo. Data was coded according to themes that emerged from case study data and divided into *Logistics*, *Technology*, *Procedure* and *Structure* as in a similar study by Jørgensen (Jørgensen, 2013). Based on the codes, the framework with the four constructs and 19 underlying indicators was developed. Data gathered in the case studies provides detailed descriptions and knowledge about each of the indicators and the relations between them. The ability of the NVivo software to identify relations between codes was used in the analysis of the indicators to identify relations between the LTPS constructs. This analysis answered SQ1.

To answer SQ2, the technologies discussed in the five case studies were analyzed in turn to assess the effect on each of the *LTPS* indicators if implemented. These effects could be anticipated as a consequence of implementing the different technologies. An example of this is the effect on lead time of implementing an automated guided vehicle. Some effects, however, would not be evident until after implementation and would not be captured in the analysis. The effects of technologies that had already been implemented were captured in SQ1. Furthermore, some relations between indicators can be found in literature, which answers SQ3.

Relations between indicators have been identified in the following ways: a) in the case studies (SQ1 and 2), b) in the case studies and supported by literature (SQ 1, 2 and 3) or c) in literature as a relation between two indicators (SQ 3). For some of the relations suggested in the case studies, there was not enough data to support the claim. In c), these relations were further investigated and supported by findings in literature. This generalization from specific observations makes the reasoning inductive.

Validity and reliability

Construct validity is mainly related to the data gathering phase and refers to the extent to which a study investigates what it claims to investigate (Denzin and Lincoln, 1994). Construct validity was ensured through triangulation by gathering and analyzing data from different sources and by adopting different strategies for gathering data. Different sources of information were accessed; managers and employees at the primary hospital and managers at the four other hospitals. The different strategies adopted for collecting data were interviews and observations. Furthermore, validation was ensured through respondent validation (Bryman, 2012) where findings were reviewed by key informants (Yin, 1994). Furthermore, a round of interviews with managers from each hospital was conducted and recommendations were presented and discussed with management at the primary hospital.

Internal validity refers to the causal relationship between variables and results. Internal validity is only appropriate for explanatory or causal studies and is mainly relevant to the data analysis phase (Yin, 1994). This paper is an explanatory case study and the internal validity is ensured through different measures. Alternative explanations are ruled out by comparing results to a type of baseline. For some of the hospitals, certain technologies had already been implemented. Effects could therefore be compared to hospitals where technologies had not been implemented or to how it had been before implementation. Some of these effects were supported by literature. Some effects were identified in literature where relations between certain identified indicators seemed plausible but had not been sufficiently supported in the case study.

Finally, reliability and external validity are considered. External validity establishes within which domain findings can be generalized (Yin, 1994). External validity in this study is limited to a healthcare logistical context and needs to be tested in other countries and logistical settings. Reliability refers to the extent to which the same results and conclusions would be reached if the study were repeated. Reliability was ensured through colleague review and triangulation (Miles et al., 2014).

Identified relations between indicators and constructs

Figure 1 illustrates the decision indicators identified for implementing technology in healthcare logistics. Each decision indicator was identified in the bed logistics case study conducted at five Danish public hospitals. Data gathered from case study interviews and observations provides details about the indicators and insights about the relationships between them. The identified relations between decision indicators and constructs are presented in this section.

To identify relations between the LTPS constructs, each of the six pairs of constructs were compared by comparing the underlying indicators. E.g. the indicators belonging to *Technology* were compared to those belonging to *Procedure* in order to identify any effects between them. One of the identified effects was the positive effect of *degree of automation* on *consistency* and consequently of *Technology* on *Procedure*. This was supported by a case example and literature. Table 1 provides an overview of the 32 identified relations and supporting evidence. Details of supporting data and literature can be found in a separate document. The indicators *future proofing* and *environmental considerations* were found to have no relations to any other indicators.

The identified relations were based on case study data, findings in literature or both. The effects have been characterized as negative, positive or with a possibility of each. Whether the effect is positive or negative reflects the effect on efficiency or effectiveness. The effects listed in Table 1 are summarized in Table 2 to provide an overview of which constructs affect other constructs the most and which constructs are affected the most.

Table 1 – Identified effects between constructs are negative, positive or possibly both

Effect of	Effect on	Ef-fect	Case ex.	Literature
Technology (T) vs. Procedure (P)				
Features and ease of use (T)	Output quality (P)	+	Yes	Automation and quality mgmt. (QM)
Features and ease of use (T)	Effect on related processes (P)	+/-	Yes	Lean
Degree of automation (T)	Risk of mistakes (P)	+	No	BPR and QM
Degree of automation (T)	Consistency (P)	+	Yes	BPR and QM
Technology (T) vs. Structure (S)				
Degree of automation (T)	Working conditions (S)	+	Yes	Ergonomics
Degree of automation (T)	Unnecessary processes (S)	+	Yes	Ergonomics
Features and ease of use (T)	Employee motivation (S)	+/-	Yes	Technology Acceptance Model
Features and ease of use (T)	Competence match (S)	+/-	Yes	Humans and automation, BPR
Degree of automation (T)	Competence shifts (S)	+	Yes	Automation
Information management (T)	Employee motivation (S)	+/-	No	Performance mgmt.
Logistics (L) vs. Technology (T)				
Traceability (L)	Enables information management (T)	+	Yes	RFID technology and performance mgmt.
Features and ease of use (T)	Lead time (L)	+/-	Yes	Automation
Downtime & maintenance (T)	Value-added time (L)	-	Yes	Lean
Downtime & maintenance (T)	Security of supply (L)	-	Yes	
Procedure (P) vs. Logistics (L)				
Risk of mistakes (P)	Value-added time (L)	-	Yes	Lean
Improved output quality (P)	Value-added time (L)	+	Yes	
Improved output quality (P)	Lead time (L)	-	Yes	
Risk of mistakes (P)	Security of supply (L)	-	Yes	Lean, risk mgmt.
Structure (S) vs. Logistics (L)				
Unnecessary processes (S)	Value-added time (L)	-	Yes	Lean, BPR
Unnecessary processes (S)	Lead time (L)	-	Yes	Lean, BPR
Competence shifts (S)	Value-added time (L)	-	Yes	Lean, BPR
Competence shifts (S)	Lead time (L)	-	Yes	Lean, BPR
Competence match (S)	Value-added time (L)	+	Yes	Learning
Competence match (S)	Lead time (L)	+	Yes	Learning
Traceability (L)	Competence shifts (S)	+	Yes	RFID technology
Structure (S) vs. Procedure (P)				
Competence shifts (S)	Risk of mistakes (P)	-	Yes	BPR
Competence shifts (S)	Consistency (P)	+/-	Yes	BPR
Competence match (S)	Consistency (P)	+	Yes	Learning
Employee motivation (S)	Output quality (P)	+	Yes	HRM and TQM
Competence match (S)	Output quality (P)	+	Yes	Learning and QM
Employee motivation (S)	Risk of mistakes (P)	+	Yes	HRM and TQM
Competence match (S)	Risk of mistakes (P)	+	Yes	Learning and QM

Table 2 - The number of effects of each construct and on each construct

	Effect of construct on others	**Effect on construct from others**
Logistics	2	13
Procedure	4	11
Structure	13	7
Technology	13	1
Total	**32**	**32**

Figure 2 shows that some constructs have a more extensive impact on the remaining constructs than others. The constructs with the widest impact are *Structure* and *Technology*. The constructs that are impacted the most are *Logistics* and *Procedure*.

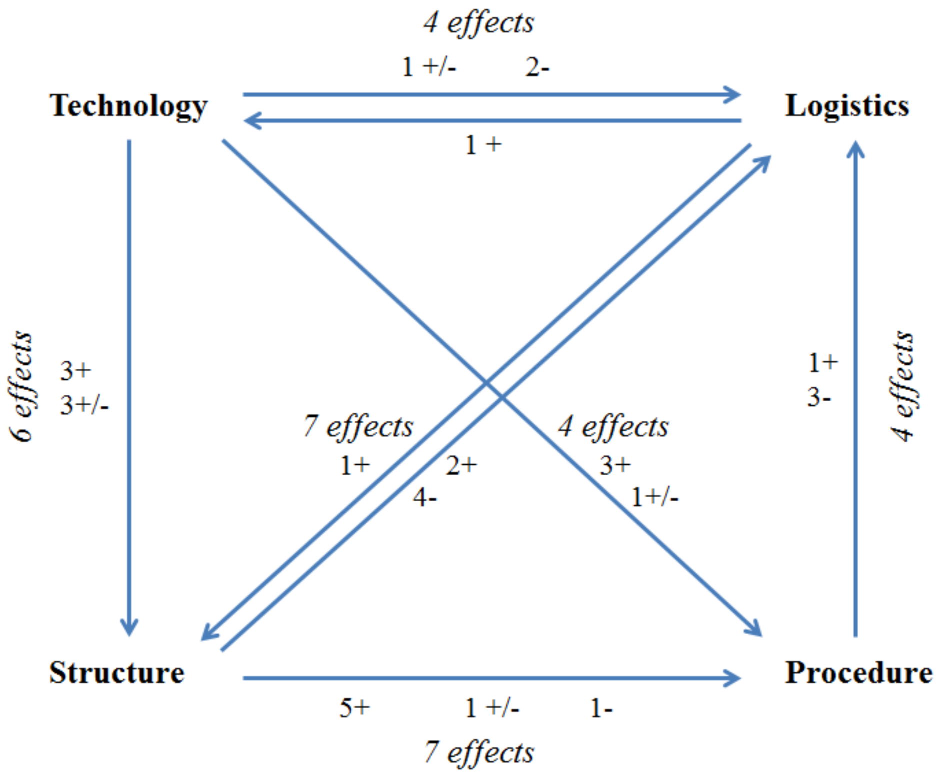

Figure 2 - Effects between each construct identified in case studies and literature

Figure 2 is a relational diagram depicting the direct effects that should be taken into consideration when implementing technologies in healthcare logistics. Three other types of relations were identified in the case studies. The first type is enablers to achieve a goal, e.g. *information management* providing knowledge about *lead time* which could then be used to identify and address challenges in the process. The second type is proactive measures to mitigate negative effects, e.g. by increasing *employee motivation* to use a technology by taking into consideration the technology's *ease of use*. The third type is trade-offs, e.g. the willingness to *increase lead time* in order to improve *output quality*. The three types of relations are not direct effects but are means to increase efficiency and effectiveness. Therefore, they are not included in this paper.

Discussion

The impact of each construct as well as impact on each construct is summarized in Table 2 and is illustrated in Figure 2. The effects between *Technology* and *Logistics* as well as *Structure* and *Logistics* lead both ways, whereas all other relations are one directional. *Structure* and *Technology* seem to have the most impact on other constructs whereas *Logistics* and *Procedure* appear to be the constructs that are affected the most by other constructs. The most extensive impacts of one construct on another are the impacts of *Structure* on *Procedure* (7 effects), *Structure* on *Logistics* (6 effects), and *Technology* on *Structure* (6 effects).

It is perhaps not surprising that *Technology* has a significant impact on the other constructs as implementing a new technology is expected to cause changes in a system. It is also to be expected that logistical aspects such as lead time will be substantially affected when changes are made to the other constructs. Re-designing a process usually leads to changes in the organizational structure. Within Business Process Reengineering, organizations are structured in process teams around outcomes (Hammer and Champy, 1993) and for Lean processes, the organization is structured in multifunctional teams (Karlsson and Åhlström, 1996). It is therefore surprising that *Structure* has such a significant effect on other constructs whereas *Procedure* is widely affected by others. *Procedure* would have been expected to have the most effect on other constructs whereas *Structure* would have been expected to be affected by other constructs.

The *Structure* indicators also reflect some *Procedure* aspects. E.g. for every competence shift, i.e. handover between employees, there is also a new process step. This could help explain why the current study suggests such large impact from *Structure* rather than *Procedure*. Therefore, findings are highly dependent on how the indicators have been defined and categorized according to *Logistics*, *Technology*, *Procedure* and *Structure*. In addition, the identified effects focus on specific indicators and the relations between them. Effects that do not include the identified indicators are therefore not included in the results. This does not mean that changes to a process do not affect the organizational structure, because they do. However, the impact of *Structure* is of greater significance to the decision process of re-designing processes and implementing technology in healthcare logistics.

Authors such as Leavitt as well as Hammer and Champy touch upon the interdependencies between constructs that are similar to *Logistics*, *Technology*, *Procedure* and *Structure*. According to Leavitt, there is a high interdependency between structure, tasks, technology and people in an organization, and any changes to one of the elements would result in changes in the other elements. Different strategies were suggested to cope with these changes (Leavitt, 2013). These interdependencies agree with findings in this study where logistics is an added construct. According to Hammer and Champy, "reengineering a company's business processes changes practically everything about the company, because all these aspects – people, jobs, managers and values – are linked together." They also argue that technology enables process reengineering and enables employees to make faster decisions through IT systems (Hammer and Champy, 1993). Thus, changing *Processes* affects the *Structure* in the organization and *Technology* affects *Procedures* and *Structure*. The effects of technology match those found in this study. However, the effect of reengineering business processes on organizational structure is reversed in this study. This is due to the focus on particular relations between certain aspects of *Structure* and *Procedure* in this study as well as the specific context of healthcare logistics.

A mutual relationship seems to exist between people and technology (Leonard-barton, 1988). However, the impact of people on technology is not included in this study as adapting the technology to the user is a choice and not a direct effect.

As discussed, some of the findings in this paper agree with existing literature whereas some of the findings contribute with new knowledge in the context of re-designing processes within healthcare logistics. The contribution is focused on the effects that should be considered in the decision process of re-designing processes within healthcare logistics. The effects between the four constructs *Logistics, Technology, Procedure* and *Structure* were identified by answering the three sub questions relating to the overall research question.

Conclusion

A relational diagram has been developed identifying the relations between *Logistics, Technology, Structure* and *Procedure*. The identified relations should be considered when re-designing healthcare logistics processes by implementing technologies. Relations between the constructs *Logistics, Technology, Structure* and *Procedure* have been identified based on the relations between the underlying indicators for each construct.

This study has shown that *Structure* and *Technology* have the most impact on other constructs, whereas *Logistics* and *Procedure* are affected the most by other constructs. The indicators related to *Procedure* do not seem to affect the indicators related to *Structure*. The conclusion is not that *Procedure* does not have an impact on *Structure*, because it does. However, in the context of re-designing logistical healthcare processes by implementing new technologies, the impact of *Procedure* on *Structure* should not be the focus of the decision process.

Each identified effect has been categorized as a negative or positive effect from an efficiency and effectiveness perspective. E.g. if the relation between two indicators comprises an effect on an efficiency indicator, the effect is negative if efficiency is impeded and positive if efficiency is improved. Some effects have the probability of turning out either negative or positive. The identified relations and the nature of the effects, i.e. positive or negative, can be used in a decision process for re-designing processes within healthcare logistics. This knowledge enables decision makers to take into account the effects of making changes.

Limitations and future research

This study includes effects that were evident in the bed logistics case or that were supported by literature. The framework needs to be validated by investigating other logistical healthcare processes. Findings in this paper have been based on qualitative data and literature and the results should be further validated through quantitative data analysis or simulation.

The identified relations are limited to the decision indicators for implementing technology in a logistical healthcare process. Thus, the list of effects between *Logistics, Technology, Structure* and *Procedure* seen in Table 1 is not exhaustive. Some relations were identified in the case study that did not relate to the indicators. E.g. the choice of technology will most likely result in changes in the procedure. Furthermore, changes to a procedure will lead to changes in roles and responsibilities in the organizational structure as well as to the number of competence shifts. These relations exist but are excluded from the study to limit focus to the most important indicators in a decision process of re-designing healthcare logistics.

Some of the identified effects are desirable whereas others are not. Some trade-offs were identified in the case studies that the managers were willing to make. These trade-offs were briefly touched upon in this paper. Future research should consider how to address the less desirable effects and take into account which of the less desirable effects could be trade-offs that managers are willing to make. A framework should be developed to function as a proactive decision tool addressing negative effects.

The economic aspect of implementing new technology is not considered in this study. Findings in this study can be used to identify important effects of implementing a new technology in logistical healthcare processes. When analyzing potential scenarios for process re-design, the analysis should be supplemented by a financial analysis.

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