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John R. Olson
James A. Belohlav, *DePaul University*
Lori S. Cook, *DePaul University*

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A Rasch model analysis of technology usage in Minnesota hospitals

John R. Olson [a,*], *James A. Belohlav* [b,1], *Lori S. Cook* [b,2]

[a] *University of St. Thomas, Operations and Supply Chain Management Department, 2115 Summit Ave., St. Paul, MN 55115, United States*
[b] *Department of Management, DePaul University, 1 East Jackson Boulevard, Chicago, IL 60604, United States*

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ABSTRACT

Purpose: To identify whether the level of difficulty varied among various healthcare technologies. In addition, to examine the whether the degree of healthcare technology adoption was related to patient safety.
Methods: The data on healthcare technology usage came from a survey of hospitals in Minnesota. There were responses from individuals within 104 hospitals for an effective response rate of 72.7%. The data on patient safety was taken from the Hospital Compare database. Rasch model analysis and regression analysis were used to analyze the data.
Results: Rasch model analysis revealed that the difficulty of implementation of healthcare information technologies varied by the particular technology. That is, some technologies were more difficult than other technologies. Further, it was found that the degree of healthcare information technology implementation within a hospital was significantly related to patient safety.
Conclusion: This study identified design and policy implications for hospital decision makers. In particular, it was shown that the technological capability of a hospital is a key consideration in determining the level of resources that are necessary to implement specific healthcare technologies within a hospital.

1. Introduction

The American healthcare sector is facing escalating levels of discussion on how to improve its overall performance. From different perspectives, several stakeholders have contributed to the discussion on the issues related to the current level of performance. There is a political perspective [1], a health policy perspective [2] and a managerial perspective [3,4].

One measure of performance, patient safety, has been of significant interest in both the managerial and healthcare literatures. There have been a variety of studies in the healthcare literature viewing quality and safety within hospitals and other subsectors within the healthcare industry [5]. In particular, there has been a focus on patient safety from a healthcare operational perspective, which has considered the influence of internal processes and activities [6–8], culture [9,10] and information technology [11] on patient safety.

The use of technology in healthcare is seen to have a variety of positive impacts, including: better operational and financial performance [12], reducing errors and improving decision making by minimizing disparities between evidence

* *Corresponding author*. Tel.: +1 651 651 5078.
E-mail addresses: Jrolson2@stthomas.edu (J.R. Olson), jbelohla@depaul.edu (J.A. Belohlav), lcook@depaul.edu (L.S. Cook).
[1] Tel.: +1 312 362 8382.
[2] Tel.: +1 312 362 5203.
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and practice [13,14]. Central to most views of technology in the healthcare setting is the concept of healthcare information technology (HIT). In fact, HIT is viewed as a key component in the performance and safety of hospitals and other health care organizations [15,16]. However, many organizations are confronted by considerable financial barriers in implementing HIT [17].

1.1. *Healthcare technology*

Even though HIT tends to be a commonly used term, in fact, it represents an amalgam of individual technologies that are organized around information technology resources within a hospital system. Within the HIT literature, there are two key focal points. One focal point examines the role of information technology and its overall impact on hospital performance. The other focal point spotlights specific technologies that use the information technology such as, electronic medical records (EMR), computerized provider order entry (CPOE), imaging, and so forth.Overall, information technology has been shown to positively impact the performance of hospitals. The usage of information technology within American hospitals is shown to be positively related to operational performance, financial performance and mortality rates [18–20]. Similar positive findings were also reported for hospitals in Thailand [21]. Certain organizational characteristics such as size of the hospital were found to affect the utilization of information technology [22,23]. Other studies found that the role information technology served (strategic, administrative or clinical) influenced the usage or performance within the hospital [24,25].

While information technology has generally been shown to have a positive effect on performance, the contributions of specific technologies within the overall HIT system have been mixed [26]. The mixed results can arise from a variety of issues that include: integration of technologies within the system, human–computer interactions, organizational issues and healthcare processes [27]. Another perspective provides several additional explanations for these inconsistencies that involve more basic issues such as: what is being measured, changes in hospital processes or simply the mismanagement of technology [28]. The diverse and sometimes conflicting findings on various healthcare technologies make technology selection decisions difficult for many healthcare organization decision makers because of the uncertainty of its relationship to financial, productivity and safety outcomes [17].

For example, the impact of CPOE on performance has been the subject of much scrutiny [29,30]. Several studies have shown positive results [31–33]. However, other studies have shown negative impacts [34,35], which have led to divided opinion on CPOE [31,36].

EMR systems have also been the subject of considerable investigation. Several studies have reported considerable levels of success in EMR implementations [37–39]. However, other studies have noted significant difficulties in implementing EMR systems [40–42]. A significant issue that has been identified has been the EMR implementation process. The more successful implementations have tended to include organizational issues along with technological factors.

Other HIT technologies have also shown similarly mixed results. There have been many benefits reported for imaging technologies [43] along with documented increases in performance for financial, operating and satisfaction outcomes [44]. However, other studies [45,46] have reported mixed results relative to imaging technology. In a similar fashion, bar coding has been shown to be usefully applied to several areas of hospital activities [47–50]. Again, negative findings [51] have been reported after the introduction of bar coding. The literature on individual health care technologies is replete with inconclusive or conflicting findings.

To address the key issues presented in the HIT literature, this study examines the relationship of individual technologies within the hospital operating system. By understanding healthcare technology relationships, healthcare planners and executives can more effectively select technologies to reach their individual organizational objectives. The first two sections present the theoretical perspectives and key research issues. The second section presents the study design and Rasch methodology. The final sections present the analysis, discussion and conclusions of the study.

2. Theoretical perspective

In the preceding discussion of healthcare technologies, the literature contains examples of technology implementations that have had positive performance results. Other studies examining similar technologies report contradictory or inconclusive performance results. Earlier discussions presented reasons why the inconsistencies might exist. Relative to the preceding commentary, one particular study provides another possible explanation for the inconsistencies in the literature [52]. Specifically, the researchers observe that CPOE should not be the first type of HIT that a hospital implements in its organization. This admonition is made by the researchers because CPOE is viewed to be a more complex or difficult type of technology.

A similar finding was made in a study examining the implementation of improvement programs within hospitals [7]. In particular, it was found that differing levels of difficulty existed among the improvement programs themselves. That is, some improvement programs were more difficult to implement than other improvement programs. In a similar fashion, there may be varying levels of difficulty that may exist among the various healthcare technologies. From the extant literature, there is a noteworthy gap in understanding the underlying factors that influence the adoption and implementation of HIT within hospitals. As a result, the first research question addresses the issue of difficulty of individual HIT.

RQ1: Are certain types of HIT more difficult to implement within a hospital setting?

In addition to any innate difficulty present in any particular HIT, there is learning that takes place relative to the technology or technologies. For example, one study [53] observes that learning occurs among doctors using an EMR system. The particular learning process that is identified in this study is most likely reflective of the more general concept of absorptive capacity [54]. From this viewpoint, absorptive capacity would suggest that a hospital's ability to recognize and integrate external knowledge would depend upon its existing level of knowledge. Thus, a hospital's ability to develop a certain technological capability is a function of a knowledge base that develops in at least two general contexts: technological and organizational.

The technological context can influence the absorptive capacity of a hospital because of complementarity may exist among technologies. The concept of complementarity suggests that one particular technology may produce a greater impact when associated with other technologies [55]. Thus, a hospital that implements greater numbers of HIT may create a particular set of dynamic capabilities within its operating structure [56,57]. In addition to technological issues, implementation of HIT can be affected by organizational issues [58,59]. Thus, the organizational context may also influence the absorptive capacity within a hospital. The organizational context may contribute to the absorptive capacity because hospitals that use a variety of technologies may develop different organizational process based on perhaps differing levels of knowledge and skills, values that may be present or other organizational relationships [60,61]. For example, one study reports the successful integration of innovative technology within the operating room setting as a function of a hospital's specific organizational processes [62].

One particular study has varied from most of the literature on healthcare technologies [63]. Rather than focusing on a specific technology, this study examined the results of four benchmark leaders using multifunctional systems. The study concluded that concrete benefits were found in these benchmark hospitals in a variety of areas including, the reduction of medical errors, decreased rates of redundant/inappropriate care and enhanced monitoring and surveillance activities. These researchers also note that no prior studies had reviewed a broad range of HIT. The focus of the current study is on examining the usage of a broad range of healthcare technologies within Minnesota hospitals, which addresses the following research questions.

RQ2: Is there a relationship between a hospital's technological capability and its operating performance?

3. Method

Health technology usage patterns among member hospitals of the Minnesota Hospital Association (MHA) were examined in this analysis. The study protocol was approved by the Institutional Review Board at the University of St. Thomas. Data analysis consisted of two facets. First, the data was examined to assess whether the usage of healthcare technology can be viewed as a unidimensional construct. That is, does the usage of healthcare technology represent some degree of general technological capability within a hospital? In addition, the level of difficulty in implementing various health technologies was identified along with defining each hospital's capability of implementing these health technologies. Finally, the relationship between the pattern of technology usage and hospital performance outcomes was assessed.

3.1. *Data*

The data for this study was obtained from two sources. One data source came from a survey that was sent to the member hospitals in the MHA to assess HIT usage. The second source of data was acquired from the Hospital Compare database to assess hospital safety performance during the same time period.

3.1.1. *Survey measures*

For this study, the data on healthcare technology implementation was collected as part of a larger survey. The initial survey instrument was piloted and after consultation with the Center for Health & Medical Affairs at the University of St. Thomas the final version of the survey instrument was constructed. The survey respondents were given a list of health technologies and asked to identify the technologies that were implemented in their hospital. The healthcare technologies that were included in the survey were: automated medical administration, automated medical dispensing devices, barcode charts, barcode labs, barcode medications, barcode patients, computerized clinical guidelines, computerized education reference tool, computerized order sets, computerized physician order entry, computerized reminder systems, computerized treatment protocols, electronic discharge instructions, electronic medical records, electronic nursing notes, electronic pharmacy orders, medical automated recording system, picture archive and communication system and benchmarking. It should be noted that one additional variable was added to the list of healthcare technologies, benchmarking. The benchmarking variable was included because it is a process that is often included as part of the selection and implementation of technologies [64–66]. The specific healthcare technologies included in this study were not intended to be a complete list of healthcare technologies, but rather a representative listing.

3.1.2. *Outcome measures*

The second stage of the analysis examines the capability of the hospitals to implement healthcare technologies relative to their operational performance. Specifically, operational performance will be viewed from the perspective of safety practices. Two sources of data on safety practices within hospitals in the United States have been employed in prior research studies: the Safe Practices survey scores and Hospital Compare scores.

A consortium of companies and other large private and public healthcare purchasers known as the Leapfrog Group created the Safe Practices survey to document hospital safety in the United States in 2001 (available at http://www.leapfroggroup.org). The Safe Practices survey gathers data from about 1300 hospitals that treat more than half of the United States population. However, the overall reliability of Safe Practices scores in this database has been questioned [67]. Another database, Hospital Compare, became available in 2005. Hospital Compare was developed jointly by an agency of the United States government, the Centers for Medicare & Medicaid Services (CMS), and the Hospital Quality Alliance (HQA), which is a public–private alliance focusing on hospital quality of care. A recent report documents that 70% of the critical access hospitals nationally participated in submitting information into the Hospital Compare database [68]. By law, all of the measures included within the Hospital Compare database must reflect accepted standards of healthcare quality (available at http://www.hospitalcompare.hhs.gov/staticpages/for-professionals/poc/technical-appendix.aspx).

The outcome measures used in this study will come from the Hospital Compare database. This database consists of two primary areas: Process of Care measures and Outcome of Care measures. The Process of Care measures views the frequency that patients receive recommended treatments when they are in a hospital while Outcome of Care measures examine the results after patients received hospital care. This study will use the Process of Care measures, which focus on the operational activities within hospitals. The Process of Care measures consist of 24 measures in 4 key patient areas: heart attack, heart failure, pneumonia and surgery.

3.2. *Sample*

The data for the study were collected from members of the Minnesota Hospital Association (MHA). There are 148 hospitals within the state of Minnesota with 145 of those hospitals being members of the MHA. Approximately 65% of the MHA member hospitals have a private, non-profit operating structure. The remaining MHA member hospitals are public (local, state or federal) with the exception of two private, for-profit hospitals. About 40% of the hospitals are within urban areas (located in a Metropolitan Statistical Area) and 60% are in rural areas.

Individuals within MHA member hospitals were sent an e-survey during the January to June 2007 time period. Specifically, the survey was sent to 674 individuals within 145 hospitals. The individuals represented a variety of positions within the hospitals. Taken as a whole, 32% of the respondents performed business roles (Chief Executive Officers, Chief Financial Officers, or Chief Operating Officers), 28% performed medical roles (Chief Medical Officers or Directors of Nursing), 30% were Quality Directors, and 10% performed other managerial roles in the hospital. It should be noted that some hospitals had one individual who performed several roles and other hospitals had several individuals with the same role. Three follow-up e-mails and a postcard reminder were sent to non-respondents. Ultimately, 210 individuals within 104 hospitals sent usable data, resulting in an effective hospital response rate of 71.7%. When there were multiple responses from an individual hospital, the respondents were aggregated to create a hospital technology usage profile. Characteristics of the responding hospitals are shown in Table 1.

Table 1 – Respondent demographics (*N* = 104 hospitals).

Number of beds (%)			
25 or less			42
26–50 beds			21
51–100 beds			14
>100			22
Hospital type (%)			
Large hospital			15
Inpatient community hospital			71
Not categorized			16
	Mean	Median	Range
Revenue ($1,000,000)[a]	82.2	24.3	4–889

[a] Data were available for 97 hospitals.

3.3. *Data analysis*

The healthcare technology data were first analyzed using Rasch Model Analysis (RMA) using Winsteps version 3.63.2. RMA identifies an underlying factor that cannot be observed or measured directly from other observable variables. Consequently, the independent variable in this analysis is a latent rather than an observed variable [69]. Further, RMA consists of a group of related models. The original model [70] was developed for assessing dichotomous data. Further development has extended the original model to rating scale data [71,72] and to graded item data [73,74]. This analysis will utilize the original model for dichotomous data.

From an overall perspective, the Rasch model is categorized as a logistic model that independently measures both healthcare technologies and hospitals on an underlying factor or dimension. The Rasch model exists as a specified model, which in its most common form appears as the equation: $p = \exp(\beta - \delta)/[1 + \exp(\beta - \delta)]$. This model consists of 2 basic parameters. One parameter relates to the difficulty of a healthcare technology, which is denoted by δ. The other parameter relates to the ability of a hospital to accomplish an activity, which is denoted by β. In the present study, we will attempt to determine whether a healthcare technology's difficulty (δ) and a hospital's ability to implement a particular healthcare technology (β) can be located on some underlying dimension.

Operationally, the Rasch difficulty parameter (δ) positions the healthcare technologies across a continuum of technological capability. Similarly, the Rasch ability parameter (β) conjointly positions the hospitals according to their ability to implement healthcare technologies on the same underlying continuum of technological capability. Further discussion of the Rasch model used in this study can be found in previous research [7,75].

RMA was employed in this study because of four key features. First, Rasch analysis identifies whether or not a hospital's ability to implement healthcare technology is a unidimensional construct, which would be interpreted as a fundamental technological capability of a hospital. Second, as a result of the analysis, all of the original data are converted into an interval scale data [76]. That is, the dichotomous data in this study are changed into equal interval units by means of logarithmic transformation. Because RMA creates an interval scale, it enables us to interpret the size differences between hospitals in their ability to implement differing healthcare technologies. A third aspect of RMA is that a fundamental requirement in this analysis is invariance. That is, the difficulty of healthcare technology items is independent of a hospital's capability of implementing technology in this analysis. If the data fit the Rasch model requirements, the results are sample independent. As a consequence, the results of this study would be applicable to other hospitals that are considered to be part of the same population even though they were not part of the current analysis [77,78]. A final aspect of a Rasch

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analysis is that it permits the same data to both estimate and test solutions [70,72,79]. Further technical descriptions of the preceding discussion and the Rasch model in general can be found in the general RMA literature [76,80].

4. Analysis and findings

4.1. *Measurement properties*

The first phase of the analysis considers the usefulness of the Rasch model in assessing the data in this study. RMA utilizes a prespecified model that exists as a unidimensional, linear measure. In Rasch model analysis, data are analyzed to see if they fit Rasch requirements, an underlying univariate relationship. As a consequence, it is worthwhile to note that the present analysis identifies whether the data in this study departs from the Rasch model requirements. When there is a suitable correspondence between the data and the Rasch model, it denotes that there is a collective underlying dimension that is shared by the study variables.

In order to assess the general correspondence of the study data to the Rasch model requirements, several different measures were utilized. Each of these measures progressively enhances the level of knowledge about the existing quality of measurement. Linacre [81] recommends a multi-step procedure to examine the correspondence between the data and the Rasch model requirements. The first step identifies whether inconsistencies exist in the latent variable (Rasch dimension) using a point measure correlation. The second step ascertains the quality of measurement using two different statistics, outfit and the infit statistics, to detect the contribution of each of the healthcare technologies. The third step explores whether any other significant dimensions can provide competing explanations for the data. To accomplish this task a principal components analysis of the residuals is undertaken. The preceding analysis examines whether the data can be viewed as unidimensional. In addition, one final assessment is made to examine the overall model reliability.

The initial step views the correspondence of each of the individual healthcare technologies to the overall Rasch model. This step is accomplished by viewing the point measure correlations of each variable with the overall model, r_{pm}, which provides an evaluation of the content validity of the healthcare technology items. The point measure correlation measures the degree of consistency of each healthcare technology in relation to the overall number of healthcare technologies supported. The function of this initial step is to view whether or not the healthcare technologies relate to the overall latent variable. In particular, we are concerned primarily with the sign of the correlation instead of the degree of correlation. In

Table 2 – Healthcare technology variables by level of accomplishment.

	Item difficulty (in logits)	Standard error (SE)	Infit MNSQ	Infit ZSTD	Outfit MNSQ	Outfit ZSTD	r_{pm}
Healthcare technology variables							
Barcode patients	1.92	0.33	1.05	0.3	0.81	−0.1	0.45
Barcode labs	1.51	0.31	1.04	0.3	1.37	0.8	0.47
Barcode medications	1.33	0.30	1.06	0.4	1.38	0.9	0.46
Computerized reminder systems	1.25	0.28	0.91	−0.1	0.90	−0.1	0.54
Computerized treatment protocols	1.08	0.28	0.88	−0.8	0.66	−0.8	0.59
Automated medical administration	0.85	0.27	0.93	−0.7	0.73	−0.7	0.58
Computerized physician order entry (CPOE)	0.42	0.26	1.12	0.9	1.45	1.5	0.50
Medical automated recording system (MARS)	0.28	0.26	1.17	1.3	1.18	0.7	0.50
Picture archive and communication system (PACS)	−0.10	0.25	1.02	0.2	0.94	−0.2	0.58
Electronic nursing notes	−0.29	0.25	0.82	−1.4	0.70	−1.4	0.67
Electronic discharge instructions	−0.41	0.25	1.20	1.5	1.29	1.3	0.50
Electronic medical records (EMR)	−0.47	0.25	0.82	−1.6	0.73	−1.3	0.67
Electronic pharmacy orders	−0.60	0.25	0.83	−1.5	0.71	−1.5	0.67
Computerized order sets	−0.72	0.25	0.84	−1.5	0.70	−1.5	0.66
Automated medical dispensing devices	−1.32	0.25	0.96	−0.3	1.30	1.2	0.59
Computerized education reference tool	−1.38	0.25	1.15	1.2	1.05	0.3	0.53
Benchmarking	−3.34	0.32	1.21	1.1	1.41	0.7	0.40
Excluded healthcare technology variables							
Barcode charts	1.59	0.31	1.35	1.9	1.89	1.5	0.30
Computerized clinical guidelines	0.14	0.25	0.73	−2.4	0.64	−1.5	0.69

Table 3 – Regression analysis for number of hospital beds, technological ability and hospital safety.

Model	Variable	R^2	R^2 change	F	F change
Model 1	Hospital beds	0.118		8.000**	
Model 2	Technological ability	0.219	0.101	15.625**	7.625**

** Significant at the 0.01 level.

general, the signs should be positive, which is what is observed in Table 2. Thus, the initial result provides a preliminary sign that a unidimensional representation of the data exists, a vital assumption in RMA.

The second step assesses how well the individual healthcare technology items contribute to the Rasch model. Traditionally, mean square item fit statistics are used to establish whether the data concurs with expected Rasch model values. In RMA, expected values are computed for every healthcare technology and hospital. The fit statistics detect the extent of misfit among the data and expected values. Two different types of misfit are customarily examined to assess the violations of assumptions of the Rasch model, outfit and infit. The outfit statistic examines differences among the observed and expected values for healthcare technologies that are distant from a hospital's current level of capability. The outfit statistic is calculated using a traditional sum of squared standardized residuals. In contrast, the infit statistic examines differences among the observed and expected values for healthcare technologies that are relatively near to a hospital's current level of capability. To mitigate the inordinate influence of outlier responses, the infit statistic examines each observation relative to the model variance. This statistic can be described as an information-weighted mean square fit statistic [72].

In addition to the mean square fit statistics, the z-score will be used to examine whether healthcare technologies relate to the requirements of the Rasch model. From Table 3, the outfit and infit statistics are deemed to be in agreement with the Rasch model: (1) if an item's mean-square value falls is within a range of 0.5–1.5 [82,83] and (2) if they are normally distributed (i.e. the z-score is within 2 standard deviations). With the exception of barcode charts and computerized clinical guidelines, all of the remaining healthcare technology variables fell within the mean square and standard deviation guidelines. As a result, the two preceding healthcare technology variables were removed from the analysis in order to create the final model. When the data corresponds to the expectations of the Rasch model, the resulting outcomes are considered to be both sample and scale independent.

Since the sample in this study largely consists of two types of hospitals: private, non-profit hospitals and public hospitals, one more analysis is necessary to assess whether any of the technology items show differing response patterns. This analysis is referred to as a differential item functioning analysis or more simply a DIF analysis. In this study, no differences in patterns of technology usage existed between private, non-profit hospitals and other hospitals in this sample.

The third and concluding action in assessing unidimensionality is examining whether any other significant explanation is available to account for the results, other than the Rasch explanation. To accomplish this task, a principal components analysis of the Rasch standardized residuals is undertaken. The principal components analysis focuses on the explained variance aspect of this analysis. To understand whether there is an alternate explanation for the data other than the Rasch explanation, Linacre [84] recommends viewing the magnitude of explained variance for the Rasch model and an unexplained variance in the 1st contrast, which would signify the presence of a secondary explanation. Linacre describes a Rasch model with an explained variance of greater than 60% along with an unexplained variance of less than 5% in the 1st contrast as a model that provides a suitable explanation of the data. In the current analysis, the variance explained by the Rasch measures was 75.1% and the unexplained variance in the 1st contrast was 3.0%. Hence, there does not appear to be any significant competing explanation for the data.

The last assessment in this study considers the overall reliability of the model. This aspect of the analysis examines whether the healthcare technology items are able to produce an internally consistent measure. This aspect of the analysis examines whether the healthcare technology items are able to produce an internally consistent measure. Using RMA allows one to independently measure healthcare technologies and hospitals. The Rasch reliability for hospitals is 0.81, which translates to a Cronbach α of 0.87, and a Rasch reliability for healthcare technologies of 0.96. The present level of reliability denotes that the final model presents an internally consistent measure. From the preceding results, one would conclude that a unidimensional latent trait is present. Thus, the variable of interest can be described as the technological capability within a hospital.

4.2. *Assessing relationships*

The relationships in this study will be assessed in two ways. Since the data were found to correspond to the Rasch model requirements, the first aspect of the analysis will look at the difficulty of healthcare technologies. The second aspect of the analysis will involve examining the ability of hospitals to implement healthcare technologies in relation to the level of the operating performance of the hospital.

The initial part of the outcome analysis will view the difficulty of implementing various healthcare technologies. To undertake this analysis, we will utilize the Item Difficulty variable and its corresponding standard error provided in Table 2. With this data, we can assess whether differences exist among healthcare technologies using a z-score.[3] If we take the logit score (measure score) along with its standard error for the 25th percentile healthcare technology

[3] The z-score was calculated using the following formula: $(\text{Measure}_a - \text{Measure}_b)/(1.5 \times (\text{SE}_a - \text{SE}_b))$.

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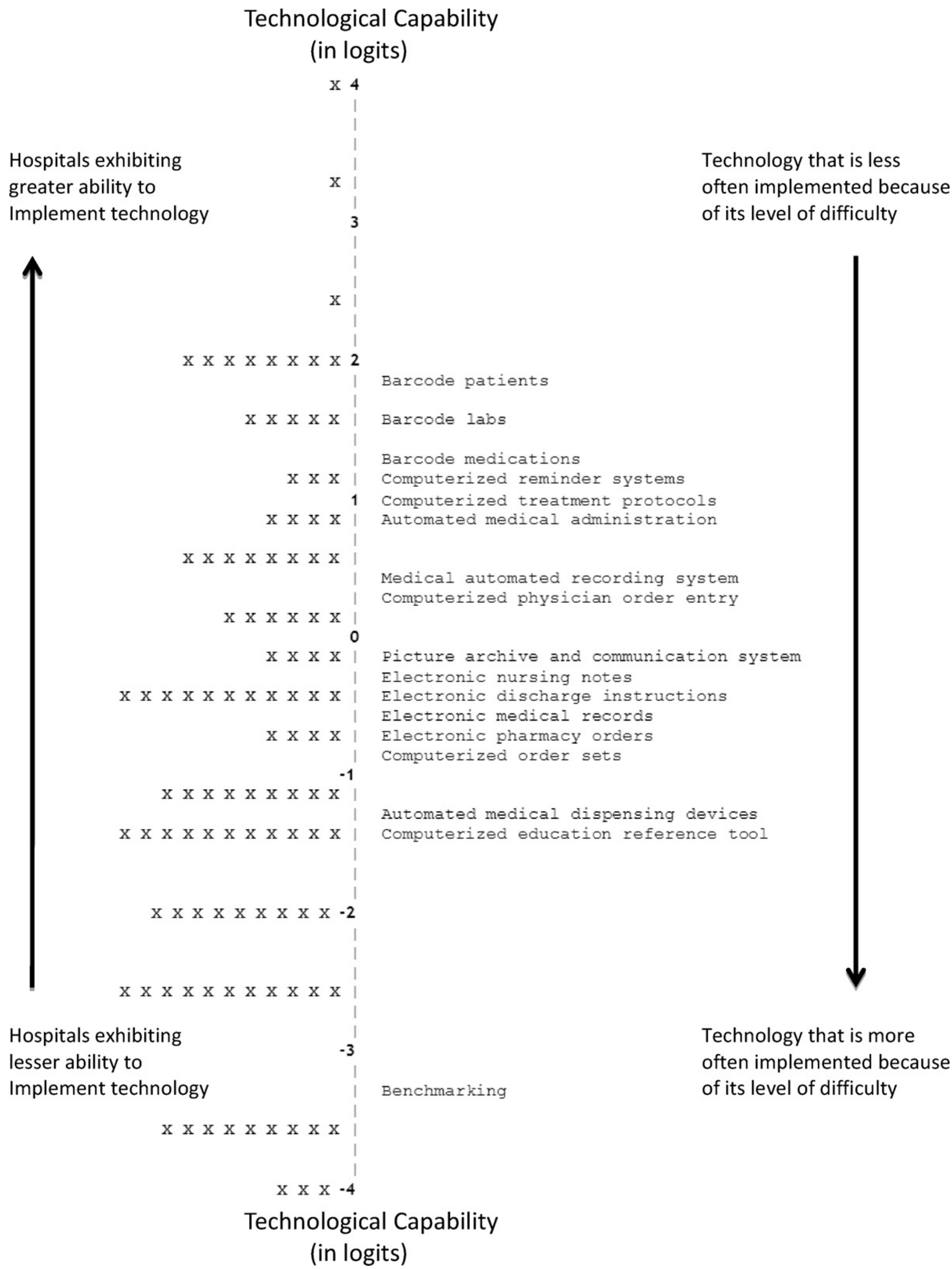

Fig. 1 – Wright Map.

(computerized reminder systems) and the logit score along with its standard error for the 75th percentile healthcare technology (computerized order sets), we note that a statistically significant difference in difficulty ($z = 2.24$) exists for these variables. This result identifies that the healthcare technologies occupying the upper part of the Wright Map in Fig. 1 are statistically more difficult to accomplish than healthcare technologies occupying the lower area of the Wright Map in Fig. 1, addressing research question 1.

The second part of the outcome analysis will consider the ability of hospitals to implement healthcare technologies relative to their operating performance. To accomplish this particular task, we examine the Rasch ability score for each hospital with respect to its Hospital Compare safety score. In this study, 70 of the hospitals had sufficient data to be included in this portion of the study, which is 65% of the hospitals taking part in this study. The dependent variable was created by computing an average score for all hospitals that reported data for at least 12 of the 24 measures that comprise the process of care measures in the Hospital Compare database. The results of the regression analysis are presented in Table 3. The first step of the regression analysis examined the impact of the demographic variable relating to the number of hospital beds to control for potential operating differences among hospitals. This variable was found to have significant relationship with safety. Next, technological ability scores from the Rasch analysis were entered into the regression analysis. Technological ability was also found to have significant relationship with safety, increasing the explained variance of hospital performance measures as measured by Hospital Compare by more than 10%. Hence, this analysis shows that a hospital's ability to implement healthcare technologies (Rasch ability score) is significantly correlated with its Hospital Compare safety score, addressing research question 2.

5. Discussion

The preceding results identify some noteworthy relationships. First, healthcare technologies differ in their level of implementation difficulty for hospitals. Some healthcare technologies are considerably more difficult to implement than other healthcare technologies. Second, our results reveal that technological capability exists as a latent or underlying process within hospitals. Consequently, a particular hospital's capability ultimately determines the level of success it will experience when implementing a technology. If a hospital is able to strengthen its technological capability, its capacity to successfully adopt more difficult healthcare technologies increases.

While the earlier discussion of the underlying theoretical relationships is important and interesting, an equally valuable insight is provided from a managerial perspective. When we view the difficulty of healthcare technologies together with the ability of hospitals to implement the various healthcare technologies, we develop an appreciation of the challenges that confront healthcare managers. If we present the difficulty scores of the healthcare technologies jointly with hospital ability scores, we construct the Wright Map that is displayed as Fig. 1. The healthcare technologies based on their difficulty scores (Item Difficulty in Table 2) are displayed on the right side of Fig. 1. The technologies on the lower right hand side of the Wright Map are accomplished more frequently than those technologies that are located on the upper portions of the map. The hospitals based on their ability score are displayed on the left side of Fig. 1. Each "X" on the map represents a particular hospital in the study. The interpretation of the left side of the Wright map is the opposite of the technologies on the right of the map. That is, hospitals that that are located at the upper end of the map have greater ability and as a consequence adopt healthcare technologies more frequently than the hospitals that appear at lower positions on the map.

5.1. *Interpreting the Wright Map*

The significance of a Wright Map analysis is that it portrays the potential operational impact for hospitals considering which healthcare technologies to implement in their organizations. The Item Difficulty scores in Table 2 are used to position the healthcare technologies on the Wright Map. In similar fashion, the hospital capability scores (not presented) are used to position the hospitals on the Wright Map. The technology difficulty scores and hospital capability scores are the result of the logarithmic transformation used in RMA and exist as equal interval scale units. The vertical axis in the middle of Fig. 1 serves as a statistical ruler, which allows us to compare both hospitals and healthcare technologies. The key points on the vertical axis are the numbers that are units of measurement created by RMA, which are presented as logit scores or more simply as logits.

How does one interpret the Wright Map? Since the Wright Map consists of equal interval units, one simply looks at the linear distance between hospitals, healthcare technologies or and any hospital and healthcare technology. Similar to a conventional ruler, we can estimate the level of performance that is required by a particular hospital in order to successfully implement a particular healthcare technology. Essentially it means that if a hospital on the right hand side of the map is situated one logit lower than a particular healthcare technology that they would like to implement it would be twice as difficult to implement as a healthcare technology that is located at the same horizontal level of the hospital on the Wright Map. For example, if we look at the Wright Map in Fig. 1, computerized treatment protocols (located near the one on the center vertical axis) would be approximately twice as difficult to implement as a picture archive system, which is located just below the zero value on the center vertical axis. In a similar fashion, a healthcare technology that is two logits higher is three times as difficult to implement as a healthcare technology that is located the hospital's location on the Wright Map.

In addition to the previous description of the relationship between a hospital and a healthcare technology based on linear distance, one can describe the same relationship in terms of its probability of success because the Rasch equation exists in the form of a log-odds ratio. That is, there is an association between linear distance and the probability of success of a hospital in implementing a healthcare technology [76]. We can arrive at the probability of success by substituting the relevant logit scores for a hospital and a healthcare technology into the Rasch equation presented in Section 3.3. To illustrate this calculation, we observe a group of hospitals that are situated just below the center of the vertical axis, the point that reads zero in Fig. 1. The hospitals at this point have developed some degree of technological capability. If any of these hospitals attempted to implement a computerized physician order entry (CPOE) system, their probability of successfully implementing this technology would be approximately 39%. If any of these hospitals attempted to implement a computerized reminder system; however, their probability of successfully implementing this technology would drop to approximately 22%. The probability of success would decrease because a computerized reminder system is further away from the hospital's ability, thus making it more difficult to implement successfully.

As a final point in the discussion, the generalizability of the current findings will be addressed. While no differences in patterns of technology usage appeared to exist between private, non-profit hospitals and other hospitals in this study, the population of hospitals in the state of Minnesota consists largely of private, non-profit hospitals. It is worth noting from earlier discussion that one of the key features of RMA is that the results of this study would be applicable to other hospitals that are considered to be part of the same population even though they were not part of the present analysis. As a consequence, healthcare systems in other countries that utilize private, non-profit hospitals should benefit from the current technology usage findings. Even though geographic and political differences can pose different challenges for hospital administration, the basic organizational structure of private, non-profit hospitals presents a similar operating environment. Thus these findings on hospital technology usage would appear to be relevant to Canadian, French and German healthcare systems, which consist of 95%, 33% and 36% private, non-profit hospitals, respectively [85–87]. In addition, private, non-profit hospitals are increasingly being utilized in developing areas of Central and South Asia [88].

Summary points

What was already known on the topic:

- Healthcare information technology (HIT) is viewed as a key component in the performance and safety of hospitals and other health care organizations.
- While information technology has generally been shown to have a positive effect on hospital performance, the contributions of specific technologies within the overall HIT system have been mixed.
- Only one study to date has viewed the simultaneous impact of a broad range of HIT within the hospital setting.

What this study added to our knowledge:

- Healthcare technologies differ in their level of implementation difficulty for hospitals. Some healthcare technologies are more difficult to implement than other healthcare technologies.
- Technological capability exists as a latent or underlying process within hospitals. If a hospital is able to increase its level of technological capability, its capacity to successfully adopt more difficult healthcare technologies increases.
- Controlling for hospital size, this analysis identified a significant and positive relationship between the level of technological capability of a hospital and its degree of patient safety.

5.2. *Limitations*

This study has several important limitations. First, the sample used in this study was based upon the responses of hospitals located in the state of Minnesota. Hospitals in Minnesota exist largely as not-for-profit organizations. Hence, the findings may not be applicable to all types of hospitals. Further, levels of technology usage may differ from other geographic locations because of governmental policies or resource availability. Second, it was assumed that the type of respondents that was selected, higher managerial and medical levels within a hospital, would have relevant knowledge relating to the various healthcare technologies implemented within their organizations. Even though the respondents attained decision making positions, they may not have been familiar with technology related activities in all areas within the hospital. Third, not all of the hospitals taking part in this study were contained in the Hospital Compare database. As a result, the statistical relationship found between hospital's ability to implement technology and its Hospital Compare scores could be overstated. Fourth, there are certain limitations in the data. The healthcare technologies examined in this study consisted of a representative list, thus some noteworthy technologies may have been excluded. In addition, the survey did not examine how widely healthcare technologies were distributed within a hospital only whether a hospital utilized a particular technology. Finally, the research design utilized a cross-sectional analysis, which is descriptive in nature.

5.3. *Conclusion*

This study does not attempt to advocate a position for any particular healthcare technology. Using a cross-sectional analysis, we attempt to demonstrate that some healthcare technologies may be more difficult to implement than other healthcare technologies for a particular hospital. Being descriptive in nature, this study does not prescribe any particular path that a hospital should follow. What this study illustrates is that hospital administrators need to understand: (1) some healthcare technologies based upon the experiences of Minnesota hospitals present greater implementation challenges than other healthcare technologies and (2) the ability level of a hospital is a key consideration in determining the level of resources that are necessary in order to successfully implement a particular healthcare technology.

Conflict of interest

No conflicts of interest result in doing this project.

Authors' contribution

All authors contributed equally to the manuscript preparation on this project. John Olson was primarily responsible for data collection and analysis. Jim Belohlav and Lori Cook were primarily responsible for advanced data analysis and results.

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