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Cloud Readiness of German Hospitals: Development and Application of an Evaluation Scale

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Abstract. Background: In the context of the telematics infrastructure, new data usage regulations, and the growing potential of artificial intelligence, cloud computing plays a key role in driving the digitalization in the German hospital sector. **Methods** Against this background, the study aims to develop and validate a scale for assessing the cloud readiness of German hospitals. It uses the TPOM (Technology, People, Organization, Macro-Environment) framework to create a scoring system. A survey involving 110 Chief Information Officers (CIOs) from German hospitals was conducted, followed by an exploratory factor analysis and reliability testing to refine the items, resulting in a final set of 30 items. **Results** The analysis confirmed the statistical robustness and identified key factors contributing to cloud readiness. These include IT security in the dimension "technology", collaborative research and acceptance for the need to make high quality data available in the dimension "people", scalability of IT resources in the dimension "organization", and legal aspects in the dimension "macroenvironment". The macroenvironment dimension emerged as particularly stable, highlighting the critical role of regulatory compliance in the healthcare sector. **Conclusion** The findings suggest a certain degree of cloud readiness among German hospitals, with potential for improvement in all four dimensions. Systemically, legal requirements and a challenging political environment are top concerns for CIOs, impacting their cloud readiness.

Keywords. Cloud computing; evaluation, scale development, hospital

1. Introduction

In various areas of healthcare and medicine cloud computing is already being successfully used: In the provision of telemedical services, such as video consultation, exchange of medical data between inpatient and outpatient facilities [1], clinical decision support applications based on real-time data from the cloud [2] as well as making use of mobile and digital health applications [3]. Although the need for this technology is widely recognized [4], knowledge on how to implement cloud computing applications and services into daily routine is limited and still heavily fragmented. Furthermore, the risks of using cloud computing technologies are high as well, due to handling of sensitive confidential

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information of patients. In the highly regulated area of healthcare several rules and regulations need to be adhered to around information and data security, but also different and conflicting federal, state, or specific hospital laws [5]. Furthermore, the largest and most powerful cloud infrastructure providers are currently United States (US)-based companies. The EU's General Data Protection Regulation (GDPR) regulates the potential collaboration with external service providers from third countries such as the USA. In accordance with Art. 44 of the GDPR companies and organizations need to guarantee a sufficient level of data protection [6]. Since the 10th of July 2023, the European Commission has adopted its adequacy decision for the EU-U.S. Data Privacy Framework (EU-U.S. DPF). The official website provides a list of US companies that have been certified under the new data protection agreement and hence data transferred between these countries is currently considered as protected [7].

Academic literature related to cloud computing technology in healthcare in Germany is rare to non-existent. Only one comparable scientific article by Putzier et al. (2024) [5] could be found, which investigated an example of cloud computing implementation at a German university hospital. In other countries like Canada [8], Taiwan [9], Malaysia [10] and Saudi Arabia [11] cloud computing adoption, acceptance and readiness has been discussed in practical and academic field as early as 2011. Alharbi et al. [11] developed a very comprehensive cloud adoption readiness assessment tool incorporating three different frameworks which include Human, Business, Organizational and Environmental factors. This tool covers a wide range of perspectives both strategic and operational, but lacks practical applicability, as it is difficult to understand due to its wide range.

There are no comparable studies found that use the TPOM framework which is inspired by the socio-technical approach by Mumford [12]. Cloud computing as well as other IT healthcare innovations are a socio-technical phenomenon and different aspects of the adopter system need to be considered. Measuring the cloud readiness along these four dimensions is unique and has not been examined in this way before.

To fill this research gap, the purpose of this study is to develop a reliable and valid scale for measuring the cloud readiness of hospitals and to test it in a survey of Chief Information Officers (CIOs) from (n=110) German hospitals.

The following two research questions are examined:

1) How can cloud readiness of German hospitals be operationalized and measured based on the TPOM framework?
2) What is the cloud readiness of German hospitals according to the scoring system developed in this study?

2. Method

2.1. Framework for the evaluation scale

For the scale development the Technology, People, Organization and Macroenvironment framework (TPOM) by Cresswell et al. (2020) [13] was used. Each of the TPOM dimensions consists of factors which define the respective dimensions [13, 14]. Already Lian et al. (2014) [9] combined the TOE (Technology-Organizational-Environment) by Tornatzky and Fleischer (1990) [15] with the Human, Organization-Technology-fit (HOT-fit) framework to investigate cloud adoption in Taiwan hospitals. Cresswell et al. (2020) created the TPOM framework to implement new innovative technology specifically in

healthcare. The different dimensions and factors within their dimensions are explained as follows: (1.) Technology: The technical capabilities of the IT system, its secure data transfer capabilities, and the available IT infrastructure. (2.) People: How different stakeholders use the IT technology, including their expectations and experiences. (3.) Organization: How organizations use IT technology and how this influences their usage. (4.) Macroenvironment: How political, economic and market factors influence the development, use, implementation, and optimization of IT technologies in healthcare.

Table 1 provides an overview of the factors and their answer statements as used in the conducted survey along with the dimensions. The rating is based on a 5-point Likert scale ranging from 1= "strongly disagree" up to 5= "fully agree".

Table 1. Operationalization adapted and based on Cresswell et al. (2020) [13] with survey answer statements

Dimension	Item (n=30)	Survey answer statements
Technology	TE1	Increase of information security through proof of certificates (i.e. BSI Cloud Computing Compliance Criteria Catalogue (BSI C5) certificate)
	TE2	Increase of data security by providing evidence of compliance with the European GDPR standards and offering data encryption
	TE3	Physical IT security through professionally operated data centers (access control, redundancy, disaster recovery)
	TE4	Guaranteeing interoperability of new IT solutions with existing IT infrastructure through standardized interfaces
	TE5	Comprehensive data protection through proof of compliance with the GDPR standards and the encryption of data
	TE6	Vendor contracts: service level agreements (SLAs) and flexible license models
People	PP1	Better data analysis: efficient use of medical research across institutions + sectors
	PP2	Provision of data for learning algorithms and artificial intelligence (AI)
	PP3	Improving quality of care: build up cooperation + networks
	PP4	Possibility of inhouse agile software development by providing modern software development architecture
	PP5	Involving patients in product development through real-time data provision
	PP6	Short-term implementation of digitization measures within a low/current IT budget
	PP7	Lack of clarity regarding the strategic approach towards digitization of the hospital
Organization	OR1	Scalability of IT services and computing capacity as required
	OR2	Flexible scalability of IT capacities and IT services on demand
	OR3	Reduced workload for internal IT staff due to lower support and maintenance costs
	OR4	Economic savings potential through savings in maintenance and support costs
	OR5	Reliable information security through professionally operated cloud data centers (protection against burglary, theft, fire, forces of nature)
	OR6	Possibility to replace outdated (non-performing) IT systems and IT infrastructures
	OR7	Outsourcing IT services to vendor: regular patch management, updates + releases
	OR8	Reduction of energy costs through savings on maintenance and servicing
	OR9	Customization of the IT solution to the clinical and patient user's needs
Macroenvironment	ME1	Unclear legal liability in the event of data loss
	ME2	Unclear accountability in case of data breach
	ME3	Fear of losing control of data in the cloud
	ME4	Legal uncertainty regarding US-cloud providers due to the omission of the EU-US former treaty based on the Schrems II ruling and the not fully established new Trans-Atlantic Data Privacy Framework
	ME5	Protection of patient data against unauthorized access
	ME6	Possible loss of data sovereignty, as the complete deletion of data in the cloud is no longer so easy if required
	ME7	General uncertainties regarding the legal situation when using external cloud solutions in the hospital industry
	ME8	Non-existent cloud capability of existing clinical IT systems in use in routine

For the scale development, the TPOM factors and descriptions were used as the initial basis and adapted to the topic of cloud readiness in consultation with cloud experts from the hospital sector.

2.2. Target population, data collection and measurement instruments

This study used a quantitative approach and its target population are 1,887 German hospitals (total number of hospitals in Germany 2022 according to the German Federal Statistical Office [16]). The criteria for selecting the experts for this study included CIOs in hospitals, hospital groups or outsourced IT organizations who work for hospital chains.

Their job description included positions in IT management, IT network and infrastructure, clinical or medical applications, administrative IT applications, IT security and data protection or IT strategy. The data was collected anonymously using the online tool LimeSurvey Community Edition Version 5.6.13 (Release 27. March 2023). After a successful pretest with 5 test subjects and shortening the questionnaire further, the data was collected over a period of 6 weeks from 12th July to 23rd August 2023. Altogether 4 reminders were sent out.

The research design was based on selected items (n=30). A questionnaire with a 5-point Likert scale was developed based on the item battery of Cresswell's TPOM framework [13]. The scale values of the 5-point Likert scale are as follows: 5="fully agree", 4="agree", 3=" neither agree nor disagree", 2="disagree" and 1="fully disagree". The then operationalized items were made measurable in a cloud readiness scale.

2.3. Validity and reliability

All data were analyzed using R (Version 4.2.1). Construct reliability is assessed by Cronbach's alpha in this study. Reliability is the assessment of the degree of consistency between multiple measurements of a variable [17]. The exploratory factor analysis is employed with a Varimax rotation to investigate the convergent and discriminant validity. The threshold of factor loading is between -0.3 and 0.3.

2.4. Data analysis

To make the answers of the survey comparable, the values in the dataset are normalized to the value of a normalized score of 0 to100, as the 4 dimensions that are measured are on a different scale. Hence, the variables need to be normalized for each variable to have the same range [18].

3. Results

CIOs of 110 hospitals participated and completed the questionnaire. Among the survey answers were CIOs who oversee more than one hospital; hence these answers were counted double resulting in mentioned 110 respondents. The information was queried with the demographics questions at the beginning of the questionnaire. The data set used is n=110.

3.1. Results validity and reliability

Table 2 presents the items and its description sorted according to their factor loading from high to low for each dimension as result of the factor analysis.

For the dimension technology, the item "information security" has the highest factor loading (0.88) and the lowest "Contract or SLAs" (0.47). For the dimension people the item "research across institutions" (0.75) has the highest loading and the item "strategic approach to digitalization" lowest (0.35). Within the organization dimension the item "scale IT according to demand" has the highest loading (0.80) and "own IT customizations" (-0.36) the lowest with a negative value. The dimension macroenvironment the "legal liability due to data loss" (0.81) is highest loading and "missing vendor cloud capability" lowest (0.30). Table 2 also presents Cronbach's alpha for each dimension.

Table 2. Validity and reliability analysis with adapted TPOM framework by Cresswell et al. (2020)

Dimension	Item (n=30)	Operational definition	Factor loading	α
Technology	TE1	**Information security**	**0.88**	0.89
	TE2	**Data security**	**0.80**	
	TE3	IT security	0.75	
	TE4	Interoperability	0.62	
	TE5	Data protection	0.59	
	TE6	Contract or SLAs	0.47	
People	PP1	**Research across institutions**	**0.75**	0.89
	PP2	**Learning algorithms and AI**	**0.74**	
	PP3	Cooperations and networks	0.71	
	PP4	Inhouse software development	0.69	
	PP5	Patient involvement	0.62	
	PP6	Rapid implementation of new IT	0.48	
	PP7	Strategic approach to digitalization	0.35	
Organization	OR1	**Scale IT according to demand**	**0.80**	0.89
	OR2	**Flexible scalability of IT resources**	**0.77**	
	OR3	Free up IT staff resources	0.59	
	OR4	Economic savings potential	0.57	
	OR5	Physical IT security	0.55	
	OR6	Replacement of old IT infrastructure	0.55	
	OR7	IT outsourcing capability	0.47	
	OR8	Energy savings potential	0.44	
	OR9	Own IT customizations	-0.36	
Macroenvironment	ME1	**Legal liability due to data loss**	**0.81**	0.90
	ME2	**Accountability in case of data breach**	**0.65**	
	ME3	Noticeable loss of data control	0.47	
	ME4	Uncertainty about laws on US-cloud providers	0.41	
	ME5	Patient data protection	0.40	
	ME6	Giving up their data sovereignty	0.40	
	ME7	Legal uncertainty cloud providers	0.38	
	ME8	Missing vendor cloud capability	0.30	

3.2. Composite score

The composite score for n=110 after normalization (minimum=0 and maximum=100) is at 76.1 mean value and the standard deviation (SD) is at +/- 8 points. The range is 60.8 and the lowest score value lies at 32.2 and the highest score at 93.1. Among the four different dimensions from high to low the mean is: macroenvironment (mean=79.1), fol-

lowed by organization (mean=78.7), and then people (mean=73.6), and finally technology (mean=72.4). The SD is from low to high: macroenvironment (SD=8.9), organization (SD=11.4), people (SD=13.3) and highest technology (SD=14.0).

Table 3. Composite score (n=110, value range: min=0 and max=100)

Dimension	Mean	Standard Deviation (SD)	Range	Min	Max
Technology	72.4	14.0	73.3	20.0	93.3
People	73.6	13.3	77.1	20.0	97.0
Organization	78.7	11.4	68.9	28.9	97.8
Macroenvironment	79.7	8.9	40.0	60.0	100.0
Composite score	76.1	8.2	60.8	32.2	93.1

4. Discussion

This study seeks to operationalize and measure cloud readiness among hospital CIOs in Germany by applying and validating the TPOM framework developed by Cresswell et al. (2020). This framework is structured around four key dimensions: technology, people, organization, and macroenvironment. Through factor analysis, the study identifies the most influential factors (marked in bold in Table 2) within each dimension that contribute to cloud readiness.

For the technology dimension, "information security" and "data security" emerged as the top factors, reflecting the critical importance of secure data handling among IT professionals. In the people dimension, "research across institutions" and "learning algorithms and AI" were highlighted, underscoring the medical staff's dual focus on patient care and scientific research, as well as their interest in advancing medical technology and AI applications. In the organization dimension, the ability to "scale IT according to demand" and ensure "flexible scalability of IT resources" were identified as key factors, driven by the challenges of staffing and the need for adaptable IT infrastructure in healthcare settings. The macroenvironment dimension revealed that legal concerns, specifically "legal liability due to data loss" and "accountability in case of data breach," are paramount, reflecting the high stakes of managing sensitive health data and the legal implications of data breaches.

From the perspective of the composite score, the study found that the macroenvironment dimension provided the most consistent results with the highest mean and lowest standard deviation, suggesting that legal and regulatory concerns are critical in the implementation of cloud computing in German hospitals. This is likely influenced by the strict regulatory environment in Germany's healthcare sector.

What do the results now mean in summary? If we look at the first research question of how to measure cloud readiness of German hospitals, then our study results indicate that their cloud readiness can be effectively measured across the four dimensions.

The results demonstrate further that all four dimensions – technology, people, organization and macro-environment – seem to be of equal importance. This confirms that socio-technical aspects, such as the legal and political environment, influence cloud computing at the macro level. At the hospital level, the focus should include both technical and people aspects. We demonstrate, additionally, that cloud readiness can be operationalized using a 30-item questionnaire.

The second research question with regards to - what is the cloud readiness of German hospitals according to the scoring system - can be answered as follows: The findings suggest a certain degree of cloud readiness in the dimensions of people and technology. However, there are more reservations within the organizational and macro-environmental dimensions, particularly regarding flexible and scalable IT resources and uncertain legal requirements. Nevertheless, further validation is needed to confirm the findings.

4.1. Limitations

Despite these findings, various limitations of the study must be considered. Firstly, there is potential self-selection bias, as the CIOs participated are inherently interested in cloud technology. Furthermore, the sample size with n=110 is small, which may not allow for very robust parametric statistical tests results.

The selected TPOM framework by Cresswell et al. has been used as formative evaluation framework for health information technology (HIT) implementations and hence implies that it evaluates already adopted HITs. It can be argued if this TPOM framework is particularly suitable for this study, as it evaluates the willingness and readiness of cloud-based solutions in the hospital industry. As the applied framework has only been used by two other authors before [19, 20], further publications applying or supplementing the TPOM framework are needed.

Future research should consider a larger and more diverse sample and include perspectives from other healthcare stakeholders, such as patients, to provide a more comprehensive view of cloud computing's impact on healthcare. Given the scarcity of studies on this topic within the German context, further research is encouraged to deepen the understanding of cloud computing in healthcare, exploring how these technologies can be effectively implemented across different healthcare systems, cultural contexts, and regulatory compliance.

5. Conclusions

This study focused on assessing the readiness of hospital CIOs in Germany to adopt cloud computing technologies. It aimed to identify and operationalize the key factors influencing this readiness. The findings indicate that hospital CIOs are generally prepared for the transition to cloud-based systems. However, they still express significant concerns regarding legal and regulatory challenges, which are inherent in the highly regulated healthcare sector.

The study highlights that while the legal and regulatory hurdles are substantial, there is a noticeable shift towards the practical implementation of cloud computing within the hospital infrastructure. Data security, compliance with stringent regulations, and effective data management are the primary concerns for hospital CIOs as they navigate the complexities of integrating cloud technology in healthcare settings. Overall, the study reveals a certain degree of readiness among German hospitals towards cloud computing.

Declarations

Conflict of Interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Author contributions

AH, JL: conception of the work, development of results, AH: writing of the manuscript; JL reviewed the manuscript, AH: revising of the manuscript.

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References

[1] Harst L, Timpel P, Otto L, Richter P, Wollschlaeger B, Winkler K, et al. Identifying barriers in telemedicine-supported integrated care research: scoping reviews and qualitative content analysis. Journal of Public Health. 2020;28(5):583-94, doi: 10.1007/s10389-019-01065-5.

[2] Oh S, Cha J, Ji M, Kang H, Kim S, Heo E, et al. Architecture Design of Healthcare Software-as-a-Service Platform for Cloud-Based Clinical Decision Support Service. Healthc Inform Res. 2015;21(2):102-10, doi: 10.4258/hir.2015.21.2.102.

[3] Jacob C, Sanchez-Vazquez A, Ivory C. Understanding Clinicians' Adoption of Mobile Health Tools: A Qualitative Review of the Most Used Frameworks. JMIR mHealth and uHealth. 2020;8(7), doi: 10.2196/18072.

[4] Morais D, Pinto FG, Pires IM, Garcia NM, Gouveia AJ. The influence of cloud computing on the healthcare industry: a review of applications, opportunities, and challenges for the CIO. Procedia Computer Science. 2022;203:714-20, doi: 10.1016/j.procs.2022.07.106.

[5] Putzier M, Khakzad T, Dreischarf M, Thun S, Trautwein F, Taheri N. Implementation of cloud computing in the German healthcare system. npj Digital Medicine. 2024;7(1), doi: 10.1038/s41746-024-01000-3.

[6] Haas P, Schneider UK. Rahmenbedingungen Cloud-basierter Krankenhausinformationssysteme. Wissenschaftliches Gutachten. Karlsruhe, Germany: Bundesministeriums für Gesundheit (BMG), mbB VPR; 2021, Januar 07.

[7] U.S. Department of Commerce TITAI. Data Privacy Framework Program Washington: U.S. Department of Commerce, The International Trade Administration (ITA); 2023 [cited: 05.12.2023]. Available from: https://www.dataprivacyframework.gov/s/program-overview.

[8] Kuo AM-H. Opportunities and Challenges of Cloud Computing to Improve Health Care Services. Journal of Medical Internet Research. 2011;13(3):67, doi: 10.2196/jmir.1867.

[9] Lian J-W, Yen DC, Wang Y-T. An exploratory study to understand the critical factors affecting the decision to adopt cloud computing in Taiwan hospital. International Journal of Information Management. 2014;34(1):28-36, doi: 10.1016/j.ijinfomgt.2013.09.004.

[10] Sulaiman H, Magaireah AI, editors. Factors affecting the adoption of integrated cloudbased e- health record in healthcare organizations: a case study of Jordan. Proceedings of the 6th International Conference on Information Technology and Multimedia; 2014 18-20 Nov. 2014; Putrajaya, Malaysia: IEEE-Institute of Electrical and Electronics Engineers, doi: 10.1109/ICIMU.2014.7066612.

[11] Alharbi F, Atkins A, Stanier C, editors. Cloud computing adoption readiness assessment in saudi healthcare organisations: a strategic view. ICC '17: Proceedings of the Second International Conference on Internet of things, Data and Cloud Computing; 2017 22 March 2017; Cambridge United Kingdom: Association for Computing MachineryNew YorkNYUnited States, doi: 10.1145/3018896.3025156.
[12] Mumford E. The story of socio-technical design: reflections on its successes, failures and potential. Information Systems Journal. 2006;16(4):317-42, doi: 10.1111/j.1365-2575.2006.00221.x.
[13] Cresswell K, Williams R, Sheikh A. Developing and Applying a Formative Evaluation Framework for Health Information Technology Implementations: Qualitative Investigation. J Med Internet Res. 2020;22(6):e15068, doi: 10.2196/15068.
[14] Cresswell K, Domínguez Hernández A, Williams R, Sheikh A. Key Challenges and Opportunities for Cloud Technology in Health Care: Semistructured Interview Study. JMIR Human Factors. 2022;9(1):e31246, doi: 10.2196/31246.
[15] Tornatzky LG, Fleischer M. The processes of technological innovation. Brief AP, Schneider B, editors. Massachusetts, USA; Toronto, Canada: Lexington Books; 1990 1 January 1990. 298 p, ISBN: 0-669-20348-3.
[16] Statistisches Bundesamt. Anzahl der Krankenhäuser in Deutschland in den Jahren 2000 bis 2021. In: Bundesamt S, editor. Anzahl der Krankenhäuser in Deutschland bis 2021. de.statista.com: gbe-bund.de; 2023,
[17] Streiner DL. Starting at the Beginning: An Introduction to Coefficient Alpha and Internal Consistency. Journal of Personality Assessment. 2003;80:103 - 99, doi: 10.1207/S15327752JPA8001_18.
[18] Hastie T, Tibshirani R, Friedman J. The Elements of Statistical Learning. Springer Series in Statistics: Springer New York; 2009. p. 417-58, doi: 10.1007/978-0-387-84858-7_12.
[19] Dumbrell J, Daneshvar H, Oteo A, Baldacchino A, Matheson C. The acceptability of overdose alert and response technologies: introducing the TPOM-ODART framework. Harm Reduction Journal. 2023;20(1), doi: 10.1186/s12954-023-00763-4.
[20] Severinsen G-H, Silsand L, Malm-Nicolaisen K, Pedersen R. Preconditions for Implementing a Nursing App to Improve Digital Maturity. Studies in Health Technology and Informatics. 2023;Volume 305: Healthcare Transformation with Informatics and Artificial Intelligence:76 - 80, doi: 10.3233/shti230428.