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MATURITY MODEL FOR IOT ADOPTION IN HOSPITALS

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Abstract. Hospitals are facing a wide variety of challenges in terms of quality and efficiency of healthcare. Internet of Things (IoT) is a technology used by organisations to increase efficiency and quality by recording measurements for historic analysis. The data thus produced can then go on to inform future decisions and predictions. Unfortunately, the benefits provided for by a successful IoT adoption are currently out of reach for many hospitals. The lack of a maturity model for IoT adoption in hospitals aggravates this situation. The goal of defining and applying such a model is to assist hospitals in reaching a higher level of IoT maturity and thereby improving the quality of services delivered. This paper develops an IoT maturity model that is tailored to the healthcare industry with an emphasis on Belgian hospitals. The developed maturity model is grounded in scientific literature and industry expert opinions. Experts found the maturity model to be relevant, clear, and helpful for the hospitals' road to IoT adoption.

Keywords: Maturity models, Internet of Things (IoT), digitalisation, hospitals, healthcare

1 INTRODUCTION

The Internet of Things (IoT) is a term used for smart, internet-connected devices which are able to transmit data to a central data repository. Bain & Company [1] predicts that the market for IoT applications will more than double by 2021. This is a natural consequence of the exponential growth in the number of so called smart devices in circulation, which are capable of partaking in the IoT enterprise as contextaware electronic devices [2]. On top of that, they state that smart devices can perform autonomous computing and can connect to other devices with or without wires for data exchange. By 2023 the worldwide number of this type of IoT-connected devices is expected to increase to 43 billion, an almost threefold increase from 2018 [2].

In the healthcare industry, maintaining and improving quality has always been one of the main concerns [3]. Accustomed to better services due to the exposure to technological advancements in all fields, patients demand a high quality of service and much shorter waiting times [4]. Recognising the importance of this trend, the Belgian government has adapted its funding criteria. To determine the allocation of funds, Belgian officials frequently require hospitals and other care providers to provide third party confirmation of their commitment to innovation, digital transformation, and higher quality of service [5]. The new regulations have set the stage for innovation in hospitals to flourish and explain why hospitals are eager to implement IoT solutions. IoT implementation can help boost a hospital's quality of care by regular monitoring and reduction of costs [6]. In order to reap the long-term benefits of IoT, the initial set-up of a reliable IoT-based monitoring system requires a huge technological investment both from a financial, as well as knowledge perspective.

A maturity model is a framework which allows an organisation to establish how far along the organisation is in its implementation process and whether it already has all the elements in play to make optimal use of all the advantages offered by the technology. This mapping process not only allows the organisation to measure the level of the domain the framework is focusing on, but also provides a pathway to lift itself to a higher level of maturity. Maturity models help an organisation (in our case hospitals) to plan their transformation process. It offers not only a yardstick to measure progress, but also useful guidelines on how to advance to a more mature level on the model in predefined phases [7].

However, to the best of our knowledge, there are currently no maturity models that are tailored towards IoT adoption in hospitals [8]. This study's main objective is to create and optimise a maturity model that can assess the maturity of a hospital in terms of IoT integration and identify aspects for improvement. To compose our hospital-specific IoT maturity model, a group of industry experts has been consulted. Due to limited availability of healthcare staff in times of the COVID-19 pandemic, we redefined the approach to a semi-structured interview methodology, combined with the application of real case studies. Before interviewing the candidates, an initial maturity model was created from relevant literature and case studies, and subsequently refined using expert opinions and feedback.

This paper is structured as follows. Section 2 outlines the methodology of the research. Section 3 discusses the construction of the initial maturity model and its subsequent refinement based on expert opinions and feedback. In Section 4, remarks regarding the validity of this study are provided, while Section 5 provides a discussion with additional remarks and paths for future research. Finally, Section 6 concludes.

2 METHODOLOGY

We will create an IoT Maturity Model using a design study based on previous research on maturity models and semi-structured interviews. In our study we will tackle the creation of this maturity model using three different approaches: We start off with a literature review on existing publications about IoT and maturity models to get a better understanding of what these topics cover. After having obtained a better understanding of these topics, especially as applied to the healthcare domain, we will create our initial maturity model for IoT implementation in a healthcare system. This initial model is meant to inform discussion and can be used as a basic foundation to further refine when we get to the interview stage. Thus, we use the initial model as a basis to validate and improve upon. We shall improve this model by gathering feedback from industry experts via semi-structured interviews. Finally, the maturity model enhanced by expert opinions and feedback will be presented to the experts for validation, and will be given to a hospital to perform a self-assessment of their IoT adoption maturity along all of the domains of the maturity model. Figure 1 provides an overview of these steps.

2.1 Literature Review

To compile the literature review, the snowball methodology was applied [9]. The study takes the guidelines for the snowballing method into account especially when focusing on Software Engineering by [10]. The snowball method uses an initial set of sources to extract information from. A selection of scientific articles is made to arrive to a limited, relevant body of scientific literature to serve as a starting point. Relevant citations in these papers are then further explored to locate more relevant literature. The snowball method is applied to both the area of maturity models in healthcare as well as IoT technology. This review of maturity model literature in healthcare and IoT literature is used to identify the domains of the initial maturity model which will be used as input for the semi-structured expert interviews.

2.2 Semi-Structured Interview

To qualify as a semi-structured interview (SSI), researchers have to follow a specific interviewing methodology. In this type of interview, the interviewer has a set of questions to propose to their interviewees, but unlike structured interviews, the interview is not limited to the questions the interviewer prepared. The conversation is allowed to flow freely. This is considered necessary given the highly specific and specialised matter of the topic and the experts' knowledge [11]. New questions can arise spontaneously during the conversation between the interviewer and interviewees. After conducting the interviews, relations need to be made between the interviews to arrive to correct conclusions. Thus, we followed the SSI guidelines put

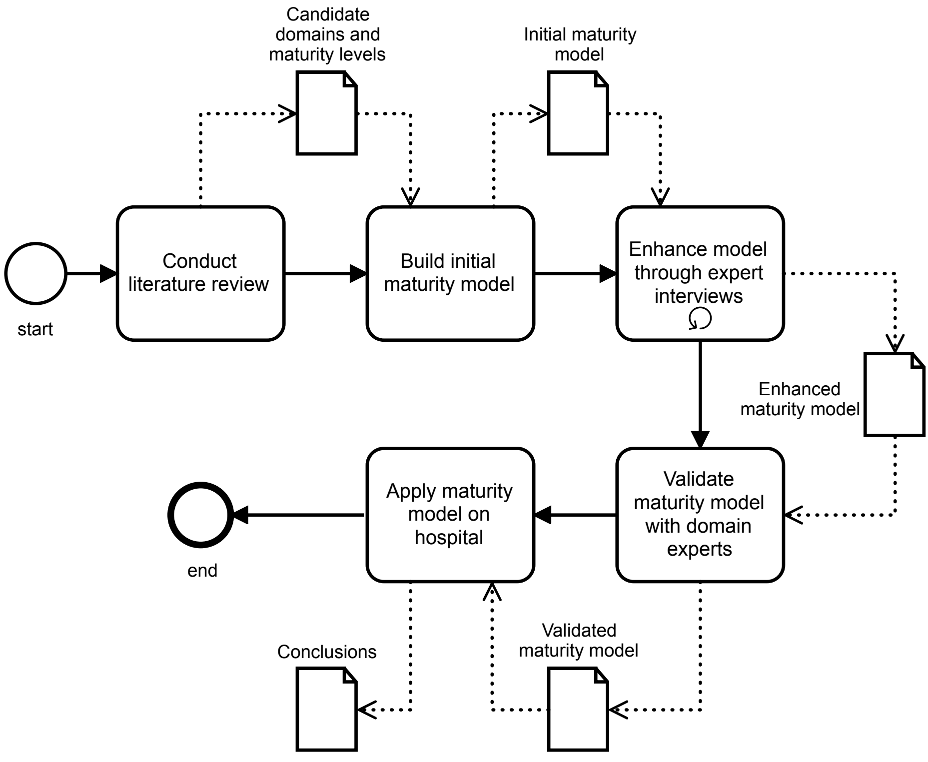

Figure 1. Methodology

in place by [11]. For optimal knowledge transfer from the interviewees to the interviewer care is taken to avoid tendentious language as that may steer the candidate and introduce bias in the research [12].

Since it is important to keep the interview on topic, we prepare an initial maturity model on which the agenda can be tuned. It is of the utmost importance to ask open questions and let the candidate speak freely, despite having the initial model as a starting point of the conversation. This allows researchers to gather a lot of information on which follow-up questions can be based, such as probe questions revolving around why, what, and how [13]. The experts' information and feedback are synthesised and the initial model is iteratively refined during the interview process.

2.3 Validation

To assess the constructed maturity model, we opted for a twofold approach to ensure the validaty of our model. The first approach we used consisted of sending out the improved maturity model to the candidates who participated in our semi-structured interviews. Their remarks are collected and inform the next iteration of our IoT maturity model. Finally, we will put the improved model we created to the test in a real-world use case. We deploy our model and use it to assess the IoT adoption in a Belgian hospital. The hospital experts are consulted for this assessment as well as for their opinion regarding the usefulness and relevance of the maturity model. Note that model construction is not necessarily final, but that these validation steps can be performed iteratively to further update and improve the model based on additional case studies in hospitals and expert opinions.

3 CONSTRUCTING THE MATURITY MODEL

In this section, we detail how we created our initial model. Afterwards we explain how we approach the semi-structured interviews and finally we shall discuss the conclusions derived from those interviews. These conclusions were then used to further improve the initial model and ultimately result in the final maturity model.

3.1 Designing the Initial Maturity Model

We built our initial maturity model based on the insights gained from our general literature review about maturity models. We performed a comparative study of existing maturity models, often measuring maturity in an IT-context. This gave us a better understanding of what our IoT maturity model needed to contain if it wanted to meet the requirements of a full-fledged maturity model.

To construct our initial IoT Maturity model, we came up with an initial bare-boned structured to obtain the intellectual scaffolding we needed to successfully complete our endeavour. In the end, we decided to base our model on Maturity and Metrics in Health Organisations Information Systems [14] and borrow heavily from the Data Governance Maturity (DGM) Model [15]. We chose to use IBM's DGM model since it is a particularly useful source of inspiration as data is seen as one of the most important artefacts of IoT applications and therefore the model will largely focus on the data aspects of IoT in healthcare. On top of that, IBM's DGM model is well-established in industry use.

Despite the fact that both the aforementioned models have five levels of maturity, we anticipated that a sixth one would be necessary if we wanted to create a collectively exhaustive model for IoT implementation. We opted for this sixth level because we believed that this would allow us to more accurately describe the various starting points for organisations in the healthcare industry, who can differ widely in terms of IT capabilities and willingness to adopt new technologies. We estimated that many hospitals would not yet have invested in any IoT projects yet, we therefore introduced a level 0 in our model.

The original domains of the Data Governance Maturity Model were strong contenders due to the strategic insights they provided. The basic framework provided by this Data Governance Maturity Model was then contextualised to the field of IoT and further extended due to having an additional level of maturity to cover. With this new level added, we had a basic structure in place that allowed us to map organisations onto a level that corresponds to the domains of the model.

Type	Name	Derived from	Source
Level	Initial	Data Governance Maturity Model – IBM	[15]
Level	Performed	Data Governance Maturity Model – IBM	[15]
Level	Defined	Maturity Model for the Internet of Things – Gartner	[16]
Level	Managed	Capability Maturity Model (CMM)	[17]
Level	Quantitatively managed	Data Governance Maturity Model – IBM	[15]
Level	Optimized	Data Governance Maturity Model – IBM	[15]
Domain	Organisational awareness	Data Governance Maturity Model – IBM	[15]
Domain	Stewardship	Data Governance Maturity Model – IBM	[15]
Domain	Policy	Capability Maturity Model (CMM)	[17]
Domain	Value creation	Data Governance Maturity Model – IBM	[15]
Domain	Risk Management	Electronic Medical Record Adoption Model – Himss Analytics	[18]
Domain	Security/Privacy/ Compliance	Electronic Medical Record Adoption Model – Himss Analytics	[18]
Domain	Data Architecture	Data Governance Maturity Model – IBM	[15]
Domain	Data Quality	Data Management Maturity Model	[19]
Domain	Data Classification/Metadata	IT Governance Maturity Model – Gartner	[20]
Domain	Information Lifecycle management	Data Governance Maturity Model – IBM	[15]
Domain	Audit & Reporting	Data Governance Maturity Model – IBM	[15]

Table 1. Levels and domains of the initial maturity model based on literature

Table 1 provides an overview of the levels and domains of our initial maturity model, along with a reference to the maturity model on which these levels and domains are based. Given the limited space, the definition matrix for each domain and level combination is provided online[1].

3.2 Conducting the Semi-Structured Interviews

We prepared an initial questionnaire regarding the initially constructed maturity model. The questions revolved around the domains that need to be included in the model, the different levels of maturity that need to be specified, and the definition posed for every combination of domain and maturity level. This initial questionnaire

[1] `https://feb.kuleuven.be/public/u0111379/IRSH/intialMM.pdf`

was used to perform a mock interview with one domain expert in order to fine-tune the questionnaire. The resulting improvement process resulted in a revised questionnaire. This new iteration consists of four main categories around which all our questions are structured. These categories are maturity model, use cases, implementation, and data. By restructuring our questions into four main categories, we are able to guide our interviewee through the interview process in a much more natural way. We are now able to demarcate our main topics of interest and make sure that the interviewees can share as much knowledge as they can with us without needing to jump back-and-forth between the questions. The final questionnaire used to guide the semi-structured interview can be found online[2].

Next to questions about the model itself, interviewees were also asked to provide us with more detailed background information on their careers and previous experience. These questions were intended to shed light on our interviewees practical experience in the field of IoT. In total eight interviews with domain experts were conducted, not counting the one additional expert with whom a mock interview was conducted to fine-tune the initial list of questions. Each interview took about an hour time. The participants were all either ICT experts working on the digital transformation and introduction of IoT in large Belgian hospitals, or IoT expert consultants working on healthcare projects. Of the in total nine experts used to construct the questionnaire and to conduct the maturity model improvement interviews, 6 were male and 3 female with 2 years to 23 years of experience in their current role.

3.3 Enhanced Maturity Model

The feedback gathered in the interviews was grouped and analysed, resulting in key take-aways that have served as pointers on how to adapt the maturity model. The maturity model enhanced with expert feedback can be found in Tables 2, 3 and 4, for maturity levels 1, 4, and 5. Due to page restrictions, levels 2 and 3 have been omitted in the paper, but have been made available online[3]. In what follows, we discuss the main adaptations that were performed.

The first point of action was to reduce the number of maturity levels from six (level 0 to level 5) to five (level 1 to level 5) levels, this is what the interviewees deemed better as it *felt* more familiar to them. This remark was very consistent, as it resurfaced in almost every interview. Additionally, interviewees often had trouble differentiating between level 3 (managed) and level 4 (quantitatively managed). These two factors lead to the reconstruction of the model with a reduced amount and renamed levels. We also decided to rename the levels after we received feedback.

Next to the maturity levels, feedback on the maturity model domains was extensive. The order in which the domains were initially arranged was found to be

[2] https://feb.kuleuven.be/public/u0111379/IRSH/Interview.pdf
[3] https://feb.kuleuven.be/public/u0111379/IRSH/Levels_2_3

Domain	1: Initial
Value creation	Internet of Things is considered an immature, novelty technology, not mature enough to provide aid or added value in healthcare in a reliable way.
Privacy & security	Some security standards exist, though they are not comprehensive, not updated on a routinely, not easily accessible and not broadly ratified.
Compliance & policy	The IoT regulatory, legal and rights related challenges are not being explored and unknown to the hospital. It would therefore be risky to engage in IoT activity.
Connectivity	The architecture currently in place is insufficient to accommodate for a pilot IoT implementation.
Data governance	It is understood that data will be an important aspect of IoT and will be a driver for key decisions in the value-chain. Data is currently not actively extracted and/or captured from the (medical) equipment and the ability to do so is not a deciding factor in choosing equipment.
Organisational culture	The basis for sharing and exploiting the value of IoT is hampered by a lack of strategic vision and coordination. New techniques and features in terms of IoT are overlooked by the organisation and not maintained.
Monitoring	There is no monitoring happening in terms of IoT.
Governance	There are no organisation-level standards for identifying IoT assets or establishing clear accountability for those assets. There is no idea on how IoT usage would need to be reported about, therefore there are no standard reporting processes. Management's ability to understand the data consistently across the organisation is limited.

Table 2. Maturity model for Level 1: Initial

counter-intuitive, despite our best attempts to cluster similar domains together. Luckily, our experts advised us on how we could mitigate this problem by giving us a different method to group and rearrange similar topics into *Why*, *What* and *How* groups. This seemed like a clear distinction that could be made, and these questions have thus lead to rearranging the order of the domains in the maturity model.

Domain	4: Optimised
Value creation	Value is clearly defined by the hospital and medical units recognise their roles in value creation. Common organisation-wide IoT-data and definitions are consistently used.

Privacy & security	Security standards are documented, published, and easily accessible. Ongoing compliance with standards is measured. Software running on the medical and IoT devices are regularly being verified to ensure the integrity of the data being sent.
Compliance & policy	The hospital has adopted a collaborative approach to IoT policy discussion. Since IoT is a challenging area for policymakers, bringing together the expertise on the topic with the development of policies, accelerates the evolution of internal policies. Formal enterprise policies are adopted, implemented, and driven down through the organisation. Policy compliance audits and feedback loops are in place.
Connectivity	There is an extensive infrastructure installed all-around the hospital, making future IoT implementation cost relatively inexpensive.
Data governance	Organisation has routine approach to data creation and acquisition. Data quality is recognised as an organisational issue and is being addressed though planned and coordinated efforts. Data definitions exist. There are enterprise standards for managing data quality supported by common definitions and processes addressing root causes and ensuring that remediation addresses immediate concerns and prohibits future contamination. There may be inconsistencies in the quality of business, technical or operational definitions but content is granular enough to be meaningful. Data valuation tends to be classified generically, e.g. high, medium, and low, rather discretely quantified. Organisation has defined processes for migration, reuse, transformation, aggregation and consolidation. Metrics for data quality exist and are actively monitored. Information is consistently defined across the enterprise, resulting in improved effectiveness and efficiency.
Organisational culture	Management is transparent with their employees about IoT implementation and thus changes to the processes. Employees feel heard by management and ideas and concerns are taken seriously. New techniques that seem interesting to the organisation are being documented for future exploration or implementation. A full, collaborative IoT team is in place synchronising between legal, management, IT and the individual medical units.

Monitoring	The hospital is on equal level with hospitals within the country or compared to neighbouring countries when measured using a unified methodology.
Governance	IoT Stewards are establishing IM programs across the organisation, and organisational structures are in place to ensure consistency in practice, compliance with Data Governance standards, and ongoing investment in IoT. A business model for accountability of data, associated standards and guidelines is in place and endorsed at the Board level. Comprehensive, conformed reporting processes and monitoring is integrated into organisational standards. Output of reporting is understood and leveraged for strategic purposes and provides an accurate and comprehensive view of enterprise performance. Reporting also supports security standards, data classification, control assessment, incident response, and reporting processes.

Table 3: Maturity model for Level 4: Optimised

Domain	**5: Beyond**
Value creation	The usage of IoT as a tool to obtain information and knowledge about different aspects within the hospital, as well as to provide better comfort and care to patients, is embraced. The technology has reached commodity status and is often iterated upon to further aid medical care in their daily activities.
Privacy & security	Security standards are documented, published, and easily accessible. Ongoing compliance with standards is measured via automated processes that are integrated with problem resolution and automated deployment systems. Penalties exist for non- compliance within hospital standards and remediation is executed in a predictable manner.
Compliance & policy	Policies are proactively designed, developed and adopted in advance of compliance or regulatory mandates. To mitigate the rapid pace of IoT technology surpassing regulatory frameworks, the hospital promotes internet and IoT with legislative bodies. The organisation is able to proactively address emerging trends related to Internet of Things as the global business environment.

Connectivity	The hospital makes recurrent investments in the IT and IoT infrastructure allowing to lower the project budgets for new IoT projects.
Data governance	Robust data classifications and definitions exist and are uniformly understood and used across the enterprise. Classification schemes focuses on business value of data and can be used to quantify the expected impact of an incident. Metadata is consistently used for reporting, new product or application development. Data quality issues are routinely identified and remedied. The use of high volumes of high-quality data allows the hospital to improve according to well defined patient segments as well as forecasting models that consider improved recovery rate as well as cost approaches. Output of data classification is also integrated into controls framework, incidents response, benchmarking, and patient processes. Hospital understands data as a corporate asset and seeks opportunities to enhance the quality and use of data for operational purposes. Data quality issues are anticipated and addressed proactively.
Organisational culture	Risk taking and pursuing change is encouraged and rewarded to empower those who adapt. The organisation is able to proactively address emerging trends related to Internet of Things as the global business environment and associated risks continue to evolve. There is an active culture of experimentation with new IoT features in a test environment. Once deemed successfully tested, the results are considered by the management. Continuous improvement is enabled by quantitative feedback from the process and from piloting innovative ideas and technologies.
Monitoring	The hospital is a significant leader compared to comparable public hospitals within the country or beyond. It sets example in terms of IoT integration and has novelty applications implemented.

Governance	Stewardship roles, structures, and processes have enabled the organisation to optimise the value of its information assets by ensuring that information is aligned with business strategy, enabling a more planned and coordinated approach and increased sharing of assets vs. unnecessary duplication of effort. Comprehensive, conformed reporting processes and monitoring is integrated into organisational standards. Output of reporting is understood and leveraged for strategic purposes and provides an accurate and comprehensive view of enterprise performance.

Table 4: Maturity model for Level 5: Beyond

Next, the domains the model covers were generally perceived as sufficient. Some remarks were however still made: the model consisted of a lot of domains revolving around the data generated by IoT. While the experts agree that data is definitely an important aspect of IoT, these domains could be consolidated into a single domain. The result of this consolidation is the new *data governance* domain we cover in the adapted model. The data governance domain encompasses the steering and responsibility in terms of data within the organisation.

Experts have also pointed out that they miss a section about governance. They strongly believe that any model worth its salt should remember to take legal requirements into account, such as for instance the General Data Protection Regulation (GDPR) in the European Union [21]. Initially, this topic only enjoyed limited coverage in our model, even though it is a huge focus in hospitals. Based on expert feedback, we decided that the domains *stewardship* and *audit and reporting* lacked specificity and could best be absorbed into a new domain which we dubbed *governance*. The governance domain took on the all-inclusive role of defining the quality control discipline in which the hospital has a clear demarcation of responsibilities assigned to different teams within the organisation.

The experts further pointed out that an essential part of the workings of IoT revolves around the architecture and infrastructure over which the devices are interconnected. It is this infrastructure that gives the IoT its ability to function. The experts claim this is an often overlooked or underestimated part in a business use case for IoT. It therefore deserves its own separate domain which was included in the adapted maturity model.

To ensure quality in a hospital, it is not enough to simply measure statistics. Quantitative statistics are meaningless if we are not able to review them properly, as stated in [22]. To combat this uncertainty, the experts point out that competent hospitals monitor their operations internally and even benchmark their results against other hospitals around the world. This insight convinced us to add *monitoring* to the maturity model.

Our interviewees also emphasised the need for our model to take *organisational culture* into account. To improve processes throughout an organisation, management support and company culture need to stimulate this kind of behaviour. As the IoT consultant experts pointed out, it is hard, perhaps even impossible to bring change and innovation into organisations that do not want to change. As such, organisational culture was included as a domain of the maturity model.

As pointed out by the interviewees, it is important to specify the context of our study since it was conducted in Belgian hospitals. The scope may differ depending on the healthcare model in place in the country of assessment. Therefore, the geographical generalisation of our maturity model would need to be tested and reviewed by experts in different countries and healthcare systems.

The interviewees also expressed a need for a tool where hospitals can fill in scores to assess their own maturity on the domains specified in the model. Therefore, we built a tool in Microsoft Excel which contains sheets for every domain in our model, supplemented with a results page. The domain sheets contain a list of basic questions about the domain topic. The results page provides an overview of the scoring for all the domains and additionally a *functional capabilities* section in which the assessor can provide a general, subjective score about their impression of the organisation in terms of IoT maturity. Every domain in the assessment model can be assigned a weight, or even be excluded if desired. The results page also computes a radar chart, visually illustrating the organisation's IoT maturity. The Excel Tool is freely available online[4].

Additionally, a recurring remark from many interviewees was that the maturity model in itself can use a guide to accompany the maturity model. This guide is meant to provide a concise, clear, and visually satisfying presentation of the model. Therefore, we have constructed such a guide explaining the maturity model and the assessment tool. The guide is also available online[5].

4 VALIDITY

4.1 Interpretive Validity and Expert Feedback

The interviews we conducted have been recorded if the expert in question agreed to it. That provided us with the possibility to listen to their answers again during the enhancement phase of the maturity model. As such, traceability between expert opinions and the established maturity model could be checked.

To validate the conclusions derived from the expert input, the revised maturity model was distributed once again among the interviewees along with the key changes as a result of the various interviews we had conducted. We asked our interviewees to validate the remarks taken from their interviews. If they agreed with this report, we were sure that we had interpreted their feedback correctly and applied it in a way

[4] `https://feb.kuleuven.be/public/u0111379/IRSH/AssessmentTool.xlsx`
[5] `https://feb.kuleuven.be/public/u0111379/IRSH/Guide.pdf`

that satisfied our experts' professional standards. The comments they provided in these feedback loops were also taken into account when constructing the final maturity model, which is presented in the previous section. Hence, the maturity model was enhanced and updated in an iterative fashion by asking the experts to validate the administered changes and to provide additional comments and feedback.

4.2 Internal Validity

Part of assessing the internal validity consists of taking a critical look at both the methodology and execution of the research. Our research made use of a technique called method triangulation [23]. In this technique, various research methodologies are combined to increase the validity of the outcome of a study. In the case of this research, our method triangulation made use of a literature review, expert interviews and the application of our model to a use case. The most important research instrument we used were semi-structured interviews, which are an example of sampled qualitative research. We opted for this method primarily because of the requirement to construct our maturity model on relevant real-world experience. This required the input of highly specialised experts in the field of healthcare, as well as experts in IoT and data processing in hospital contexts. Our IoT experts are all employed at the same consulting firm, which imposes limitations on our scope in terms of the variety of IoT specific expertise available. To partially mitigate this issue, we consulted employees from different units on top of finding experts in hospitals.

In total our sample size consisted of nine interviewees. One of these interviews was a mock interview which helped us improve the questions and structure of our semi-structured interview. The remaining eight interviews served as input for the enhancement of the maturity model. While the interviewees were all highly specialised experts in the field, a larger sample size would generate more confidence in the accuracy of the provided results.

4.3 External Validity

After creating our initial model on the basis of our literature study, we gathered expert input and used this to revise our initial model into a better version. This final version of the initial model was translated into an easy-to-use assessment tool accompanied with a model guide. However, this product still needed to be validated externally. Therefore, we applied the model to a hospital that maintains a global overview of the activities and processes performed within the hospital in terms of quality. This was done through interviews with three persons charged with digital transformation within the hospital. The assessment resulted in domain scores varying between 2 and 3. The radar chart in Figure 2 depicts the scores for every domain.

The radar chart provides a general overview of IoT maturity in the hospital, however, the in-detail answers to every question in the assessment tool have not

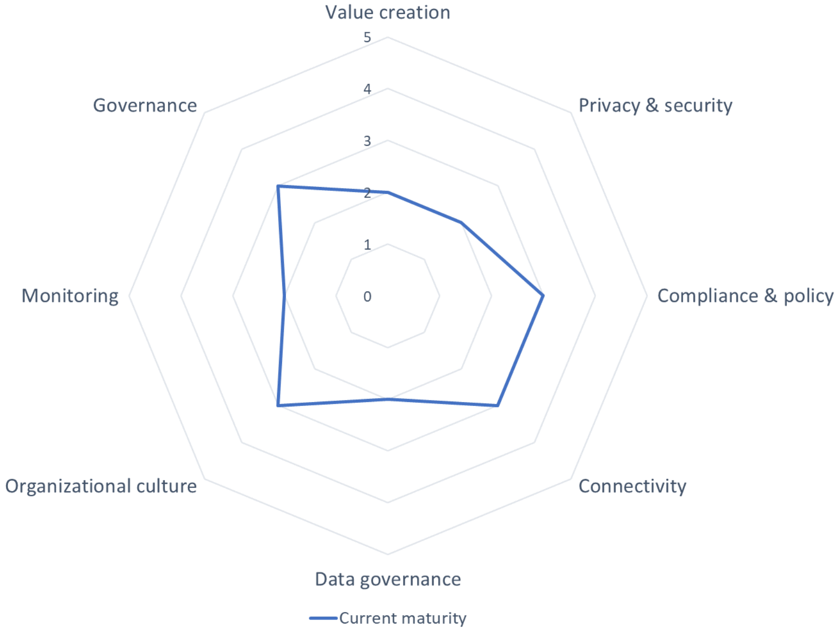

Figure 2. Radar chart depicting the IoT adoption maturity of a large hospital in Belgium

been included in this paper due to the sensitive nature of the information. The model was thoroughly discussed during the external validation interviews. The interviewees were asked whether the maturity level definitions were aligned with the IoT implementation in their hospital, and whether other levels would be a better fit. The answers of the three interviewees were consistent with the *privacy and security* domain attracting most of their attention given the high demand for confidentiality when dealing with medical information. Overall, the interviewees found that the maturity model was clear, useful, and helpful for helping determine the hospital's road to a more advanced IoT adoption.

5 DISCUSSION

This section provides additional remarks on the study performed in this paper and addresses future research opportunities.

5.1 Additional Remarks

Due to the fact that our research had a design outlook, the outcome of our research is a maturity model that can be applied to make decisions on IoT implementation in the healthcare industry, specifically Belgian hospitals.

The generalisability of our research result is limited by the type of organisation the model can be applied to. We performed our study specifically to benefit Belgian hospitals. Belgian hospitals are quite uniform in terms of organisation and financial structure. This might, however, also introduce the limitation that our maturity model is geographically constrained and that it will only be applicable to hospitals operating in a similar context.

Another remark that can be made is that bias was introduced in our study by creating an initial maturity model and distributing it among the experts. The reasoning in this case would be that by forcing interviewees to examine the initial model, we have clamped down on original thought and made it harder for interviewees to think of salient alternatives. A method to avoid the aforementioned problem is to construct a maturity model through a Delphi-study. The Delphi technique is a systematic and interactive research methodology relying on a panel of individual experts in a certain domain [24]. The experts are consulted about a specific subject within their domain. The technique is suitable for developing novel models in a methodological manner for fields of study which do not yet have a large body of academic papers devoted to them. For the initial questionnaire, the researchers would need to construct a list of questions that would result in the experts producing responses on what the initial model would need to consist of. As such, the initial model is built from expert input as well, rather than from literature as was the case in our study. The reason a Delphi experiment could not be applied in our study was due to the limited availability of resources in the healthcare industry due to the COVID-19 pandemic which reached its peak in Belgium during the course of this study.

5.2 Future Research

Future studies should consider that not all data in hospitals are highly sensitive and should take into account the different types of data hospitals handle. Often, patient data is held to the highest standards in terms of privacy and security, in contrast to IoT data about hospital logistics or smart environment systems that for instance monitor the temperature of medicine or the location of medical equipment on the hospital site.

Additionally, this study revolved around Belgian hospitals and Belgian experts. Thus, further validation is needed to ensure the geographical generalisation of the results. The experts that have participated in the construction of the maturity model also contributed to the validation study. The model should be further tested with hospitals and experts that are geographically distributed and that did not participate in the construction of the maturity model.

Another interesting line for further research is to investigate the common aspects our maturity model may share with other maturity models in different domains and industries. To do this, the final maturity model could be subjected to another validation process in which experts from different industry sectors are involved.

6 CONCLUSION

The research presented in this paper aimed at developing a maturity model for IoT implementation in Belgian hospitals. To develop the initial maturity model, we relied on existing literature. We made use of expert interviews to enhance the model. This study included experts who could offer a healthcare perspective, but also experts with business and technological expertise in IoT. Additionally, the enhanced model was validated with domain experts and applied to assess the IoT adoption maturity of a Belgian hospital.

The initial model contained six levels of maturity and had too many domains applied on data. Furthermore, less emphasis was put on assessing practical aspects such as the existing infrastructure and the connectivity needed to build the IoT applications on. After going through various iterations with the experts, a final model was established. This model differed from our initial attempt in substantial ways. New domains about connectivity and governance were introduced, while the different data domains were consolidated into one domain. The amount of maturity levels was reduced, and the remaining domains were reviewed. The maturity model was implemented in an intuitive Excel tool accompanied by a guide providing insights into every aspect of the model.

Important to note is that our model currently targets Belgian hospitals and that additional validation is needed with more domain experts, hospitals, and geographical regions. However, the experts and hospitals involved in this study, concluded that the maturity model helps them in their assessment of their current IoT maturity. Such an approach enables them to detect their weaknesses and set goals to strive for. The IoT maturity assessment should however take place on a continuous basis. Either after a predefined amount of time or alternatively at the end of an IoT project implementation.

On a final note, it is important to clarify that our maturity model does not offer an easy road towards IoT maturity, but that it can help hospitals reflect on their current state regarding IoT adoption and the decisions and actions needed to enhance their IoT maturity.

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