Using Task Technology Fit Theory to Guide the Codesign of Mobile Clinical Decision Support Systems

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Abstract

A clinical decision support system (CDSS) is designed to assist health professionals in perioperative patient management. Robust CDSSs are vital to deliver enhanced healthcare services. Incorporating the latest advancements in digital technologies, mobile device based CDSSs are being introduced to healthcare settings at a considerable pace. However, given the nascency of this tech-health synergy, well-defined systematic approaches to be followed to design and develop mobile CDSSs to ensure developed technological solutions are of best fit-for-purpose, are lacking. To address this void, this study proposes an approach combining Task Technology Fit theory and Design Science Research Methodology, to guide the design and development of mobile CDSSs. The proposed approach is applied to a case study to design a mobile CDSS to assist perioperative optimization of surgery patients. The learnings from the case study are reported.

Keywords: Clinical Decision Support Systems, Perioperative, Surgery, Task Technology Fit, Smartphone.

1. Introduction

Quality healthcare delivery requires sound clinical decision making as shortcomings in clinical decision making can lead to medical errors. Medical errors are defined as human errors that occur in healthcare provision [22]. The results of medical errors manifest in the form of adverse health outcomes and cost implications [22], [27]. This makes accurate and effective clinical decision making an essential component for quality healthcare delivery.

Clinical decision making is a complex cognitive process. It involves the interplay between knowledge of pre-existing pathological conditions, explicit patient information, caring and experiential learning [3]. The thinking behind clinical decision making is often based on a hypothetico-deductive approach. This approach involves acquiring initial cues, generating multiple hypotheses, and making decisions through evidence-based acceptance or rejection of the generated hypotheses [3], [4], [15]. This approach has later evolved into shapes of various clinical decision-making models. Some such clinical decision-making models can be accompanied by Clinical Decision Support Systems (CDSSs) [3].

In the early days, CDSSs were either paper-based record keeping systems, or legacy-based desktop computer systems [28]. As healthcare provision evolved over time, limitations of such systems became apparent [28]. The need for improvement of CDSSs in terms of mobility, interoperability and scalability was seen [28], [31]. Technology also advanced simultaneously to enable the desired advancements of CDSSs. The necessary tech advancements came through technology generations like Industry 4.0 [19] and Healthcare 4.0 [14]. Through this backdrop, mobile device-based (e.g., Smartphone and Tab-based) CDSSs have at present been introduced to the healthcare setting. The possibility of mobile CDSSs to deliver in some healthcare settings (e.g., perioperative optimization of surgery patients) has already been realized [6].

The introduction of mobile CDSSs to healthcare, however, has introduced several new issues as well. This is to be expected as designing information systems involves adapting them to specific requirements of the domain of application. These issues vary from fitness for purpose of technology, to perceptions and tendency (or lack of it) of people when

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it comes to adopting these technologies. A recent review about mobile CDSSs [31] has identified these issues as: complexity and performance-related issues in technologies; difficulty in validating the efficacy of the introduced technologies; costs involved in introducing new technologies; lack of data quality; lack of generalizability, expandability and scalability of the introduced technologies; lack of streamlining the technologies and clinical workflows; privacy and cyber security-related issues; surveillance capitalism; risks and accountability; policy and legislative challenges; slow adoption of certain technologies in healthcare; perceptions and biases of technology users and potential users; and competence (or lack of it) in technology among technology users and potential users. There is also a call for better standardization of mobile technologies in healthcare to counter some of the aforesaid issues [20].

Despite there being no shortage of technology at present, the presence of diverse issues as noted above, indicates the lack of a systematic approach for designing and developing mobile CDSS. This lack represents a void in this field today. Motivated by that void, this study aims to explore how mobile CDSSs can be designed and developed to ensure superior fit for purpose. This study, thus, aims to answer the overarching research question: "How can mobile CDSSs be designed and developed to be more fit-for-purpose?"

Through answering this question, the main contribution to theory made by this paper is proposing an approach combining Task Technology Fit (TTF) theory [11] and Design Science Research Methodology (DSRM) [12], [13], [26] to guide the design and development of mobile CDSSs. The proposed approach is applied to an exemplary case study. This case study focuses on preventing thromboembolism (i.e., prevention of disruption to blood flow caused by undesired blood clotting) in oncology surgery patients. A contribution to practice is made through this case study, by applying the proposed approach to design, develop, and assess a smartphone based CDSS (i.e., the CLOTS App [7-9]) for clinicians to help with perioperative optimization of surgery patients. The setting for the case study is a leading cancer hospital in Australia. Thromboembolism being a leading cause of death and complications in surgery patients in Australia and worldwide [6] is the motivator behind this case study.

The remainder of this paper is arranged as follows. Section 2 provides a brief systematic review of related works. Section 3 provides a brief review of related theoretical constructs. The methodology followed in this work is detailed in Section 4. Results are summarized in Section 5. The implications of this study are discussed along with concluding remarks in Sections 6 and 7.

2. Review of Related Work

Since our work involves developing a mobile CDSS (i.e., Smartphone-based) for clinicians to help with perioperative optimization of surgery patients, the following keyword search was carried out: ("perioperative" OR "surgery") AND "smartphone". The keyword search was carried out in the Google Scholar database since Google Scholar is a publicly accessible database that usually enlists items from almost all academic databases. The keyword search was carried out between May 1st and May 5th of 2022. The items written in English language and include those keywords within the item's title were considered. The time limit was set to publications published since 2021 in order to capture the latest results. Twelve articles were retrieved matching the search criteria.

These articles were reviewed to understand their objectives to see how similar or different they are to the objective of our paper, i.e., proposing an approach to guide the design and development of mobile CDSSs. It must be emphasized that our search is deliberately restrictive and thus may not be complete. Our objective here was to scan the latest literature within the previous year to grasp the very latest updates.

From the results of our search, none of the twelve papers had focused on systematic workflow for design (i.e., a design approach) as we do. Although works such as [1], [2], [5], [25], [29], [32], [33], and [34] have all performed some degree of design and development, their primary focus has been the technology solution rather than the design approach. As such, their design approaches are more specific to their solutions, and could be improved and generalized by grounding on more theory. Therefore, our paper offers an increment to current thinking by proposing on a systematic design approach that can be replicated irrespective of the health or technology context.

The need for a systematic design approach is further strengthened by some points raised by the review articles found from our search: [16], [17], and [21]. The work of [16] concludes that most applications (designed for plastic surgery in the UK) were not certified as a medical device and had not been validated in any peer-reviewed research. The work of [17] highlights that the input from healthcare professionals during application development is important. Furthermore, [21] has noticed some institutional and governmental barriers to the adoption of mobile health (i.e., mHealth) applications. Such

points too complement our argument by reemphasizing the importance of proposing systematic design approaches, to overcome persistent barriers and enable smooth and seamless introduction of latest technology solutions to healthcare.

3. Synopsis of Relevant Theories

The research question and the focus of this work are on maximizing the fit of mobile CDSSs for a healthcare setting. As such, this work focuses on maximizing the fit of a technology (i.e., mobile CDSS in the context of this work) to a decision-making task (i.e., a healthcare task in the context of this work). A well-known theory that covers this focus is the theory of Task Technology Fit (TTF) [11] which has been adopted as the primary guide for this work. Furthermore, since the case study involves designing an artifact (i.e., a mobile CDSS for clinicians to help with perioperative optimization of surgery patients), Design Science Research Methodology (DSRM) [12], [13], [26] is followed to guide this work. The two aforesaid theoretical lenses are reviewed briefly in the following subsections.

3.1. The Theory of Task Technology Fit (TTF)

The theory of TTF states that IT systems are more likely to have a positive impact on individual performance and be used if the capabilities of the IT system match the tasks the user must perform [11]. The works [10] and [11] have discussed the applicability of the theory for the level of individual performance. Goodhue & Thompson (1995) [11] presented a list of factors to measure the influence of TTF on individual performance. Our work makes use of this list [30].

3.2. Design Science Research Methodology (DSRM)

DSRM [12], [13], [26] is important for creation of successful artifacts. This is a way of systematically creating an artifact to address an issue and recording learnings along the way for future benefit. The design science process includes six steps [12], [26]: (1) Problem identification and motivation; (2) Defining the objectives for a solution; (3) Design and development; (4) Demonstration, (5) Evaluation, and (6) Communication. Research can be integrated at any or all of the first five steps in order to better understand relevant issues that need be addressed in designing an artifact to optimize desirability. This description is only a brief summary outlining the DSRM. The landmark publications [12], [13], and [26] are useful resources for more details about the mentioned steps.

The focus of our work is to involve DSRM through co-creation and codesign. Co-creation is defined as "A two-way, open and dialectical process of interaction, collaboration and knowledge sharing between a firm and its stakeholders, whereby the participating parties engage in a dialogue to jointly define and solve problems in a shared distributive environment" [24]. Codesign is defined as the process of creating with stakeholders, specifically within the design and development processes to ensure the results meet the needs of the stakeholders, and the design is usable.

4. Methodology

This work is based on a single exemplary case study design [35], in which a mobile CDSS is designed and developed for a leading cancer hospital in Australia. The background of the case study is as follows.

4.1. Background of Case Study

Thromboembolism is a leading cause of complication surrounding surgery [6]. A Smartphone-based mobile CDSS was designed, developed and used in a leading cancer hospital in Australia since 2013 to help address this issue [6]. Reduced case fatality rates and complication rates have been observed since the introduction of this mobile CDSS. The CDSS is a four-model decision support tool that helps clinicians optimize perioperative patients by providing point-of-care assistance in making decisions to help minimize thromboembolism surrounding surgery. A review of this CDSS is available in [23]. A 5-minute video demonstration of this CDSS is available at [9]. An Apple version of the App can be downloaded and used from [7].

This solution has been designed through the collaboration of a leading hematologist of the cancer hospital and an app developer. This development focused purely on point-of-care decision support, and had no connection to a backend database, and did not focus on capturing any usage data about this CDSS. Furthermore, since 2013, this CDSS has been used only by the caner hospital in question.

In 2020, the lead hematologist who initiated this CDSS commissioned a new research project. This was initiated in partnership between the cancer hospital and an Australian government funded Digital Health Collaborative research center, and an Australian

university. The project is still ongoing. The aim was to enhance the capability of the CDSS through data capture and thereby enabling insight through data analytics. A secondary objective was to explore the opportunities for commercialization of this CDSS and extending it to become a gold-standard clinical practice. Given the nature of the objectives, it was agreed amongst the partners that this project required a rigorous form of codesign following Design Science Research Methodology (DSRM) principles since this project required synergy between computer and behavioral scientists and clinicians, and this required designing a CDSS to be fit for the purpose of clinicians' use in their usual practice. As such, this project was carried out governed by DSRM principles as discussed by [12], [26] where DSRM is discussed in relation to information systems. In the context of this project, the CDSS is an information system.

Moreover, this project required measuring how fit a particular information system (i.e., the CDSS) is for a decision-making task (i.e., the work of a clinician). The theory of Task Technology Fit (TTF) is an established means for this measurement. Therefore, the theory of TTF was selected as the governing principle to assess how fit-for-purpose the CDSS enhanced through this project is.

Combining DSRM and TTF, this project was executed as depicted Figure 1. The steps are derived from DSRM as discussed by [12], [26]. For the 'Assessment' stage is informed by the theory of TTF. The process is agile and there is space for multiple design iterations. This paper reports on the first design iteration.

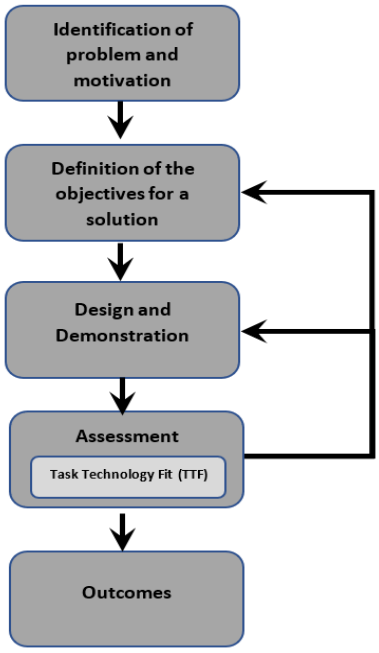

Figure 1. The followed design processes.

4.2. The Case Study

The case study was executed as described in Figure 1. The first three steps were carried out by the participants whose details are in Table 1.

Table 1. Details of participants.

Participant's code	Description about the participant	Role in the project
C1	Senior hematologist	Project Lead
C2	Senior anesthetist	Clinician Facilitator
C3	Senior anesthetist	Clinician Facilitator
A1	Professor in Digital Health	Principal Investigator
A2	Professor in Behavioral Science	Chief Investigator
A3	Associate Professor in Computer Science	Chief Investigator
R1	Research Fellow in Computer Science	Associate Investigator
R2	Junior researcher in Digital Health	Junior Investigator

4.2.1. Identification of problem and motivation. This step was carried out between January and June 2020. Participants C1, A1, A2 and A3 participated. The problem and motivation were identified alongside drafting and reviewing the project proposal. The primary aim was to enhance the CDSS through data capture and enable insight through data analytics. A secondary objective was commercialization and extending this to a gold-standard for all surgical practice. The outcome of this phase was a project proposal document with high level objectives listed.

4.2.2. Definition of the objectives for a solution. The specific objectives for the solution were identified between May and October 2020. This was done through 1-hour semi-structured virtual meetings organized at a monthly frequency. Participants C1, A1, A2, A3, R1, and R2 participated in all the meetings. Participants C2 and C3 participated under special invitation when extra clinical consultation was deemed necessary by the other participants. Minutes of each meeting including action items were documented and shared among the participants after each meeting for consensus. To align with the primary aim of this project (i.e., enabling data capture), participants R1 and R2 proposed creating a database backend that interfaces with this CDSS as a primary objective to capture CDSS usage data. In addition, R1 and R2 proposed creating a web-based data analysis dashboard to enable data analysis and visualization. Those objectives gained consensus among the

participants. Apart from that, specific inquiries were made from participants C2 and C3 about what they deem necessary to be updated in the CDSS. They highlighted two models in the CDSS, both were related to anticoagulant drug admission and reversal. As such, the outcome of this phase was a report with refined objectives identified as:

1) Backend database to capture CDSS usage data.
2) Analytics and display dashboard (web-based).
3) Updating certain clinical rules about anticoagulant drug management.

4.2.3. Design and demonstration. This phase was carried out between October 2020 and October 2021. Similar to the previous phase, hour-long virtual meetings among the participants were carried out in this phase too. The meetings were carried out at a mutually agreed upon frequency that matched the availabilities of the participants (roughly once a month). At this stage, participants C1, C2 and C3 performed the roles of clinician facilitators and clients where they expressed their needs. Participants A1, A2, and A3 assumed the roles of research leadership and supervision. Participants R1 and R2 played the role of design and implementation executives.

The meetings were conducted as codesign workshops. Agendas were planned by participants R1, R2, A1, A2 and A3 beforehand to be semi-structured conversations that were led by R1, R2, A1, A2, and A3. The purpose was to understand the needs of the clinicians. Demonstration of any design implementations were also carried out during these meetings. All participants could review the designs and make suggestions for improvement. Minutes of all meetings were recorded and circulated among the participants after the meeting for consensus. The meeting minutes were maintained as records of evidence of progress and agreed upon actions items.

In the 'Definition of objectives' phase, it was understood that the basic components of this CDSS (a 5-minute video demonstration is available at [9]) need not change, except for several clinical rules about anticoagulant drugs as proposed by participants C2 and C3. Therefore, it was agreed to maintain the already available architecture of the CDSS, and to make modifications only to the respective clinical rules. With that decision, designing the backend database was aligned with the already available architecture of the CDSS. It was agreed to identify the CDSS users anonymously based on CDSS App downloads, and to record all data entered to the CDSS (e.g., patient demographics and other clinically relevant data), and screen clicks performed.

The objective of capturing such data was to investigate the general trends and patterns of how the clinicians use this CDSS, and thereby find niches to improve at specific pain points to make the CDSS more fit-for-purpose. Participant R1 implemented the database with the assistance of participant R2.

A particular architecture was not discussed for the analytics and display dashboard since the dashboard was considered a secondary priority at this stage. Therefore, participant R1 designed a web-based data display facility on which all the recorded data can be visualized by a lead clinician or someone with privileges to access. A document demonstrating this web-based data display facility is available at [8].

Updating clinical rules required communication through a translation layer. A translation layer in this context, means a communication medium where clinical rules are written down in a structured manner so that they can be interpreted and coded by computer science specialists. At the start of the project, such a translation layer was not available. Therefore, the translation layer had to be written as a part of this phase. The translation layer was written by participant R2. It was created by studying the available CDSS, and by writing down its sequence of screen clicks (or decision points) as flowcharts. An example is given in Figure 2. This flowchart refers to the management of a patient that has been using the anticoagulant drug Aspirin. The entailing recommendations denoted by 'Rec 1', 'Rec 2' and so on were written down in a table that accompanies each flowchart.

Such translation layers (i.e., flowcharts and tables of recommendations) were written for all components that were identified by participants C2 and C3 to be updated. These were created as MS Word documents, and were shared with the clinicians. The clinicians were asked to write down their proposed updates on top of the provided translation layers.

An example of a clinical rule updated by a clinician is shown in Figure 3 (please zoom to read the text in Figure 3). This shows the update to the Aspirin model in Figure 2 proposed by participant C2 as a senior anesthetist. Such proposed changes were then discussed among all participants for consensus and were then collated and handed over to participant R1, who programmed them and updated the CDSS while creating the backend database and the analytics dashboard.

With the translation layer involved, the sequence in which this 'Design and Demonstration' step was carried out can be depicted as in Figure 4. Once the necessary changes were done, an internal check was carried out for consistency between the two versions

of the CDSS. This was carried out by participants R1 and R2. A comparison between the old version and new version was carried out. After the internal consistency check, the new version was made available for clinicians online (e.g., iPhone TestFlight) to download and use. The participants C1, C2 and C3 were asked to download the TestFlight version during a codesign workshop and were asked to test it as a demonstration and testing activity. This initial testing led to the agreement of a pilot rollout of the new version for clinicians to trial and give further feedback, leading to the Assessment phase. The outcome of this phase was the mobile CDSS (i.e., the CLOTS App [7-9]) and the accompanying backend facility [8].

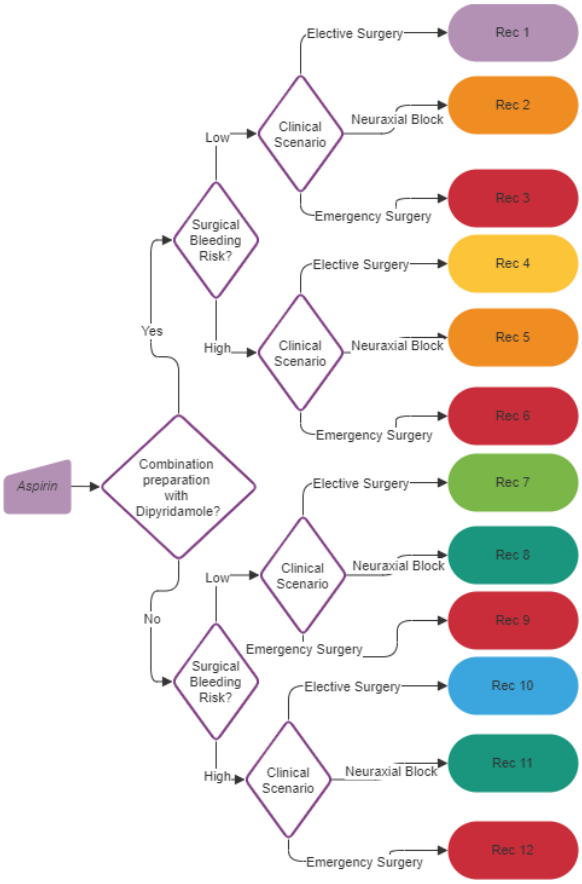

Figure 2. The flowchart-based translation layer. (please zoom to read the text in this figure).

4.2.4. Assessment. The assessment phase was carried out between November 2021 and February 2022. The purpose of the assessment phase was to measure how fit the redesigned CDSS was for the clinicians' work. The theory of Task Technology Fit (TTF) as discussed before, was chosen for this purpose as it provides a framework for such measurement. The TTF questionnaire surrounding individual performance as discussed by [11] was chosen for this task. The themes and the questionnaire published by [11] were taken and rephrased to match the healthcare context at hand (i.e., to assess a CDSS). The CDSS-related TTF questionnaire that was adapted (using a five-point Likert scale) is available at [30]. The objective was to get clinician who use the CDSS to participate in a survey to fill out this questionnaire and also provide any qualitative feedback. This TTF-based questionnaire was designed to measure the fit-for-purpose across three aspects: (1) Characteristics of the clinician's task and the technology usage; (2) Characteristics of the technology (i.e., the CDSS), and (3) The impact of technology on the clinician's performance. The questionnaire used had 28 questions (the questionnaire is available [30]).

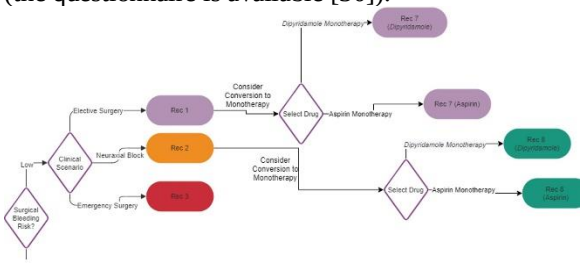

Figure 3. A section with updated clinical rules for Aspirin (please zoom to read the text in this figure).

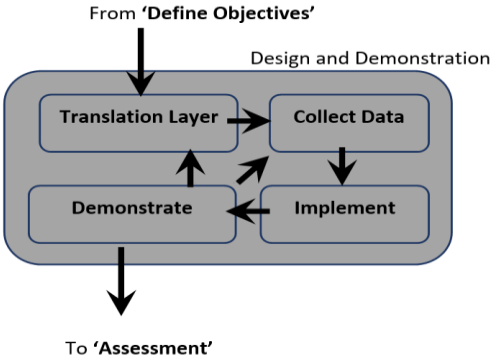

Figure 4. Procedure followed within the 'Design and Demonstrate' step.

The objective of measuring the fit-for-purpose was communicated to participant C1. Then, a group of clinicians were recruited through snowball sampling under the leadership of participant C1. They were asked to participate in a focus group to answer a questionnaire and also to provide any qualitative feedback about the CDSS. A group of Seven participants could be recruited. This sample including participant C1 and C3. The participants were asked to participate in a one-hour virtual focus group in which they to answer the TTF questionnaire as well as provided qualitative feedback regarding any issues.

The qualitative feedback was recorded as meeting minutes, and they were compiled as a report summarized under several themes emerging from the feedback itself (inductive analysis). These themes are discussed in Section 5. Interpreting the feedback, deducing the themes, and compiling the report was done by R2. The report was then shared with the focus group participants for consensus and consistency of the themes. The outcome of this phase was a report summarizing the end-user feedback and list of desired further developments.

5. Results

The results obtained from the assessment phase were both quantitative and qualitative. Since the number of participants was small (i.e., Seven participants) the quantitative results obtained at this stage were considered indicative measures only, and not statistically significant. However, this pilot study indicates the proposed TTF-based approach, provides a means to obtain statistically significant quantitative results on recruiting a larger number of participants.

The qualitative feedback received revealed several important factors regarding the CDSS. These factors are discussed under the three TTF themes, i.e., (1) Characteristics of the clinician's task and the technology usage; (2) Characteristics of the technology (i.e., the CDSS), and (3) The impact of technology on the clinician's performance.

5.1. Characteristics of the clinician's task and technology usage

Three factors emerged under this theme. The three factors were:

5.1.1. Frequency of use varies: The frequency that the CDSS is used varies significantly among users. It was revealed that junior clinicians used the CDSS more often (i.e., almost on a daily to weekly basis) while more senior clinicians admitted that they almost never used certain components of the CDSS.

5.1.2. Technology adoption is high: All participants agreed that they use at least some components of the CDSS, meaning the adoption rate was 100% among the participants despite variability in the frequency of use.

5.1.3. Purpose of technology use is refreshing memory: The purpose of use was mainly identified as "the CDSS helps refresh memory." This is understandable as if the CDSS was not available, clinicians would be relying solely on their memory for complex clinical rules surrounding perioperative patients.

5.2. Characteristics of the technology (i.e., the CDSS)

Three more factors emerged under this theme. The three factors were:

5.2.1. Clinicians are generally satisfied about the technology: There was consensus about the clinicians being satisfied about the technology characteristics. These included factors like quality of data and ease of using the system. This meant that no major improvements were expected by the participants in terms of overhauling any of the key technological features or the user interface.

5.2.2. Difficult to update the CDSS: There were two "Highly Dissatisfied" votes, one about accuracy of the recommendations provided by the CDSS, and the other about how up to date the recommendations were. On further enquiring, it was found that this vote was given by a senior clinician since it is not easy to update the recommendations nor to check their accuracy in an efficient manner. This issue arises because there was no mechanism or workflow in place at this point to update the CDSS in an efficient manner with the most up-to-date clinical evidence and knowledge. This issue was noted as a critical factor to be addressed in the subsequent design iterations.

5.2.3. Need more references on the clinical rules: Adding to the second point above, another point was made highlighting that there is lack of real-time accessible references to support the recommendations and clinical rules in this CDSS. A suggestion came from a clinician to include links to references regarding all possible recommendations included within the CDSS. This issue was noted for consideration in the subsequent developments of the CDSS.

5.3. The impact of technology on the clinician's performance.

The quantitative results under this theme revealed that there was again consensus that the CDSS has made a "significant positive impact" on enhancing individual performance. This was indicated by the responses received for four questions that measured different aspects about perceived impact on performance. For instance, 100% of the respondents

agreed that the CDSS helped them in saving time as well as in making their work easier.

6. Discussion

Our attempt was to address a key void in digital health; by discussing a systematic approach that can be followed to design mobile CDSSs to be of greater fit-for-purpose. We tried to address that gap by synergizing existing theories to formulate a design approach and using it in an exemplar case study.

A design approach was proposed combining Task Technology Fit (TTF) theory and Design Science Research methodology (DSRM), to guide the design and development of mobile CDSSs to enable better fit-for-purpose. The design process is guided by DSRM while the specific steps are informed, and outcomes are assessed through TTF. This approach was applied to a single exemplary case study in which a mobile CDSS to assist in perioperative optimization of surgery patients was developed for a leading cancer hospital in Australia. The design steps followed, the issues encountered along the way, and an intermediate outcome that was assessed after one design iteration have been discussed in this paper.

The design process guided by DSRM had several benefits. DSRM provided a sequence of steps covering the whole design process from concept to design and development to assessment as well as enabled the key users, clinicians to participate in and contribute to the design process. The design process also gave an agile architecture following a top-down design approach to do multiple design iterations as depicted in Figure 1. The initial steps of problem and objective identification offered the opportunity to understand the problem, in depth, which permitted the planning of intermediate steps that may be necessary for a particular design. For example, a key intermediate step that was necessary for this project was designing a translation layer. It was through the translation layer the clinicians could communicate clinical rules in a manner efficiently comprehensible to computer scientists. For this project, the translation layer followed the flowchart form as depicted by some examples (Figures 2 and 3). Identifying such vital intermediate steps was possible since adequate attention was given to problem and objective identification phases following the DSRM approach.

Moreover, the DSRM-based design approach mandated codesign between clinicians, computer scientists and academics. This is in stark contrast to how the initial version of the CDSS was designed and developed. The initial version was designed between an app developer and a lead clinician (i.e., participant C1). While the technology solution was implemented, there was no facility to capture user satisfaction or user-reported issues. In the DSRM approach, the liaison between clinicians and the designers occurred from beginning to end. Along the way, critical design requirements could be captured from the end-users (i.e., clinicians) themselves. Also, intermediate development and demonstration was possible. Clinicians provided continuous feedback that could be continually integrated along the design.

At the end of the design process, there was a formal 'Assessment' phase as well. The 'Assessment' phase was guided by TTF theory. This assessment measured end user perspectives across three main themes. The themes were: (1) Characteristics of the clinician's task and the technology usage; (2) Characteristics of the technology (i.e., the CDSS), and (3) The impact of technology on the clinician's performance. The themes proposed by [11] were made use of here and were rephrased to match the healthcare context. The themes coupled with their subthemes and the 28 questions (see [30] for the full list of questions) gave a structured approach to measure end user perspectives. The assessment of the CDSS carried out using this TTF questionnaire revealed that the original TTF questions have been well thought-out and they covered the most crucial aspects of information systems as there was no striking feedback or issues discovered from the clinicians that fall outside the themes of TTF. Another notable benefit of the proposed DSRM and TTF approach is enabling this facility for rigorous assessment of how an information system impacts individual performance. Such an assessment of end user perspectives was not possible and not done before with the clinician and developer-led CDSS design that happened before. The key with this TTF-coupled assessment phase is that it gives the facility to capture quantitative as well as qualitative feedback and it can be incorporated with a diverse audience and with varying numbers of participants.

A challenge encountered during this study was in recruiting participants. As described before, the assessment was limited to only seven participants, mainly because of the busy schedules of clinicians in the COVID-19 era, and participation in this codesign process was voluntary. In such instances, no meaningful statistical analysis of quantitative data is possible because of the small sample size. Therefore, making conclusions based on statistical analyses was not possible in this case study. However, based on TTF, the mixed method approach enabled participants to provide qualitative feedback. Qualitative feedback comes in as a valuable source of information where statistically significant results cannot be obtained. Although the number of participants was low, they were able to provide key insight that helped in the

development of the CDSS. Therefore, the ability to assess user perspectives through both qualitative and quantitative method stands as another advantage of the proposed DSRM and TTF-based approach. This also means that there is flexibility in this approach to conduct codesign with smaller samples as well as larger samples.

The qualitative feedback received from the assessment phase revealed several key aspects. They revealed that the usage trends of a mobile CDSS have variability. Some clinicians use the platform often while others use hardly ever. It was interesting to notice from the small sample in the focus group, that junior clinicians tend to use more often while some senior clinicians tend to use less. Irrespective of seniority, the common purpose of using a mobile CDSS was refreshing memory. Conversations with clinicians also revealed that there is potential for such CDSS be used as self-learning educational tools. The participants were generally satisfied with the technological characteristics of the CDSS, however there were concerns raised about the ability to update and check the recommendations efficiently which will be improved in subsequent codesign rounds. There was also consensus among the participants, that mobile CDSSs do impact positively in enhancing clinicians' performance. The ability to measure end user perspectives underscores the applicability of TTF in this context.

It must be noted that this paper reports on a work-in-progress project, and all the features of the design including the analytics capabilities and analytics dashboards were not assessed in the present codesign round. The objective of this paper was to present progress of a single codesign round, and thereby highlight the merits of our design approach—i.e., the DSRM and TTF-based approach for designing and developing mobile CDSSs. Future work will focus on extending further with more codesign rounds and improving the CDSS while capturing unique perspectives of end user clinicians.

7. Conclusions

This paper attempted to address a key void in digital health; by discussing a systematic approach that can be followed to design mobile CDSSs to be of greater fit-for-purpose. This paper contributes to both theory and practice. In terms of theory, the paper proffers the combination of TTF and DSRM and demonstrates how TTF can provide a systematic and rigorous approach to inform the DSRM cycles to ensure high rigor, useful and useable solutions that are fit for purpose. Our proposed TTF and DSRM combined approach is sufficiently robust that it has generalizable appeal. Therefore, it can be used to guide the design of information systems, agnostic of the domain of application. In terms of practice, we have developed, and are continuing to improve a mobile CDSS (i.e., the CLOTS App [7-9]) for a key clinical issue around thromboembolism in oncology surgery which provides high fidelity, timely decision support which is consistent with a value-based care paradigm. This contribution cannot be understated in terms of its impact on clinical outcomes and its support of a value-based healthcare paradigm. Some domain-specific perspectives and requirements of end-user clinicians we discovered when designing this CDSS were also discussed.

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