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Integrated Operating Room: A Systematic Mapping Review

Sala de Cirurgia Integrada: Um Mapeamento Sistemático de Literatura

Quirófano Integrado: Un Mapeo Sistemático de la Literatura

Carolina Arenas[1], Lina Garcés[2]

Keywords: Operating Rooms, Systems Integration, State-of-the-Art Review, Anesthesia, Software

ABSTRACT

Objective: To analyze existing IORs reported in scientific literature, verifying how they are designed and if they really help improve patients' safety and professionals' quality of work. **Method:** We conducted a systematic mapping review. **Result:** We analyzed 13 primary studies that propose or use software systems of IORs. We found that IORs have contributed to improving surgical procedures in hospitals, especially those related to anesthetists' work. We also noticed that, despite different implementations, there is little understanding about IORs' software designs. **Conclusion:** The engineering of IORs is in its early stage; hence more contributions from scientific and technological communities are required.

Descritores: Sala de Cirurgia, Integração de Sistemas, Revisão do Estado da Arte, Anestesia, Software

RESUMO

Objetivo: Analisar as implementações de SCIs existentes reportadas na literatura, entendendo seu design e às contribuições à segurança dos pacientes e à qualidade do trabalho dos profissionais. **Métodos:** Realizou-se um mapeamento sistemático de literatura. **Resultados:** Treze estudos primários que propõem ou usam SCIs foram analisados. Descobriu-se que as SCIs contribuíram para melhorar os procedimentos cirúrgicos nos hospitais, especialmente aqueles relacionados ao trabalho de anestesistas e que, apesar de existirem diversas implementações, há pouco entendimento sobre os sistemas de software das SCIs. **Conclusão:** A engenharia das SCIs está em seu estado inicial e necessita de mais contribuições da parte das comunidades científicas e tecnológicas.

Descriptores: Quirófanos, Integración de Sistemas, Revisión del Estado del Arte, Anestesia, Software

RESUMEN

Objetivo: Analizar las implementaciones de QIs existentes y reportadas en la literatura, verificando su diseño y los beneficios a la seguridad de los pacientes y a la calidad del trabajo de los profesionales. **Métodos:** Fue ejecutado un mapeo sistemático de la literatura. **Resultados:** Trece estudios primarios fueron analizados. Se observó que los QIs contribuyeron para mejorar los procedimientos quirúrgicos en los hospitales, especialmente a los relacionados al trabajo de anestesistas. Pese a que existen distintas implementaciones, hay poco entendimiento sobre la estructura del software de estos sistemas. **Conclusión:** La ingeniería de los sistemas de QIs está en su estado inicial y son necesárias más contribuciones por parte de las comunidades científicas y tecnológicas.

[1] *Undergraduate Student at the Institute of Mathematics and Computer Sciences, University of São Paulo, ICMC/USP, São Carlos, SP, Brasil.*
[2] *Assistant Professor at the Institute of Mathematics and Computing, Federal University of Itajubá, IMC/UNIFEI, Itajubá, MG, Brazil.*

Autor Coorespondente: **Carolina Arenas**
e-mail: **carolina.arenas@usp.br**

INTRODUCTION

Currently in Brazil, most hospitals surgeries' data recording is still manual. Anesthetists have to manually write more than 15 different data types on patients' vital signs and medication information every five minutes, possibly resulting in data loss or misunderstandings. Additionally, physical registers and distributed information can result in delays during anesthetists' decision taking (i.e., about the next procedures they need to do with the patient) because they are focused on saving data.

An Integrated Operating Room (IOR) connects all devices inside of surgical rooms. Through IORs all surgeries information is integrated, allowing their access and control from a centralized software[1]. Health professionals that work in an IOR can focus more on the patient, because they do not need to walk around the room to access physically distant equipment. IORs also improve data acquisition from many devices, since it concentrates all data in only one system's repository. These are some of the improvements IORs can bring to surgery procedures. In that way, it is notable that IORs are important to healthcare evolution. Considering IORs are real-time and safety-critical systems, in which a failure could harm patients. Henceforth, it is of utmost importance to design them carefully. In this context, this study intends to map existing IORs, reported in academic literature, specifically by investigating how they are designed and technologies used for their construction. It is intended this work can help to better understand IORs design, reducing time to take decisions and providing information about which implementations help in which problems.

This study is structured as follows. In section II, we report some related work. In section III, we describe the methods used to plan, conduct, and report this systematic mapping review. The results and some discussions are described in Section IV. Finally, Section V concludes this work.

Related Work

A systematic review on health systems integration was previously executed[2], identifying ten principles for successful health systems integration. The use of such principles could help the implementation of integrated systems, as this mapping intends to do. Also, one of the principles, physician integration, is much related to this study since it is about the importance of developing the systems next to the physicians to understand their needs and improve the quality of their work, trying to avoid that they feel replaced by the systems, which is not the goal of the integration. In[3], an analysis of integration types in health systems was made. They considered that any type of integration can improve quality of care. Although the focus was more organizational and economical related, it shows how the integration has been seen in the health area until that time. Also about types of integration in health systems, a meta-review (review of reviews or tertiary study) was made recently[4]. It intended to show, for example, how the secondary studies reported service integration types. It concludes there is a need for more research in this area since they found important gaps in this topic. Also, they highlighted the complexity and variety of health service integration. Ruwan et al.[5] investigated the correlation between surgical errors and ORs' equipment failures. It verified a high correlation in a vast variety of values. This showed an important gap to be overcome regarding OR equipment development, what would help improve patient safety.

Our systematic mapping study advances the state-of-the-art synthesizing information about how the integration has been approached in ORs. This study complements previous studies by approaching another vision about integration in health systems, specifically those systems used during surgical procedures.

METHODS

A systematic mapping review is a secondary study vastly used by software engineering researchers, that intends to make a synthesis of the data about a specific topic. It is used to find gaps in the topic to verify where there is a need to do more research[6]. For this, a mapping study analyses primary studies recovered from scientific databases. To perform this systematic mapping review, we used the guidelines for systematic literature reviews defined by Kitchenham and Charters[7], as recommended by the software engineering research community. This method consists in three phases: (i) Planning; (ii) Conducting; and (iii) Reporting. The first one includes the verification of the need of a mapping (described in the section I of this work) and the protocol definition. In the protocol, the research questions, search strategy, inclusion and exclusion criteria, data extraction strategy and study quality assessment should be defined. The second phase refers to really doing the mapping, following the protocol. And the third stage is about writing the results of the mapping, to spread them, which is the goal of this article.

Research Questions

The research questions are the study guides, since the goal of the mapping is to answer them. In every phase they are considered as follows: (i) in the search process, the objective is to find primary studies that address them; (ii) in the data extraction, the data extracted needs to be useful to answer them; and (iii) in the data analysis, them should be answered with the obtained data. The research questions for this study are: RQ1: "which evidence exists to guarantee that IORs improve the quality of anesthesiologists work?"; RQ2: "in which ways could be integrated ORs?"; RQ3: "which are the technologies used to develop IORs?"; RQ4: "which requirements of quality attributes are important for IORs?"; RQ5: "which architectural strategies have been used to design IORs?". More information about their rationale and possible answers can be found in the review protocol[8].

Inclusion and Exclusion Criteria

The inclusion and exclusion criteria are a way to determine if a study is relevant to answer the research questions. It also allows excluding studies that cannot be used in the mapping for some reason (such as language limitations)[7]. In this study, we defined three inclusion (IC) and five exclusion (EC) criteria: IC1, studies that intends to design IORs; IC2, studies that analyses IOR's uses; IC3,

studies that intends to justify the need of IORs; EC1, studies that can not be included by IC1, IC2, or IC3; EC2, short studies (less than 5 pages); EC3, studies that are only abstracts; EC4, studies unavailable to access; EC5, studies that are not in English or Portuguese.

Search strategy

To search for primary studies, we defined the keywords we considered important to answer the research questions, as well as their synonyms that are used in the research domain. In that way, after some testing to verify which words were really used in the studies of the area, we considered three groups of keywords, each of the synonyms of "operating room", "anesthetist" and "integration".

We established that studies must present one word of each keyword set to be considered in our mapping. The search string and its adaptation to each database can be found in the review protocol[8]. We conducted the search in the following databases, since they are recommended for performing secondary reviews in the computer science area[7,9]: IEEExplore, Scopus, PubMed, and SpringerLink. The number of studies returned by each database was 13, 389, 185 and 104, respectively. In total, we obtained 691 studies. Furthermore, we removed 148 duplicated studies recovered from different databases, remaining 543 studies to start the selection process. The title and abstract of each were read to verify if they meet one or more inclusion criteria. In a positive case, the study was selected to a posterior full text reading. In the case no abstract was available or the study was a joint or poster session (many short studies together), the study was removed. After selecting for full text reading, we first verified if they met any exclusion criteria. Then, the rest of the studies were fully inspected and it was verified if they really met any inclusion criteria. If so, the study was selected for data extraction. Figure 1 presents the number of studies resulted for each review phase. A brief description of each primary study is in the extracted data set[8].

Research Questions

For this systematic mapping study, we defined the following five research questions:

RQ1: Which evidence exists to guarantee that IORs improve the quality of anesthesiologists work?

This research question intends to map any evidence about the improvement IORs can make in the quality of anesthetists' work. To do that, we verified if there is evidence that guarantees improvement, or evidence that guarantees that there is no improvement. If we verify the first one, it is trivial to answer this research question. However, if we do not find this information, verifying if there is evidence that guarantees no improvement shows us the possibility that we could not find it because there is no improvement. On the other hand, if there is no evidence that does not improve too, we could identify a lack of research in the area. For both possibilities, the guarantee could be made by stats about the anesthetist's work, such as missing information in patients' records, the anesthetist's satisfaction or the efficiency in the anesthetist's decisions.

RQ2: In which ways could be integrated ORs?

In this research question, we intend to answer how IORs are designed, showing in which ways they are integrated. To do that, if the study explicitly one or more ways in which could be integrated ORs, we resumed how it did it. Also, we find it important to know if the study proposed a way to design or just analyzed existing ones. About how to integrate ORs, we answered explicitly if there was a design of the software architecture for the IOR, if the work considered the OR as a System-of-Systems and if it proposed to change all the equipment of the OR to already integrated ones. Furthermore, we verified if the work presented a requirement engineering process or a software development method, so we could know which ways were already used to design the IORs. Besides that, we answered where the study was made and if it was only academical or some enterprise were involved. Other important information was if there was a test or validation to the developed IOR and, if yes, how it was done (it could be, for example, by simulating or using prototypes), since with this we could evaluate the quality of the study.

RQ3: Which are the technologies used to develop IORs?

In this research question, we want to know specifically the technologies used to develop the IORs. It complements RQ2, because in that we were focusing on the idea of the design and, in this, we focus on how to implement it. To do that, we verified if in the study was an analysis of the technologies that could be used and if there was a choice of the best ones, and which were them.

RQ4: Which requirements of quality attributes are important for IORs?

For this research question, we verify if the study contains an analysis of which quality attributes are important, and which ones were considered important, being or not in the ISO25010[10]. We also verify if it cites sub-attributes and, if yes, which ones.

RQ5: Which architectural strategies have been used to design IORs?

In this research question, we want to analyze the

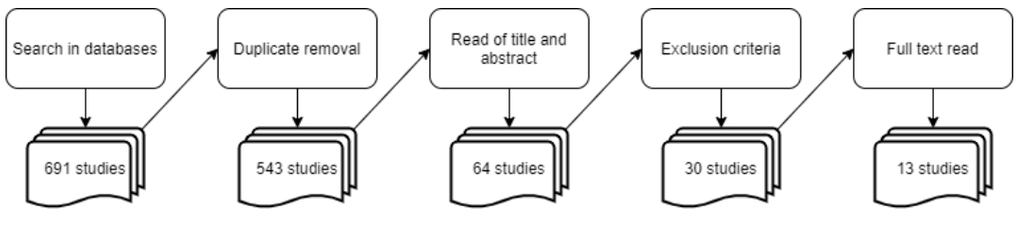

Figure 1 – Number of studies in each search process' phase

architectural strategies to the IORs' design, such as patterns, tactics and styles. We verify if the study does an analysis about it and which ones were considered, describing them. Also, if some were chosen, we explicit them. We as well verified if the study considered reference architectures, if it did an analysis about them and which were chosen.

Data extraction

To extract data from the selected studies, we made a form in Google Forms available in[8]. It consisted of four main sections: (i) study information; (ii) research questions; (iii) quality assessment; (iv) reviewer comments.

Quality assessment

The third section of the data extraction form was used to determine the quality of the studies. It considered if the study tested an IOR in a theoretical and/or practical way, if developed an IOR that was or are being used, and if it presented real stats about the benefits or the harm of IORs.

RESULTS AND DISCUSSION

In this section, we present the results obtained from the data extraction. The number of studies included by each inclusion criteria was: eight by IC1[11-18], five by IC2[19-23], three by IC3[11,20,23]. It is important to notice that one study could meet more than one criteria. About the quality of the studies, we noticed that almost any presented real stats about the IORs' benefits or harms. Also, six studies[14-15,18,20-22] did not test an IOR in a theoretical way and six[11,14-15,19-20,23] did not test in a practical way, not necessarily the same studies. The results for each research question are described below.

RQ1: Which evidence exists to guarantee that IORs improve the quality of anesthesiologists work?

About the RQ1, the main data extracted was if there is evidence that IORs do or do not improve the quality of the anesthetists work. Approximately 30.8% of the studies[17-19,21] had evidence that guarantee that IORs improve the quality of anesthesiologists work and 15.4% that do not improve[18,21]. The results obtained show that the impact of IORs in anesthesiologists work is not much documented. Although, the number of evidence showing an improvement were the double of which were showing that they did not improve. It is relevant that the studies that showed stats about not improving also showed stats that improved, but in different areas. The studies that did not show any stats were always very confident that the IORs would improve the quality of patient care in some way, being it in patient safety, professionals satisfaction, among others.

Considering the results of this mapping, we can answer that there is evidence of improvement, in stats about, mainly, anesthetists' satisfaction, but also in less missing information in anesthesia records, the efficiency of anesthetists' work and in what the anesthetists think IORs will help them.

The evidence that IORs do not improve were relative to two studies. In one[21] the anesthetists were concerned about how the architecture of the IOR could make harm to their heads, since many equipment were ceiling positioned. In this case, we can assume that is not a problem about IORs in general, but in the way the IOR was implemented. That should be considered in future IORs and maybe could be solved with a quality analysis of the IOR, unified with a requirement engineering process. The second study[18] analyzed the efficiency of using an IOR, comparing it to the time of the procedures before the installation of the IOR. They did statistical analyses and showed the efficiency were not statistically different, but the same study showed improvement in other areas. In that case, we can conclude that IORs may not be the answer to all of the problems in ORs, and an analysis of its cost-benefit should be done before its implementation. As in the first study, a requirement engineering process could help in establishing a better way to design the IORs, letting it improve more areas of the OR procedures.

RQ2: In which ways could be integrated ORs?

Regarding the RQ2, only one study[22] did not explicitly one or more ways in which could be integrated ORs. An interesting information from this part of the data extraction was the countries where the studies were made. Seven were in the USA[11-12,14-16,18,20], four in Germany[13,17,19,23], one in Italy[22] and one in China[21]. Also, we noticed that just one study[16] explicit a requirement engineering process and none explicit a software development method. About 30% of the studies[12,16,18,20] had a design of the software architecture to the IOR, but none considered it as a System-of-Systems. It is relevant to note that just one study[21] intended to change all the equipment in an OR to transform it in an integrated one. The percentage of studies that had a form of test or validate the IOR they were working with was 69.2%[11-13,16-19,21-22]. This result shows that there are many ways in which integrated ORs could be integrated. However, these ways could be biased considering the little variety of countries in which the studies were made. Also, it is interesting to notice that there is a lack of research about the requirements engineering process to design IORs. That could negatively influence the designs' quality or even prevent us from seeing that IORs may not be the solution to the current problems in ORs. Without a well-established requirements engineering is difficult to know if the development is going in the right direction. A validation or testing after the development could show it is, but if it is not, a lot of costs would be made without benefits. The fact that any study showed a software development method could be because they did not consider it important to be explicit in the research since it was not the focus of their research or this mapping. We added this question to the data extraction because, if there was this information, it would be very useful to know which methods were already used, how they worked and if it would be interesting to use them in other scenarios.

About the software architecture, we noticed that there was not much focus on showing how their designs were made. This implies it is difficult to understand how the IORs really work, since there is a lack of details about

their implementations. We ponder whether any design considered the OR as a System-of-Systems, but just one proposed to change all the OR equipment. In that way, the proposals implicitly integrate the equipment considering each one as an independent system. But, if the studies did not notice they could work with them as a System-of-Systems, they probably did not use any strategies that could be used in these scenarios. That shows there are, probably, more ways to interpret and design IORs, using techniques that are already tested and validated. Coming back to the fact that only one study proposed to change all the equipment, we can say it shows the academia notices that changing everything is probably not the best cost-benefit. This is important, because it shows a concern to improve the quality of the health within the costs limits. Also, almost 70% of the studies[11-13,16-19,21-22] tested or validated the IORs in some way. It shows a concern about the quality and functionality of the development. Also, it lets us verify which ways to integrate ORs are the best ones. To finish, the answer to the research question includes many ways, by using: intelligent controllers, IEEE 11073 SDC standard, an architecture of reactive agent system, ceiling mount architecture, "plug-and-play" technologies, a simple personal computer, among others that were not deeply described by the studies.

RQ3: Which are the technologies used to develop IORs?

About the RQ3, we noticed a big variety in technologies used to develop IORs and a different focus of describing it. Some studies[12,20], for example, explicit which programming languages were used while some studies described which communications standards were used (such as HL7[15-16,19-20,23] and DICOM[12,15-16,19-20,22]. One study[21] used ceiling LCD monitors. Two[15,18] cited the Medical Information Bus. Considering that, we verify there is no consent in which technologies to use in IORs, besides the will to use standard communication protocols. In that way, we consider HL7 and DICOM the most important technologies used in the analyzed studies.

RQ4: Which requirements of quality attributes are important for IORs?

Regarding RQ4, 11 studies[11-12,14,16-23] demonstrated concern about the quality of the system. We noticed a big reference to attributes such as safety, usability, reliability and efficiency. It shows the designers have in mind that working with operating rooms demands thinking about patient safety all the time. It also presents that the system needs to be reliable, getting and sending information fast, with precision and being fault-tolerant. Finally, the usability attribute shows a concern about the human-interaction to the system. The professionals should be comfortable to use it, know how to do it and trust in it, being capable of doing their activities with efficiency. It makes sense that these attributes were the most referred, since the most important stakeholders to an IOR are the professionals (such as anesthetists) and the patient. Considering that, the answer to the question is that the most important ones are safety, reliability and usability.

RQ5: Which architectural strategies have been used to design IORs?

For the RQ5, just one study[19] did an analysis about the architectural strategies to use in IORs design, and none of them used reference architectures. So, it is difficult to answer this research question. Although the studies intended to design or analyze IORs, only 30% presented a software architecture to it[12,16,18,20]. They explain how it worked but only one[19] cited an architecture strategy: to use an adaptation of the Service-Oriented Architecture. They explained that IEEE 11073 SDC included it. Besides it was not cited, the study[17] also used it because it is about the OR.NET, an architecture to implement the IEEE 11073 SDC. We are not able to answer this research question since we did not find enough information about this topic in the mapping. This could mean that no architectural strategies have been used, they are not documented and spread, or the search strategy of this mapping was not appropriate to find this information.

Threats to Validity

We mitigated different threats to the validity (i.e., construction, completeness, and conclusion) in this work by following different strategies. We followed well-established guidelines for conducting systematic reviews which help us to mitigate construction threats in our study. Moreover, to ensure the inclusion of all possible primary studies important for our review, we systematically followed the mapping study's protocol[8], besides adopting relevant scientific databases in the computer sciences area[7,9]. Evidence was synthesized by systematically analyzing extracted data from primary studies that was registered making use of digital forms[8].

FINAL REMARKS

As important findings, we identified the IC3 was the inclusion criteria with less studies. This shows a gap in the research about the need of implementing IORs. Many studies that presented a way to design an IOR briefly described their necessity. That may be noticed in the stats about the studies that explicit a requirement engineering process. It shows there is a lack of knowledge in what the IORs should do to really improve the quality of the surgery operations and the involved professionals work. We also verified that, even though we could answer four out of five research questions, there is little information available about the IORs implementation. This could indicate that the area is still starting to be developed or the equipment and software are private for some reason. Anyway, it is important to do and spread more research in this topic, especially considering the relevance of healthcare.

Therefore, in this study we mapped primary researches related to IORs. We verified that there is no much information about their design, showing a research gap in IORs software architectural design. Although, the results of the existing implementations are promising. In that way, we considered it important to do more research in how to design IORs, focusing on the functional and quality attributes requirements. In this perspective, further work could be to design an open-source reference architecture

for IORs that allow the community to have a common understanding on how to architect such systems and enhance their further standardization. Therefore, it would be possible to guide IORs engineers to achieve important requirements of interoperability, patients' data protection, safety, integrity, security, systems' usability, among others qualities.

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