Development of a Risk-aware Business Process Modeling Tool for Healthcare processes

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***Abstract*—Healthcare organizations are environments of high management complexity and are subject to risk. Indeed, risk management is one of the most relevant aspects put forward in the literature which highlights the necessity to perform comprehensive analyses intended to uncover the root causes of risks. However, the healthcare sector still suffers from a lack of attention in this context, especially with regard to the establishment of risk management and process-oriented management, which is the motivation for the study described in this paper. In light of these observations, it would be essential for healthcare organizations to explore new risk management approaches. Contributing to this field, the present paper applies a risk-aware business process management method to work out a systemic methodology to study risks impacting healthcare processes. This framework aims to improve healthcare organizations' maturity towards risk management. A case study related to the management of potential risks in a given healthcare process shall illustrate the usage of the developed framework.**

***Index Terms*—Risk-aware Business Process Management, Healthcare Risk Management, BPRIM, Modeling Method, Healthcare process**

I. Introduction

Risk management is an important aspect of healthcare practices due to the complex interaction of multiple potential hazards, and the possibility of serious adverse events if these are not prevented or controlled [1].

In the healthcare field, risk management can be defined as a set of activities and methods that is used to identify circumstances which put patients at risk of being harmed and to act to prevent or control those risk for improving quality in healthcare [2]–[4]. The aim is to both improve safety and quality of care for patients and to reduce the costs of such risk for healthcare providers [2], [3].

In this way, performing risk management in the healthcare field is particularly difficult due to the highly dynamic, complex, and multi-disciplinary nature of healthcare processes. In this context, several healthcare risk management methods exist [2]–[5] and are used in healthcare organizations. However, none of the currently available methods consider the complexity of risk, its strong connection to the healthcare process activities, and the influence of organizational and human factors. Following these findings, healthcare organizations must investigate new risk management techniques that take into account all relevant concepts to risk, as well as the dependencies that exist within the healthcare process activities.

To fill the shortcoming of existing approaches, in this work, we suggest studying the potential of a Risk-aware Business Process Management (R-BPM) approach [6]–[9] to manage risk related to the complex healthcare processes.

This paper is structured as follows. First, Section II provides an overview of the risk management methods in the healthcare field and a short overview of the related works on R-BPM. In Section III, we present the adopted framework. The Section III-C is dedicated to illustrate the use of this framework for studying several potential risks which might arise from a given sterilization process. Finally, the paper is closed with a conclusion and some directions for future work.

II. Background

A. Risk management in the healthcare field

The risk management (RM) in hospitals includes processes, methods, tools and activities used in handling risks in patient care to increase the safety of patients and those involved in their care [2], [3], [10]. A RM process has to describe the procedure for handling risk and consists of: risk identification, risk analysis, risk assessment and risk treatment [10].

In the literature, various risk management methods have been proposed to assist healthcare professionals in ensuring patient safety [2]–[5]. However, studies and literature reviews we have conducted on some of them reveal their limitations.

A comparative study of the most relevant risk assessment methods currently used in the healthcare domain can be found in Table I. This comparison is carried out in accordance with the following criteria: (1) **Process based:** whether the method describes in which system process or activity the risk occurred; (2) **Reactive/Proactive:** whether the method is reactive or proactive. Proactive methods are based on a systematic data collection. Reactive methods apply a systematic investigative technique to analyze adverse events that aims to achieve a comprehensive identification of both systemic aspects as well as individual causes; (3) **Qualitative/Quantitative:** whether the method follows qualitative and/or quantitative analysis; (4) **Causes ranking:** whether the method classifies different risk causes; (5) **Causes chronology:** whether the method provides a chronological reconstruction of risk causes; (6) **Input:** the

Method	Process based	Reactive	Proactive	Qualitative	Quantitative	Causes ranking	Causes chronology	Input	Output
Association of Litigation And Risk Management (ALARM)	☑	☑	□	☑	□	□	☑	Questioning	Form/ Report
Causal Tree Analysis (CTA)	□	☑	□	☑	☑	□	□	Questioning	Tree
Failure, mode, effects, and criticality analysis (FMECA)	☑	□	☑	☑	☑	□	□	Identified causes	Table
Fault Tree Analysis (FTA)	□	□	☑	☑	☑	□	☑	Identified causes	Graph
Ishikawa	□	☑	□	□	□	☑	□	Questioning	Graph
ORION	□	☑	□	☑	□	☑	☑	Questioning	Table/ Report
Preliminary Risk Analysis (PRA)	☑	□	☑	☑	□	□	□	Identified causes	Table

TABLE I: Comparing current healthcare risk assessment methods

reasons for which the method has to start being applied; and (7) **Output:** which description type is used to represent results.

As shown on Table I, only three out of seven methods attempted to incorporate system processes or activities where the causes occurred in the analysis process. However, among these approaches, none of these methods provides a graphical representation to represent system activities and relationships between multiple risk causes. In fact, working with graphs enables a wide range of analysis to be covered. In addition, none of them qualifies the dynamics of risk, as well as to the detailed explanation of the relationships that generate risk.

In summary, as shown on Table I, none of these methods is able to satisfy all the following aspects:

- Identify and classify potential risks;
- Deal with the complex healthcare processes at the correct level by describing all related and collaborative activities composing the process;
- Provide a complete description of risk causes;
- Understand the strong relationships between risks and activities of healthcare processes;
- Consider the organizational and human factors which intervene the risk occurrence;
- Produce a dynamic map ranking all risks;
- Produce a graphical representation of process activities and relationships between multiple risk causes;
- Provide a modeling tool that ensures the easy use to manage risks related to healthcare processes.

As a result, in order to improve patient safety, healthcare organizations must implement an effective detection policy, as well as prevention and management of hazards associated with complicated healthcare processes. To address this problem, we recommend looking into new research domains, particularly the integrated management of risk and business processes.

B. Risk-aware Business Process Management Methodology

For several years, there has been a strong interest in combining the two traditionally separated fields of risk management and business process management into a single concept known as Risk-aware Business Process Management (R-BPM) [6]–[9]. This integration improves the efficiency of risk detection, assessment, and mitigation in relation to business processes. The relevance of this integration has been acknowledged by the scientific community [11], industry guidelines [11], and a number of studies [6]–[9].

Business Process-risk management - Integrated Method (BPRIM) [8] is one of the important approaches in the R-BPM context. The method suggests an integrative approach with three components: (1) A conceptual unification between the business process conceptual-model proposed by the ISO/DIS 19440 and a risk conceptual-model, (2) a modeling language extending the ISO/DIS 19440 constructs with risk modeling constructs, and (3) A synchronized lifecycle that forms a procedure for integrated business process and risk management.

III. Proposed Framework

In this work, we adopt a framework based on the BPRIM method, called *e*-BPRIM. The latter consists on the digitalization of BPRIM. The *e*-BPRIM framework, with ADOBPRIM, a modeling environment based on the ADOXX meta-modeling platform [12], promotes and supports risk-aware process management methodology. The adopted framework suggests three main components: a *modeling language*, a *modeling procedure*, and *mechanisms & algorithms*. These latter form, according to [13], the main components of a modeling method.

In the next section, we present our proposed framework with an explanation of all its features and components.

A. *e*-BPRIM *core components*

e*-BPRIM *Modeling Procedure: As mentioned before, the BPRIM [8] proposes an integration of the two lifecycles of risk

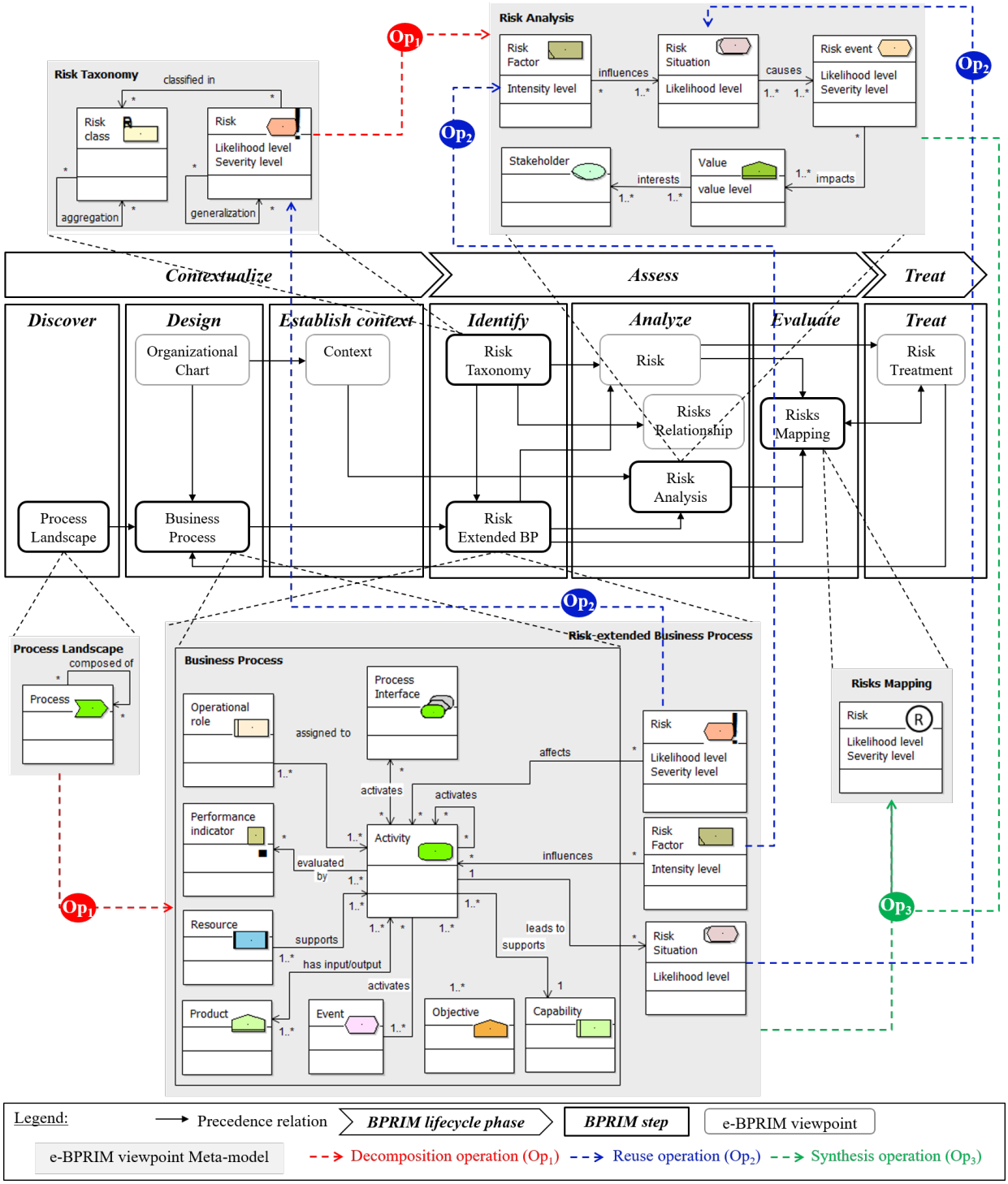

Fig. 1: *e*-BPRIM modeling procedure, some meta-models viewpoints and some operations

management and business process management. The BPRIM lifecycle identifies four main phases (1-Contextualize, 2-Asses, 3-Treat and 4-Monitor), each of which is divided into steps. Considering information exchanged between the three first steps, a set of eleven viewpoints was identified. The *e*-BPRIM modeling procedure introduces then the sequence to be applied while creating and working with these multiple viewpoints. The complete modeling procedure is illustrated in the middle of Fig. 1.

e*-BPRIM *Modeling Language: The latter is composed of abstract and concrete syntax. The abstract syntax is described by a meta-model based on the BPRIM conceptual model, called *e*-BPRIM meta-model. The concrete syntax is based on the BPRIM modeling notation and describes the graphical representation of each *e*-BPRIM meta-model concept, called *e*-BPRIM notation. It needs to be noted, that the *e*-BPRIM meta-model can be divided into eleven meta-models corresponding to the eleven viewpoints of *e*-BPRIM. Fig. 1 shows an example of some *e*-BPRIM viewpoints meta-models annotated with corresponding notations. For example, a blue rectangle is used to represent the "Resource" concept.

e*-BPRIM *mechanisms & algorithms: These latter support the *e*-BPRIM modeling procedure and also provide functionalities to use and evaluate viewpoints.

B. Current functionalities of ADOBPRIM *modeling tool*

The ADOBPRIM tool supports the steps of the *e*-BPRIM modeling procedure and also provides functionalities (i.e. operations) to use and evaluate viewpoints. In Fig. 1, we present some of these functionalities. In the following, we present a short description of some functionalities :

- **Editing** of eleven *e*-BPRIM viewpoints corresponding to the viewpoints depicted in Fig. 1
- **Verification** of created models. This functionality ensures the validity/accuracy of created models by checking their structure according to several defined syntactic and semantic rules.
- **Risk Assessment** of identified risks. The risk analysis model is analyzed and evaluated using a risk assessment matrix. The latter is a classical method to conduct qualitative risk assessment. The objective of this mechanism is to automatically produce a risk matrix which visualizes the different risk levels.
- **Navigation & Synchronisation** between all *e*-BPRIM viewpoints and between all objects in different models.
- **Process decomposition** (Op_1), indicated as red dotted arrows in Fig. 1, which deals with breaking down a system into progressively smaller subsystems that are responsible for some part of the problem domain.
- **Reuse** (Op_2), indicated as blue dotted arrows in Fig. 1, which allows the reusing of one or several concepts from one or more existing viewpoints.
- **Synthesis** (Op_3), indicated as green dotted arrows in Fig. 1, which allows the gathering the information of several viewpoints and then generating a synthesis viewpoint.

A comprehensive introduction to the ADOBPRIM modeling tool has been developed as a project within the Open Models Laboratory. A free download and further information on ADOBPRIM are available through the corresponding project page[1].

C. Application on healthcare processes

To evaluate usage, feasibility, relevance, and capabilities of the proposed framework and tool, we applied the *e*-BPRIM framework with the ADOBPRIM modeling tool on three real-world healthcare processes, in France, to manage related risks:

- The first application deals with the management of Adverse Drug Event (ADE) risk related to the Medication Use Process (MUP) of elderly patients. The application was carried out in collaboration with several actors of the Intercommunal Hospital Center of Castres-Mazamet (CHIC) in the Geriatric Department. The result of this application can be found in great details in [6]–[8], [14]
- The second application deals with the crisis management process of the COVID-19 pandemic in France. The result of this application can be found in great details in [15]
- The third application deals with the management of risks of Medical Devices (MD) contamination related to the Sterilization process. The application was based on the works of Di Mascolo et al. [16], [17]. In these works, a real-world case study was conducted in the sterilization service of the University Hospital of Grenoble. The result of this application will be presented in great details now.

In the following, we present the application of the ADOBPRIM modeling tool on a given hospital sterilization service to analyze its robustness [16], [17]. In order to understand the sterilization process and analyzing related risks, the following presentation focuses to demonstrate how an ADOBPRIM user should address the environment tool to create models. For greater clarity, we exclusively work on selected *e*-BPRIM viewpoints namely the "Process Landscape", "Business Process", "Risk Taxonomy", "Risk-extended Business Process", "Risk Analysis", and "Risk Mapping" viewpoints.

To this end, an ADOBPRIM user should follow the phases of the *e*-BPRIM modeling procedure:

1) **Contextualization phase**: In this phase, the user should create:
   a) A "Process Landscape – (PL)" model which describes an overview of the value-added processes of the system under study. In our case study, this model describes eight sub-processes of the hospital sterilization process (see the top left of Fig. 2).
   b) A "Business Process – (BP)" model which provides a deeper understanding of the functioning of each identified sub-process in the PL model. In our case study, each identified hospital sterilization sub-process can be described by a BP model. For example, in the top right side of Fig. 2, the "Wash

[1] *e*-BPRIM project space within OMiLAB [online]: https://austria.omilab.org/psm/content/BPRIM, last visited: 01.08.2021

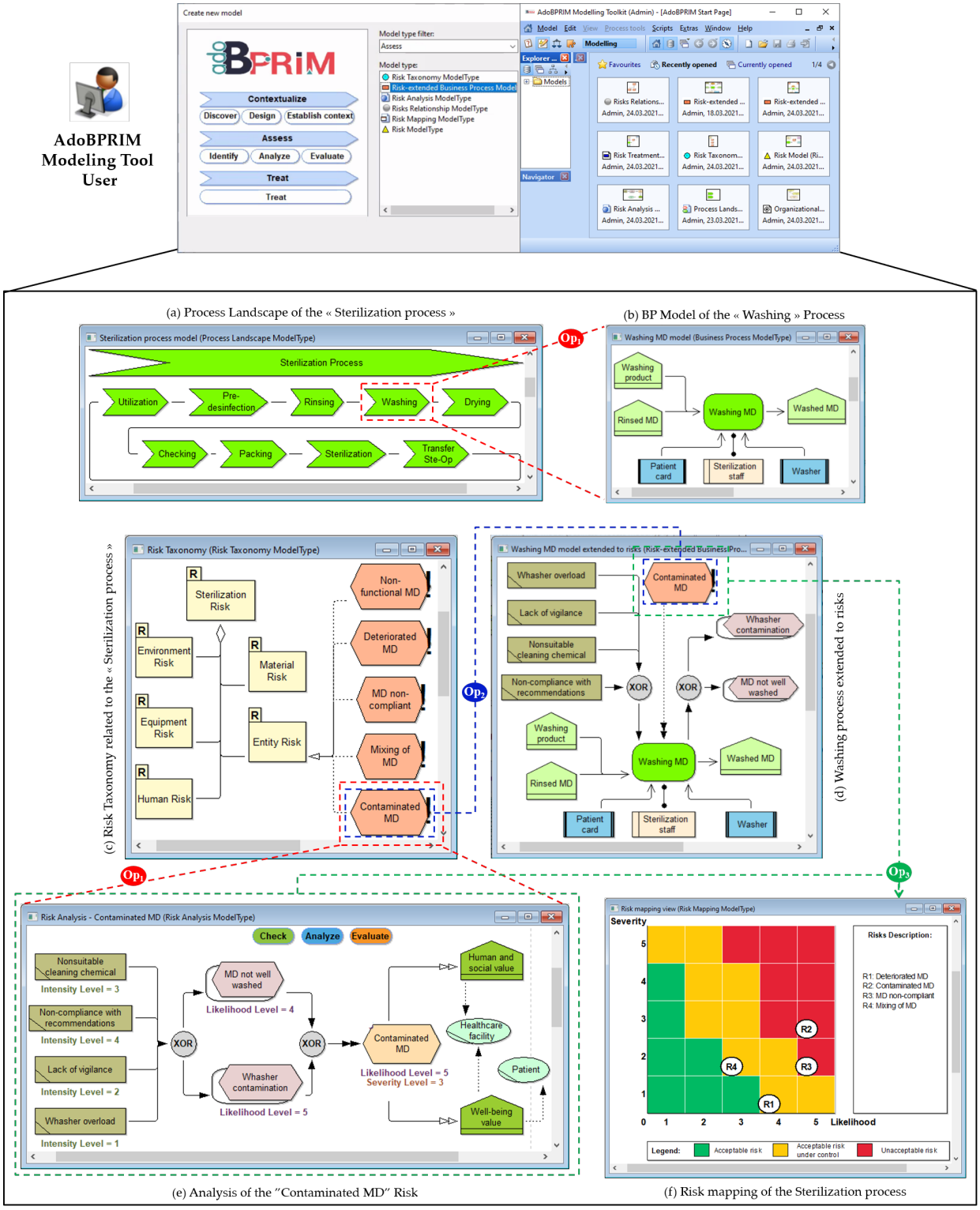

Fig. 2: ADOBPRIM modeling tool screenshots

medical devices" process is described in greater detail.

2) **Assessment phase**: In this phase, the user should create:

a) A "Risk Taxonomy – (RT)" model which provides an inventory of potential risks. In our case study, we differentiate between five risk classes (see the middle left of Fig. 2).

b) A "Risk-extended Business Process – (R-BP)" model which aims to assign individual activities of the BM model to potential risks from identified risks in the RT model. In our case study, as shown in the right middle side of Fig. 2, we can assign the "Contaminated MD" risk to the "Washing MD" activity.
c) A "Risk Analysis – (RA)" model which aims to analyze each identified risk in the RT model by the calculation of the likelihood and the severity levels of each identified risk. In our case study, we focus the analysis on the "Contaminated MD" risk (identified in the RT model). The analysis result is given in the bottom left side of Fig. 2.
d) A "Risk Mapping – (RM)" model which aims to produce a two-dimensional risk matrix showing the risk level of each analyzed risk. The risk position in the matrix will be according to likelihood and severity levels as calculated in its RA model. In our case study, the bottom right side of Fig. 2 illustrates the mapping of different analyzed risks. For example, according to the analysis result, we can see the risk "R2" (corresponding to the "Contaminated MD" risk) placed in the position (5,3).

Thanks to the ADOBPRIM tool use, all developed models using the ADOBPRIM tool allowed to: (i) improve the understanding of a hospital's risk profile, and (ii) clarify thinking about the nature and impact of risks, taking into account both the organization as a whole and the context of the risk situation and its relationship to healthcare process activities. In this way, vulnerabilities can be more effectively mitigated or managed.

The application result of the ADOBPRIM tool on the three real-world healthcare processes has proved the feasibility and the relevance of the *e*-BPRIM framework with the ADOBPRIM modeling tool. Indeed, according to ADOBPRIM users feedback, the tool has been valued as: (1) an easy tool giving a comprehensive vision of risks, and (2) a useful brainstorming and analyzing tool for improving the quality of management as well as the patient care processes.

CONCLUSION

To assist healthcare professionals in ensuring patient safety, various risk management methods have been proposed in the literature. However, our research and literature reviews on a few of them have shown their shortcomings. To move forward a more efficient approach, we introduce, in this paper, a new R-BPM framework called *e*-BPRIM, which is a recent result of our research in this field. To evaluate the usefulness and relevance of this framework, we used ADOBPRIM, the dedicated tool for *e*-BPRIM, to analyze the vulnerability of three real-world healthcare processes: the medication-use process, the management process of the COVID-19 pandemic, and the sterilization process. Users ADOBPRIM feedback have shown that R-BPM approaches can overcome some of the limitations of conventional risk management methods. Obviously, the *e*-BPRIM framework is not restricted to analyze risk related to healthcare processes, it may be used to other industries as well. At this stage, we are working on a new version of ADOBPRIM, which will add new features such as simulation capabilities to study risk propagation and to assess the effectiveness of the risk mitigation activities.

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