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RISK-AWARE BUSINESS PROCESS MODELING: A COMPARISON OF DISCRETE EVENT AND AGENT-BASED APPROACHES

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ABSTRACT

Risk analysis is one of the most challenging task in a business process management perspective. In healthcare, risk management focuses on events having a relevant impact on patients safety. We investigate the context of a blood-bank, which is one of the most critical hospital department, by comparing two different modeling approaches to perform a risk-aware business process management. Our main interest here is to discuss advantages and disadvantages of discrete-event and agent-based modeling approaches. We adopt two specific tools and collected feedback from modelers, staff and decision makers. We identify differences in the analysis of risks from the two perspectives, such as the possibility to include agents-environment interactions, as well as structured approaches to discover potential failures. Our results include assessment for risk management, shedding some light on practical applications of process modeling and simulation in healthcare.

1 INTRODUCTION

An increasing number of private and public organizations is adopting a Business Process Management (BPM) approach (Dumas et al. 2018) to support, manage and improve business processes. Risk analysis is one of the main relevant area of BPM (Suriadi et al. 2014), including modeling of the activities of an organization also by considering the compliance to internal and external regulation (Van Der Aalst 2013). These legal aspects have to be applied by workers to ensure process compliance. In addition, a reorganization has to be implemented with the introduction of new procedures (i.e. for privacy control), which includes redesign business processes in the context of change management (Hayes 2014). Business process modeling and simulation (Van der Aalst 2018; Martin et al. 2016) provides results for different scenarios (*What-if analysis*) in order to evaluate process changes in real process (Chang 2016). On the top of such analysis, risk management concerns the detection of failures in the context of business management (Hornstein 2015) with the application of enforcement to activities (Parker and Nielsen 2011).

This paper provides a comparison between different approaches for modeling and simulating the functioning of an organization. In particular, we focus on the methodological framework in the design phase, by referring to design science framework (Hevner et al. 2004). In the context of risk management (Sadgrove 2016; McNeil et al. 2015; Haimes 2015), most studies investigate specific use cases to describe benefits of new practices or tools (Tomiyama et al. 2009; DeRosier et al. 2002). In healthcare studies this kind of analysis is particularly important for both the direct and indirect consequences of errors (Rose 1992; Vincent et al. 2000; Fishman 2013; Chartier 2014). In this respect, we focused on health sector which is relevant for the impact on population, facing increasing costs in a resource limited setting. A BPM approach improves healthcare outcomes as well as performances of the operators, for instance focusing on the role of business processes (Rojas et al. 2016; Fernandez-Llatas et al. 2015), as well as capacity for

change in public hospitals (Braithwaite et al. 2017). In similar works related to the monitoring of business processes, it is possible to find several studies concerning compliance with laws, rules or regulations. This aspect is of particular importance in the case of processes related to patient health (Buddle et al. 2005; Racz et al. 2010).

In the following of the paper, Section 2 introduces the methodological framework to analyze and to improve business processes, based on the construction of the model and the simulation of actual workflow (As-is). The execution of *What-if* and scenario analysis describe the possible evolution (To-be) of the process. The methodology includes related task on risk analysis and compliance of processes with current laws and regulations. Section 3 details the case study, before describing the different approaches for discrete-event and agent-based simulation, respectively in Sections 4 and 5. A comparison of the two modeling techniques, as well as some considerations about the application in the medical field will be presented in Section 6. Finally, some remarks and future works concludes the paper in Section 7.

2 THE METHODOLOGICAL FRAMEWORK

This section briefly introduces the methodological framework adopted in this study to perform process modeling to analyze an organization which involve humans, documents, and technological applications (Van der Aalst, Nakatumba, Rozinat, and Russell 2010). We refer to four initial phases of the traditional life-cycle of Business Process which consist of design, modeling, execution, monitoring, and optimization (Amantea et al. 2018).

As our aim is to compare two different kinds of approaches such as discrete event and agent-based modeling, we selected two tools among the existing ones. First, to perform Discrete Event Simulation we adopted a software which is based on the standard modeling language *Business Process Modeling and Notation* (BPMN) (Allweyer 2016). In our opinion this modeling language is easily understandable by not specialists such as doctors and hospital decision makers. Moreover, this language becomes quite a "de facto" standard for process modeling. In our case we adopt the iGrafx Process tool (iGrafx 2015) to implement process modeling and simulation. The tool includes some extensions to perform risk analysis, e.g. structured approaches for discovering potential failures as well as to classify potential risks within the process (Amantea et al. 2019).

To perform Agent-Based Modeling (ABM) we adopted one the most used open-source tool, NetLogo (Wilensky 1999), available at (NetLogo 2019). The platform collects twenty-years of improvements in several directions by offering extensions to programming languages such as Python and R, as well as libraries for Geographical Information System or Social Network Analysis. The modeling approach includes the creation of autonomous agents interacting each others as well as acting in an environment of static agents (so called *patches*). The Graphical User Interface of the tool allows the creation of different agents and scenario, as well as use monitors to visualize the output of the simulation, both at the conclusion or in real time. A NetLogo feature called *behaviour space* easily introduces sensitivity analysis and scenario planning by running models many times across different parameters.

To compare the modeling strategies in the context of a risk-aware business process simulation, we adopted the eight following criteria:

- Time to build the model. We investigate how long does it take to manage the process from the initial conception to the modeling conclusion.
- General impression. This aspect concerns the ease of understanding of the model.
- Output results. The focus here is on the readability of the resulting model. In particular we focus on immediateness, ease of identify main patterns and the general understanding of the output processes.
- KPIs of the process. This aspect relates to the introduction of performance indicators in the model.
- Modifying flow setting. We investigate how the process flow is easy to manipulate and how immediate is to change parameters in the model.

- Integrating the detection of failures. We analyse what would be the effort to integrate in the model traditional methods as Failure Mode and Effect Analysis (FMEA) (Chiozza and Ponzetti 2009) or Cause and Effect analysis (Nicolini et al. 2011).
- Adding behaviour. This topic define how it is possible to change the model accordingly to new input/variables.
- Process mining. This topic refers to how the approach is suitable to be addressed by recent advances in reading event logs for process discovery.

We investigated these aspects with both modelers of the business process and workers of the hospital, e.g. decision-makers, mostly medical staff (doctors, biologists) as well as nurses and employees of the specific department.

3 USE CASE OF BLOOD-BANK DEPARTMENT

The case study here afforded refers to the Blood-Bank department (BB) of the main hospital in the "City of Health and Science" of Torino, one of the biggest public health hub in Europe (CHS 2019), as detailed in (SanPaolo 2019). This department collects blood and hemocomponents to supply several different hospitals located in the surrounding areas, and it includes several laboratories to perform tests (e.g. immunohematology, pre-transfusion, prevention of hemolytic diseases).

The arrival of a blood request is the starting point of the BB process. For every request, BB staff verifies and check that the appropriate blood request goes to the right patient. The number of requests managed each year by this hospital department is about 125,000. The organization of the work includes three different areas: Acceptance, Laboratory and Distribution.

Acceptance manages the arrival of new requests, which can be both ordinary and urgent. Several tasks are performed by nurses and employees to verify the validity, by applying barcode and eventually correcting the request. After this step, the activities on the request move to the *Laboratory*. Here the patient's request involves a large set of standard tests, e.g. blood typing (AB0 group), Rh typing searching for positive or negative antigen, screening for eventually red blood cell antibodies. This step includes different kinds of workers: nurses, medical and biologists to perform the analysis and check their validity.

Finally, the requested units of blood or components arrive in *Distribution* area. Here the correct units of blood are taken from blood refrigerators. Several checks ensure the correctness of the registry data about the patient and the features of the blood unit. Once these units are ready to be delivered to the requesting department, they remain in the last office waiting for the arrival of the appropriate staff for the recovery. An exceptional pathway involves emergencies, i.e. very urgent requests, which are rare but as expected they have immediately the highest priority. Some activities are speeded up and others avoided depending on the specific cases, in accordance with medical considerations of patient's conditions. In very critical and urgent situations, some activities in *Laboratory*, as the acquisition of the formal document for the request, are left for at a later time.

The analysis of risks in this hospital department has the ultimate goal of increment the safety of patients involved in the process. The wide set of internal procedures and other tasks to manage risks includes the following ones:

- *Risk identification:* the hospital management takes into account notifications about errors reported and stored by the information system.
- *Risk causes:* this step determines the causes of risks and factors related to errors.
- *Risk assessment:* managers determine the kind of risks should be treated with priority, by eventually defining some thresholds.
- *Risk treatment:* a risk can be treated by introducing preventive measures, also including proactive or reactive methods (Vincent et al. 2016).

The adoption of a proactive method may include FMEA and scenario analysis from simulations based on both systematic data collection and a model of the actual department.

4 RISKS AND DISCRETE-EVENT SIMULATION

Accordingly to the graphical notation BPMN, rectangles represent tasks, circles refer to arrival/end/time related events (i.e. delays), while rhombus are gateway branching or merging the activity flow. Figure 1 provides an example of the model referring to the BB *Acceptance* unit. The model clearly defines tasks

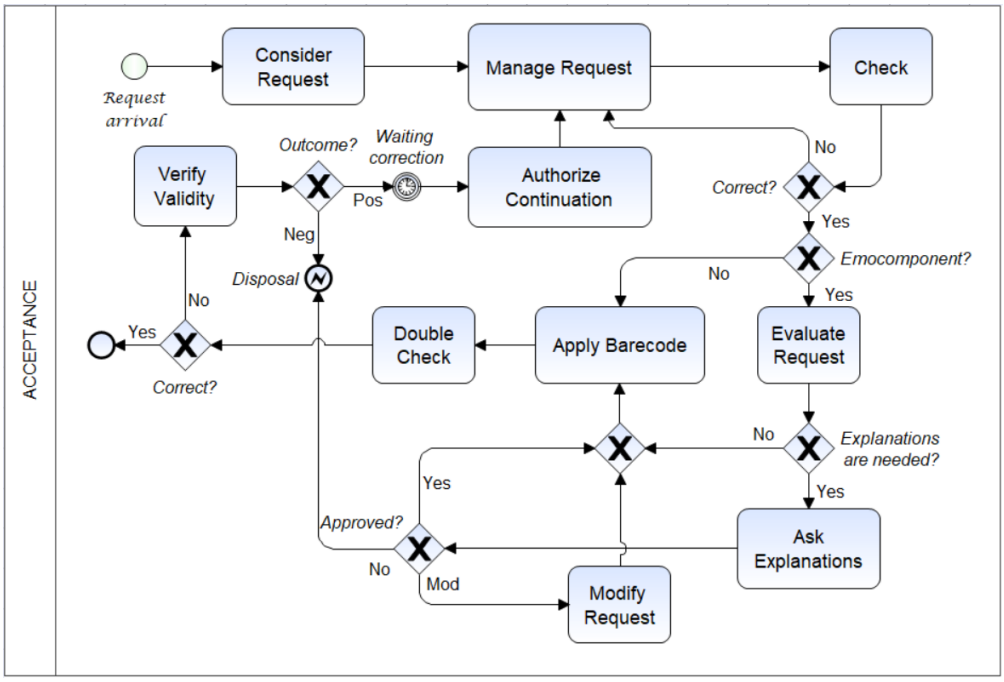

Figure 1: The model of the *Acceptance* process related to the Blood Bank department defined by using Business Process Modeling and Notation.

regarding risk prevention and risk management (i.e. check, double check, verify validity). Simulations based on this model, following a discrete-event approach, involve the detection of risky activities and risk-aware activities: every transactions arriving in the process may have some errors accordingly to the real distribution based on the statistical analysis of previous years. Every control activity can intercept errors depending on a predefined probability. Once the model has been verified by managers and validated with the comparison to real values of error intercepted, it is possible to produce *what-if* and scenario analysis. Figure 2 describes data of BB related to year 2017 for each of the three areas, concerning errors as reported by workers (Reported), estimated by managers (Detected) and the official Claims coming from patients corresponding to errors not detected.

5 AGENT-BASED MODELING AND RISK MANAGEMENT

Our interest here concerns the exploration of Agent-Based Modeling of BB including risk analysis of business processes. The agent-oriented perspective involves the distinction of behavioural rules for patients and staff. Moreover, as they act in an environment, the map of the actual department can be used to implement a more realistic flow. Each agent follows quite simple rules as defined in Table 1.

Each activity is modeled as an object, including some variables (e.g. the duration, the number of workers, the type of workers). Agents interact with other agents and activities: i.e. agents can move

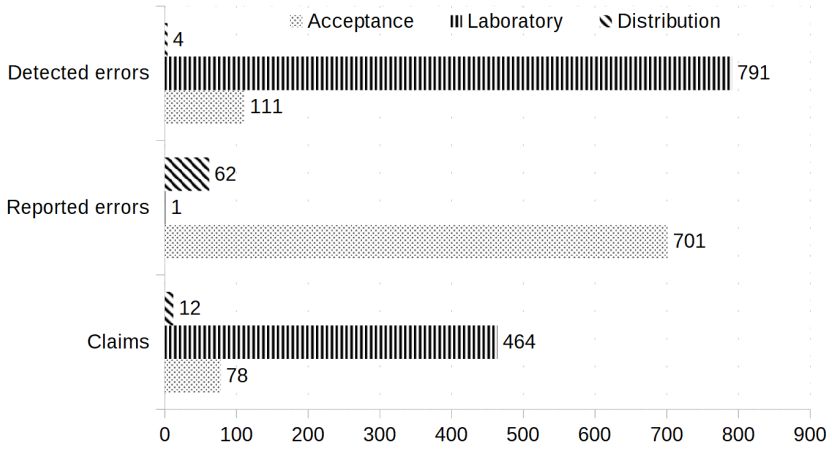

Figure 2: Errors reported by BB staff (Reported), errors estimated by managers (Detected) and errors not detected (Claims).

Table 1: State and behavioural rule of agents.

Rule/State	Patients and Workers activity
waiting-for-task	wait to be addressed for the next task
moving-to-task	move to the next activity
waiting-on-task	wait to start next activity
working-on-task	work in the next activity

to them, or they can read the corresponding variables to consequently modify their behaviour. Figure 3 describes a view of the model of the BB department in NetLogo 3D, which allows a nice visualisation by posing tasks on the current stylized map of the department. This can provide an immediate understanding of the organization, as well as of the detection of bottlenecks and queues of patients in the activity flow. Regarding the model, tasks are modeled with the white patches in the ground, while the red lines indicates the paths followed by patients and workers. This is a graph of nodes, where the weight of the arc includes the average duration of the walk between the two nodes. In this way, it will be possible to address also logistics analysis, on the basis of the time needed to move patients and operators between different wards. The agent-based modeling and simulation perspective includes the arrival of patients and movements of workers and patients to perform different business process activities (Sulis and Di Leva 2017). Risk analysis can be performed in a similar way of discrete-event simulation, by including errors and risk in each tasks. In addition, an agent oriented simulation may include personal features for each agents to address risk management (e.g., experts or beginners may have different percentage of working ability in error detection).

6 A COMPARISON OF MODELING APPROACHES

We performed discrete event and agent-based modeling, initially observing how both kinds of modeling necessarily start with a relevant effort to exactly define activities with the corresponding duration, resources and related risks, in order to clearly define the process flow. Nevertheless, we noticed some differences in practical consequences of the modeling perspectives.

As our work refers to an hospital department, we collected several suggestions from medical staff and other stakeholder to consider their impressions about different methodologies. In general, discrete event simulation was perceived more practical and in particular the adoption of a notation similar to flow-charts (e.g. the standard notation BPMN 2.0) is perceived as a nice solution really easy to be directly managed also by doctors/nurses and well separated from the semantic model. Similarly, risk management officer

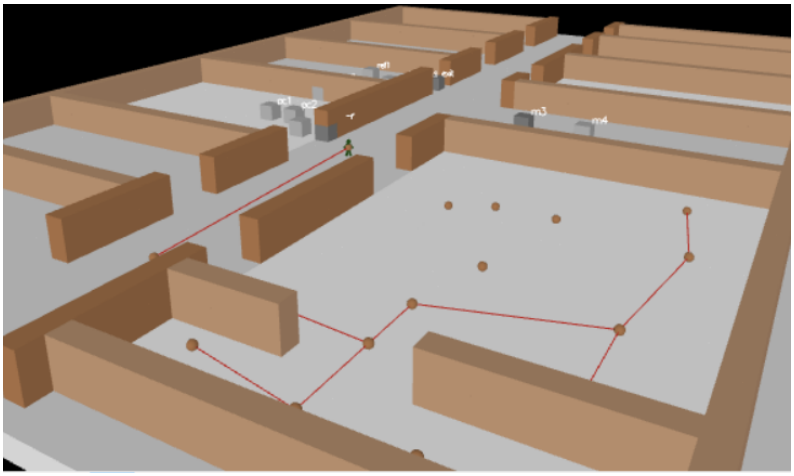

Figure 3: A 3D agent-based model of BB.

can add/remove tasks to investigate the impact on the organization, i.e. the introduction of a new check in the process and the resulting impact over the other activities.

Agent oriented modeling appears promising as a bottom-up approach to shift the focus on the behaviour of agents, i.e. patients and workers. Moreover, the ease of interconnecting and relating agents each other *by design* offers more interesting opportunities to dynamically investigate some behaviour. For instance, agent level of attention can be modeled as a variable decreasing with respect to the number of time and working hours, the presence of other colleagues and patients in the surrounding as well as other distractions related to the environment. Table 2 summarizes the main advantages and disadvantages of the two approaches as detected in our healthcare use case.

Table 2: Advantages and disadvantages of two methodologies in Hospital Blood-Bank Department.

Feature	BPMN & DES - iGrafx Process	ABM - NetLogo 3D
Time to build the model	Assign duration/resources to tasks	Requires programming effort
General impression	Intuitive and coherent results	Interaction of agents/environment
Output results	Generally clear but not so immediate to identify bottlenecks	Rotate and zoom in the world improves the understand
KPI of the process	Somewhat difficult to interpret	Buttons allow to modify indicators
Modifying flow setting	Easy to manipulate	Not immediate as requires coding
Integrate failure detection	Added to single activities	Somehow tricky
Adding behaviour	Limited to parameters and variables	Provided by the tool
Process mining	Direct mapping from event logs	Need an extension

7 CONCLUSIONS AND FUTURE WORK

In this paper we focused on risk management in healthcare organizations by considering two modeling and simulation perspectives. We initially applied a quite traditional framework involving interviews, document and data analysis to define activity flow. Then, we adopt business process modeling notation as a standard language, with the main goal to perform a discrete-event simulation. In addition, we applied agent-based modeling of the same hospital department. In this case we adopted the 3D version of NetLogo, to investigate advantages and disadvantages of the two approaches, as clearly emerged during the construction of the models. We demonstrated also how the different modeling perspective includes some practical consequences

in the analysis of risks, e.g. the possibility to includes agents/environment interactions, as well as structured approaches to discover potential failures, as FMEA.

Future works includes three directions: firstly, we aim to analytically compare not only the modeling approach but also the output results of simulations concerning risk detection. Secondly, we intend to apply the same comparison to a different department, e.g. an Hospital Emergency Department already initially investigated in (Sulis and Di Leva 2018). Thirdly, we aim to address risk management exploring the consequences of different logistics allocation and staff variation in agent-based models, e.g. modifying agents behaviour accordingly to the introduction of stressful condition.

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