SIMULATION BASED ANALYSIS OF ECTOPIC PREGNANCY TREATMENT PROCESS TO SUPPORT PROCESS REDESIGN

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ABSTRACT

Many healthcare delivery processes are managed according to deep-rooted rules and process redesign is challenging. Simulation can provide evidence to support redesign decisions. However, introducing simulation in organizations having limited previous experience with the method requires a lot of effort. In the case study reported, it is proposed to use business process based simulation. A business process is constructed jointly with domain experts and a simulation model is created directly from the business process model, where simulation specific features are represented in sub-processes. That streamlines model validation and communication of modeling results with stakeholders. Business process simulation is used to compare ambulatory treatment and hospitalization in the case of ectopic pregnancy treatment. Simulation results show that the ambulatory treatment should be adopted according to the cost minimization criterion. However, appropriate measures should be taken to mitigate potential negative effects exhibiting in the simulation results as an increase of waiting time.

INTRODUCTION

Simulation is a valuable tool for policy making (Jacobson et al. 2013). However, in many domains such as healthcare stakeholders expect extra assurances that recommendations provided are transparent and risk-averse. Business process modeling has emerged as one of the techniques bringing together various stakeholders in analysis of complex issues and combining managerial and technical perspectives of policy evaluation (Van der Aalst et al., 2003). It is also successfully used in healthcare (McNulty and Ferlie, 2002). BPMN is widely used standard language for representing business processes (OMG, 2011). Many business process management suites support simulation of processes developed (Pereira and Freitas, 2016; Wagner, 2015). However, simulation capabilities of BPM suites are often limited (Wagner et al., 2009; Wagner et al., 2017). These limitations apply to both: 1) inability to simulate all constructs used in modeling of rich business processes; and 2) inability to represented in BPMN some aspects necessary for simulation of complex processes (e.g., queuing, resource management). One solution is to use BPMN for initial representation of the process and implementation of the process simulation model in a fully-fledged simulation tool (Wang et al., 2009). However, that requires extra development effort and might result in detachment of business stakeholders.

This paper investigates application of simulation for evaluation of policy decisions in a healthcare organization unfamiliar with simulation. Simulation is necessary because the organization follows some well-entrenched policies and it is important to combine static analysis, dynamic analysis (e.g., visualization of process dynamics) and numerical analysis to show potential benefits of policy changes. Business processes based simulation is deemed suitable for initial exposure of the organization to these technologies.

The main requirements for simulation modeling in this case are: 1) model should be comprehensible for various stakeholders; 2) model should support evaluation from multiple perspectives; and 3) limited effort can be devoted for a pilot study. From the applied perspective, the objective of this paper is to develop a business processes based simulation model for evaluation of healthcare policy decisions for an organization with limited prior exposure to simulation. The particular case studied is about treatment of ectopic pregnancy and policy decisions should be made about switching from hospitalization to ambulatory care. This case requires that particular attention should be devoted to representation of exceptional events what is supported by BPMN though with limited support for simulation. Therefore, from the theoretical perspective the challenge is to simulate these exceptional events without sacrificing clarity of BPMN models and relying heavily on custom development.

The rest of the paper is organized as follows. Section 2 reviews some of the current research in healthcare simulation with emphasis on process improvement. It also describes the ectopic pregnancy condition and its treatment. Section 3 discusses business process based simulation. A ectopic pregnancy treatment process redesign case study is presented in Section 4. Section 5 concludes.

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BACKGROUND

This section discusses general aspects of using simulation in healthcare and introduces the particular process to be analyzed in this paper, namely, the Ectopic Pregnancy Treatment (EPT) process.

Simulation in Healthcare

Simulation is frequently used for operations management in healthcare. In the context of this paper, the most relevant aspects of healthcare simulation are evaluation of healthcare policies, process improvement and applications of business process modeling based simulation.

Hulshof et al. (2012) classifies types of operations management decisions made in healthcare. They indicate that demand for ambulatory care services is growing. Simulation is often used to investigate these issues. There is an increase of ambulatory surgeries, which are often shorter, less complex and less variable (Hulshof et al., 2012). Improvement of healthcare process requires balancing of efficiency and risk management (Zeigler et al. 2016). The authors have elaborated a simulation based framework for evaluation of healthcare processes to reduce cost and improve service quality. Mielczarek and Uziałko-Mydlikowska (2010) survey different simulation applications, which are categorized as epidemiology, health and car4e systems operation, health and care systems design, and medical decision making. The survey of simulation tools indicate that ARENA, which is a specialized process-oriented simulation tool, is most widely used.

Barjis (2011) identifies managerial simulation as one of types of simulation in healthcare. It concerns strategic planning and policy implementation. The authors identifies user acceptance as one of the main concerns of using simulation in healthcare and stakeholder involvement is critical for adoption of recommendations made as the result of simulation studies.

Antonachi et al. (2016) argue that business process improvement techniques are becoming more common in healthcare and simulation is an essential part of the improvement cycle. A business process model is transformed into a simulation model to enable quantitative and dynamic analysis of healthcare processes. Transformation processes are always associated with some information loss and a need to update the resulting model. Simulation based process reengineering has been successfully used in optimization of sterilization processes (Cassettari et al., 2013). In order to clearly highlight process inefficiencies and to improve the process, as-is and to-be models are developed and evaluated. The evaluation has resulted in development of a new sterilization strategy. Hamrock et al. (2013) point out that simulation is an important tool for improvement of healthcare processes to maximize operational efficiency without sacrificing service quality. Process improvement initiatives often are a result of intricacies of modern cost reimbursement policies. Simulation allows replacement of subjective decisions with decisions motivated by quantitative analysis.

Ectopic Pregnancy and Its Treatment

The EPT process treats an ectopic pregnancy. The ectopic pregnancy is a pregnancy outside of uterine cavity. Management of ectopic pregnancy has changed over the years (Murray et al. 2005). The guiding principle has become an early detection and a medical treatment rather than surgery. However, this condition is still potentially life-threatening and accounts for 4 to 10 percent of all pregnancy related deaths (Creanga et al. 2011). The overall incidence of ectopic pregnancy is approximately 20 per 1000 pregnancies.

The diagnosis of ectopic pregnancy is based upon a combination of risk factors of ectopic pregnancy, clinical presentation, measurement of the serum quantitative human chorionic gonadotropin (pregnancy blood test) and ultrasonography (Murray et al. 2005). The symptoms of ectopic pregnancy most often appear six to eight weeks after the last normal menstrual period. In the case of later detection of ectopic pregnancy sever life-threatening hemorrhage can occur due a tubal rupture.

Any fertile age patient presenting with pelvic pain and vaginal bleeding have to be evaluated for ectopic pregnancy. Main goals and steps of the investigation are confirming pregnancy with the pregnancy blood test, evaluation the patient for hemodynamic instability, ultrasonography for determination the site of pregnancy. Before to start a treatment of ectopic pregnancy, additional blood tests are indicated. These include blood type and screen, complete blood test, liver and renal function tests, in severe cases-coagulation tests.

The three approaches to the management of ectopic pregnancy are surgery, medication or expectant management. Approximately one-third of patients with ectopic pregnancy are candidates for medication – Methotrexate (MTX) therapy (Van Den Eeden et al. 2005). The remaining patients will require surgery due tubal rupture, large ectopic pregnancy, inability to comply with the follow-up of the MTX therapy. Some patients prefer surgery rather than the MTX treatment.

Table 1: Comparison of ambulatory care and hospitalization.

Policy	Advantages	Disadvantages
Ambulatory care	Cost effective No interruption of daily activities	Need for a good medical help access Late response Dependence on patient's self-discipline
Hospita-lization	Easy access Quick treatment for sever conditions	Expensive Necessary to skip daily activities Unnecessary add-on treatments

Most of guidelines advise to perform the MTX treatment in out-patient clinics but there are some hospitals where patients receive hospital based treatment (see Table 1 for comparison of policies). The MTX therapy is noninvasive, safe and cost effective option for ectopic pregnancy treatment. The overall success rate of medical treatment in properly selected patients is nearly 90 percent. During the treatment patients can have abdominal pain. Occasionally pain may be severe, but hemodynamically stable patients often do not need surgical intervention. A patient with severe pain may be further evaluated with transvaginal ultrasonography. There appears to be no clinical benefit from routine serial ultrasound examinations.

SIMULATION APPROACH

The simulation procedure followed combines features of typical simulation modeling projects (e.g., Law and Kelton, 2014) and business process modeling and improvement. Figure 1 indicates the main steps of this procedure with emphasis on aspects characteristic to this project.

Although the simulation procedure described focuses on the particular process redesign case, some of the principles can be applied in other projects as well. In particular, simulation models are developed using the variants based approach frequently used in business process management (Kumar and Yao, 2011), policy decision are explicitly represented in the model, the same model is used for both business process analysis and simulation without transformations and simulation modeling features are encapsulated in business process sub-processes.

Alternative policies to be evaluated are treated as process variants. Business process management literature suggests that business processes variants are either represented in one large model with conditions or developed in separated models (La Rosa et al., 2017). The former approach yields large models, which are more difficult to comprehend while redundancies of activities across multiple model variants are kept at minimum. The latter approach better shows each individual process variant while maintenance of the separate models is more difficult and the same activities are replicated in multiple process variants.

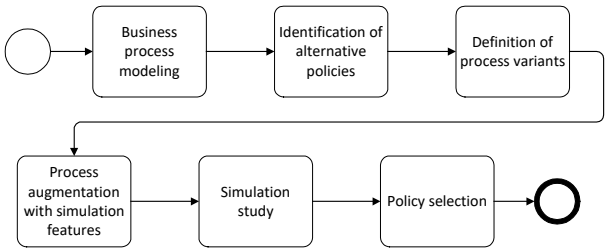

Figure 1: Business process modeling based simulation

Simulation model is implemented by augmenting the business process models. Representation of exceptional events is one of the key aspect in the EPT process. These events imply that exceptions can occur at any moment during the process execution and appropriate measures should be taken to treat them.

It is proposed to model these exceptional event following these steps:

1. Generate entity representing a patients
   a. At this moment generate a Bernoulli random variable indicated whether an exceptional event will occur for this patient;
   b. Generate a random variable representing a time moment when an exceptional event will occur.
2. Create a Collapsed sub-process with a boundary event. This sub-process is used to model exceptions and the boundary event catches exceptions thrown by the exception process. The process execution is interrupted upon caching the event and an exception handling tasks is invoked.
3. Create a sub-process simulating exceptional event
   a. Wait till exception activity delays the sub-process execution till exception should be thrown as indicated by the generated random variable;
   b. If the Bernoulli random variable indicates occurrence of the exceptional event then an exception is thrown.

This procedure is illustrated in Figure 2 showing the main process (left side) and the exception simulation process elaborated in the sub-process (right side).

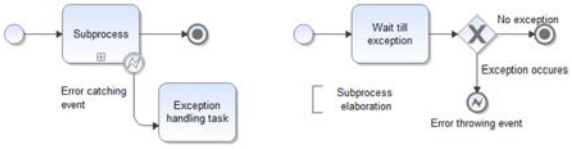

Figure 2: Boundary event in BPMN.

CASE STUDY

The simulation modeling is used to evaluate EPT policies at a large hospital in Latvia. This hospital treats about ectopic pregnancy cases annually. Due to long entrenched policies, patients requiring EPT are hospitalized despite ample evidence that this approach is costly and provides few benefits to the patients. The aim of this simulation study is to provide preliminary evidence that the ambulatory treatment is preferable in majority of cases. Although the hospital is ISO certified, neither business process modeling nor simulation have been previously used in process analysis and improvement

Process Model

The general treatment process introduced in Section 2.1 is mapped using BPMN (Figure 3). The process starts with a doctor visit and regular blood testing and ultra sound investigation for any patient regardless her condition. Ectopic pregnancy is diagnosed as a result of this testing to around 2% patients and the doctor decides on pursuing medical treatment or proceeding with surgery. Surgery is beyond scope of this paper and the

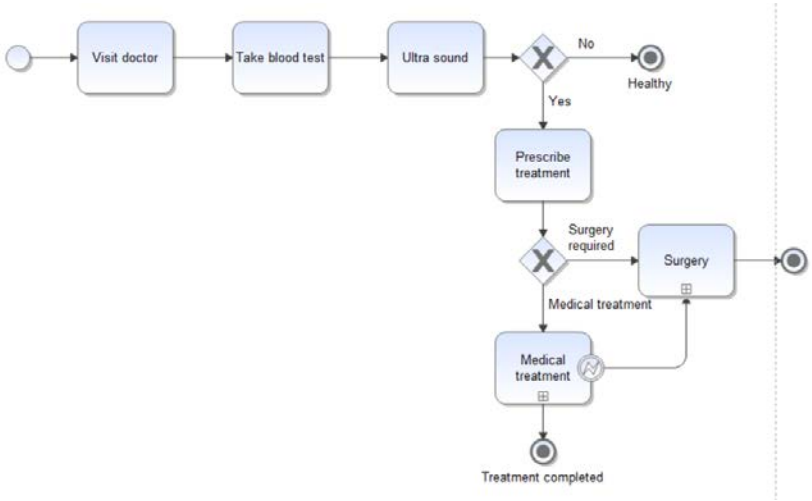

Figure 3: EPT process.

further investigation focuses on medical treatment. The medical treatment is represented as a sub-process in the overall model and it is also indicated that in the case of unsuccessful medical treatment surgery still may be required.

The medical treatment requires continuous observations of patients who are required to have regular blood tests to check treatment efficiency and potential side effects. Medical staff uses test results to decide on further actions. During the treatment process, patients can experience sudden pain. If that is a case and the pain is persistent or severe, the patients seek emergency medical assistance. The medical treatment can be provided either ambulatory or at hospital. Currently, the hospital practices hospitalization what allows for greater responsivity. On the other hand, ambulatory treatment often preferred by other medical institutions might be more comfortable to patients and should be less expensive.

Data and Experimental Planning

The objective of the simulation study is to compare policies of ambulatory treatment and hospitalization. Two main performance measures used are treatment cost and waiting time. The treatment cost is comprised of hourly personnel cost, cost of testing aids and materials and infrastructure cost. The study focuses only on cost factors for which differences between ambulatory treatment and hospitalization might be observed and calculation of actual cost of the whole process is intricate and beyond scope of this study. The infrastructure cost (i.e., cost accrued for having a patient in the hospital) is incurred only in the case of hospitalization. In the case of ambulatory treatment, there could be extra costs of providing emergency treatment in the case of pain. The waiting time is a time spent by patients waiting to see doctor or nurse. Even if appointments are scheduled, there are frequent delays causing patients to experience anxiety. It is assumed that scheduling difficulties are mostly experienced in the case of ambulatory treatment (i.e., if a doctor is late a hospitalized patient does not always need to leave her premises).

Two main experimental factors are considered: 1) medical staff availability; and 2) frequency of pain events. The medical staff availability is associated with the waiting time. The frequency of pain events affects a need for additional and emergency care. The full factorial design combining policy, medical staff availability and frequency of pain events is considered. Simulation is performed for a time-span of one year with random patient arrivals resulting in about 300-400 cases of medical treatment. The business process and simulation models are developed using iGrafx Process.

Data gathering if performed in three steps:

1. Process mapping;
2. Analysis of medical records;
3. Literature data and indirect evidence.

During the process mapping, duration of procedures and their costs are determined. Analysis of medical records yields data about number of patients, frequency of exceptional events (e.g., pain and rupture) and treatments used. These data also yielded interesting insights about medicine taken by different patients and other medical practice what are beyond direct interest of the simulation study. Unfortunately, there were no data about medical staff availability. Indirect observations were used to provide estimates for these data and they were treated as experimental factors to evaluate impact of the assumptions made on the simulation results.

The values of experimental factors considered are reported in Table 2. It is assumed that the low and high values of availability for the ambulatory treatment are lower than for the hospitalization policy. The frequency of pain percentage means the percentage of patients experiencing pain. A single patient can experience pain multiple times.

Representation of Treatment Policies

The medical treatment sub-process of the overall EPT process is further elaborated (Figure 4). Since there are only two policies to be evaluated, it is decided to model

both process variants, namely, ambulatory treatment and hospitalization in a single business process. Initially, a common part of the process is modeled. The general idea of the process is that current condition of a patient is evaluated, medicine is taken and new tests are performed to benchmark treatments outcomes. If treatment is not successful it is repeated but no more than two time. Otherwise the patients enter continuous monitoring process and hopefully successful pregnancy.

Table 2: Values of experimental factors.

Policy	Factor	Low value, %	High value, %
Ambulatory treatment	Availability of medical staff	50	75
Hospitalization	Availability of medical staff	75	90
Both	Frequency of pain events	5	20

The common part is supplemented with the observation branch, which simulates exceptional events occurring during the treatment. These exceptional events are pain occurrences and rupture. The exceptions simulation sub-process is shown in Figure 5. If rupture occurs, this event is captured in the overall EPT process and lead to surgery. If pain is observed, this event is captured in the medical treatment sub-process. The exception simulation process is designed following the approach established in Section 3. For every patient (i.e., transaction in the simulation model), potential occurrence of pain or rupture is evaluated upfront. That includes determining whether the exception should be thrown and when. The rupture and pain activities use this information to decide whether and when to throw an exception and to interrupt the normal flow of the medical treatment process. The exceptions simulation sub-process is not necessary for communicating the business process model with stakeholders but is introduced for simulation modeling purposes.

Refinement of the medical treatment process also includes specifying the pain treatment procedures, which are different depending on the policy. Pain treatment can be accommodated as a part of the overall treatment for hospitalized patients. However, emergence measures might be required for patients having ambulatory treatment. That includes an extra visit to the hospital probably using emergency care services. The pain treatment branch is merged with the main branch at Take Day 4 Blood Test activity. That is a simplification to make model better comprehensible because the pain treatment can occur at every stage of the process.

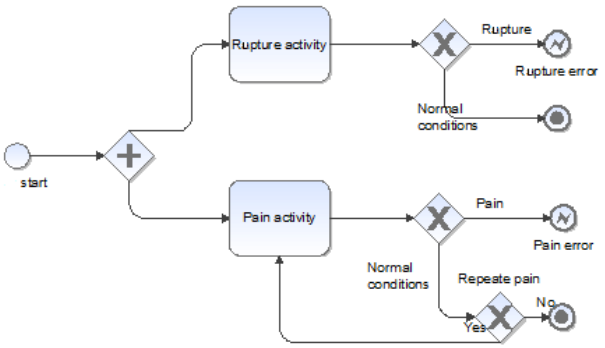

Figure 5: The exception simulation process.

EXPERIMENTAL RESULTS

Simulation experiments are carried out according to the experimental design. The waiting time and cost performance measures for each experiment are reported in Table 3. The cost is expressed in relative units taking hourly rates as the basis. The results indicate that as expected the waiting time is higher in the case of ambulatory treatment and cost is higher in the case of hospitalization. The ambulatory treatment yields slightly higher personnel cost because of involvement of emergency services. However, cost of infrastructure is almost 75% of the total cost making hospitalization an unviable approach according to the cost measure. Medical staff availability has significant impact on waiting time but does not affect cost (because measures to ensure higher availability are not taken into account). The impact is similar for both policies. The pain level influences both waiting time and cost because patients need to take more procedures (and probability of waiting is higher) and additional treatments require

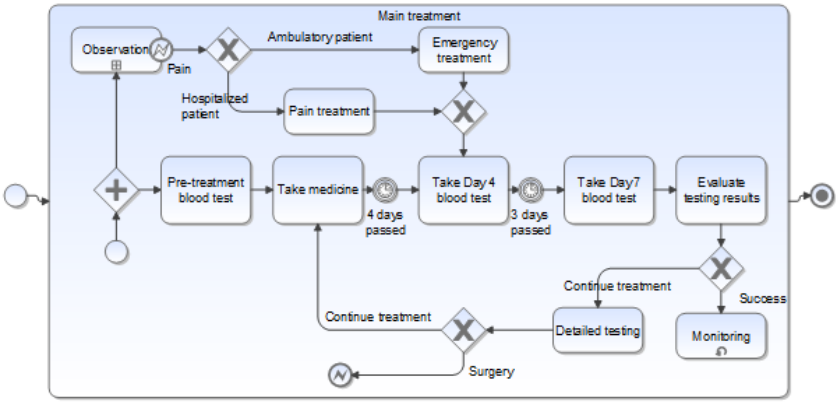

Figure 4: Elaboration of the medical treatment sub-process.

additional personnel hours. Figure 6 shows the waiting time and cost performance measures averaged over all experiments. It confirms the finding that switch to the ambulatory treatment would result in major cost savings. The waiting time increase and the resulting increase in anxiety could be addressed by improving medical staff scheduling and proving extra assurances to patients that their concerns will be addressed in a timely manner.

Table 3: Simulation results.

#	Treatment	Pain level	Availability	Waiting time	Cost
E1	Ambulatory	Low	Low	1.06	57
E2	Ambulatory	Low	High	0.43	57
E3	Ambulatory	High	Low	1.2	63
E4	Ambulatory	High	High	0.51	63
E5	Hospitalization	Low	Low	0.36	188
E6	Hospitalization	Low	High	0.18	188
E7	Hospitalization	High	Low	0.37	191
E8	Hospitalization	High	High	0.19	191

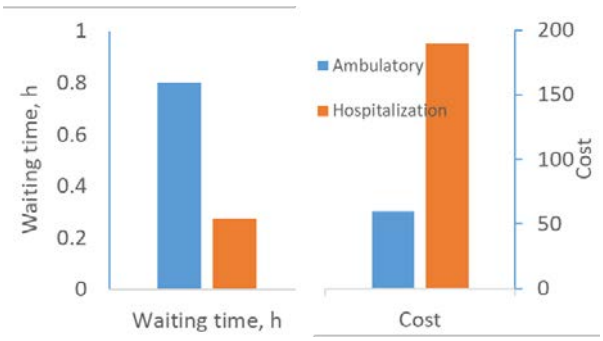

Figure 6: Waiting time and cost depending on policy.

There are some concerns that in the case of the ambulatory treatment some patients would not take medicine as apportioned or violate other treatment requirements. That could result is more frequent pain events. First and foremost this could be alleviated by rising patient awareness and improved communication. From the simulation perspective, this issue is addressed by additional experimenting on waiting time dependence on frequency of pain events (Figure 7). This time availability is 75% for both policies and frequency of pain events is varied from 1% to 30%. It shows that the waiting time increases depending on the frequency of the pain events in the case of the ambulatory treatment. However, this increase is highly variable.

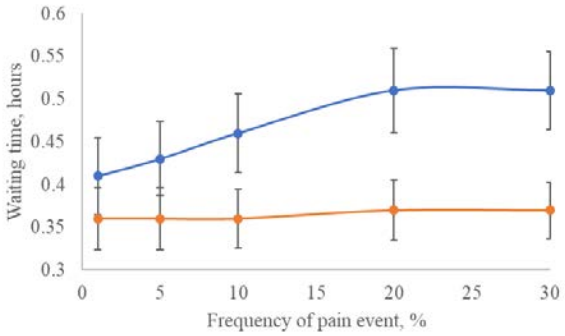

Figure 7: Waiting time dependence on frequency of pain events with 95% confidence bounds provided.

CONCLUSION

The paper has presented business process modeling based simulation of healthcare processes. In order to introduce business process modeling and simulation as a decision-making tool, it is required to use modeling techniques attainable for different stakeholders. The simulation modeling should justify the associated effort and to provide persuading evidence of a positive effect of process improvement initiatives suggested. In order to achieve that business process simulation is used without transforming business process models into platform specific simulation models or relying on custom development. The simulation specific features are encapsulated as sub-processes. The BPMN event handling features enable for representation of exceptional events characteristic to healthcare processes. The particular healthcare process analyzed in this paper is the EPT process. The objective of the analysis is to compare ambulatory treatment and hospitalization. The simulation results show that from the cost perspective the ambulatory treatment is more efficient. However, this policy also yields higher waiting times what might be negative for patients' well-being and treatment efficiency. These results imply that transition from one policy to another should be accommodated with extra effort to provide timely consultations and relief to patients treated ambulatory.

The simulation results confirm conclusions made in medical literature. However, it was important to highlight these differences for the particular hospital to persuade decision-makers. The business process model was developed jointly with experts from the hospital and this approach was confirmed to be beneficial for validating the model and communicating the modeling results.

The paper's limitations are that not enough data are available to assess all parameters of the simulation model and process simulation has limited scope to evaluate treatment outcomes. Particularly, there is limited data available on medical staff availability what is a major parameter in the study. Additionally, the healthcare process redesign is significantly influenced by medical and human considerations, which are not always represented in the simulation model. The

simulation modeling results can be used just as an additional factor for weighting adoption of specific healthcare policies.

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