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APPLICATION OF PREDICTIVE SIMULATION IN DEVELOPMENT OF ADAPTIVE WORKFLOWS

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ABSTRACT

Context aware workflows are adapted to changing circumstances to meet their execution performance requirements. Adaptation can be performed reactively or proactively. Predictive or runtime simulation can be used to adapt workflows proactively. This paper proposes an approach for using the predictive simulation in improving efficiency of customer service workflows. The predictive simulation is invoked during the workflow execution to evaluate expected workflow performance in the current context and to adapt workflow execution accordingly. Efficiency of the predictive simulation is evaluated experimentally using an example of the digital service design at the museum. It is shown on the basis of simulation results that the proactive adaptation is more efficient than the reactive adaptation, especially, in the case of high visitor flow.

1 INTRODUCTION

Advanced computational techniques such as computational intelligence, data mining and simulation increasingly find applications in consumer-oriented information technologies as consumers expect customized and context-aware solutions. The adaptive and context aware workflows (Smanchat, Ling, and Indrawam 2008) are frequently used to provide process-oriented services specifically tailored to the current operating circumstances. Adaptive workflows are used to handle exceptions and changes occurring during the workflow execution (Muller, Greiner, and Rahm 2004). Different techniques can be used to support dynamic and adaptive workflows (Kammer et al. 2000). Recently techniques such as case-based reasoning (Minor, Bergmann, and Görg 2014) and process mining (Chen, Li, and Yang 2012) have found applications in this area.

The context awareness is built-in into the workflow during the design time or dynamically evaluated during the workflow execution at runtime. The runtime adaptation can be performed either reactively in response to changing circumstances or proactively in anticipation of changes. Simulation has been used in workflow design and in evaluation of workflow adaptation at the design time (Kamrani, Ayani, and Moradi 2012; Narendra 2004) while there are few applications of simulation in workflow adaptation at the runtime. In the case of runtime adaptation, simulation is performed in real-time for every adaptation decision to be made and actual workflow and context measurements are used as they become available. The runtime simulation has been shown effective in construction and manufacturing industries. Dalal, Groel, and Prieditis (2003) use the real-time decision making using simulation in flexible manufacturing systems. Actual and near real-time data are often used to improve accuracy of simulation (Rozinat et al. 2009) or to design complex simulation models (Wang et al. 2011). A similar approach is taken by Song and Eldin (2012) where real-time tracking information is used to improve predictive capabilities of simulation models. A review of real-time decision-making using simulation in manufacturing is provided by Yoon and Shen (2006).

This paper proposes to use simulation for runtime adaptation of customer service workflows according to the current execution context. It is assumed that a customer service workflow should be able to cope with the customer flow of varying intensity, and there are multiple alternative service delivery options. The workflow performance is measured by both the throughput rate and customer satisfaction. At the design time, the customer service workflow is modeled allowing for different execution alternatives at the runtime. Simulation can be used at the design time to identify the most viable alternatives for implementation. At the runtime, the workflow execution context and performance are measured, and simulation is invoked during the workflow execution to predict workflow evolution and to make adjustments if necessary. The paper describes a general approach for application of predictive simulation in workflow adaptation and defines ways to integrate predictive simulation models in the workflow model. As an illustration of the approach proposed, predictive simulation is applied in a case study. The case study presents workflow design for an interactive museum exhibition. Efficiency of proactive workflow adaptation relative to reactive adaption is experimentally evaluated.

The rest of the paper is organized as follows. Section 2 introduces the simulation based workflow adaptation approach. Section 3 describes a case study based evaluation of this approach. It includes description of the case study and discussion of the workflow development at the design time while the main attention is devoted to experimental evaluation of efficiency of the predictive simulation. Section 4 concludes.

2 APPROACH

A customer service delivery is defined in a form of business process model. It is implemented using a workflow management system. During the process execution, customers interact with the workflow management systems as well as with physical objects. The workflow management system is context aware implying that its behavior can be adapted to changing circumstances such as customer flow intensity measured by sensors, customer preferences in a form of devices used and others. The workflow can be adapted by changing the process logics, altering customer interactions with the system and other means.

The context aware workflow management system is based on the workflow reference model (Hollingsworth 1995). The reference model is extended to include simulation components (Figure 1). The workflow model defines the process execution logics including different alternative pathways for completing the workflow. The design time simulation component is used to identify the most promising alternatives and to evaluate the workflow before its deployment. The workflow engine executes workflow's instances, and the execution is monitored by the workflow monitoring component. Besides monitoring the workflow's characteristics, the workflow execution context is also monitored. These data are fed into the runtime simulation model, which is used to make adaptation decisions in real-time. The workflow engine changes the process execution accordingly and modifies the workflow presentation in the client if necessary. The workflow instances can be adapted reactively and proactively. The reactive adaptation implies that the context dependent adaptation rules are incorporated in the process definition and are dynamically involved during the workflow execution if context changes have been observed. The proactive adaptation implies that runtime simulation is used to predict potential changes in workflow execution performance depending on the current context, and the workflow adaptation is performed in advance based on the predictions.

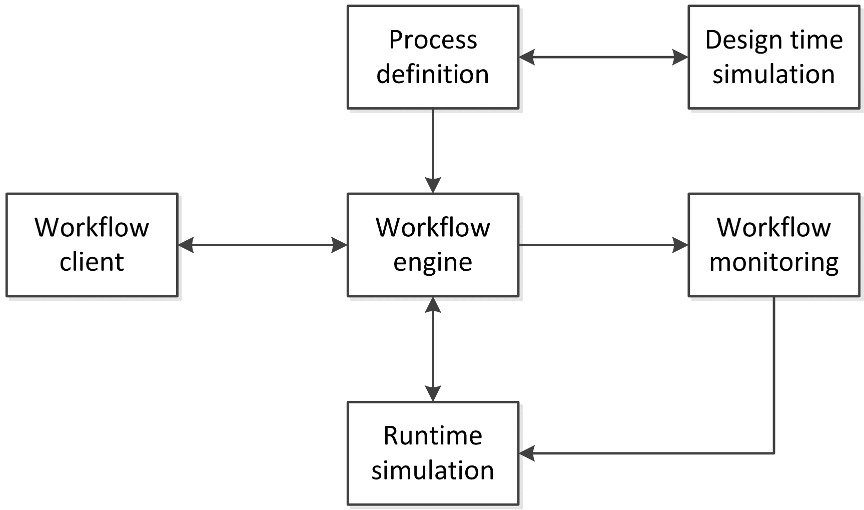

Figure 1: Integration of simulation components with the workflow management system.

The workflow is modeled using BPMN (OMG 2012). There are several ways context dependent adaptation can be represented in the workflow models: a) calculation of attributes of the flow elements (e.g., tasks, gateways, events); b) decision-making at the complex gateway; c) throwing a regular event; and d) throwing an attached event. The runtime simulation is associated with conditional and error events. That implies that during the workflow development it is indicated that a simulation model will be invoked to calculate the workflow execution characteristics. Figure 2 illustrates association of the runtime simulation with the complex gateway and the attached event.

Given that there could be a large number of adaptation alternatives in the workflow model, the design time evaluation of all alternatives is impractical. Therefore, at the design time the number of alternatives can be narrowed down by using analytical evaluation and the design time simulation is performed only for the selected alternatives.

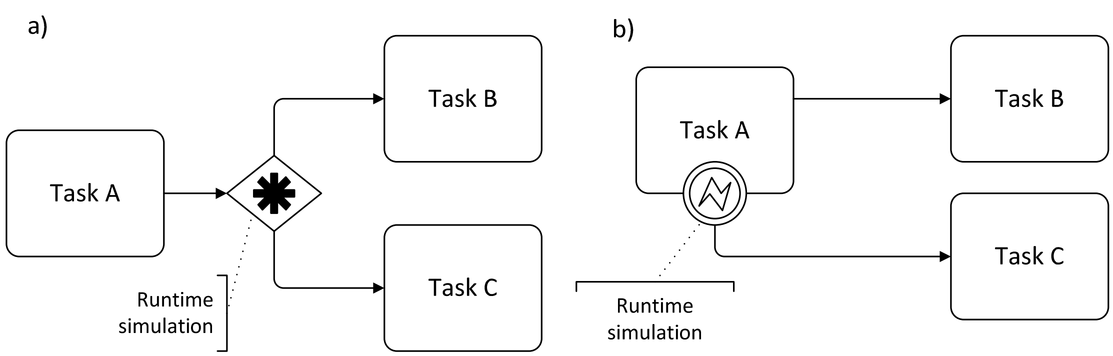

Figure 2: Incorporation of runtime simulation models into the workflow model using a) complex gateway; and b) attached event.

3 APPLICATION

A sample case is used to demonstrate application of the predictive simulation in workflow adaptation and to evaluate its efficiency. The evaluation is performed by simulating the customer service developed in the case.

3.1 Case Description

In this case, an interactive customer service workflow is designed for a museum. The museum offers to visitors several digital expositions and interactive services as a part of the overall exhibition. One of these interactive services is a photo corner where the visitors can make retro styled pictures of themselves and take away the pictures as memorabilia. During the design stage of the Photo Corner service, one of the main concerns was to avoid excessive queuing to get access to the service because that would significantly affect the overall visitor experience. Therefore, different alternatives for providing the service and keeping the visitors satisfied are investigated.

The main steps of the process are receiving service usage instructions, process setup, making photos, decorating photos and delivering photos. Different alternatives for conducting these steps are available for implementation (Figure 3). The visitors receive instruction about using the Photo Corner upon entering the exhibition. The instruction can be received in a form of on-screen instructions, oral instruction by a museum assistant or virtual assistant. The `Start photo session` event initiates the photo session. The initiation task may include different setup or registration procedures. The visitor can be requested to scan her ticket, the ticket can be checked manually by the museum assistant or no specific initiation activities are required. The visitor dresses-up for the photo scene and takes photos. The photos made are displayed to the visitor who can add different visual effects to the photos and send the photos to selected outlets (e.g., printing center, photo sharing websites, e-mail). The task also includes the final delivery of the photos to the visitor at the museum printing center.

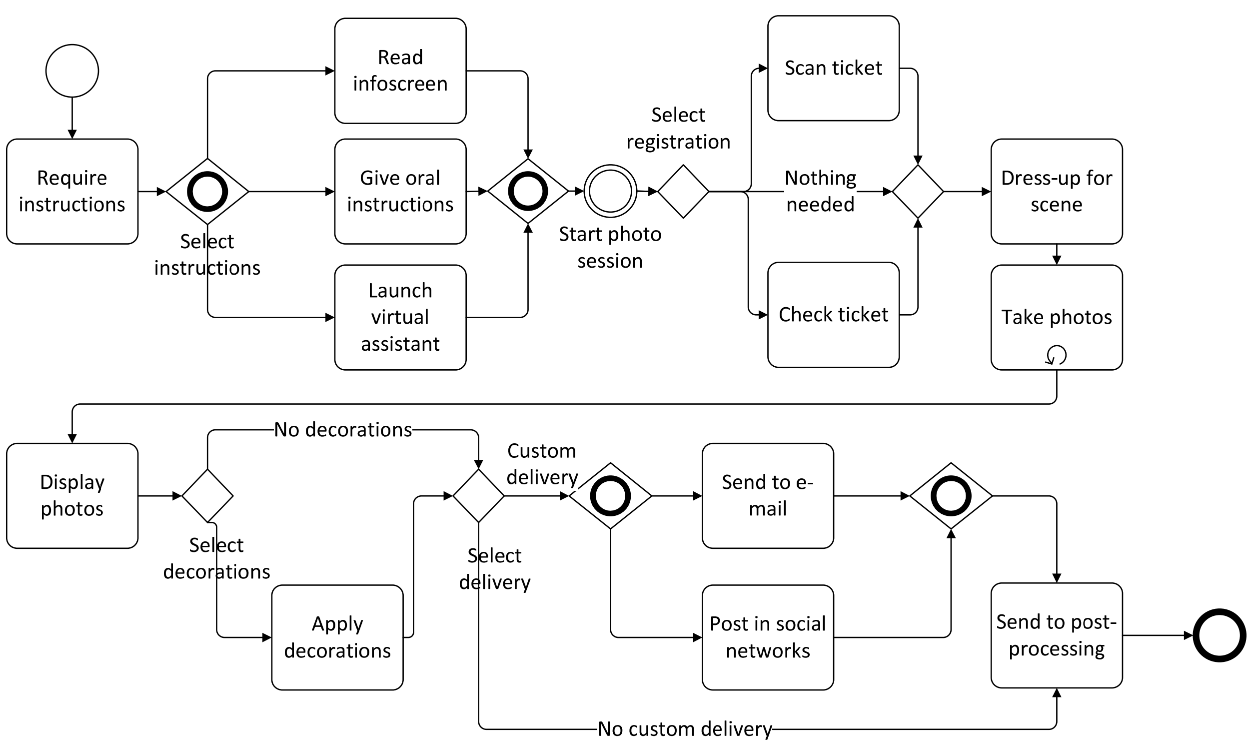

Figure 3: The expanded process model for the Photo Corner service.

It is assumed that the different alternatives selected have varying impact on the process performance and customer satisfaction. The process showing all potential alternatives is referred as to an expanded process. The expanded process usually is not implemented as a whole but only the alternatives providing the best balance among the process performance, customer satisfaction and the implementation cost are implemented.

3.2 Design of Experiments

The workflow development goal is to establish an efficient Photo Corner service. The experimental objectives are: 1) to identify the most appropriate workflow implementation alternatives; and 2) to compare efficiency of the reactive and proactive runtime adaptation.

The experimental studies are performed in two stages: 1) design time evaluation; and) run-time evaluation. At the former stage, the expanded process is evaluated to identify alternatives for implementation. At the latter stage, the workflow established is simulated. It is simulated using either reactive or proactive approaches to simulation based process adaptation.

The workflow performance is measured using the average waiting time in minutes for all visitors of the museum W and customer satisfaction S. The workflow execution context is defined by the number of customers arriving at the exhibition. That is captured by a sensor installed at the exhibition entrance. The adaptive behavior of the workflow depends upon the number of visitors currently waiting for the service q. If the q exceeds a certain threshold value Q then the adaption is performed.

The expected workflow performance both at the design time and at the runtime is evaluated using simulation. Two experimental factors are considered: 1) customer arrival rate λ (customers per hour); and 2) the threshold Q (number of customers). The threshold actually is a control variable, which can be set to improve the workflow performance. The customer arrival flow is modeled using an exponential distribution. The task execution uncertainty is represented using a lognormal distribution. The task execution durations are reported in Grabis (2013). At the design time, the museum is simulated for one month. 100 replications are performed. The same simulation settings are used to evaluate the workflow adaptation at the runtime. In the case of reactive adaptation, the workflow execution is simulated and the adaptation mechanisms is invoked according to the workflow monitoring results. I the case of proactive adaption, the runtime simulation model is executed for every visitor to predict the required adjustments.

3.3 Design Time Evaluation

The design time evaluation was performed to limit the number of workflow execution alternatives. Its detailed results were published in Grabis (2013). The analytical evaluation and discussions with the stakeholders yielded two workflow implementation variants named as basic and advanced. In the basic variant, all gateways were removed from the process leaving just a sequence of tasks. These tasks include Read infoscreen, Nothing needed for registration, No decorations and No custom delivery. The runtime adaptation is not possible for this variant. In the advanced variant, the only named gateway retained was Select delivery mode, and the runtime adaptation can be made at this gateway. The basic and advanced variants were simulated (not shown here) and both alternatives yielded satisfactory performance. The advanced variant (Figure 4) is retained for further investigation.

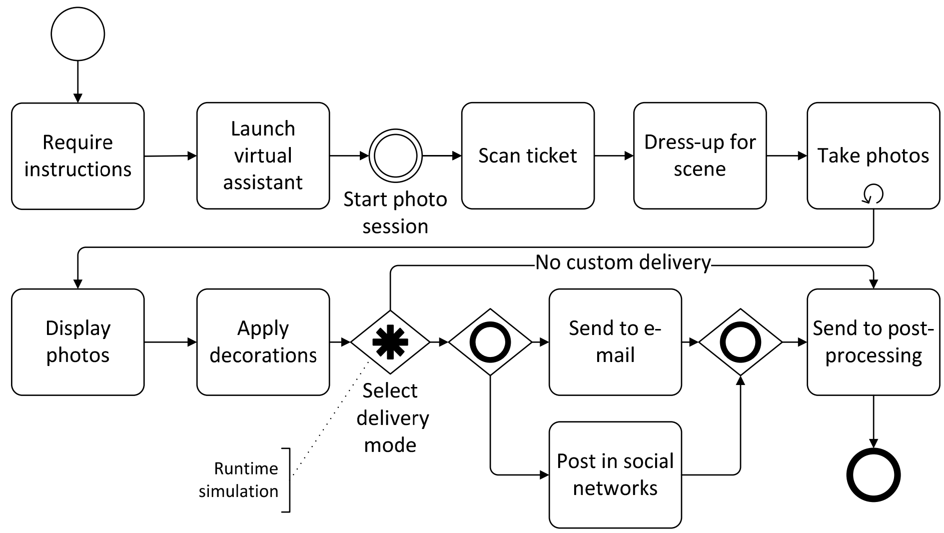

Figure 4: The advanced Photo Corner service workflow variant.

3.4 Run-Time Adaptation

As the result of the design time evaluation, the workflow shown in Figure 4 is established for further investigation to appraise the adaptation approaches. Reactive or proactive adaptation takes place at the complex gateway `Select delivery mode`. The selection between `No custom delivery` and `Custom delivery` is made at the gateway. If the custom delivery alternative is selected than the full service is provided what is more preferable from the visitor satisfaction point of view. The adaption mechanism is as follows:

1. Reactive adaptation – the number of visitors in the queue waiting to use the Photo Corner service is monitored and if its current value exceeds the threshold the workflow is executed along the `No custom delivery` alternative and along the `Custom delivery` alternative otherwise.
2. Proactive adaptation – the runtime simulation model is executed for every visitor to select between the `No custom delivery` and `Custom delivery` alternatives. The selection for the *i*th visitor is denoted by x_i, and $x_i = 1$ indicates selection of the `Custom delivery` alternative and $x_i = 0$ refers to selection of the `No custom delivery` alternative. The runtime simulation is performed for the next hour of the museum operations and the number of replications $R = 100$. The selection is made for every *r*th replication and $x_i = 1$ if $R^{-1}\sum_{r=1}^{R} x_{ir} \geq 0.5$. In every replication, x_{ir} is set to zero if the current value of q exceeds threshold and is set to one if otherwise.

For the given Photo Corner service, the customer satisfaction S is measured as a ratio between visitors receiving the full service and the total number of visitors.

The experimental results are reported in Table 1. Generally, higher threshold value and using the proactive approaches tends to favor providing the full service. The reactive approach strongly depends upon the threshold. Controlling the threshold value allows reducing the waiting time at the expense of decreasing ratio of the visitors receiving the full service. In the case of high flow, the ratio of visitors receiving the full service decreases to 29% and the waiting time is also unacceptably long implying that other means for improving the customer service should be considered. For the low flow of visitors, the reactive approach has better waiting time performance while the proactive approach has higher ratio of visitors receiving the full service. In the case of high flow, the proactive approach yields significantly better waiting time performance and the customer service level is comparable with the reactive approach.

The proactive approach provides better waiting time performance in the case of high flow because runtime simulation allows identifying the queue build-up in advance and switches to the `No customer` delivery alternative before the queue exceeds the threshold. That is illustrated in Figure 5, where the results of the proactive and reactive approaches are compared for a single simulation replication. It can be observed that the queue regularly exceeds the threshold value. That is very often caused by some visitors taking exceedingly long time to complete the process. The assistance should be provided in these situations. The predictive simulation is not always accurate. That can be observed for the 35th visitor when the proactive approach fails to predict to queue increase.

Table 1: Experimental results (95% confidence intervals are given below the measure).

Q	*λ*	Reactive		Proactive	
		W	*S*	*W*	*S*
2	6	35 ±1,7	0,29 ±0,02	28 ±1,7	0,26 ±0,02
2	4.6	25 ±1,2	0,53 ±0,03	23 ±1,2	0,49 ±0,03
2	2.4	11 ±0,7	0,91 ±0,02	15 ±1,3	0,95 ±0,01
4	6	56 ±2,2	0,39 ±0,03	45 ±1,8	0,35 ±0,03
4	4.6	44 ±1,9	0,62 ±0,03	38 ±1,8	0,62 ±0,03
4	2.4	14 ±1,4	0,98 ±0,01	15 ±1,6	0,99 ±0,00

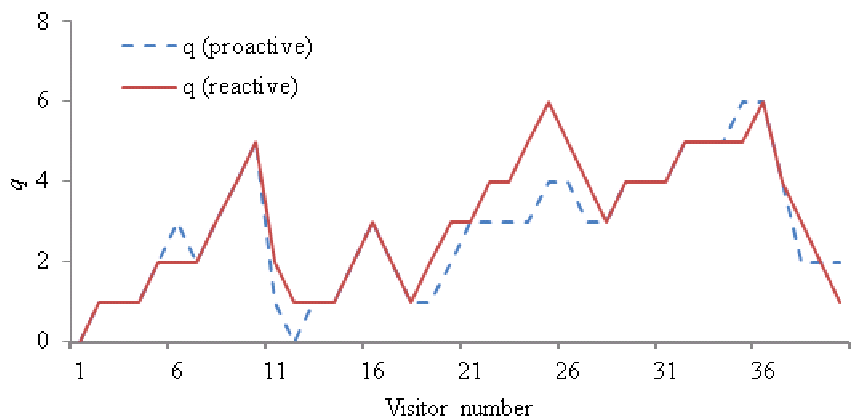

Figure 5: Comparison of queue dynamics for a single replication, *Q*=2 and *λ*=4.6.

4 CONCLUSION

The runtime simulation model has been used to predict workflow execution performance for the customer service system at the museum. The prediction results are used to adapt the workflow execution to the current context describing the current number of visitors at the museum. The predictions based proactive adaptation is shown to provide better results than the reactive adaptation. It has to be noted the adaptation is achieved by varying the service delivery mode. This approach cannot be applied to all kind of customer service systems, and wider implications on the customer satisfaction should be evaluated.

Design time and runtime simulation models were developed and run using different modelling environments. The design time simulation models were built using iGrafx Process while the runtime simulation model was custom developed. During the workflow execution, the runtime simulation can be integrated with the workflow management system as an external service. The runtime simulation must take into account the time available for executing simulation runs. That was not an issue for the current application but is one of the most important concerns for many other applications. The complexity and computational requirements would increase significantly if multiple simulation models are used and they are mutually interdependent. The same also applies to design time simulation of adaptive workflows. Many alternatives might results in an intractable design of experiments and traditional methods of design of experiments are difficult to apply for dealing with process execution variants.

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