On the Prediction of the Mutual Impact of Business Processes and Enterprise Information Systems

Robert Heinrich, Barbara Paech

Institute of Computer Science, University of Heidelberg
Im Neuenheimer Feld 326, 69120 Heidelberg, Germany
{heinrich, paech}@informatik.uni-heidelberg.de

Abstract: Frequently, the development of business processes and enterprise information systems (IT systems) is not well aligned. Missing alignment of business process design and IT system design can result in performance problems at runtime. Simulation is a promising approach to support the alignment of the designs by impact prediction. Based on the predicted impact, the designs can be adapted to enable alignment. However, in current simulation approaches, there is little integration between business processes and IT systems. In this paper, we present a simulation-based approach to predict the impact of a business process design on the performance of IT systems and vice versa. We argue that business process simulation and IT simulation considered in isolation is not an adequate approach as this neglects the mutual impact on workload distribution. Furthermore, we sketch a solution idea to adequately represent workload distribution in simulation.

1. Introduction

In the development of business processes and IT systems, the non-trivial mutual impact between both is often neglected. Performance problems at runtime such as long IT response times, long process execution times, overloaded IT systems or interrupted processes often result from missing alignment of business process design and IT system design. For example, if an IT system is invoked by too many actors in a process, its response time will increase or the IT system might even not be available any longer. As a result, the process is impeded or even interrupted. Simulation is a powerful approach to predict the impact of a business process design on the performance of IT systems and vice versa. Business process design and IT system design can be aligned by making adjustments based on the predicted impact.

Simulation approaches are widely used in the business process domain as well as in the IT domain. In the business process domain, simulation is applied to predict business process performance and financial impact (e.g. [HJK97]). In the IT domain, computer network simulation is used to estimate the performance of network topologies. Moreover, software architecture simulation is applied to evaluate the performance of component-based architectures (e.g. [BKR09]) as well as service-oriented architectures (e.g. [Sav12]). These approaches are adequate to predict the performance of business processes or IT systems in isolation as they are focused on a certain domain. Currently, there is little integration between the business process domain and the IT domain in simulation approaches. However, integration is required to predict the impact of one domain on the other. In literature, there are few approaches (cf. [Pai96], [GPK99], [Bet12]) concerned with the alignment of business processes and IT systems via simulation. These approaches attempt to address missing alignment by exchanging information between isolated simulations but do not consider the mutual impact of business processes and IT systems in detail.

In line with these approaches, we developed a simulation-based approach to predict the impact of a business process design on the performance of supporting IT systems and vice versa. Based on our approach, we discuss how the mutual impact of business processes and IT systems is reflected by isolated simulations and present limitations of the approach. Moreover, we propose the integration of business processes and IT systems within a single simulation as a solution to adequately represent the mutual impact.

Our approach supports several roles in the joint development of business processes and IT systems using model-based performance simulation. Based on the predicted impact:

i. Requirement engineers can verify in the design phase whether an IT requirement can be fulfilled by a proposed IT system design for a given process design.
ii. System developers can compare proposed design alternatives of IT systems invoked in a given process without implementing IT system prototypes.
iii. Hardware administrators can evaluate the utilization of IT resources such as CPU or hard disk drive for a proposed IT system design or process design.
iv. Business analysts can verify in the design phase whether a process requirement can be fulfilled by a proposed process design and a given IT system design.
v. Process designers can compare process design alternatives without performing a process in practice. The IT system impact is included in the comparison.

The paper is structured as follows: In Section 2, we introduce definitions required to understand the paper. We describe the mutual impact of business processes and IT systems in Section 3. In Section 4, we discuss related approaches. Our approach is presented in Section 5. In Section 6, we describe in detail how to derive an IT usage profile from a business process model. In Section 7, we argue why business process simulation and IT simulation considered in isolation is not an adequate approach to represent the mutual impact of business processes and IT systems in simulation. Moreover, we propose an integration of both simulations. Section 8 concludes the paper and presents future work.

2. Definitions

A *business process* is a “set of one or more linked activities which collectively realize a business objective or policy goal, normally within the context of an organizational structure defining functional roles and relationships” [WMC99]. Each activity within the business process is composed of a set of one or more linked steps. Steps either are performed completely by a human actor – called *actor step*s – or performed completely by an IT system – called *system step*s (or system calls). A human actor performs actor steps lined up in his/her *worklist*. A worklist is similar to a waiting queue of an IT resource (cf. [BKR09]) in which jobs to be processed by the IT resource are lined up. Business processes are typically specified on several levels of abstraction which are composed hierarchically. Processes consist of subprocesses, subprocesses are composed of activities, and activities consist of actor steps and system steps. Hierarchical composition is useful to keep track of large processes. We focus on the level of steps as fine-grained actor steps and system steps are needed to predict the mutual impact of business processes and IT systems in simulation. In Section 3, the mutual impact is discussed in detail based on an example.

A *business process instance* is the "representation of a single enactment of a process" [WMC99]. An *IT system instance* is an executable representation of the IT system design. A business process design P and an IT system design S are *aligned*, if

i. System steps of S are invoked in P, and
for all the process instances P' of P and all the IT system instances S' of S holds:
ii. S' meets the requirements of S when used in P', and
iii. P' meets the requirements of P when uses S'.

Workload is "the amount of work to be done" [Oxf12]. Business process workload determines the amount of process instances that traverse the business process. Often workload is measured in process instances per time unit. Process instances traverse all the actor steps and system steps on a certain path through the process from the process starting point to a process end point. The total time required by a process instance to traverse a system step is called *response time*. The total time required by a process instance to traverse an actor step is called *execution time*. The time needed to traverse an activity within the process or an entire process is named execution time, too. If the workload does not change over time, it is called *time-invariant*. If the workload changes over time, it is called *time-variant*.

The difference in time in which the process instances reach a certain point in the process is called *distance*. The distance in which two process instances start the execution of the process is named *inter-arrival time*. *Workload distribution* refers to the distance between process instances within the process. For example, three process instances can occur with a constant distance (30 seconds) between each other, or they can occur in *burst*s, e.g. all three process instances occur directly after another or even at the same time. In all cases, the workload is three process instances in one minute. While traversing the process, the distance between process instances can vary. Bursts of process instances or gaps between the process instances can emerge.

3. Mutual Impact of Business Processes and IT Systems

In this section, we present a process from practice in order to describe the mutual impact of business processes and IT systems based on an example.

3.1 The Process of Order Picking

Currently, we are conducting a case study to apply the approach presented in the paper in practice. As the case study is not yet completed, we show a simplified representation of the process of the case study as an example in this section.

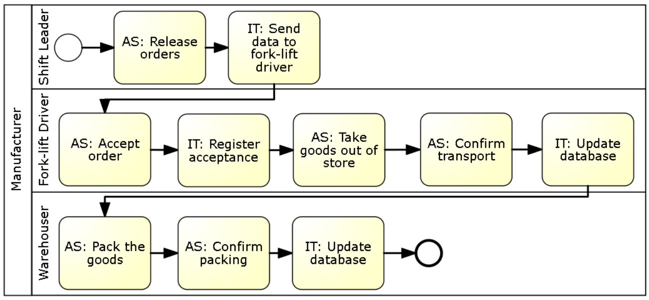

Fig. 1: The Process of Order Picking

Figure 1 shows the process of order picking in the stock of a manufacturer. Goods requested by an order are taken out of the stock and are packed to be transported by trucks. Requested orders have to be packed for transport at the time the trucks arrive. Delays are very expensive in the logistics business. Thus, it is a time-critical process. The process has a starting point and an end point, depicted by circles. Steps are visualized by rectangles with rounded corners. “AS:” denotes actor steps. “IT:” denotes system steps. Arrows visualize the control flow in the process. Lanes represent organizational roles of human actors. For each role, several human actors are available. Thus, orders can be processed concurrently. The shift leader releases the orders that need to be packed. The IT system inserts the order data into a database and transfers the order data from the database to a mobile client of the fork–lift driver. Then, the fork–lift driver accepts the order. The IT system registers the acceptance in the database. The fork–lift driver takes the goods out of the stock. S/he puts the goods to a place where they are packed for transport. Afterwards, s/he confirms the transport. The IT system updates the database and informs the warehouser. The warehouser packs the goods for transport and puts them to a place where they are picked up by trucks later. Then, s/he confirms the transport. Lastly, the IT system updates the database.

3.2 Process Impact on IT System Performance

The IT system performance is affected by the business process design as well as by the business process workload. The business process design specifies for example, which system steps are invoked in the process, when a specific system step is invoked and which system steps are invoked concurrently. Suppose a business process that includes two system steps of an IT system. The IT system performance may differ depending on whether the steps are invoked sequentially or concurrently. The Business process workload represents the amount of process instances that traverse the process, as introduced in Section 2. Process instances traverse all the actor steps and system steps on a certain path through the process. Consequently, the business process workload also determines how often an IT system is invoked. The IT system performance may differ depending on whether the system is invoked once per second or 100 times per second.

3.3 IT System Impact on Process Performance

The IT system performance affects the business process performance twofold. First, if the IT system is overloaded as too many actors invoke the system, it is no longer available for actors in the business process. As a consequence, the execution of the business process is impeded or even interrupted. For example, if the order data cannot be transferred to the mobile client of the fork–lift driver (e.g. as the IT system is overloaded by too many actor requests), the goods may not be available for loading the trucks in time. Second, the response time of system steps may affect the business process performance if their extent is comparable to the extent of the execution time of the actor steps within the process. In this case, the IT system response time may significantly increase the execution time of the entire process or of single activities within the process. See Section 2 for a definition of response time and execution time. For example, in our case study, the transfer of order data to the mobile client of the fork–lift driver lasts up to 40 minutes and more which heavily impairs the process execution time as it extends accordingly.

3.4 Mutual Impact of Actor Steps and System Steps on Workload Distribution

The IT system performance as well as the business process performance is affected by workload distribution within the process. A definition of workload distribution is given in Section 2. According to Mi et al. [Mi08], workload distribution has "paramount importance for queuing prediction, both in terms of response time mean and tail" as it impacts performance significantly. Unequal distribution of workload (i.e. burstiness) often leads to increasing IT response times. The more unequal the workload is distributed, the higher can be the variation in the lengths of the waiting queues. Increased queue lengths result in increased waiting times. Human actors as well as IT resources process steps in a similar manner. They both process steps lined up in their work list or respectively their waiting queue at a certain processing rate. Thus, it is straightforward that workload distribution impacts the execution time of actor steps (i.e. the process performance) in the same way as it impacts the response time of system steps (i.e. the IT system performance). The Workload distribution in the process is affected by actor steps as well as by system steps. For example, assume the FIFO (First-in first-out) scheduling principle. If an actor is already busy when an actor step is to be performed by this actor, the execution of the actor step must wait until the actor is ready to perform the actor step. If an IT resource used in a system step is already busy when it is invoked by an actor request, the request must wait until the resource is ready to process the request. Several other scheduling policies are possible for human actors and IT resources. Waiting times hinder the process instances in traversing the business process. For each step in the process, waiting times may differ from process instance to process instance. Consequently, the distances between the process instances in the process may vary during the process execution. Table 1 shows an example of how the distance between process instances is decreased which may then result in a burst.

Assume there are two actors A1 and A2 of the role fork–lift driver. The waiting queues of both actors have a length of five time units at t_0. There are two process instances I1 and I2 which reach the actor step "AS: Accept order" at a distance of two time units. Both instances put a demand of three time units on the actors. At the point in time t_0 the process instance I1 is allocated to the actor A1, because the queues of both actors have the same length but A1 is the first in line. At the point in time t_2 the process instance I2 is allocated to actor A2, because its waiting queue is the shortest, now (see Table 1). The processing of I1 is completed at the point in time t_7. The processing of I2 is completed at the point in time t_7, too. I1 and I2 reach the system step "IT: Register acceptance" at the same time which, according to Mi et al. [Mi08], can result in a higher mean response time than if the process instances reach the system step with a distance of two time units. Note: according to [HJK97] we assume in this example that each actor has the same processing rate. Different processing rates can be taken into account in the future (cf. [HHP12]).

Table 1: Decreasing the Distance

Time	t_0	t_1	t_2	t_3	t_4	t_5	t_6	t_7	t_8
Actor A1	5 (+3 from I1)	4 (+3)	3 (+3)	2 (+3)	1 (+3)	I1	I1	I1	–
Actor A2	5	4	3 (+3 from I2)	2 (+3)	1 (+3)	I2	I2	I2	–

4. Related Work

We conducted a literature research on approaches that consider business processes as well as IT systems in performance simulation. The literature research included the digital libraries of ACM, IEEE and Springer as well as Google Scholar as sources of publications. There are few related approaches in literature. In analogy to our approach, these approaches use process simulation and IT simulation in isolation as described in the following. In contrast to our approach, related approaches are described on a high level and do not provide details on the representation of the mutual impact in simulation.

The approaches by Serrano and den Hengst [SH05] as well as Tan and Takakuwa [TT07] only predict the impact of IT systems on process performance but do not consider the impact of processes on IT system performance.

We identified three approaches that predict the impact in both directions – process to IT and IT to process. Painter et al. [Pai96] propose a three-layered structure to describe the relationship between business processes, information systems and computer networks. This approach uses business process simulation and computer network simulation in isolation in order to predict process and IT performance. IDEF 3 models that represent information systems are used as a "middle" layer between business processes and computer networks. Giaglis et al. [GPK99] present an approach to support concurrent engineering of business processes and IT and to facilitate investment evaluation. Business process simulation is used to predict business process performance. Computer network simulation is used to depict several alternative network architectures and topologies. IT level analysis provides the link between the business process and computer network levels, although the IT level itself may not be explicitly included in the simulation models. Betz et al. [Bet12] sketch a framework to integrate the lifecycles of business processes and business software for requirements coordination and impact analysis. However, also this approach uses business process simulation and component-based software architecture simulation in isolation.

All these approaches do not clearly define interfaces between business processes and IT systems. Using separate simulations requires the specification of an IT usage profile based on the business process. This is needed in IT simulation to adequately represent the impact of business process design and business process workload on IT system performance as described in Section 3.2. However, none of these approaches describes the specification of an IT usage profile. Performance metrics supported by the approaches are not described. The approaches do not provide enough details to understand how the mutual impact of business process and IT system is represented. Moreover, it is hard to assess their applicability in practice. Thus, we decided to develop our own approach to analyze how isolated simulations represent the mutual impact of business process and IT system. This is described in the following.

5. An Approach to Predict the Mutual Impact

The prediction of the mutual impact of business processes and IT systems requires well defined interfaces between both domains in order to transfer information from one domain to the other. The interfaces are visualized in Figure 2.

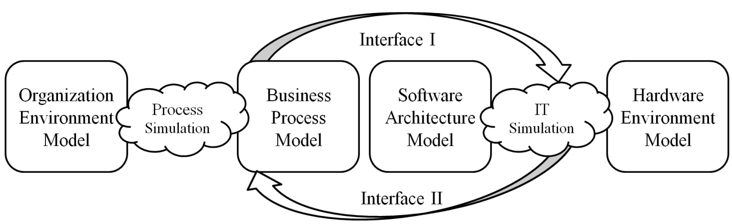

Fig. 2: Interfaces between Business Process Simulation and IT Simulation

The central artifact of our approach is the business process model. The business process model depicts the actor steps and system steps as well as their dependencies. It describes the behavior of the human actors involved in the process and the interaction between human actors and the IT systems. The organization environment model contains information about the human actors in the organization such as their roles or availability. The software architecture model includes information about the software components and their dependencies. The hardware environment model contains information about the hardware nodes the software components are allocated to. Examples of information represented in the models and further details on the simulation concepts we build upon can be found in [HJK97] and [BKR09]. From the business process model, an IT usage profile for the IT performance simulation is derived. The results of the IT simulation are written back to the process model to be available for the process performance simulation. Thus, the IT usage profile and the extended business process model characterize the alignment of business processes and IT systems in simulation.

The approach consists of two parts which are used for different purposes. Part 1: The performance of an IT system is predicted based on a specific IT usage profile derived from a business process model. The prediction output can be used by requirement engineers to verify a proposed IT system design against requirements and by system developers to compare alternative IT system designs. Moreover, hardware administrators can check the utilization of hardware nodes for a proposed IT system design or business process design, and adapt the hardware if necessary. Part 2: The performance of a business process is predicted considering the performance of supporting IT systems. The prediction output can be used by business analysts to verify a proposed process design against requirements and by process designers to compare alternative process designs. Figure 3 gives an overview of the approach.

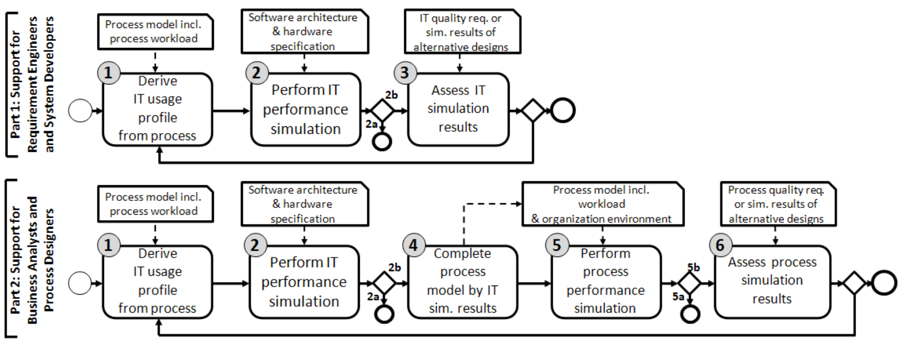

Fig. 3: Overview of the Approach

The single steps of our approach are described in the following ordered by their number.

Step 1, an IT usage profile, which contains information about the usage of the IT system, is derived from the process model (Interface I in Figure 2). This step consists of three substeps detailed in Section 6.

Step 2, IT performance simulation: The derived IT usage profile and the existing software architecture model and hardware environment model are used for IT performance simulation. The models include performance-specific annotations such as IT resource demands (see [BKR09] for details). Based on queueing networks [Bol98], the IT performance simulation predicts the utilization of IT resources and the response times of the invoked IT system steps. The simulation result indicates one out of two possible cases:

a. The IT system is overloaded for the given usage profile. In this case, a stable mean response time of the system steps cannot be predicted. The procedure ends. There are two ways to handle this case. The first way is to reduce the workload of the business process (if it is acceptable to change this requirement) or to revise the process design. The second way is to revise the IT system design (including software design and hardware design).
b. The IT system is not overloaded. In this case, the simulation predicts the mean response time per system step and the utilization (ratio busy/idle) of the IT resources.

Step 3, the output of the IT performance simulation is compared to IT requirements for requirements verification. For example, for each system step the predicted mean response time is compared pair wise to a mean response time requirement. If the requirement is not met, the IT system design or the process design or the requirement has to be adapted. In the case of design changes, the approach (steps 1-3) has to be repeated. Moreover, simulation output can be used to compare design alternatives based on the predicted performance. Part 1 of our approach is necessary as requirements may be missed on the IT level even if all requirements on the business level are met. For example, an actor has finished the business process in time, but s/he is not satisfied because s/he had to wait several minutes for each system answer.

Step 4, the process model is completed by the IT simulation results (Interface II in Figure 2): Actor steps within the process typically last several minutes. The response time of a system step is often in a millisecond range. In this case, there is no need to consider the response time values of the system steps in process simulation as they have only negligible impact on the process performance. In the case that the response time of a system step is in its extent comparable to the execution time of an actor step, it must be considered in process simulation. For example, large database requests, complex calculations or data transmission to mobile systems as in our case study may have a response time of several minutes. So, the response times are annotated to the corresponding system steps in the process model.

Step 5, process performance simulation: The completed business process model is used for process performance simulation together with information about the organizational environment such as the availability of actors. Based on queueing networks, the process performance simulation predicts the utilization of human actors and the execution times of the actor steps within the process. The response times of the IT system steps, if annotated to the process model, are used as predicted in step 2. The simulation result indicates one out of two possible cases:

a. The actors cannot handle the assigned actor steps as there are too many steps assigned. A stable mean execution time of the actor steps cannot be predicted. The procedure ends. There are two ways to handle this case. To revise the process design (e.g. rearrange the steps or allocate more actors) or to reduce the process workload (e.g. reduce the number of process instances).
b. The actors can handle the assigned steps. The simulation predicts the mean execution time per actor step and the utilization (ratio busy/idle) of the actors. Moreover, it predicts the mean execution time of the entire process and of the single activities within the process.

Step 6, the output of the process performance simulation is compared to the process requirements for requirements verification. If the process requirements are not met, the process design, the IT system design, or the process requirements have to be adapted. In the case of design changes, the approach has to be applied again (steps 1-3 and 4-6) to predict the impact of the changes. Moreover, the simulation output can be used to compare design alternatives based on the predicted performance.

The proposed approach allows verifying requirements against a business process and IT system design. If the requirements are not met by the simulation results, there are basically two options: Adapting the requirements or adapting the design of the process or the IT system respectively. The decision what to adapt is highly dependent on the specific context and requires expertise. So our approach cannot identify what is best to adapt. However, our approach provides guidance. For example, if overloaded resources limit performance, our approach shows which resources are overloaded. Moreover, our approach provides decision support by exploring the impact of several design alternatives using performance simulation. Thus, our approach supports the selection of an adequate design out of a set of proposed design alternatives.

Our approach is not focused on a specific simulation tool support. In order to realize our approach, we build upon the existing tool supports of the simulation approaches ADONIS [HJK97] and Palladio [BKR09]. ADONIS enables the simulation of business processes and organizational resources such as actors. Palladio allows the simulation of software architectures on component level and of IT resources.

6. Deriving an IT Usage Profile from a Business Process Model

In this section, we discuss step 1 of our approach in detail using the example of Palladio by describing three substeps necessary to create an IT usage profile based on a process model. The substeps are not specific to Palladio but generally applicable. In Palladio, the interaction between actors and the IT system is described in the form of one or more usage scenarios contained in a usage model [BKR09]. Each simulation in Palladio refers to one usage model. For each usage scenario, a time-invariant workload has to be specified which represents the load on the IT system. The challenge of step 1 is to create usage scenarios and related workload specifications based on a process specification.

As a first substep 1.1, a business process is segmented into subprocesses so that each subprocess can be traversed by process instances without interruptions and has a time-invariant workload specification. The segmentation highly depends on the specific process. One has to consider when a specific part of the process is performed, which parts of the process are performed concurrently and thus may create concurrent accesses to IT resources (concurrent process parts have to be simulated concurrently), and which parts of the process exclude each other and thus have to be simulated separately (e.g. one part is performed during the day, another part is performed at night). For example, suppose a business process consisting of a sequence of three IT-supported activities A, B and C. Each day 1000 process instances start the execution of the process. In the following, we discuss two different cases.

First case: A is performed during the day (8am to 10pm). B consists of calculations the IT system does exclusively at night (10pm to 8am). C is performed the next day (8am to 10pm). Thus, the process is segmented into three subprocesses. Each subprocess covers one of the activities A, B or C. Two separate IT simulations are required. The first simulation covers A and C as two concurrent subprocesses (the day simulation). Although A and C are performed on different days, except for the first and the last day of process execution, every day A and C are performed concurrently. The workload of each subprocess in this simulation is 1000 process instances in 14 hours or on average one process instance every 50.4 seconds. The second simulation covers the subprocess B (the night simulation). The workload of this simulation is 1000 process instances in 10 hours. The simulation can be split as B is executed during the night and A concurrent to C

(A || C) is executed during the day. B and A || C exclude each other. Thus, there are no concurrent IT resource demands between B and A || C.

Second case: B is not executed at night but also executed during the day but only from 8am to 1pm. Concurrent resource demands are possible. Thus, B is a subprocess concurrent to A || C which has to be considered in a simulation concurrently to A and C. The workload of the subprocess of B is 1000 process instances in 5 hours. The second case has to be investigated using the two separate IT simulations A || B || C from 8am to 1pm and A || C from 1pm to 10pm. There is no activity performed during the night. The two separate simulations may result in different mean response times of the same system steps of A and C. Thus, we recommend using the maximum of the two values per system step for further processing. The result of substep 1.1 is a set of subprocesses which have a time-invariant workload and which can be traversed without interruptions.

In substep 1.2, the workload of each system step in the subprocess is determined based on the workload of the subprocess and the control flow of the subprocess (e.g. probabilities of path branches or number of loop iterations). The determination of the workloads of the single system steps is based on the assumption that there is no overload of the IT resources or the actors (i.e. that continuously process instances arrive at the system step in a certain distance). If the assumption is incorrect, it will become apparent in the course of our investigation (see step 2 in Section 5). Depending on the control flow of the subprocess, the workload of each system step within the subprocess is calculated as demonstrated in Figure 5.

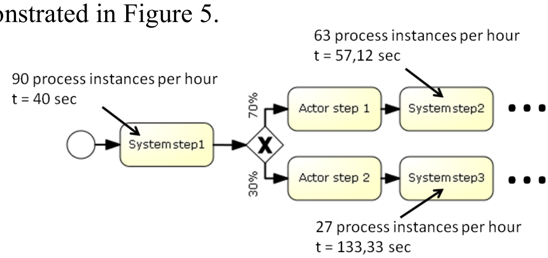

Fig. 4: Determining the Inter-arrival Time

For example, there are three system steps in the subprocess. The subprocess workload is specified in the form of an average inter-arrival time (t) of 40 seconds. Moreover, there is a branch. The probability of one path is 70%. The probability of the other path is 30%. Based on the probability of the path branch, the process instances split up on the paths which results in the inter-arrival times depicted in Figure 5. In the case of parallel steps, there is no distribution. In the case of a loop, the workload adds up depending on the number of loop iterations.

Finally, in substep 1.3, each system step in the subprocess is represented by a usage scenario in a Palladio usage model, which only contains the system step and which is annotated by its specific workload. Moreover, for usage model creation, one has to consider which subprocesses are performed concurrently and which exclude each other as described above. All the system steps of concurrent subprocesses have to be modeled within the same usage model.

7. Discussion of the Approach

In contrast to related approaches, we worked out a detailed description of our approach as presented in Section 5 and 6. This was required to analyze how the mutual impact is represented using business process simulation and IT simulation in isolation. In this section, we discuss how the mutual impact is reflected by our approach and show limitations identified while working out the approach. Moreover, we argue for a new approach that integrates business processes and IT systems in a single simulation.

In our approach, IT system performance is considered as a factor of process performance. The business process model is extended by IT simulation results before process simulation as described in Section 5. Thus, using our approach, IT system performance impacts process performance.

IT simulation requires a specification of the usage of the IT system. Using process simulation and IT simulation in isolation requires deriving an IT usage profile for IT simulation from the business process specification. We described the derivation of an IT usage profile in Section 6. However, the execution of a business process typically lasts several hours or even days. Thus, there may be changes in the workload during the execution, which have to be represented in simulation, too. For example, from 9am to 11am the process is triggered 100 times per minute, and from 1pm to 5pm, the process is triggered 50 times per minute. From 11am to 1pm, the process is not triggered at all, due to a lunch break. As shown in the example, inter-arrival time changes over time. IT simulation approaches typically rely on the strong assumption of time-invariant workloads. Workloads changing over time cannot be mapped to a time-invariant workload without approximation. Approximation usually results in reduced accuracy of the predicted IT response times. We are currently extending Palladio to include time-variant workloads in simulation to address this open issue.

An important finding of the research presented in this paper is that using isolated simulations, workload distribution (e.g. bursts) within the process is not correctly represented in simulations. Workload distribution within the process is only influenced by system steps in IT simulation or by actor steps in process simulation respectively. The impact of steps of the other domain on workload distribution is neglected in both simulations. Thus, in the example in Table 1, the distance between both process instances would not decrease in IT simulation which may result in a distorted response time prediction. Moreover, suppose actors interrupt their work in the lunch break mentioned above. Process instances are stuck in the work lists of the actors and cannot reach the IT resources. As the IT resources keep on processing process instances from their waiting queue during lunch break, waiting queues of IT resources empty during lunch break. This effect cannot be represented in simulation without considering the actor step's impact on workload distribution. As workload distribution may impact the performance significantly, the prediction accuracy of approaches using isolated simulations is limited. Mi et al. [Mi08] showed how big the deviations can be. In an experiment, they observed bursts in workload distribution of an IT system. They compared the response time of a system step in the case of a random workload distribution to the response time of the system step in the case that all the requests are compressed into a single large burst. In case of the burst, they observed that the mean response time is approximately 40 times longer than in random distribution. The 95th percentile of the response times is nearly 80 times longer in bursts. Although this is an extreme example, it demonstrates that one cannot expect accurate simulation results by neglecting workload distribution. As human actors process jobs in a similar manner as IT resources, we expect similar results for actor steps in the case of bursts.

Although the impact of workload distribution on performance is easily comprehensible, to the best of our knowledge the mutual impact of actor steps and system steps on workload distribution was not discussed in literature before. All the related approaches presented in Section 4 do not consider the mutual impact on workload distribution as they use isolated simulations.

Nevertheless, in performance prediction often a rough estimation is sufficient. For example, one wants to check whether a system step lasts a few milliseconds or minutes, or whether a process comes to a standstill because too many steps are assigned to the actors. Therefore, approaches based on isolated simulations are helpful although they have limited prediction accuracy. Thus, our approach is adequate for performance prediction in many cases. For this reason, we currently apply our approach in practice. In those cases where a higher precision is needed, e.g. if there is little distance between requirements and expected performance, another approach is required. We propose the integration of business processes and IT systems within a single simulation as a solution to adequately represent the mutual impact of actor steps and system steps on workload distribution. An integrated simulation seems to be a promising approach, as there are several analogies if we abstract from the different semantics of business process simulation and IT simulation. Both kinds of simulations...

- ... can be built upon queuing networks (queuing theory [Bol98]).
- ... simulate the utilization of resources (human actor resources or IT resources). A human actor resource is the representation of a human actor in simulation.
- ... use a specification of a workflow of actions to be processed by the resources, either in the form of a process model or in the form of an IT usage profile.
- ... use actions that can be composed hierarchically.
- ... use a specification of workload.
- ... acquire and release shared passive resources. Passive resources in a business process are non-IT devices or machines such as a fork-lift. Passive resources in IT systems for example are threads in a thread pool or database connections. They are available in a limited capacity and shared among all process instances.

Palladio seems to be an adequate foundation to be extended by business process simulation concepts. The Palladio meta-model can easily be extended by a process model and an organization environment model, as it is already structured in several sub models on different layers such as hardware layer or software component layer. In contrast to ADONIS, Palladio provides an Eclipse-based open source tool support. A lot of existing simulation behavior can be reused or easily be adapted for the new process elements as actors and IT resource often behave similarly while processing jobs. A first sketch of an integrated simulation of business processes and IT systems as well as tool support is presented in [HHP12].

8. Conclusion

In this paper, we presented a simulation-based approach to predict the impact of a business process design on the performance of supporting IT systems and vice versa. We discussed how the mutual impact of business processes and IT systems is reflected by isolated simulations. We concluded that when using process simulation and IT simulation in isolation, workload distribution within the process is not represented correctly which can significantly reduce the performance prediction accuracy. Even so, our approach is helpful in many cases where rough estimations are sufficient. We argue for an integrated simulation to achieve a higher accuracy as there are several analogies in business process simulation and IT simulation. We are currently extending Palladio by business process simulation concepts in order to realize an integrated simulation of business processes and IT systems. In a case study, we are currently evaluating the feasibility and acceptance of our approach in practice. In the future, we want to evaluate the prediction accuracy of the integrated simulation by comparing it to the approach presented in this paper as well as to data measured in reality.

References

[Bet12] Betz, S.; Burger, E.; Eckert, A.; Oberweis, A.; Reussner, R.; Trunko, R.: An approach for integrated lifecycle management for business processes and business software. IGI Global, 2012.

[BKR09] Becker, S.; Koziolek, H.; Reussner, R.: The Palladio component model for model-driven performance prediction, JSS, vol. 82, pp. 3–22, 2009.

[Bol98] Bolch, G.; Greiner, S.; de Meer, H.; Trivedi, K.S.: Queueing networks and Markov chains: modeling and performance evaluation with computer science applications, Wiley-Interscience, 1998.

[GPK99] Giaglis, G.M.; Paul, R.J.; O Keefe, R.M.: Research note: Integrating business and network simulation models for it investment evaluation. Logistics Information Management, Vol. 12(1-2), pp. 108-117, 1999.

[HHP12] Heinrich, R., Henss, J., Paech, B.: Extending Palladio by Business Process Simulation Concepts, in Palladio Days 2012 Proceedings, ISSN 2190-4782, pp.19-27, 2012.

[HJK97] Herbst, J., Junginger, S., and Kühn, H.: Simulation in Financial Services with the Business Process Management System ADONIS, in Proceedings of the 9th European Simulation Symposium, pp. 491-495, 1997.

[Mi08] Mi, N.; Casale, G.; Cherkasova, L.; Smirni, E.: Burstiness in multitier applications: symptoms, causes, and new models, in Proceedings of the 9th International Conference on Middleware, Springer-Verlag, pp. 265–286, 2008.

[Oxf12] Oxford dictionaries online, Available: http://oxforddictionaries.com/

[Pai96] Painter, M.K.; Fernandes, R.; Padmanaban, N.; Mayer, R.J.: A Methodology for Integrating Business Process and Information Infrastructure Models. WSC, IEEE, pp. 1305-1312, 1996.

[Sav12] Jboss community, Savara, Available: http://www.jboss.org/savara.

[SH05] Serrano, A.; den Hengst, M.: Modelling the Integration of BP and IT Using Business Process Simulation. Enterprise Information Management, 18(6), pp. 740-759, 2005.

[TT07] Tan, Y.; Takakuwa, S.: Predicting the Impact on Business Performance of Enhanced Information System Using Business Process Simulation, WSC, pp. 2203-2211, 2007.

[WMC99] Workflow Management Coalition: Document No. WFMC-TC-1011, 1999.