Visual Simulation for the BPM-Based Process Automation

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Abstract. A graphical standard notation for the analysis and execution of operational business processes is available since 2011 the Business Process Model and Notation (BPMN) 2.0. A new possibility is now established to automate complex, longer-than-average, interdisciplinary process chains including a powerful human task management cost-efficiently. The end-to-end process automation in life science automation demands comprehensive systems integration in heterogeneous, hybrid automation environments. Already at the early stages of the development of such solutions exists a great need for simulations of process execution. The presented simulation solution, interesting also for other target industries, is an important tool to an early staged quality assurance, to a definition of the components related automation demand and a validation of the process model. This visual simulation system shows the potentials of a BPMS-based automation using an animated process model, application simulations of the distributed automation and information systems, controlled video sequences or application screenshots and corresponding detailed information. It supports the argumentation for process-controlled, model-based applications, which transform the currently autonomous sub-systems and isolated applications into an overall system with a comprehensive, reproducible process control and monitoring. This article explains the solution and the impact of the BPM-oriented process simulation.

Keywords: Business Process Simulation, Business Process Automation, Model-Driven Automation, Life Science Automation, Laboratory Automation.

1 Introduction

Nowadays, laboratory processes in the life sciences are often dominated by high throughput applications. In the field of drug discovery for example substance libraries containing hundreds of thousands or millions of substances are tested for their biological activity against chosen targets. This screening results in less than 1% of potential therapeutic candidates for further investigations. Such high throughput applications require a high degree of automation. In the laboratories so called islands of automation are established today, which are able to execute special, but often isolated subprocesses. Extensive preparatory and accompanying subprocesses, like

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method development, storage, maintenance, analytical preparation, evaluation, interpretation and knowledge extraction are usually time-consuming manual tasks, which are insufficiently integrated into the automated processes. Different software systems are applied in each subprocess to control and monitor the process (process control systems - PCS) as well as to capture, manage and process data (Laboratory Information Management Systems - LIMS, Spectroscopy / Chromatography Data Systems - SDS/CMS, Electronic Laboratory Notebooks - ELN, spreadsheets, data visualization and analysis systems, etc.). This situation results in many different interfaces to exchange data.

As an interdisciplinary research institute the Center for Life Science Automation (celisca) at the University of Rostock (Germany) develops high throughput applications for key processes of the life sciences, for example, in the fields of screening technologies and analytical measurement. The high-end system solutions consist of necessary equipment systems, the controlling software, and the professional applications. Innovative solutions are created for more and more complex processes by using modern technologies. Thereby new areas of application are opened up.

The objective of the BPM-based automation approach is a flexible end-to-end automation to control and monitor processes with technologies of modern business process management (BPM). The core component is a specific kind of technology that is particularly suitable to achieve process automation, co-called Business Process Management Systems (BPMS) [1]. This is a new approach in the application field of life sciences. All tasks or subprocesses, which influence the process result, will be integrated regardless of their degree of automation. Fig. 1 shows typical examples of such process components and puts the corresponding devices and systems into the hierarchically structured laboratory automation. Such end-to-end processes are performed across the islands of automation, across the disciplines and organizations. They integrate manual tasks as well as all needed automation and IT systems. Thereby an important challenge is to consider the dataflow in the automation. This is especially significant for the quality assurance and its obligation to prove the compliance with regulations, which is particularly relevant in this field of application.

The model-driven automation approach is based on the standardized business process modeling. For the definition of such business processes the graphical notation standard BPMN (Business Process Model and Notation) has been established in the recent years, which pursues the goal to overcome the understanding gap between IT-specialists, automation engineers and business users [2],[3],[4]. With the BPMN 2.0 published in 2011 a direct executable notation is available. The fact, that the notation is an executable end-to-end integration language as well, is especially helpful to the objective of automation efficiency in R&D laboratories as it allows understandable and easy adaptable complex process models for the immediate process control. The concept presented in [5] has been positively validated over the past two years. During this evaluation the idea of an animated and media supported simulation to demonstrate the potential of the process-oriented approach has been created.

This article describes the developed web-based workflow simulation as a supplementary tool for the development process of the innovative BPM-based process automation. The simulation solution takes into account characteristics of life science applications as well as requirements of automation engineering.

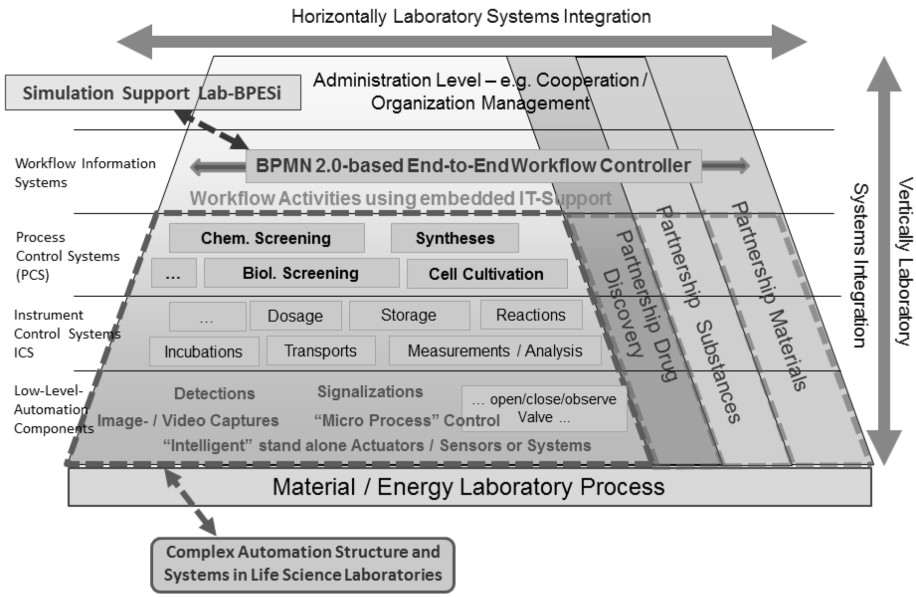

Fig. 1. Application background of the model-driven end-to-end process automation in the life sciences

1.1 Business Process Simulation

Often a simulation component is a substantial part of BPMS [6], [7] either as embedded tool within the modeler or through third-party integration [8], [9]. The second option requires an additional mapping of process model and simulation model as well as simulation skills of people or proper training in simulation analysis [7].

For example, in [8] a mapping algorithm is presented to simulate the flows generated by the BPM tool Netflow in the simulation environment of Arena. Januszczak [9] describes a standard for defining business process simulation scenarios (Sim4BPM), which combine the business process definition and the set of scenario parameters. Simulation models are just one possible consumer of these business process scenario definitions. Therefore, this standard is not based on BPMN. In contrast, the simulation engine L-SIM [10] developed by the Lanner Group uses BPMN diagrams for animated visualizations and quantitative statistics. Waller et al. suggest in [10] resource-related extensions to BPMN. The behavior of resources is often modeled in a simplified manner [7].

A comparison of embedded simulation components of current tools on the market can be found, e.g., in [11], [12]. The pursued objectives of business process simulation within the scope of workflow management are [13], [14], [15], [16], [17]:

- Identification of critical paths and bottlenecks in the resource allocation (prevention of bottlenecks / optimization of cycle times / prediction of resource utilization),
- Determination of the predicted execution time (cycle time, waiting time), e.g., for dimensioning of resources,
- Testing the executable model before deployment on servers to validate the ability of execution of process models (formal correctness and consistency),
- Comparison and evaluation of alternative process configurations, and
- Graphically visualized validation of process models using an animated simulation.

The stochastic, discrete event simulation is most prevalent. It allows an analysis of the dynamic behavior [17]. Often the simulation model is based on the respective system specific meta-model of the BPMS. To simulate a business process more than just a business process definition is needed. It needs also real-time, historical and estimated data values [6]. Such simulation relevant information including times, costs and quantities for single tasks are requirements for the determination of process variables related to the flow and the resources as an answer to the above-mentioned objectives.

1.2 Requirements

The success of the new methods and technologies of BPM as an innovative standardized and at the same time cross-disciplinary approach for workflow automation and systems integration is depending on the acceptance achieved on early stages of process development. During the process development phase the process simulation should be utilized to visualize potentials of the process-oriented and BPM-based automation approach as well as to support the argumentation for process controlled applications. As a result there is the demand for a graphically visualized and media supported validation of the process model using an animated simulation. A helping tool should be provided for a team of developers and professional users to define the specific process behavior and the automation demand. It can be used as a basis for discussions on the support of operational decision processes.

The animated simulation can focus different specific scenarios (e.g., human task support, task-related IT-support, full automation, integration of islands of automation with differentiated degree of integration, quality assurance procedures, etc.) to be optimally adjusted accordingly to the current objective of a presentation. This requires an easy configuration of the underlying simulation model as well as a suitable comprehensible definition language.

The dataflow is not visible in executable process models. Process variables represent data. During the process development phase, however, decisions have to be made regarding the automation of the dataflow, e.g.:

- Who requires which data?
- How has data to be transformed using which kind of resources?

- At which places and when has data to be provided?
- How are data transmitted in respective stages of the process progress?
- Which data are to be captured and in which scope to be protected and archived?

Therefore the integration of the dataflow into the visualization is an essential requirement. Usually a simulation is an execution of a process without any calls of real services or external applications. Thereby return values of the integrated services are predefined. This way an analysis of the dynamic process behavior is only possible if errors of external systems can be ruled out. This is a useful option in the case of testing. Regarding the intended discussion on an automation concept, however, it is beneficial to have the possibility to interactively trigger a reaction of an external system and define its return value. Effects on the further process execution can thus be observed.

2 Procedure Model for Business Process Automation with Simulation

A typical development process of the end-to-end automation of life science processes complemented by the process simulation could be described as follows:

Analysis of Existing or Planned Workflows. The flow of existing or newly to be developed workflows will be analyzed in detail. Thereby also subprocesses are considered, which will not be controlled in detail by a BPMS later, but already are automated by an island of automation. The analysis of those subprocesses is crucial to the determination of the demand for automation. Often the control systems of these automation systems do not consider the dataflow. The not executable BPMN model, the result of this step, also serves as part of the end-to-end process documentation. Thus methods and workflow descriptions of integrated subprocesses, which have usually been vendor-specific and only been locally accessible, are available in a common standardized notation now. In this way long-term knowledge management is possible.

Identification of the Demand for Automation. The BPM-based workflow automation allows an improved level of documentation of the current process instance by an automated IT-based recording, e.g., of manually executed process steps, without increasing the personnel effort. IT systems are integrated and adequately provided to the user at the right moment. At this step the identification takes place of how and what is documented during the process and of how the dataflow and the data provision could be automated. The resulting basically executable BPMN model lacks programming-intensive components like interfaces towards external systems. Roles and resources are being assigned to activities and notifications as well as dialogs are being implemented. The incomplete but executable process model acts as the basis of the simulation model. Furthermore it supports further discussions involving professional users to proceed with the requirement analysis.

Simulation. The simulation model is based on the BPMN process model developed in step two. It is expanded with important data objects, input and output data of activities, as well as screenshots, screencasts and videos to visualize activities. Relevant activities are being identified and relevant process paths are being determined considering the objective of the simulation. Parallel process paths can be visualized in a sequentialized manner.

By the animated process flow professional users as end users of life science applications can realistically examine and understand the process, review the fulfillment of their requirements and discuss implementation alternatives and already achieved solution effects. This is especially supported by the PCS simulation component. As a result there is a final description of requirements.

Process Development and Deployment. The implementation of the final executable process model requires adjustments to new requirements as well as the implementation of interfaces towards external systems including data transformation and error handling. In the course of this the development of reusable components is aimed.

Utilization of the Process Model and Optimization. During utilization of the process model adjustments to changed boundary conditions or optimization of the process model are often needed at some point. This especially applies to the flexible, quickly changing processes of the life science research and development. This effort is expected to decrease using visual simulation at the development stage.

3 Visual Simulation System Lab-BPESi

The simulation components of business process management systems are insufficient related to the above-mentioned objectives, which are most relevant to the LSA, because their focuses are different ones (section 1.1). Furthermore no human interaction is usually wanted in the BPMS-embedded simulation. This, however, can be helpful in the LSA development process to discuss different scenarios and process paths. For these reasons, the visual simulation described below has been developed. It takes into account the complex automation objectives and typical automation structures of life science laboratories. The intended visualization for the standard driven workflow automation cannot be limited to a simple BPMN control flow visualization, but must integrate the components aspect and therefore the partial solution aspect corresponding to the Fig. 1. In this sense it is an industry-oriented business process execution simulation for laboratories of life sciences (Lab-BPESi).

3.1 Architecture Overview

The web based simulation tool consists of three functional, configurable modules (Fig. 2):

Business Process Execution Simulator (BPESi). This module is responsible for industry independent presentation of the process model, the marking of the current BPMN 2.0 element and the display of respective detailed data like a description or in-/output data. The control flow is visualized using an animated process model. The BPESi allows a time-controlled process flow and a single step mode.

Task Visualization. This module visualizes operations belonging to the current activity using graphics, images, animated images, and/or videos.

Lab Robot Simulation. This module represents many different typical automation systems like transport robots or various islands of automation, which are usually controlled by vendor-specific process control systems (PCS). It provides an automated as well as an interactive access to reflect the different degrees of automation of the provided interfaces of these systems for an external control. This module can also be used separately.

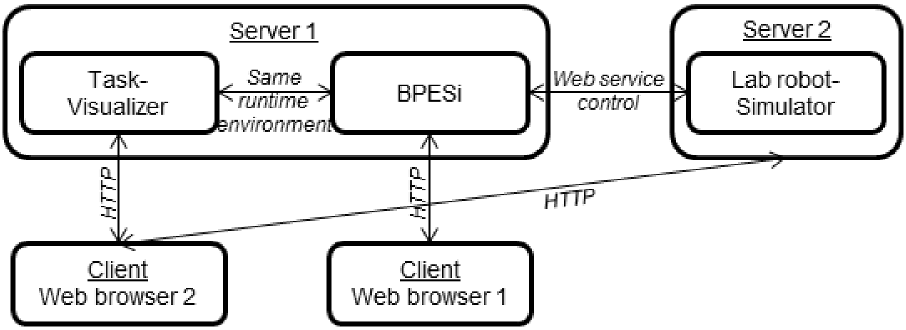

Fig. 2. Architecture of the simulation solution Lab-BPESi

3.2 Business Process Execution Simulator

The BPMN process diagrams are the basis of the process simulation component as they provide a descriptive, well interpretable and at the same time informative representation. Due to complexity and length of a typical end-to-end process chain in the field of application the animated presentation is divided into an overview diagram (1) and the detailed process diagram (2), which contains all relevant activities (Fig. 3).

An animation of the diagrams allows a transparent presentation of the control flow. A color highlighting (yellowish background) is used to relate the different subprocesses in the overview diagram with the current process model. A further differentiation can be achieved by a color coding of the current subprocess element in the overview diagram (green), which allows a better orientation any time. The current activity or gateway (or any other BPMN 2.0 element) is visually marked by a token (red circle) in the detailed process diagram (2), which facilitates an intuitive understanding of the control flow. Furthermore an automated scrolling function has been implemented to ensure readability of large activity networks.

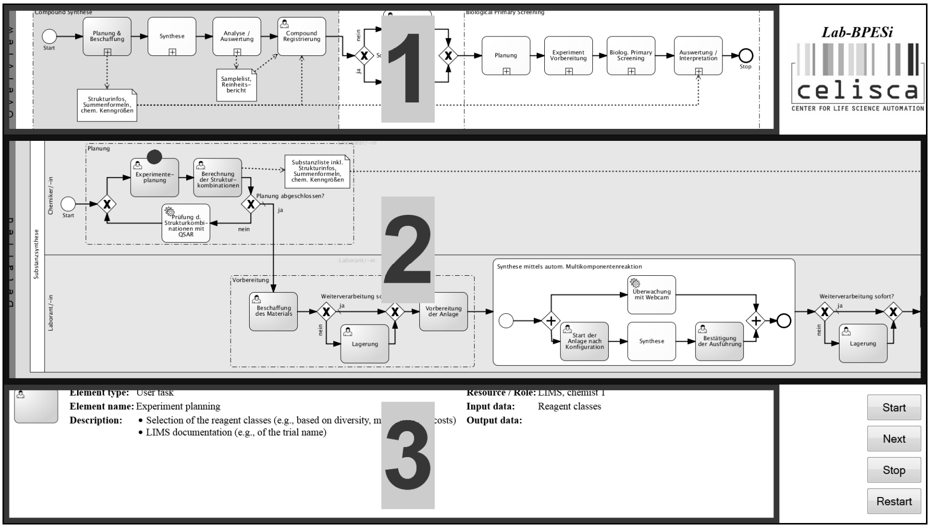

Fig. 3. The user interface of the BPESi with its three areas: (1) overview, (2) animated process diagram and (3) data on the current activity

The structured information area (3) provides details about the current activity:

- Label and type (user task, service task, etc.),
- Description stating the effect on the overall objective of the process,
- Involved process roles and resources,
- Dataflow (input/output).

The animation is controlled by a time-based fixed order and can be broken at any time. Activities or elements can be early terminated (and thereby also skipped) while being in the single step mode. Besides breaking the simulation it can also be restarted. The time-based process progress is preconfigured in the simulation model or interactively determined in the single step mode. The simulation model, containing all important data on the animation, is the basis of the simulation and is described below. The BPESi component communicates with the other two components "Task Visualization" and "Lab Robot Simulation" to check the status or call functions.

3.3 Task Visualization

This module visualizes the operations and the "just-in-time IT-support", which belong to the current activity, using graphics, screenshots or videos (Fig. 4). Those activities are especially user tasks, meaning activities, in which humans are directly involved. Additionally, the reference to all involved information systems, utilized during the task execution, will be shown. This points out the resolved or yet unsolved task-related systems integration. The effect of the task visualization allows evaluating the respectively targeted and actually achieved degree of automation. Specifically, e.g., alternatives of the information transmission, selective corresponding system calls, process data visualization or the controlled data processing can be shown.

The simultaneous use of multiple information systems is typical for the task support in life science automation. To visualize this situation the area for graphics and videos has to be split. A typical combination of such visualizations of task support consists of live visualizations of robot operations, remote access for PCS, and the capture of process parameter.

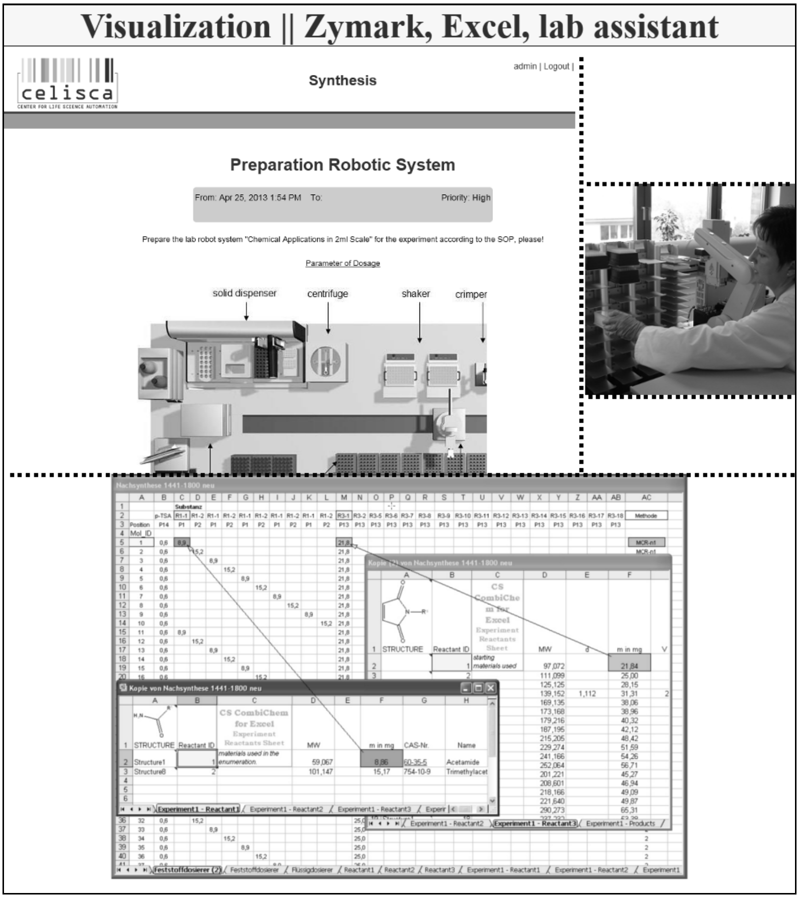

Fig. 4. The user interface of the Task Visualization being just one big area for graphics or video

3.4 The Lab Robot Simulation

As opposed to the BPM-method application in the commercial-administrative workflow automation the integration of structured, often hierarchical automation systems is essential in life science applications. The general automation system will be represented by a set of process control systems and device controls such as method controller for analytical systems, controls for transport robots or automated islands with a different degree of automation of the integration interface (Fig. 1). Additional automation components, e.g., at the intelligent sensor level, can be solved by the Task Visualization. Largely independent of the purpose and the complexity of integrated islands of automation some basic functionalities for a sufficient abstraction of process control systems in life science applications can be found. This abstraction approach of the simulation objective for PCS is limited to the following features:

- Naming the PCS and the device / automation system,
- Visualization of the user interface of the PCS (in parts, visualizations of workflow as well),
- Display and input options for important process variables (method, run duration, current status, file interface for parameterization),
- Triggering of errors with an error message, e.g., by defining time from start,
- Interactive control options: start, stop, error, reset,
- Automated control via web service,
- Sufficient interaction between PCS and BPMS or BPESi regarding the workflow control flow (status, error, process variables).

Fig. 5 shows the features realized in the graphical user interface. The Lab Robot Simulation is configured in a file. This allows multiple preconfigured alternatives of this module to simulate different automation systems simultaneous.

The Lab Robot Simulation has been developed as a completely independent module with a web service interface. This enables the usage in executable BPMN models as alternative to external systems (like real PCS) regardless of the availability of such systems. Furthermore this allows the usage of the process model at an early stage at which there are no interfaces to the final backend system yet or if a real automation system is occupied by experiments. Using the web service interface the Lab Robot Simulation module is controllable and relevant data (e.g., the current status) are retrievable for the BPMN-defined flow control.

3.5 Simulation Model

Considering the requirement for easy exchanging and modifying possibilities the Extensible Markup Language (XML) has been chosen as notation of the simulation model.

The underlying grammar in form of an XML schema describes two main elements. The element having the tag *bpmProcess* represents one process or subprocess. It contains any desired number of elements having the tag *bpmElem*. These elements represent the single BPMN 2.0 elements within the process including activities or

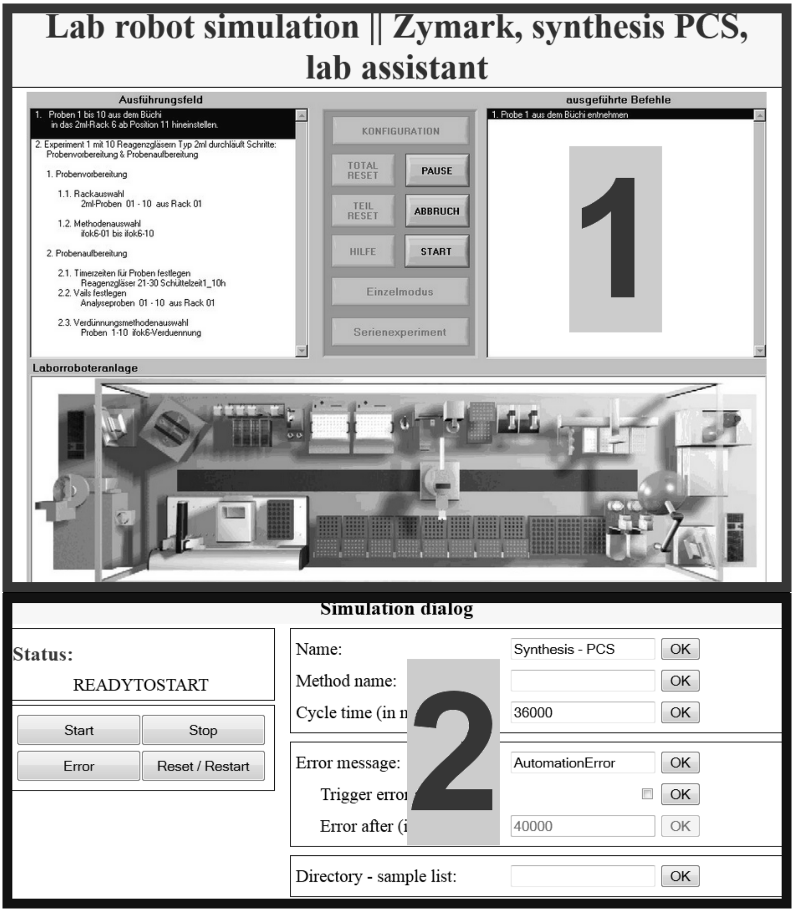

Fig. 5. The user interface of the Lab Robot Simulation with the areas System Presentation (1) and Simulation Dialog (2)

gateways. Subordinated elements describe all relevant data for the simulation. The start element contains details on the overview diagram and the detailed process model to be displayed, among others. Thereby multiple detailed process models can be used for single subprocesses.

Task-related Configuration of BPESi. The sub-elements of each *bpmElem* element contain all the data necessary for the animated simulation and the area for the details:

- *name* *(Type: String)*
  Name of the task.
- *desc* *(Type: String)*
  Detailed description.

• *resource (Type: String)*
All in the task involved resources (e.g., devices or humans).

• *posX und posY (Type: int)*
Position of the token marking the current task.

• *runtime (Type: int)*
Execution time in seconds, which will be simulated.

• *inputData und outputData (Type: String)*
Required input data and generated output data.

Task-related Configuration of the Lab Robot Simulation. As the BPESi has the ability to control multiple instances of the lab robot simulation simultaneous, the simulation model needs to provide information on whether the current element requires such activities. Whether the control of the lab robot module is fully automated or has to be done manually is stored in sub-elements as well:

• *robotXMLPath (Type: String)*
Relative path to the configuration file of the special version of the PCS.

• *isRobotSimulatorStart (Type: boolean)*
Start the lab robot simulation.

• *isRobotSimulatorAutoStart (Type: boolean)*
Automated start of the lab robot simulation.

• *isRobotSimulatorStop (Type: boolean)*
Wait for the execution of the lab robot simulation to finish.

Task-related Configuration of the Task Visualization. A graphic or a video inclusively its viewing time can be defined for each simulated BPMN 2.0 element. It is also possible to specify multiple graphics or videos, which then will be consecutively shown. All graphic formats supported by the utilized web browser (like PNG, JPG or GIF) or video formats supported by the HTML5 element <*video*> (like MP4, WebM and Ogg) can be used.

```
<media>
    <mediaElem time="25">Grafic.jpg</mediaElem>
    <mediaElem time="240" video="true">Video.ogg</mediaElem>
</media>
```

3.6 Technologies

The simulation is implemented object-oriented on the server side. As many BPM tools are developed in Java this simulation component is also programmed in Java (version 7) to ease subsequent integration. On the client side simulation parts are implemented using HTML5, JavaScript and Cascading Style Sheets (CSS). The user interface is generated on the server using servlets and Java Server Pages (JPS). These servlets are also endpoints to dynamic requests by the client to the server.

3.7 Application of the Process Simulation

The developed BPM-based process execution simulation has been tested using an above-average complex life science application. The representative end-to-end process in the field of drug discovery includes subprocesses on multiple islands of automation with differentiated external access possibilities, manual activities and several integrated IT systems.

Aspects, to be especially emphasized, which are only now realizable by the BPM based workflow automation without any additional personnel effort, are:

- The integration of manual activities into the central process control by notifications using work lists of BPMS human task management or e-mails,
- The coordination of automated and manual subprocesses and activities,
- The usage of digital signatures for the purpose of archiving documents created during the process (relevant to the quality assurance),
- The automation of the data and file transfer (including transformation) for provision for other involved components or for archiving,
- The time-controlled process monitoring and triggering of notifications in the case of timeouts,
- The provision of selective data,
- The automated recording of activities in a central documentation system,
- The integration of an information system common in the targeted industry (that is e.g. a LIMS in life science laboratories) as a central source of information, a documentation system, a middleware for the device system level, a visualization tool and a data processing engine.

During the simulation the stated aspects are shown by utilizing application simulations of the distributed automation and information systems, controlled video sequences or screenshots and the respective corresponding detailed data. In this way it is possible to visualize to which extent and using which new possibilities a BPM based workflow automation could support and automate the process execution in the life science automation.

4 Conclusions

For the first time a graphical standardized automation language of the workflow layer is available with the BPMN 2.0 across all industries. Therefore BPMS can act as a new high level integration platform of the process automation. The new automation approach of BPMN 2.0-based BPMS allows extremely flexible and unlimited process control. Manual subprocesses and any heterogeneous hybrid information and automation systems can be combined in one integration platform for controlled end-to-end processes. An executable BPMN 2.0 process model is an interesting basis for cross-disciplinary teamwork. Often automation objectives are only realizable while closely cooperating. Equally important is, however, an early process simulation, which focuses on the controlled cooperation of all information and automation components without forestall in detail the achieved or purposed degree of automation. The addition of the BPM approach and an accompanying preview simulation offers an extensive solution and efficiency potential in the future life science automation. Procedures with higher complexity in research laboratories, increasing numbers of analysis as well as strict regulatory requirements demand higher degrees of automation and/or human task support, which also effects data management and data processing. The presented process oriented end-to-end automation supports this in a manner, which meets the special flexibility requirements of fast moving research applications. Compliance with the different regulations is an important topic in all fields of application of the life science engineering. The BPM based workflow automation serves that purpose by integrating manually executed tasks into the time- and state-controlled end-to-end process control including of automating their recording and safe documentation.

The combination of BPMS development environment and the presented laboratory process execution simulation (Lab-BPESi) allows shortening the life cycle of the standard based workflow automation. In contrast to the commercial administrative fields of application this especially applies to the special requirements of the structured laboratory automation including numerous information systems. The web based simulation platform ensures an open integration concept for the simulation components and a high availability in cooperation networks of involved application and automation developers. At the same moment the presented simulation explains the benefits of BPM-based process automation. In this way it can operate as a basis for motivation, a descriptive basis for discussions on the project development, and, therefore, effectively support operative decisions.

To reduce the development effort for further simulations it is pursued to directly use the BPMN 2.0 process model as the basis of the simulation model and to extend it by the simulation specific attributes in the future.

References

1. Dumas, M., La Rosa, M., Mendling, J., Reijers, H.A.: Fundamentals of Business Process Management. Springer, Heidelberg (2013)
2. OMG: Business Process Model and Notation (BPMN) Version 2.0 (formal/2011-01-03), `http://www.omg.org/spec/BPMN/2.0`
3. Allweyer, T.: BPMN 2.0. Introduction to the standard for business process modeling. Books on Demand, Norderstedt (2010)
4. Silver, B.: BPMN method and style. With BPMN implementer's guide, 2nd edn. Cody-Cassidy Press, Aptos (2011)
5. Holzmüller-Laue, S., Göde, B.: B.: Agile Business Process Management in Research Projects of Life Sciences. In: Grabis, J., Kirikova, M. (eds.) BIR 2011. LNBIP, vol. 90, pp. 336–344. Springer, Heidelberg (2011)
6. Hill, J.B., Cantara, M., Deitert, E., Kerremans, M.: Magic quadrant for business process management suites. Gartner Core Research Note G00152906, Gartner, Inc., Stamford (2007)
7. van der Aalst, W.M.P.: Business process simulation revisited. In: Barjis, J. (ed.) EOMAS 2010. LNBIP, vol. 63, pp. 1–14. Springer, Heidelberg (2010)

8. Kanalici, I., Erdem, A.S., Ozturan, M.: Integration of a simulation platform into a business process management tool. In: Proceedings of the European and Mediterranean Conference on Information Systems, EMCIS (2009)
9. Januszczak, J., Hook, G.: Simulation standard for business process management. In: Proceedings - Winter Simulation Conference, art. no. 6147801, pp. 741–751 (2011)
10. Waller, A., Clark, M., Enstone, L.: L-SIM: Simulating BPMN Diagrams with a Purpose Built-in Engine. In: Proceedings of the 2006 Winter Simulation Conference (2006)
11. Mühlbauer, K., Bartmann, D.: Marktübersicht über moderne Werkzeuge zur Simulation von Geschäftsprozessen-forFLEX Report: forFLEX-2011-002, Bamberg, Erlangen-Nürnberg, Regensburg (2011)
12. Jansen-Vullers, M., Netjes, M.: Business process simulation - a tool survey. In: Workshop and Tutorial on Practical Use of Coloured Petri Nets and the CPN Tools, Aarhus, Denmark (October 2006)
13. Becker, J., Kugeler, M., Rosemann, M.: Prozessmanagement-Ein Leitfaden zur prozessorientierten Organisationsgestaltung. Springer, Berlin (2005)
14. Gadatsch, A.: Entwicklung eines Konzeptes zur Modellierung und Evaluation von Workflows. Lang, Frankfurt am Main, Hagen (2000)
15. Gadatsch, A.: Grundkurs Geschäftsprozess-Management-Methoden und Werkzeuge für die IT-Praxis: eine Einführung für Studenten und Praktiker. Vieweg+Teubner Verlag, Wiesbaden (2010)
16. Liem, S., Blecher, G., Gehr, F.: Simulation in der Geschäftsprozessoptimierung: Konzepte und Weiterentwicklungen. In: Information Management, Sonderausgabe 1997, pp. 64–68 (1997)
17. Rücker, B.: Business Process Simulation selbstgemacht. JavaMagazin, 20–25 (2011)