A BPM-Based Approach of Human Task Support within Automated Workflows

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Abstract. The contribution addresses the potential of model-driven workflow automation that allows new kinds of human system interaction. A control of the end-to-end process includes the seamless control of human tasks in conjunction with distributed automation solutions in addition to the simplified application-technical system integration. The human task support for applications in the life science automation increases significant the efficiency in the execution of experiments, serves to reduce stress for involved employees, and provides important contributions to the improvement of the quality management in the research. Mobile devices assist interesting opportunities for notifications and provision of information. The presented approach takes up the standard BPMN 2.0 published in 2011 as the graphical modeling and automation language for any business processes.

1 Introduction

The generalized life science automation (LSA) includes all application areas of the laboratory automation, e.g. healthcare, pharmaceutical developments, chemistry and biology. The current workflow automation in the R&D laboratories is limited by the structure of the subprocesses. On so-called automation islands special applications are performed automatically controlled by appropriate process control systems (PCS). The automated workflow is defined in a manufacturer-specific method on such automation island. Not all tasks can be performed by machines. Manual activities (e.g., preparatory lab activities, documentations, experiment evaluation with result computation, interpretation, knowledge extraction and reporting) are supported by various information systems, but without embedding of these „Human Tasks“ in a sufficiently continuous workflow control function. There are regulations, e.g., so-called Standard Operation Procedures (SOP), which are basis of the daily experimental work. But nobody in research labs checks and documents the compliance with these regulations. To a large degree, the documenting information systems are isolated from the solution of the process automation such as the control functions in Process Control Systems (PCS) or the method management of lab device systems.

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The flexibility in the research currently limits the automation level particularly with regard to the process documentation and the data handling. A large, reliable documentation level is an important tool for quality assurance not only in the regulated area but also in the research, where the extensive process documentation ensures the availability of the process know-how. Due to the growing amount of data resulting from the process automation (e.g. by complex lab robots for high sample throughput) the automation of data handling is of enormous importance. It also provides important contributions to improve efficiency and quality assurance.

The challenges and goals of the work presented here address the integration of all involved subprocesses - whether automated or manually performed, independently in which organizational unit – in a centrally controlled workflow, which is called “end-to-end-process”. One of the key tasks is the flexible system integration of all used IT systems and automation islands of the high hybrid and heterogeneous laboratory environment. This paper focusses especially the subtheme of the integration of manual processes, which is not considered in common automation concepts. The human task integration includes the consideration in an automated time- and state-dependent control of the workflow, notifications of pending tasks, and the selective allocation of relevant information and functions. This can speed up the workflows and relieve the laboratory staff, who is often involved in several simultaneous processes.

The solution proposed in this paper is based on process automation with methods of the advanced business process management (BPM). BPM provides now an interesting approach to the fusion of process analysis including numerous documentation options with the generation of executable process flow models and in the end automation solutions and execution systems with process engines. The connection of various automation islands with different manufacturer-specific process control systems into one process description requires a uniform notation. The proposed solution uses the Business Process Model and Notation (BPMN) that is established to model and perform business processes. A model-based automation concept provides the flexibility of research processes with short life-cycles. The opportunities of BPM-assisted workflow control benefit the efficiency and the quality of end-to-end-processes in R&D in addition to time savings and stress reduction for involved employees.

The presented paper is organized as follows: section 2 explains the background regarding to BPM and the process notation BPMN followed by remarks to typical processes of the application domain LSA. In section 3 explanations of appropriate automation strategies for selected classes of subprocesses follow. Finally, an application example in which the focus is on manual activities shows results of a performed proof of concept and highlights the potential of BPM for the human task interaction.

2 Background

2.1 BPM and BPMN

The scientific and business discipline Business Process Management provides industry-independent concepts, methods and technologies to support the design, simulation, execution, monitoring and the analysis of business processes. A business process is an arbitrary sequence of activities that go from an initial state to one or more final state(s). The process logic combines the activities with events and gateways to route processes. The activity can be executed automated, semi-automated or manual. The human task support occurs via automated messages, signaling to members of a role, user forms or a just-in-time support of required integrated information systems for a suitable working environment.

For the definition of such processes the graphical notation standard BPMN has been established in the recent years, which pursues the goal to overcome the understanding gap between IT-specialists, automation engineers and business users [OMG 2011; Allweyer 2011; Silver 2011]. With the BPMN 2.0 published in 2011 a direct executable notation is available (ISO/IEC standard 19510:2013). Until now transformations from one notation into another (e.g. BPEL) are necessary to execute the process. BPMN 2.0 displaces this problematic and time-consuming task. A graphical notation of the process flow leads to a simple changeability. This is an important requirement in the flexible daily work in the life sciences. An executable BPM process model consists of the BPMN diagram as the graphical description and all necessary information to perform the model such as process variables, roles, actors, decisions, event definitions, user interfaces for tasks, input and output data for tasks including their mapping to process variables, messages and interfaces to external system, or the business logic for tasks. The process engine is capable of executing this model directly. Thereby users will be notified of pending tasks, user interfaces are provided and external systems are accessed via defined interfaces. Business Process Management Systems (BPMS) connect process modeler and process engine in one platform enhanced by functions for process monitoring, process administration and for the human task management. Such systems usually provide extensive opportunities for the integration of third-party systems (databases, information systems etc.). The understandable notation, smarter tools and process libraries with preconfigured process models allow non-technical users to discuss, create and update powerful workflow projects.

2.2 Characteristic of Processes in the Life Science Automation

Typical, recurring subprocesses of experimental workflows in the life sciences are on the one hand manual activities such as the preparation and the follow-up of experiments: the design and planning of experiments; the supply of chemicals, tools, and labware; the storage and removal of substances including the monitoring of

storage conditions; the sample preparation; the evaluation and interpretation of experiments as well as the reporting. And on the other hand there are the typically automated tasks and subprocesses such as reaction processes (synthesis of substances, biological screening or elementary steps like heating, cooling, shaking, stirring) or the characterization of samples in the chemical analytics. Depending on the used materials and existing devices, process steps like sample preparation, sampling or dosage are performed by both: manually by laboratory staff or automatically by appropriate laboratory equipment. In each sub process different software systems are used for process control, data capture, data management, and data processing. These subprocesses are connected to structured process chains partly multiple. This can result in recursive processes, e.g. sampling and chemical analysis of samples during the running reaction with feedback effect to the reaction parameter.

Service tasks or subprocesses (here as term for the process structuring, not BPMN elements) that are modeled machine-readable and performed by an automation system (assisted by PCS or instrument control system (ICS)) represent the typical island automation of a laboratory application. Table 1 shows a summary of exemplary benefits of the process-oriented approach for manual as well as IT- and automation-assisted activities related to LSA with varying complexity.

Table 1 Workflow Components and their Automation Effect

Components	Examples	Automation Effect
Elementary manual	Supply of labware; Prepare, observe, abort process on automation island; Documentation; Transport; …	Multiple information; Control of timing; Control/ signaling of status; Selection and supply of resources; Work lists; Documentation during processing
Elementary IT-assisted	Raw data transfer Raw data processing; Process documentation; Data analysis: …	Automated raw data management; Automated evaluation of measurements / extraction of results / statistical experiment planning; Automated data capture and tamper-proof storage
Complex IT-/automation assisted	Syntheses robots; Liquid handling systems; Analytical measurement system; Cell culturing	Multiple information and control of timing; Configure/ start of subsystem; Automated control of status; Exception handling within workflow automation

3 Methods

The target workflow automation for LSA does not address a fully automation by machines primarily, but a continuous IT-support of process control along comprehensive process chains with full involvement of human tasks. The last one is supply by a widespread provision of information and a just-in-time-IT-support. Improving the interoperability accelerates the handling of processes, helps to avoid errors and improves the traceability of processes, results and findings. The data flow, which is necessary for the workflow automation, can be done automatically or with the addition of human interaction. Thereby existing established information systems act as a communication buffer or central information storage for experimental data, context data, documents, and results. Such information systems are to be integrated into the overall workflow control. The benefits of the proposed workflow automation result from the integration of all process steps into a homogeneous concept for overall process control, whose definition is accessible for all end users in form of a process model. BPMN is a suitable instrument to do this. The executable process model merges all service tasks, callable subprocesses and manual activities to an end-to-end-workflow control.

3.1 Integration of Human Task-Control and Monitoring

Even in a laboratory equipped with modern automation technology, there are many manual works. Until now application rules like SOPs (standard operation procedures) define what, when, until when and with what a specific preparative or experimental work is performed. But, who does control and document the execution? The integration of human activities in the control flow provides exactly this control and the synchronization with automated tasks. For the lab personnel that results in a guided workflow. The process control sends notifications about the next tasks and provides all execution-relevant information at the right time - without paper, without mistakes. The implemented workflow automation replaces the previous time management using kitchen timer.

BPMN distinguishes two types of human tasks: the “manual task”, which provides no system interfaces to the performer, and the “user task”. For executable BPMN models “user tasks” are preferred because they are performed via computer interface which allows to capture results, status or comments and to publicize process-relevant information (parameter, method, device …) or documents (SOP, sample lists ...). External interactive IT systems or their components are called.

BPMS usually offer a Human Workflow Management with user management and roles assignment or allow the integration of existing central Identity Management Solutions (e.g., LDAP server). Based on this, work lists are created for each user to assign the pending tasks priority-driven. The performer assignment is made according to the role, the mapping of a specific user or by a parameter-based query evaluated at runtime. A good example is the supply of

compounds for a screening test by the lab staff (marked in Fig. 1 with 2). Initially, the notification with the information about the compounds to be supply is sent to all employees with the role „lab staff“. A laboratory technician takes the order and executes it. This technician is the owner of this task. In the further workflow only this user gets a request to confirm the execution and to comment the results. For all other members of the role „lab staff“ this request is not relevant. With the knowledge about the task owner the confirmation request can assign to the correct technician and the execution can be documented automatically with a time stamp and the name of the person immediately after the confirmation, e.g., who does supply the compounds at which time.

Another application example for this conditional assignment of users is the pre- and post-preparation of the automation island. For reliable results it is useful the same technician prepares and cleans up the automation system (Fig. 1 – 3/4). Another variant of the task assignment is to iterate the performer over a list of users. This strategy is applicable for instance in an interoperator study within a method validation (see the example).

In addition to the task lists and corresponding dialog components, traditional communication channels such as e-mail or SMS are available to provide required information. This is especially relevant for transmission of larger amounts of information, which will be processed by the users. Thus an e-mail to start the step „barcode labeling“ includes the needed codes in the attachment or as a copyable section in the e-mail text area (Fig. 1 - 1).

The use of mobile devices is very interesting, just for the integration of manual activities into the central process control. It helps to further increase efficiency but also to relieve the lab staff. Work lists and e-mail accounts can be accessed anytime and anywhere, execution confirmations can be sent via appropriate web clients or apps. Field data can be captured on the spot (in sterile rooms or sampling points without desktop PC too). Furthermore the camera function of mobile devices can be used for visual documentation.

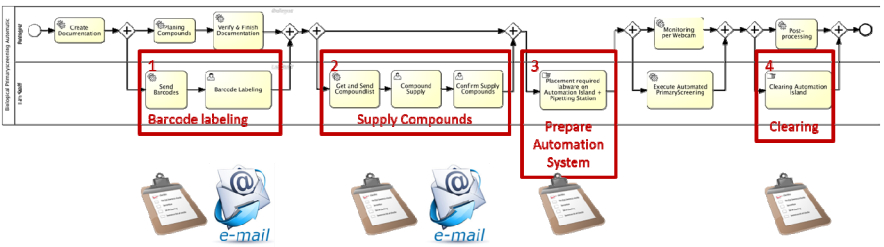

Fig. 1 Workflow with human tasks for pre- and post-preparation of experiments

3.2 Integration of Interactive Computer Systems

Besides of manual experimental work there are different human tasks using diverse IT applications. Typical examples are the experiment planning, the experiment documentation, the data visualization and analysis or the data

archiving. Goals for the workflow automation are the provision of selective functions and components of the IT systems and data in the respective form and place.

Especially in the context of a detailed process documentation within an information system an IT-assisted documentation opens a considerable potential for process optimization and quality assurance. Laboratory Information Management Systems (LIMS) are established information systems for result management and documentation of experiments in the laboratories. A LIMS developed by the authors is used at celisca [Thurow 2004]. The effort-reduced, semi or fully automated completion of the process documentation with detailed information about the process flow results in fewer gaps within the process documentation and increases the traceability of processes and results. Measurements and results are integrated in the context of their generation. Functionalities of the used LIMS are integrated via web service interface to consider the authentication and the verification of access rights. In less complex information systems a direct writing access to the database of the information system with appropriate SQL-statements is possible.

The navigation effort within the information system can be significantly reduced if the current process documentation is linked directly from the process instance. Suitable dialog components of the information system can be used with appropriate context information. In Fig. 1 the task “Planning Compounds” uses the LIMS-internal user interface to assign compounds from the library to the experiment documentation. The above mentioned LIMS has a library of process documentation templates, which may be basis of new process documentations. The functionality for template-based creating can be used via web service. Current parameters are considered. In addition to the elimination of this often tedious manual work this brings the particular advantage that the documentation style of all process instances is the same, and it is guaranteed that the equal process steps and parameters have the same name. Therefore process variables and results are researchable and can evaluate together automatically.

Beneficial for transparency and reproducibility is also a reference from the LIMS documentation to the corresponding BPMN model. Thus shows exactly how the data is created. This can be done in different ways depending on the specific possibilities of the used BPMS. The possibilities range from the inserted image of the model, using a special class of information "BPMN model" (BPMN stored in the database in conjunction with BPMN editor to display) to a link to the process model in the model repository with versioning of the BPMS.

In consideration of the fact that the main objective of all laboratory activities is the generation of data, information and knowledge, the automation of the data flow is of particular importance. The aim is to make the process data, generated anywhere in any subsystem, available to all other participating systems without any delay. This requires not only data transfer mechanisms but also data transformations are necessary.

Current semi-automated analytical application systems (e.g., ICS, chromatography data systems (CDS)) of laboratory automation often offer only a data interface. In part, input parameters such as sample lists etc. can be imported and the

results are available in report files in a predefined directory. The sample list is a result of a previous experiment and stored anywhere in the file system. Already simple command-line directory replication commands such as the Robocopy ("Robust File Copy" is a standard feature of current Windows, Microsoft) allow with several options for flexible copying of directories, including sub-directories on the network an automated file transfer. If the CDS report files of individual experiments are requested in its original format for data analysis, they are automatically copied in this manner to a central location too. An enterprise service bus (ESB) can automate data extractions and transformations. An ESB offers numerous ways to read data from different sources, for data selection and data extraction or format transformation, and supports the data-driven decision making related to the further process routing. The integration and automation of these rather trivial processes save time considerably and mainly avoid error in practice.

3.3 Integration of Automation Systems

To integrate the various applications of the heterogeneous lab system environment and BPMS, several interfaces have to develop individually. Between the functional integration (e.g. remote procedure call, web service) and the data integration (such as shared files or database, message- oriented middleware, enterprise service bus) can be distinguished. The application domain focuses here functionalities to start a device-specific method, which is defined in a PCS/ ICS, and the transfer of data to parameterize this method as well as the collection of results (measurements, status or location of result files). Primarily these functions and the integration strategies, which are described in the following, relate to the control of PCS/ICS- assisted automation islands. But they are applicable for automated transport steps or for predefined data processing as well.

If a laboratory system provides no possibility for external access to functions or methods, and to transfer data, then a manual initiated start of the method have to be used. In this case an authorized person receives all the necessary process-instance-specific information with the request to execution of a run on an automation system. The process engine notifies the user via the work list and/ or other communication ways. The confirmation of the execution with the resulting status allows continuing the process depending on the status (e.g. error handling by relevant experts) as well as an IT-assisted documentation of this process step. Further simplifications of the integration conditions in the structured laboratory automation by SOA interfaces are expected in the next future.

For elementary, automated functional coupling with short execution times can be accessed synchronously by a web service call or a remote procedure call on the system to be integrated. Applications of life sciences often process an experiment for a long time. For example, an automated screening can run several hours or days. Using message queuing allows an asynchronous communication and thus a loose coupling of the involved systems. Ordering and processing reaction are separated in time. The main advantage of the message queuing is the guaranteed delivery regardless of the current availability of the receiver. A message will be

stored in a buffer until the receiver picks up the message. The sender can continue the work after sending a message regardless of how long the receiver needs to process the message. The systems linked by messaging have to know nothing of each other apart from syntax and semantics of the messages themselves. On this way for example a status query can be realized, which reduces the communication load on the part of the PLS considerably.

The linking of diverse automation islands to the central-controlled overall workflow increases the automation degree. This fact results in changing working environment for the laboratory personnel with a growing part of monitoring tasks. The workflow control supports this with monitoring activities using webcams or signalizations about errors or critical situations during the automated sub process.

4 Results

Typical processes of life sciences were selected for a proof of concept. These examples represent the various activities of table 2 and are used for a representative cross-evaluation of advanced BPM methods in LSA. The following example focusses the new interaction concepts for setup, configuration and execution of lab workflows provided by the BPMS-based workflow automation.

The selected process describes validation experiments in the context of the development of methods for the analysis of chiral compounds. Steps in sample preparation, dosage and evaluation of the experiment build the frame around the device-level automation of the measurement processes using a CDS (MassHunter, Agilent Technologies, Böblingen). The process described here results from the development of a high throughput chemical analysis for the determination of chiral compounds based on mass spectrometry [Fleischer 2011]. The solution can be analyzed as part of the validation methods used to evaluate the precision of interday (repeated measurements on different days), intraday (repeated measurements within a day) as well as for inter- operator experiments (repetitions by different operators). These experiments are repeated whenever the suitability of the method has to be checked for another class of materials. Intraday and interday experiments differ only in the waiting time between two experiments. In the inter-operator variant the actor assignment iterates over a user list. For these reasons the proposed model-driven workflow automation is extremely useful for this application.

The investigator is already supported in the experiment planning. The integrated LIMS provides a feature for automated template-based setup of test documentations via web service. This subprocess template will be parameterized by a number of repetitions of experiments. The supply of samples is automatically documented in the LIMS with timestamps and the name of the operator, immediately after the execution confirmation by the operator. The orders for each step will be published in the work lists of users in the human workflow management of the BPMS client. The client is also available on mobile devices. As a result, employees are immediately notified of pending tasks. Together with these task

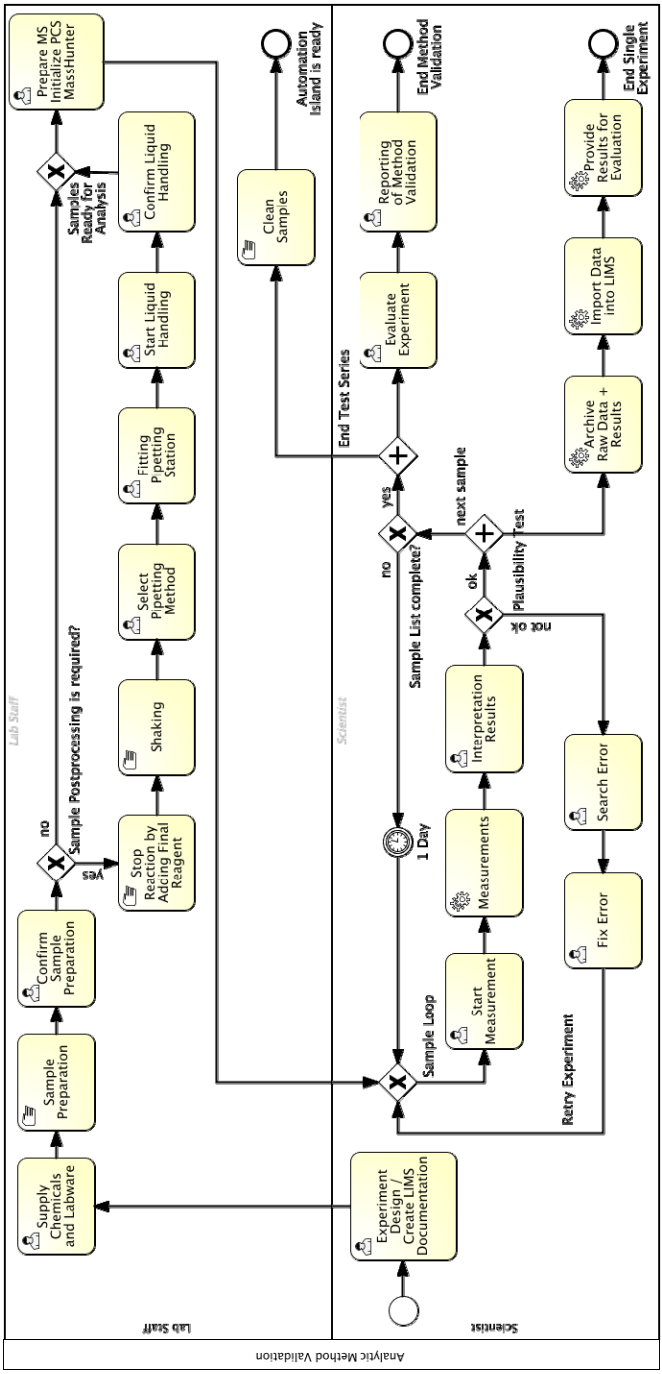

Fig. 2 BPMN process diagram of the example process

requests functions of involved information systems required in the respective process step are provided via URL calls (selection of test series in LIMS for information about experiment setup, help desk for master data information, remote desktop of ICS, knowledge base, etc.). The just-in-time method of correct pre-selection of functions and information result in noticeable reliability and time savings. This process-related human task interaction leads to the expected significant relief of laboratory staff who are involved in multiple, simultaneously running processes.

A direct online communication with the CDS is not possible due to a lack of appropriate interfaces of the CDS. The CDS-method has to be parameterized and initiated manually. After the measurement the raw data of the daily measurement are imported automatically by an in-house developed, Excel-based evaluation tool, in order to determine the mean values of the replicates, standard deviations and coefficients of variation of the enantiomeric excess. After a positive result of the plausibility test by the senior chemist, these files with derived data are copied automatically to a central backup server (file moving by Robocopy). The next step of the workflow automation controlled by BPMS integrates an ESB-job which monitors the report directory and processes incoming files. The ESB-subprocess selects the interesting data from the result file of the daily experiment and distributes them to various target locations: firstly in the database of LIMS and secondly additionally in another Excel template for the complete experiment evaluation. Until now, this task has been performed by manual copying. Now the time-consuming, error-prone manual data capturing and copying is eliminated by BPMS control. The use of the described process in all causes of method validation results in always the identical process flow, which increases the plausibility and reproducibility, especially in the method development and validation.

5 Conclusions

The tools and methods of the BPMN 2.0-based BPM open new automation targets at the workflow level in life science laboratories. BPMSs as the central component offer a comparatively open approach to adaptive workflow automation. In hybrid and heterogeneous environments of the established structured laboratory automation BPMSs provide an economic integration platform for both automated and manual subprocesses. BPMN 2.0 is confirmed as a proper process notation.

The article focuses the aspect of human system interaction of modern model-driven workflow automation from concept to effects in examples. The end user benefits from the presented model-driven approach by a much better IT support using the just-in-time method for all required IT components. The integrated documentation methodology relieves the users of an annoying part of their workload. The achieved increased degree of documentation with lower expenses for the documentation has enormous importance for life science laboratories to fulfill quality standards. The example application points out that the integration of the manual tasks in the time control by a process engine. Beside the accurate

documentation of the process in the LIMS it allows a safe time-critical process handling, reducing the execution times, and finally the traceability to detect errors. In the field of complex life science applications, the combination of graphic, arbitrary detailed directly executable process models as well as a link between the process documentation and the process model allows an until now not achieved quality of know-how processing, storing and sharing.

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