Monitoring and Visualisation Approach for Collaboration Production Line Environments: A Case Study in Aircraft Assembly

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Abstract

In this paper, the SPMonitor tool, which is designed to monitor and visualise run-time execution of productive processes, is proposed. SPMonitor enables the dynamic visualisation and monitoring of workflows running in a system. It displays versatile information about currently executed workflows, thus providing a better understanding of processes and the general functionality of the domain. Moreover, SPMonitor enhances cooperation between different stakeholders by offering extensive communication and problem-solving features that allow the actors concerned to react more efficiently to different anomalies that may occur during a workflow execution. The ideas discussed are validated through a real-life case study related to aircraft assembly lines.

Keywords: Collaboration, Productive Lines, Workflow, Monitoring, Visualisation.

1. INTRODUCTION

The field of computer-supported collaboration work is often associated with office work. However, industrial production lines such as products assembly lines are highly relevant as a case for this research field. Several issues are involved considering the complexity of products manufactured:

- In such processes, various teams with different areas of technical expertise are involved in activities to be performed synchronously. These activities are not always sequential.
- There is an increasing complexity of subsystems to assemble, along with the fact that supply components come from various industry parties and players.
- One activity in the process may influence another, therefore the coordination is required.
- There is heterogeneous information all over the shop floor and interdependencies exist within the information spaces.
- There are external factors impacting operational status, such as unavailable or multifunctional equipment, delay in supplier components or changes in the human resources involved.

In addition, tight deadlines and a reduction in the time-to-market place additional pressure on the organisation and monitoring of working processes towards their productivity and the quality of the final product.

The design and development of modelling and analytical techniques of the production lines was the subject of extensive study in the past. The use of commercial digital mock-up systems (DMU) enabling different visual qualities and functions are becoming more common [1][2][3]. However, effective real-time progress monitoring tools supporting DMUs are still immature.

The complexity of modern production lines and the dynamic nature of the domain make it difficult to maintain the ‘As-Planned’ progress during the actual execution (e.g. discrepancies and frequent changes). This results in schedule and cost overruns, which accordingly call for the efficient monitoring and coordinating interfaces with the production process, which is able to provide a real-time view of the current state of processes and relevant attributes (‘As-Is’ view).

Existing coordination solutions developed and reported in the literature so far are mainly based on public interactive displays. The andon system [4] made famous by Toyota is simply a way of reporting the occurrence of a problem on the assembly line (‘andon’ is the Japanese for ‘signal’). In case of a problem, the operator pulls an alarm cord and an electronic board is activated. Early projects, such as LiveBoard [5], focused on supporting collaborative activities through large electronic whiteboards using novel interaction techniques. Later on, this work was extended in recent projects by embedding several interconnected displays in the environment to support more complex collaboration activities, including Trauma’s center Whiteboard [6] iLand [7] and iRoom [8]. From an application point of view, the closest to our research is a study presented by [9] targeting user acceptance issues in the environment composed of large public displays to facilitate the collaborative process in the aircraft final assembly lines in Toulouse. There are also other applications that have exploited large displays to make information on activities available to a community of users.

These systems are developed with the objective of supporting a broad spectrum of group activities, creating a common information space and providing the background awareness on activities that a number of various groups/teams are involved in and tasks that have been accomplished. However, for a productive assembly project, as-built progress or DMU should be constantly monitored and compared with as-planned assembly progress, and real-time prompt corrective actions should be taken in case of observational discrepancies. Current tools such as graphs, charts and photos may not facilitate the communication of progress and ensure corrective action is taken clearly and quickly enough. More advanced means aiming at anticipating problems like overlaps of assembly parts and proposing corrective actions in an intuitive and promptly intelligible way are still lacking.

Based on the aspects discussed above and through the exploitation of the close cooperation with the EADS R&D team in the European Smart Products project [10], this paper presents a novel approach to support the collaboration of various actors involved in the processes related to production line environments.

Leveraging recent advances in semantic technologies, 3D visualisation techniques and contextual workflow modelling mechanisms, SPMonitor provides intuitive and convenient visual aids to support various actors involved in overall processes running on industrial production lines. By managing the interdependencies between numerous activities running concurrently, it aims to provide support for the combining, storage and distribution of various statuses, scheduling information, tasks, the usage of resources and tools, and updates providing contextual views to operators, support teams and managers responsible for the overall processes on the line. The combination of interaction means and interface elements to run-time environment and DMU facilitate the ability of the tool to quickly sort and display the performance metrics and deviations, possible unexpected events and anomalies in order to highlight the high priority requirements and actions required for recovering from errors and assembling resources.

In addition, from a scientific point of view, this research contributes with the novel approach of semantically annotated contextual workflow-based production process description. Semantically described workflows provide powerful reasoning potential to align information spaces of productive lines and enable richer visualisations showing comprehensive data in a single view. The ontologies used to describe workflows, environmental features and sensory perception devices can be flexibly extended. With new plug-in domain-specific ontologies, the tool can support additional application domains.

Moreover, the visualisation layer of semantically defined workflow descriptions supporting real-time progress monitoring is proposed. Various contextual views empowered by 3D functional graphic elements provide the value for the coordination and control of production lines. The visualisation libraries can be extended with domain-specific needs.

This paper is divided into six sections. Section 2 presents the background of the application domain for our study and the most important requirements that guided the development of the SPMonitor. Section 3 details the design and implementation of the tool. The run-time execution of SPMonitor and experiments that were accomplished to validate the prototype are described in Section 4. Section 5 provides the initial evaluation results performed by researchers and domain experts to measure the usability and perceived usefulness of the tool. Finally, Section 6 presents the conclusions drawn from the research project.

2. CONTEXT AND REQUIREMENTS

On an aeronautical final assembly line, the aircraft goes through several stages before completion. The process is often not sequential: several operator teams can be involved at the assembly station. Apart from operators performing assembly tasks, there are also support teams and a manager. The support teams help operators to solve operational problems and verify the technical issues, deal with logistics and ensure that the necessary tools are available for operators. The manager is responsible for the overall process of assembly and is also able to take action in cases where discrepancies are detected. Paper-based coordination between various actors is still used on the lines. Operators facing a problem or needing to validate an operation have to walk over to the support offices, write a report and verbally notify the appropriate support person. This all takes time.

In our context, the realistic scenario provided by EADS for research purposes involves two operators who have received a work order to tighten two electric harnesses onto an aircraft panel. Both operators work simultaneously on the same work order, which may contain several sub-tasks. The operators are also equipped with tools, a nomadic device and a smart tool (e.g. a smart rivet gun, a smart glue gun or a screwdriver). The nomadic device guides the worker through the workflow and the smart tool is used to tighten assemblies. The scenario also includes a support team that monitors the assembly procedure remotely and reacts in case of unexpected events during the process, and a station manager who is in charge of the overall organisation of the assembly line. More information about the background to the scenario can be found in [11] [12].

The main purpose of SPMonitor is to support cooperation between different actors in the scenario. First of all it should provide better understanding about work processes by representing an up-to-date visualisation of the current state of the assembly process. Besides visualising work processes, SPMonitor should be able to show illustratively the possible anomalies that may occur during a workflow execution and help the support team to react more efficiently to the problems. Moreover, SPMonitor is supposed to be used as a collaborative tool to exchange information between operators and the support team when resolving anomalies. Finally, SPMonitor can be utilised in the subsequent diagnosis, in which the support team and the station manager analyse the workflow performance data and any possible anomalies in cooperation.

3. DESIGN AND IMPLEMENTATION

Based on the context and requirements discussed previously, an approach that supports the collaborative visualisation of assembly processes was built. SPMonitor contains three main building blocks: a workflow management system, communication middleware and monitor software. The role of the workflow management system is to manage and execute processes and provide the necessary information for external applications. The communication middleware intermediates, either remotely or locally, between data from different components, and finally, the monitor software implements functionalities required for workflow monitoring. Figure 1 represents the compositional structure in more detail.

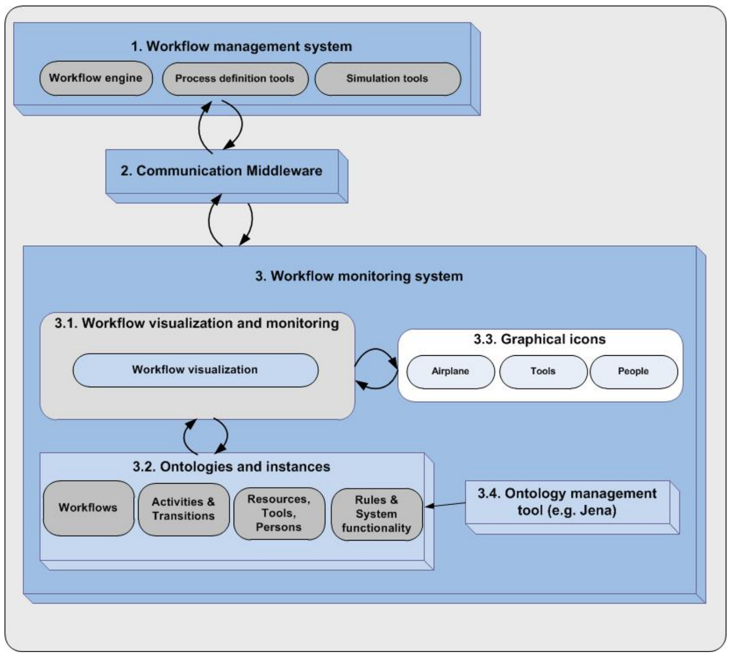

FIGURE 1: FMC block diagram of the SPMonitor components

The different components are described below in more detail:

- **Workflow management system** contains software tools for designing, defining and executing workflows. Additionally, it provides the necessary data for workflow monitoring using publish/subscribe mechanisms, for example.
- **Communication middleware (API)** acts as an intermediary between workflow management and monitoring systems. Moreover, it provides a means to remotely discover different components in the line system. Mundocore middleware [17] is used to provide the communication infrastructure for the information exchange in the line.
- The **workflow monitoring system** realises the different functionalities needed for semantically modelling and visualising different processes and reacting to anomalies. The main parts of the workflow monitoring system:
    - **Workflow visualisation and monitoring** is a core component of the system. It provides mechanisms for visualising workflows and other related information, as well as possible anomalies. Additionally, it implements the different interactive elements needed, for example, for managing anomalies.
        - The **ontologies and instances** component is a semantic library represented by ontologies which contains a workflow-related knowledge base. This component hosts the semantically

modelled workflow descriptions that are visualised with the monitor tool. It may also contain other semantically modelled information, such as rules and data describing different resources that are associated with workflow activities.

- **Graphical Icons** provide visualisation libraries containing domain-specific 3D icons that are used in workflow visualisations
- The **ontology management tool** allows querying and updating ontology instances.

3.1 Semantic Workflow Data Model

One of the requirements that arose in the scenario was enabling the integration of heterogeneous workflow-related information into a single data model, which in turn facilitates more sophisticated data analysis and diagnostics capabilities through automatic reasoning and richer query opportunities, for example. The diverse work process data includes information such as activities, transitions, resources (e.g. people, tools), restrictions (e.g. deadlines, required skill levels) and preconditions. Semantic technologies play an important role in realising this requirement as they allow describing workflow activities, transitions and resources in a semantically rich form, and additionally, they provide powerful reasoning potential [29]. The data fusion capabilities also enrich the visualisations because the integration of data from multiple sources increases the amount of available workflow information, thus leading to more comprehensive visual representations.

As explained above, SPMonitor acquires non-semantic workflow information from a workflow engine and converts it into semantic form. Currently there are several [20][21][22] usually domain dependent approaches that define ontologies for semantically describing workflows. Moreover [19] defines a semantic workflow language OWL-WS (OWL for Workflow and Services) and a specific semantic workflow representation model for describing dynamic work processes that also enable the specification of higher-order workflows.

However, for this study it was decided to design a new workflow ontology that adopts some elements from the existing approaches but is especially adapted and optimised for visualisation and monitoring purposes. This more lightweight and flexible ontology is unencumbered by the burden of providing a means for workflow task processing. On the other hand, the defined ontology structure offers enough expressiveness to allow for the performing of sophisticated diagnosis and analysis operations. Additionally, the workflow ontology is general enough to be able to address various problem domains. The specified ontology was influenced by our earlier work on designing expandable ontologies for facilitating heterogeneous data integration for data mining and visualisation purposes [24].

The ontology specified in this study defines concepts, relationships and attributes needed for describing workflows and other related information. This workflow ontology holds the class and property definitions of the entities that the SPMonitor workflow models are built on. The class hierarchy of the workflow ontology is presented in Figure 2.

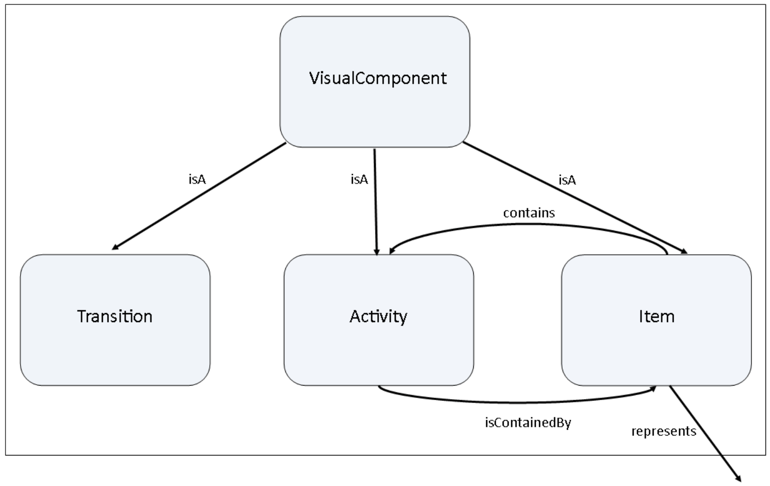

FIGURE 2: Context taxonomy

The main class of the workflow ontology is ‘VisualComponent’, which is divided into three subclasses – ‘Transition’, ‘Activity’ and ‘Item’. The class ‘Transition’ represents transitions that link different activities together. For each transition an ID, a source activity and a destination activity must be determined. Additionally, a transition may have a type property, which describes the type of relationship between source and destination activities. Possible type values for transition are “otherwise”, “condition”, “default exception” and “exception”. The class ‘Activity’ represents different steps or tasks of a workflow. Each activity instance defines its own ID and state values. The possible state values for activities are “not started”, “open - running” and “closed – completed”. Moreover, an activity may hold some additional properties such as resource requirements or time constraints. The third sub-class, ‘Item”, refers to entities that are contained by an activity. A typical item may be an operator that is assigned to a certain activity. Items may also have their own property values describing them in more detail.

SPMonitor forms semantic descriptions of workflows according to the ontology presented above. These models are dynamically updated each time a workflow management system sends an event message informing of activity state changes or anomaly occurrences, for example. The semantic workflow models are saved as OWL [23] files that can be used by other applications or opened with SPMonitor to be visualised or analysed later. Although the presented ontology is quite concise, its true power resides in its expandability. The ontology can be extended by integrating “plug-in” ontologies into it. This can be carried out through sub-classing or mapping concepts together with the ‘owl:sameAs’ statement, for example. With these plug-in ontologies, the tool can be adapted to support multiple different problem domains or integrated with other existing workflow ontology definitions.

3.2 Interactive Visualisation

The support for the enhanced understanding of work processes was released by designing illustrative and transparent workflow visualisation views that give a good overall representation of the data, and also provide the opportunity to acquire more detailed information on demand. Effective visualisation approaches enable humans to observe, manipulate, search, navigate, explore, filter, discover, understand and interact with data rapidly and effectively, to discover hidden patterns [30][31]. Moreover, interactive visualisation allows for the examination of the presentation of data on the fly from different perspectives and angles, helping the end user to understand the results of analysis and information retrieval better [13]. Thus, the different visualisation schemes were implemented to allow users to see various aspects of monitored workflows with different levels of abstraction and to interact extensively with the data being visualised.

The visualisation of workflows in SPMonitor is based on the Model-View-Controller (MVC) framework, which is a widely used architectural approach for interactive applications. The framework is successfully utilised earlier in the interactive visualisation of semantic context data, for example [25]. The Model-View-Controller framework divides functionality between objects involved in maintaining and presenting data to minimise the degree of coupling between the objects [14]. In the Model-View-Controller architecture, objects of different classes take over the operations related to the application domain (the model), the display of the application's state (the view), and the user interaction with the model and the view (the controller) [15].

The modularity of components has enormous benefits, especially when building interactive applications. Isolating functional units from each other as much as possible makes it easier to understand and modify each particular unit, without having to know everything about the other units. This three-way division of an application entails separating the parts that represent the model of the underlying application domain from the way the model is presented to the user and from the way the user interacts with it [15].

SPMonitor presents a novel way of visualising semantically defined workflow descriptions by providing four distinct views to examine models: a general view, a text view, a 2D view and an isometric view. In the following, each of the four views is described in more detail.

- **General view** gives a general picture of the overall situation. It shows the workflows that a currently active in a workflow management system and their current states.
- **TextView** provides a representation of a workflow model as it is written in OWL format. The view allows examining a workflow model in a textual form enabling also to discover the hidden workflow data that cannot be visually represented.
- **2DView** represents activities and transitions of a workflow in a “ground plan” like view. Activities are visualised as squares that are connected by transitions and the colour of the squares indicate the state of different activities. Similarly, the types of transitions are presented using colour codes. The purpose of the 2D view is to provide a better general insight of a workflow. In general, 2D views are considered better for navigating, establishing precise relationships and performing spatial positioning [16][17].
- **Isometric view** builds a visual representation of workflows from an isometric perspective. The visualisation provides a general picture of the monitored workflow and additionally it allows for the integration of varied workflow-related information within a single view perspective. For example, a visualisation of an activity defining an assembly task may include icons that represent the operator that is assigned to that activity or tools that are needed for executing the assembly task.

4. RUN-TIME EXECUTION

During the assembly process where several working processes are running in the background, a support team may examine the situation and select a workflow to be monitored. SPMonitor acquires the necessary information from the workflow management system and forms a semantic model of that workflow. To enable the dynamic monitoring of a selected workflow, the workflow management system notifies SPMonitor of different changes in the workflow execution data. For example, each time a monitored workflow proceeds from one activity to the next, a notification is sent to SPMonitor and the views are updated accordingly. The sequence diagram shown in Figure 3 illustrates the monitoring of workflows with SPMonitor in more detail.

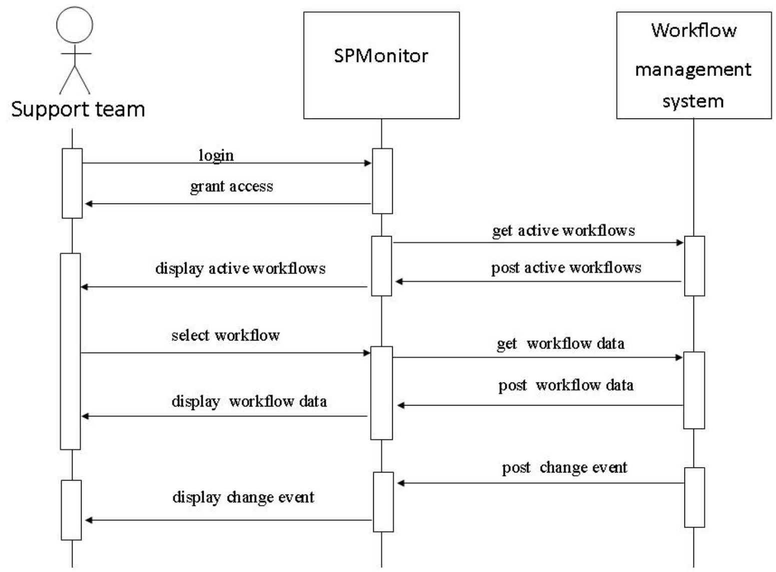

FIGURE 3: A sequence diagram of workflow monitoring

As previously discussed, SPMonitor contains three different views to visualise a single workflow. A graphical representation of the workflow model illustrates the different activities and transitions that are contained in the monitored workflow. The support team has also the opportunity to acquire additional information about a single activity by browsing for it. The opened information dialogue contains such information as work order name, operator performing task, state of activity, and possible sub-flow and sequence order of the selected activity. The status of different activities is indicated with the use of colours. The light blue colour means that the status of an activity is “not started”, a darker blue colour indicates that an activity is currently in the state “open - running” and the darkest blue shade symbolises the “closed – completed” state. Finally, if an activity is red, it means that an anomaly has occurred during the execution of that activity.

The different transitions are also indicated using colours. For example, a conditional transition is represented using yellow and an activity that is only entered in the case of an anomaly is interlinked with a red transition. If a transition does not have a type property, it is coloured grey. Figure 4 represents a screenshot from SPMonitor in which the workflow of the assembly case is visualised. The 2D view is shown in the upper panel and the isometric visualisation is represented in the lower part of the picture. As can be seen, the 2D view provides a more general picture of the monitored workflow, showing all the activities and transitions within a single view, whilst offering zoom in and zoom out functionalities. The isometric view represents a more detailed view of the workflow, populating different activities with icons that represent the operators and tools assigned to those activities.

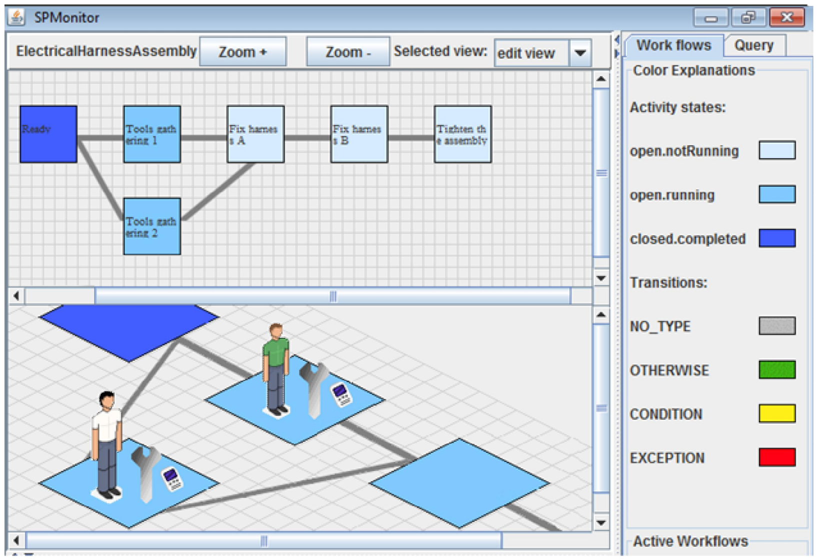

FIGURE 4: Visualisation views representing the monitored workflow

In the domain of aircraft manufacturing, work orders are often so complex that they cannot be expressed with single-level workflows and thus multi-level work processes must be utilised. In multi-level work processes, workflows contain activities that comprise a workflow of their own. These sub-workflows define the tasks that must be performed inside an individual main-workflow activity in order to complete it. Additionally, several operators may be assigned to a single workflow, which demands that activities are performed in parallel. In order to address these challenges, the functionalities of SPMonitor were designed to support the monitoring of workflows that include numerous of sub-workflows and various operators. For example, when a monitored workflow proceeds to an activity that launches a sub-workflow, SPMonitor automatically opens that sub-workflow to be monitored in a currently active visualisation view

4.1 The Management of Unexpected Events

An important part of the EADS scenario is the treatment of an unexpected event during the process. First, SPMonitor must dynamically inform the actors concerned about an occurrence of an anomaly and second, it must provide the means to recover from a problem situation. The sequence diagram presented in Figure 5 illustrates the interaction between SPMonitor and the support team in the scenario.

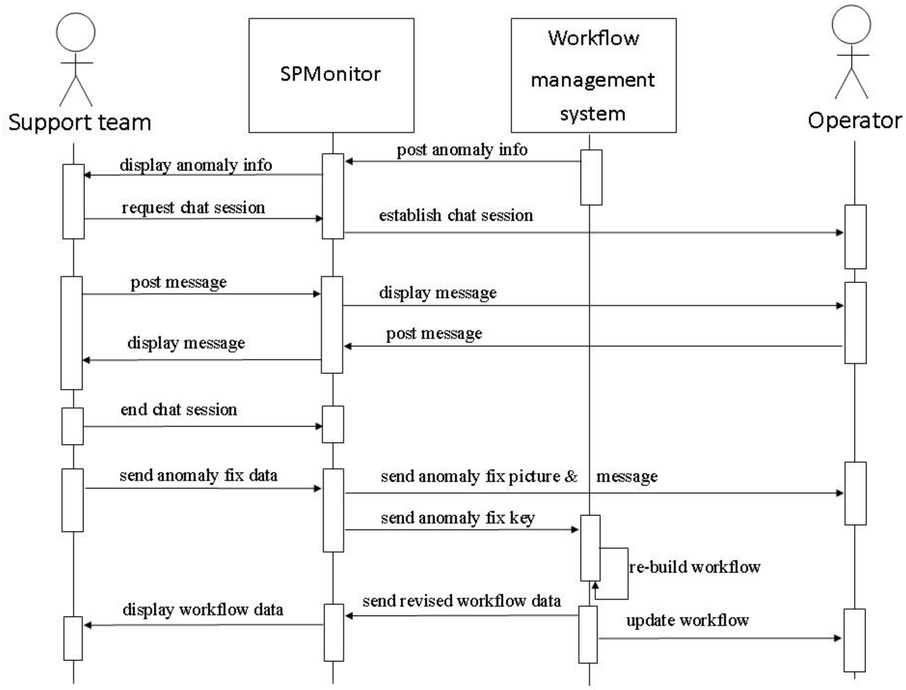

FIGURE 5: The sequence diagram for anomaly management

To facilitate the interaction between various actors involved, SPMonitor defines an interface element that enables the workflow engine to send a notification about unexpected events. The notification contains the necessary information for addressing different problems. Additionally, SPMonitor includes various communication features and problem-solving functionalities that assist users in managing unexpected events. For example, the support team is able to dynamically modify process definitions at run-time.

Any anomalies that occur are usually managed in cooperation with operators and a support team. SPMonitor enhances the cooperative work by disseminating information about anomalies and providing communication mechanisms to exchange data between employees. In the example scenario an operator notices that an earth wire is missing and thus decides to interrupt the procedure as it cannot be finished properly. The operator is also able to describe the problem in more detail by writing an anomaly message using the nomadic device.

In SPMonitor, the anomaly is indicated by representing the involved activity in red and opening an anomaly information dialogue. The anomaly information dialogue contains such necessary details about the unexpected event as the activity in which the anomaly occurred, a descriptive picture and the message that the operator has written. If the support team perceives that the data contained by the anomaly information dialogue is inadequate, it can start a chat session with the operator to acquire more details about the problem. SPMonitor establishes the chat connection with the operator's PDA device by using a communication middleware solution.

Once the support team has enough information about the anomaly, it can decide how to proceed with the task orders. If the support team feels that the assembly process can be completed despite the anomaly, it can informally advise the operator on how to work around the problem and press the 'Proceed' button in the anomaly information dialogue. However, if the unexpected event prevents the workflow from proceeding, the support team can interrupt the workflow by pressing the 'Stop workflow' button. In this case, the support team will usually need to completely redesign the process definition with the workflow management system.

The final option is to dynamically redesign the workflow using the communication capabilities of SPMonitor. In that case, the support team defines a ‘fix key’ that indicates to the workflow management system how the problem can be resolved in run-time. Besides the fix key, the support team defines a descriptive picture and a textual message that guide the operator in solving the problem. The information is transmitted to the workflow management system that re-directs the descriptive picture and the message to the operator’s nomadic device and adds a complementary activity into the workflow. In this case, the new activity is called “Fix earth wire”. Subsequently, it notifies SPMonitor of the changes in the workflow so that the monitor visualisation can be updated. The data flows between the operators and the support team is illustrated in Figure 6.

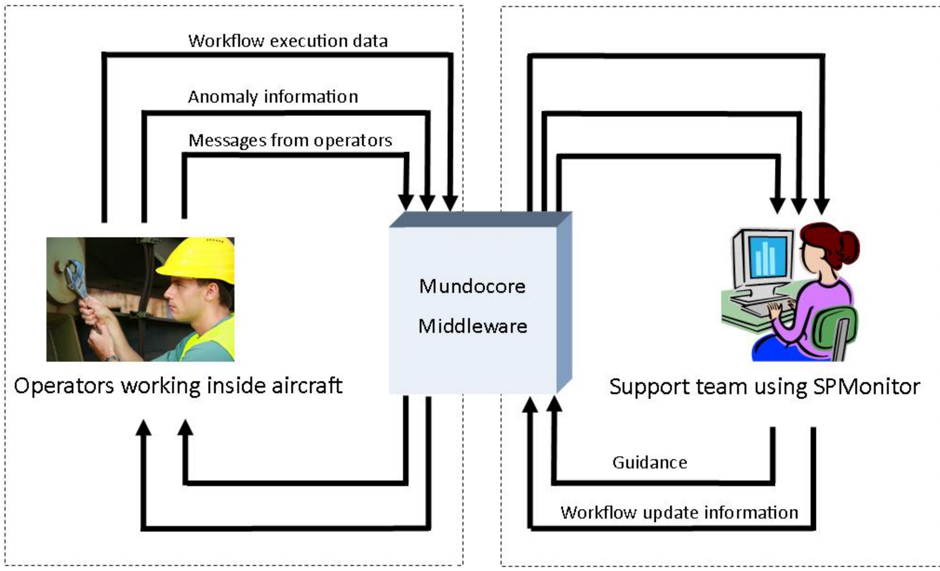

FIGURE 6: Data flows between the operators and the support team

5. EVALUATION

SPMonitor aims at supporting cooperation work by enabling the remote monitoring of workflows proceedings and providing communication mechanisms to exchange information among different actors. The tool also provides interactive means to acquire additional information about workflow activities and react to unexpected events during processes. Due to the purpose of the tool, we think that usability and the perceived usefulness are the most important characteristics to be evaluated. Apart from evaluating the usability of the tool, we were interested in obtaining evaluation results regarding the acceptance of the SPMonitor as new technology in the aircraft assembly processes.

According to the Technology Acceptance Model (TAM) [26], a number of factors influence users’ decisions about how and when they will use new technology. These are ‘perceived usefulness’ defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" and ‘perceived ease-of-use’ defined as "the degree to which a person believes that using a particular system would be free from effort". A six-indicator measurement for the usefulness of technology using the example of email was introduced by Davis. In our evaluation we reused some of these metrics.

For the evaluation we used an empirical usability testing approach, which relied mainly on the coaching method, thinking aloud protocol [27] and post-test questionnaires constructed to mirror the usability measurement discussed above, and secondly a focus group method [28]. The focus group comprised seven researchers with heterogeneous experience in workflow management, semantic knowledge modelling, services and support tools.

The practical implementation of the evaluation followed the aircraft manufacturing scenario, in which the electrical assembly procedure is presented from the planning stage to its certification, including the treatment of an unexpected event during the process. For the empirical usability testing, the researchers, usability specialists and domain experts from EADS were invited to participate. The test was started by clarifying the goals, objectives and intended purpose of use of SPMonitor. Instructions for completing the test tasks were also given on paper so those involved in the test could familiarise themselves with the tasks before starting the test. After the introduction of software, the participants were asked to perform the aircraft manufacturing scenario related tasks with SPMonitor.

First of all, the empirical usability testing gave us confirmation that SPMonitor is considered a useful tool by its end users and that the chosen visualisation techniques are suitable for monitoring workflows. In addition, the provided interaction functionalities were seen as adequate by the test participants. For example, a test participant from EADS estimated that the chat feature is sufficient for resolving 90% of the encountered problems. At the same time, usability testing revealed some ideas on how to improve the tool. For example, the distinction between main workflows and sub-workflows should be clearer in the visualisations. The activities that contain sub-workflows should be represented more explicitly and more general views representing hierarchy levels of different workflows should be provided. Another feature that received some criticism was the anomaly information dialogue. It was suggested that the dialogue should provide more detailed information about the unexpected event. Finally, participants felt that the graphical user interface should indicate more clearly those activities which were being performed in parallel.

In the final phase of the test process, the test participants were asked to fill out a questionnaire, which included questions related to the perceived ease-of-use and usefulness of the tool. The questionnaire contained both questions on a Likert scale from 1-5 and open questions requiring a written answer. Figure 7 presents the average response levels with numerical answers.

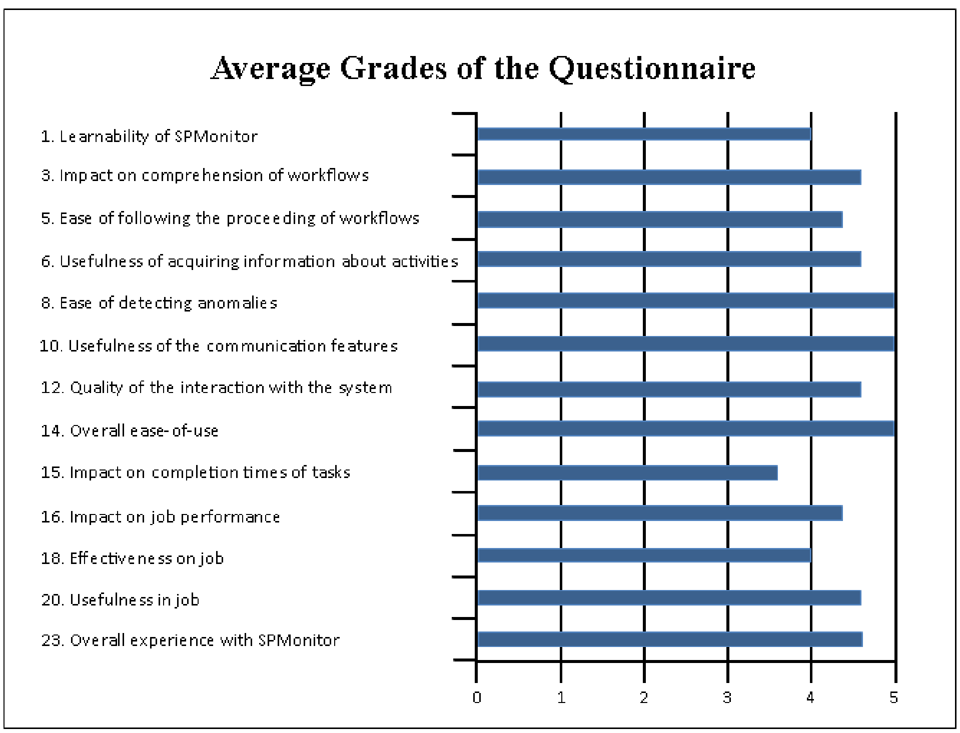

FIGURE 7: The results of the questionnaire

As can be seen the overall response level is quite high. Only statement number 15 has an average grade of below 4. One of the objectives of SPMonitor is to provide time savings in aircraft manufacturing processes, especially by enhancing anomaly management procedures. Apparently, some of the test participants were not convinced that they could save a substantial amount of time in dealing with unexpected events by using SPMonitor. On the other hand, it may have been difficult for test participants to provide any accurate estimates of how much time the system would save them, as some of them were not the intended end users of the approach they evaluated. The written responses also reflected the positive reception of SPMonitor, as they included many encouraging comments. For example, one participant stated that “It’s an interesting tool to present to EADS business units”. These kind of comments increase the motivation to further develop the tool.

The feedback obtained from the focus group session gave us many fresh ideas for future research work and the development of SPMonitor. For example, many of the focus group members suggested that SPMonitor could be useful in the domain of project management. A concrete use case example is monitoring the progress of a software development project in order to see the current state of different tasks and examining potential problems that may come up. Potential was also seen in using the tool in project planning, where SPMonitor could enhance such tasks as project configuration and resource assignment. Finally, the focus group suggested numerous other domains in which SPMonitor could be useful. These domains include education, real estate maintenance and health care.

Many of the focus group session participants also considered that SPMonitor could use the capabilities provided by semantic technologies more effectively. Currently, SPMonitor stores data related to past workflows, which enables the performance of sophisticated analysis and diagnostics reports. Thus it supports the design phase of workflows, by enabling to better estimate how long the execution of workflows with certain types of activities, transitions and resources (e.g. tools and operators) will take and what kind of anomalies can be expected. However, if the tool were to use the powerful reasoning capabilities provided by semantic technologies more efficiently, it could dynamically produce more sophisticated analysis containing information describing issues such as data dependencies of a workflow in run-time. Additionally, the more efficient utilisation of semantic technologies could improve the SPMonitor’s ability to deal with unexpected events.

Although, the evaluation carried out in this study gave some insight into the potential of the tool, it must be borne in mind that the actual verification of the approach can only be done in a real production environment where the way in which the approach copes with the demanding requirements of final aeronautical assembly lines can be tested. The feedback provided by end users is also likely to provide a more accurate picture of the usefulness of the tool, as they have more experiences from using the approach. Moreover, the testing in a real production environment will facilitate the gathering of quantitative data, which will provide more accurate information on how much time SPMonitor actually saves, or whether it has an impact on the occurrence rate of anomalies, for example.

6. CONCLUSIONS AND FUTURE WORK

Digital means and computer-supported collaboration techniques are being used widely in engineering in many production domains. It is adopted in particular in the modelling and simulation of the manufacturing processes in large industrial companies. However, the monitoring and visual support to facilitate the coordination functions of run-time productive environments is still a challenge.

In this paper, we have proposed semantically empowered visualisation aids to support collaborative processes and corrective decision-making for various actors, such as operators, support teams and station managers involved in the execution of the productive process. The resulting approach dynamically visualises information related to workflows, including the processes, participants and other resources involved. An important aspect is also to show illustratively the possible anomalies that may occur during a workflow and allow users to react more efficiently to the problems. The ability to provide a "global view" of workflows improves the overall comprehension of processes and allows users to gain a better overall picture of the whole ecosystem.

The approach also specifies a new workflow ontology that defines concepts, relationships and attributes needed for describing workflows and other related information. The semantic modelling and processing of workflows has many benefits as it enables more sophisticated diagnosis and analysis possibilities, and also facilitates more efficient run-time decision-making capabilities. Moreover, the use of semantic technologies enhances the integration of heterogeneous workflow-related information into a single data model. However, the utilisation of semantic technologies also presents a challenge and therefore further research must be carried out on how to better exploit the full potential they offer. Additionally, more information regarding what kind of diagnostics and analysis information would be most useful for end users should be acquired from domain experts.

The approach has been validated within the actual application and use cases associated with final aeronautical assembly lines. The evaluation was carried out in two phases: firstly a focus group session was organised and secondly, analytical user tests were performed. The focus group session provided numerous suggestions on possible directions in which the tool could be developed. The analytical user tests provided information on the system's ability to meet its requirements in terms of usability and perceived usefulness. Through the light evaluation performed in this stage, SPMonitor has demonstrated its potential in terms of the improvement of productivity, flexibility and product quality. However, a thorough verification of the tool would require more extensive testing in a final production environment.

Apart from the aeronautical domain, we believe the tool can also bring about benefits to other application domains such as logistics, education, real estate maintenance and health care, thanks to the extensible capabilities of the tool in terms of domain-specific ontologies and additional visual graphics libraries.

7. REFERENCES

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