RULES FOR ADAPTIVE LEARNING AND ASSISTANCE ON THE SHOP FLOOR

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ABSTRACT

Today's shop floor, the area of a factory where operatives assemble products, is a complex and demanding work environment. The employed and produced technology becomes ever more complex, and employees are responsible for an increasing amount of tasks. As a consequence, the employee is under constant pressure to solve problems occurring on the shop floor as fast as possible, and simultaneously to improve his work-related knowledge, skills, and capabilities.
This paper gives an account how adaptive technology can support the employee on the shop floor in these respects. It describes the organizational requirements to take into consideration and describes a set of rules that support the employee in problem solving and knowledge acquisition.

KEYWORDS

Workplace-integrated learning, adaptivity, assistance, artificial intelligence in education

1. INTRODUCTION

Today's workplace on the shop floor (the area of a factory where operatives assemble products) is highly demanding (Mavrikios, et al., 2013). The foremost goal is to maintain productivity to fulfill customer orders by producing the required number of products. The environment is a highly complex one: the machines become ever more complex, as do the products. The increasing automation requires maintaining a highly fragile equilibrium to enable the machines to run without human intervention for as long periods of time as possible. Furthermore technological innovation results in new materials and new technologies being used in production and for processing and assembling products. Last but not least, a decreasing workforce requires employees to become more flexible and master larger number of skills, for instance to be able to stand in when colleagues are not available. This requires to use machines that are not the primary area of expertise.

As a consequence, the employee is under constant pressure to solve problems occurring on the shop floor as fast as possible, and simultaneously to improve his work-related knowledge, skills, and capabilities.

This makes the shop floor an area where the usage of technology to support problem solving and learning of the employee can result in significant benefit (Mavrikios, et al., 2013). Especially the usage of adaptive technology methods based on artificial intelligence methods carries a high potential: ideally, the support is context-depend (based on the affected machine, its state, the current product) and adapted to the individual employee (capabilities, work history, development goals).

In many domains, adaptive learning environments based on artificial intelligence methods have enabled significant flexibility and adaptivity of learning processes with respect to the individual learner. These systems follow the same general design pattern, which is based on three components: a domain model, a learner model, and a pedagogical model. The domain model consists of a semantic representation of the concepts of the area to be taught and their relationships (an ontology) (Gruber, 1995). The learner model represents the current knowledge state of the learner and is used as a basis for adaptivity and personalization. It updates itself according the learner's progress. The pedagogical model contains the knowledge how to select, adapt, and sequence content, and how to provide support with respect to the information from the learner model.

In some domains, especially highly structured ones such as mathematics, physics and computer science, research has shown the benefits of adaptive learning environments, mostly for school and university. For instance, ActiveMath (Melis, et al., 2001) is a web-based learning environment for Mathematics that creates on the learners' demand courseware adapted with respect to their knowledge state and learning goals. Similarly, the physic tutor Andes generates problems specifically targeted to the individual learner in order to achieve the best possible learning gain (VanLehn, et al., 2005). Yet, regarding the workplace and especially the shop floor, research on the potential of adaptive learning is rare.

Service-oriented architectures for learning go one step beyond the traditional design pattern of adaptive systems (Ullrich, et al., 2015). There, a set of basic services covers basic functionality, with respect to the user (authentication, authorization, session management), to integrated (Internet-of-things)-devices (device sensor information, sensor data visualization) and software (such as learning management systems in university, schedule software in industry), and to user-interaction (services that implement user interface depending on the specific output device). Advanced services use the basic services' functionality to provide adaptive functionality to the user.

This paper gives an account how adaptive services can support the employee on the shop floor. We start by discussing related work in Section 2. Section 3 describes the organizational requirements to take into consideration, and Section 4 gives a detailed account of the rules used by adaptive services that support the employee in problem solving and learning. Section 5 concludes the paper.

2. RELATED WORK

The relevance of educational technology in supporting employees in manufacturing (Mavrikios, et al., 2013) as well the potential of smart and adaptive environment for workplace-based learning (Koper, 2014) have been clearly recognized. However, most existing work investigating support on the shop floor has focused on very specific areas, such as assembly, in order to increase process quality (Stoessel, et al., 2008) (Stork, et al., 2012), collaboration between machine and operator (Sebanz, et al., 2006) (Lenz, et al., 2008), control (Bannat, et al., 2009) and monitoring (Stork genannt Wersborg, et al., 2009). Recent work investigated how to use data from factory-wide sensor networks to control information flow so that cognitive overload of employees can be avoided (Lindblom & Thorvald, 2014) or how to display the data in a way that employees' satisfaction is increased (Arena & Perdikakis, 2015).

Limited research focused on employing adaptive learning environments for the workplace based on artificial intelligence methods. The potential of such methods has been shown for generating assembling instructions automatically from product lifecycle data (Stork, et al., 2012), for supporting the transfer of practical knowledge (Blümling & Reithinger, 2015), as well as for providing manufacturing assembly assistance (Alm, et al., 2015). However, none of this work has described specifically the rules underlying the functionality of a pedagogical model or an adaptive service that provides adaptive worker support on the shop floor.

3. ORGANIZATIONAL REQUIREMENTS

Before we come to the description of the specific rules that determine the adaptive functionality of the different software services offered to the employee, we give an account of the organizational considerations that define the background within with any technological solution will be implemented.

3.1 Organization of work and learning

Despite the increasing automation, human operators will have their place on the shop floor albeit with changed roles. Thus, technological innovation cannot be considered in isolation, but requires an integrated approach drawing from technical, organizational and human aspects, forming a socio-technical system. Possible structures of work organization range from hierarchical structures where low-skilled employees execute tasks set by their supervisor to scenarios where teams of qualified personnel have the leeway to plan and organize their work independently (Hirsch-Kreinsen, 2014). The design of any technological solution aiming at supporting employees is influenced by and shapes the work organization it is used in. Broadly speaking, in a hierarchical work organization, services will prescribe actions and direct the employees, while in contrast in a team-based scenario, services will offer and enable alternatives.

We designed the here-described services and rules to provide support in the second scenario: The services offer information and support, while keeping the locus of control in the hand of the employee.

3.2 Main/Secondary Activity

The primary goal of team leaders and others responsible for the shop floor is to keep the production running to meet the planned numbers of products. This also sets the goals for the employees. The question then becomes how to create time for learning, due to the fact that the problem solving as required on the shop floor does not lead to learning per se: when performing the steps required for refilling an adhesive, there is no time for reflection and thinking about alternatives. The production has to restart as soon as possible and the goal of the software becomes to assist in this process as much as possible.

In work systems, the employee's activities contributing to this goal are considered main activities (REFA, 2002). In addition, employees often have to perform activities called ancillary or secondary activities, such as preparing the workplace, cleaning, etc. In order to incorporate meaningful learning into the workplace, a company has to create time for learning, so that employees can perform learning activities. In the following, we will therefore distinguish between an employee being in the “state” for main activities or in the state for secondary activities. Typically, a shift schedule assigns an employee to states during the day.

As the information required by the employee differs depending on their current state, i.e., what type of activities they are currently performing, the services have to distinguish between these states, whether they suggest actions to perform or content to be read.

It should be noted that creating “time for learning” is not a trivial task for an organization. It has to consider the views of various stakeholders, from the management to the labor representatives. A typical method consist of creating a time budget for learning. However, the topic falls outside the scope of this paper and in the following we will assume that “time for learning” has been created.

3.3 Development Goals

The goal of support when an employee performs the primary activity is to enable the employee to maintain production. This goal is the same for all employees, even though their specific actions will differ. In contrast, the goal of support for the secondary activity depends on the individual qualification and learning goals of the employee. Here, we assume that the employee together with his supervisor identified individual development goals in regularly hold performance reviews. These range from enabling an increased understanding of the current workplace to getting prepared for a new position.

From a technical perspective, in the context of this paper, the development goals refer to entities defined in the domain ontology and marked in the user model of individual employees as their goals, as well as to content the employee has to become acquainted with (e.g., specific safety instructions or learning material).

3.4 Assistance and Learning

Assistance supports an employee in her work-related tasks by specifying which work procedures to perform and how to perform them with the goal of completing the tasks as fast as possible. It aims at enabling the production line to fulfill the key performance indicators. The goal of the presented work is to go beyond providing assistance and to explore what forms of learning can be supported or even enabled. The services should enable learning by detecting topics relevant to the employee and suggest available content about these topics. Relevant topics can be inferred from recently occurring events (e.g., a large number of correctly or incorrectly performed work procedures) but also development goals. To summarize, adaptivity is realized with respect to three dimensions:

1. Assistance: depending on the context by reacting to the current situation on the shop floor. The aim is to fulfill production key performance indicators.
2. Learning: depending on the employee by reacting to recently occurring events (e.g., a large number of correctly or incorrectly performed measures).

3. Learning: depending on the employee by supporting the achievement of development goals (e.g., gaining a better understanding of the current workplace, learning about new technology, and working towards a new job position).

3.5 Pilot Scenarios

To better understand the specific requirements of the manufacturing industry, we analyzed working scenarios in three different companies. The three companies range from small- over medium- to large-sized companies:

- The small-sized company produces complex customer-specific tools and devices for car manufacturers and their suppliers. The working scenario focuses on installation and use of devices (milling machines), with the focus on support for highly qualified experts who have to stand in for other colleagues for commissioning a machine.
- The medium-sized company produces customer-specific welding and assembly lines for car manufacturers. The working scenario focuses on error diagnosis and correction in the customer-specific machines, with the focus on support for customers who buy a production line that includes a software support system.
- The large-sized company produces pneumatic and electric controllers for the automation of assembly-lines, which are used in customer-specific products as well as in their own production. The working scenario focuses on maintenance and repair, in particular outages (replacement of adhesives), with the focus on support for unskilled and semiskilled employees to enable them to perform maintenance tasks for which they are not actually qualified.

For each scenario, we modelled the work procedure on the level of the activities the employee has to perform. This results in a very fine-grained model that includes all detail necessary for an employee who has performed the procedure only a few times. It is also hierarchical, that is, steps that encompass a self-contained part of the overall procedure are combined into a sub-procedure. The modelling included several feedback loops with domain experts for refinement. Then, the work procedures were represented in the business process language BPMN ((OMG), 2011). For each step, we authored content that explains the required action.

In parallel, we analyzed the shop floor domain to identify the entities relevant for assistance and learning and their interrelationships. From this, we formalized an abstract domain model that represents the shop floor domain in general, and we then created one concrete instantiation for each company. The rules use the domain model for reasoning, i.e., determining which procedures and content to suggest to the individual employees. Regarding content, due to the fact that companies typically have vast amounts of information and data available (often distributed in different databases and network locations), the services aim at simplifying access to that content, by selecting and ordering potentially relevant information. The rules described in the following section define the precise meaning of “potentially relevant”.

4. RULES FOR ADAPTIVE SERVICES

This section describes the rules underlying the services in charge of selecting and presenting work procedure descriptions (i.e., providing assistance) and content (i.e., supporting learning) taking into account the position of the users, their work and learning history, and their current state (main activity or time for learning).

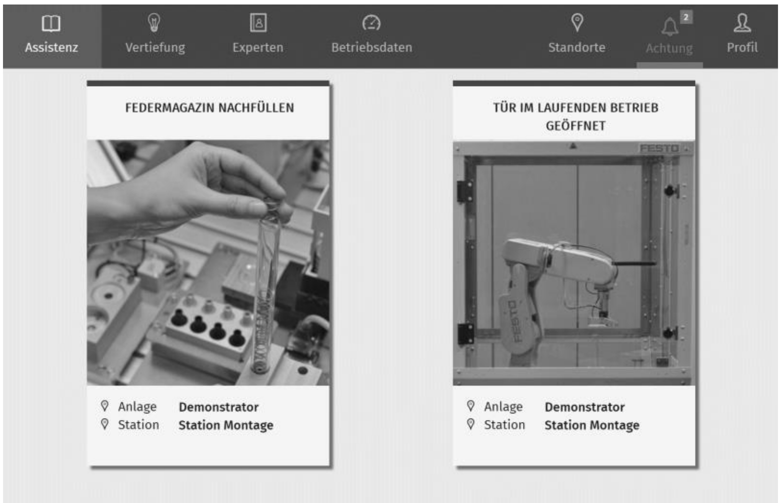
The rules are abstract in the sense that they perform their reasoning on the abstract domain model and do not encode information about the specific company in which they are used (the instances of the domain). Thus, they are transferable between companies. They thereby implement knowledge analogous to what a trainer or instructor possesses: given a specific set of circumstances, a trainer knows how to help the learner. The following rules “know” how to select adequate work procedures or pieces of content.

The use case is as follows: An employee logs on to the system on a tablet. She can then ask for assistance or content. Depending on whether she has to perform tasks for the main activity or time for learning, the services select different items.

Figure 1 contains a screenshot of the implemented system. The top row contains the main menu showing the available tabs, with the currently opened tab ("Assistenz" meaning "assistance") being highlighted. The main screen below shows two work procedures the system determined to be relevant to the employee in the current situation ("Federmagazin nachfüllen" meaning "refill spring magazine" and "Tür im laufenden Betrieb geöffnet" meaning "Door opened while under operation"). If the employees selects one of the work procedures, she will see instructions for each step of the process. The other relevant tab is the second from the right ("Vertiefung" meaning "consolidation"), which provides access to content relevant to the current situation.

To ease understanding, the following rule descriptions use pseudo-code. The software implementation uses a combination of ontology queries (in SPARQL) to perform the domain reasoning and Java code for retrieving data from other services, such as information about the user from the user-model-service and information about the state of machines from the machine-information-service. The entities defined in the domain model are emphasized using italics.

Figure 1. Screenshot showing recommended work procedures



4.1 Selecting Procedures

First, we describe the rules that suggests to the employee which work procedures to perform.

4.1.1 Main Activity

If the employee is in the state "main work activity" and asks for assistance, then select work procedures relevant for current station und machine state:

Algorithm:

1. WU = *workplace unit* to which *employee* is assigned to. Determined through request to user-model-service.
2. S = *sort*(*stations* ∪ *installation*) of AG. Determined by querying the domain model: There, each *workplace unit* is assigned to work with specific *installations* (e.g., the machines a maintenance team is responsible for or the machines assembly workers perform their assembly upon). An *installation consists* of *stations* (represented by the relation *part-of*). Sort the *stations* according to *priority* of each *station*. The priority represents the importance of the order currently executed on the installation.
3. MS = *machine state* of S, sorted according to priority of machine state. This is determined through request to machine-information-service.
4. P = *Procedures* for MZ. This is determined through a query of the domain model: *Procedures* are *applicable* to *machine states* (represented by the relation *applicable-to*).
5. P_a = those *procedures* of M the *employee* is authorized to perform (with or without assistance). This is determined through request to user model.

Result: P_a

4.1.2 Secondary Activity

If the employee is in the state secondary activity (“time for learning”) and asks for procedures, then select procedures that are relevant to her development goals. The employee and her supervisor defined the development goals *content* C_A, and/or *position* PO, and/or *production items* PI_A.

Algorithm:

1. PO = agreed future *position* of employee. Determined by query to user model.
2. P = relevant *work procedures* for PO. Determined through query to domain model: Each *position has tasks*, and *work procedures perform tasks*.
3. P_U = P without mastered procedures. Determined through query to user model (which keeps track of mastered procedures).

Result = P_U.

4.2 Selecting Content

The following rules suggest to the employee which content to read. Content is residing in the company’s databases or intranet and ranges from technical documentation to learning materials.

4.2.1 Main Activity

If the employee is in the state “main work activity” and asks for information, then select content relevant for the stations she is assigned to and their machine states:

Algorithm:

1. WU = *workplace unit* to which *employee* is assigned to; P = *position* of *employee*. Determined through request to user-model-service.
2. S, MS = *Machine states* and *stations/installations* relevant for WU (see rule in 4.1.1).
3. I = *Content about* S∪MS for *target-group* = P or without *target-group*. This is determined by querying the domain model, which contains metadata that relates content to domain model entities (by the relation *about*) and specifies its target-groups, if any. All queries for content take the target group into account, and in the following we no longer list this requirement.

Result = Content I. This rule selects for instance operation manuals, circuit diagrams, and other content that provides information about the current situation, which might enable the employee to overcome occurring problems.

4.2.2 Secondary Activity

If the employee is in the state secondary activity (“time for learning”) and asks for content, then select content that is relevant to her current work history (machines and procedures she has been working with). The employee and her supervisor defined the development goals *content* C_A, and/or *position* PO, and/or *production items* PI_A.

Algorithm:

1. PI = the *production items* with which the employee has worked with in the last four weeks, P_S the *procedures* that she performed successfully and P_N those not performed successfully. This information is stored in the learner-record-service.
2. C_P_N = *content* about P_N and *production items used by* P_N, with already seen content sorted to the back (this information is stored in the learner-record-service).
3. C_P_S = *content* about P_S or about *production items used by* P_S or about PI.
4. C_P = Content that covers one/several of the following: position PO, tasks of PO, or production entities PI_A.
5. C_PI_PO = Content that describes production entities relevant for PO.
6. C_P_PO = Content that describes production entities used for performing procedures relevant for PO.

7. $C\_T = C\_P\_S \cup C\_P \cup C\_PI\_PO \cup C\_P\_PO$, with already seen content sorted to the back.

Result: Content $C\_P\_N + C\_A + C\_T$, with duplicates removed.

4.3 Example

John Doe is an assembly worker in the workplace group “assembly of standard cylinders”. In addition to his assembly tasks, he cleared to perform the maintenance procedure “refill adhesive”. As he is new in his workplace group, he is supposed to learn about the produced product (the standard cylinder ABC) and prepare for performing the maintenance task “replace grease barrel”.

Fiona Smith is a machine operator in the workplace group “assembly of standard cylinders” and cleared for all maintenance procedures. She is supposed to get a better understanding about Industry 4.0 and the standard cylinder ABC, and to prepare for a customer meeting.

While John and Fiona are working their shift, two problems occur. The adhesive as well as the grease both drop to low levels. Both use their tablets to request support. John is shown the procedure “refill adhesive” at the first place, followed by procedure for less important tasks, such as cleaning the work environment. Fiona sees “refill adhesive” and “replace grease barrel”, also followed by less important procedures. When they switch to assisting content, John sees security information and the spec sheet about the adhesive. Fiona is shown additional material, suited for the job, such as the layout of the stations and technical documentation.

At a later time, John and Fiona have time for learning. John is shown the procedure “replace grease barrel”, which he can work through. Fiona sees maintenance procedures of the installations of the customer. For content, John sees general technical information about the standard cylinder, a video showing how it is used in other machines, and general information about site. Fiona is shown a course on Industry 4.0 and specific technical information about the cylinder.

5. CONCLUSION

This article showed how problem solving and learning on the shop floor can be supported by adaptive services. It described the general organizational requirement adaptive services have to consider and specific rules how to select work procedures and content. These rules are to be seen as the first steps into researching adaptivity on the shop floor on the very precise and formal level as they have long been in, for instance, mathematics learning and as such complement the overall research of workplace-integrated learning.

Several additional points are noteworthy. First, in industry, one should design work procedures with low-skilled employees as the target group and author the corresponding instructions accordingly. The reason is due diligence: one has to avoid that accidents occur due to missing information while an employee works through the steps of the procedure. This also has an effect on adaptivity: the only save way to hide information such as already mastered parts of procedures, is to indicate clearly in the user interface that information was hidden and to make that information available on request.

Secondly, we formulated the rules to be applicable on the shop floor in general. They can be applied for un- and semiskilled employees as well as experts, and are independent of the specific kind and size of manufacturing company. We measured the usability of the services that use the rules using the System Usability Scale (SUS, an established industry standard) (Brooke, 1996). Six employees of each industry partner received a number of tasks to solve using the system and were asked to think aloud while working on the tasks. Afterwards, they scored the system according to the SUS criteria, yielding an average score of 86.9, which is a very high score (a rating of excellent). Also the analysis of the think-aloud protocols did not show any problematic points. The results for all three partners were comparable. However, more long-term evaluations with larger numbers of participants have to follow to better understand the effects of the system after longer periods of usage.

ACKNOWLEDGEMENT

This publication is a result of work performed in the context of the project "APPsist – Intelligente Wissensdienste für die Smart Production", funded under the initiative "Autonomics for INDUSTRY 4.0" at the German Federal Ministry for Economic Affairs and Energy (BMWi), number 01MA13004C and supervised by the DLR. The authors are solely responsible for its content.

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