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The Role of User Guidance in the Industrial Adoption of MDE Approach

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Abstract: Model-Driven Engineering (MDE) has emerged as an actively researched and established approach for next generation control application development. Technology transfer to the industry is a topical research problem. Since most professional factory process control engineers do not have computer science backgrounds, there is an urgent need for studies of the role of user guidance in the professional learning, and thus, of industrial adoption of MDE approaches. In this study professionals were invited to a hands-on assessment of the AUKOTON MDE approach for factory process control engineering. Qualitative empirical material was collected and analyzed to identify the role of user guidance in the context of other factors impacting industrial adoption. Challenges in adoption that could be solved by user guidance were identified with the theory of organizational knowledge creation (SECI) model.

Keywords: MDE adoption, industrial assessment, user guidance, professional learning

1 Introduction

Model-Driven Engineering (MDE) is an actively researched and established approach for next generation control application development processes and tools [SSV08; SRH+09; LHB09]. Technology transfer to the industry is a topical research problem. Since most professional factory process control engineers do not have computer science backgrounds, our interest has been to investigate the role of user guidance in the professional learning, and thus, the industrial adoption of MDE approaches. In this paper, guidance refers to any supporting technology in the range from interactive, context-sensitive help and wizards to ordinary manuals and documentation.

The role of technology evaluation based on industrially credible evidence is identified as a key stage of the technology transfer process [Pfl99]; a seemingly comprehensive analysis of the kinds of evidence required for convincing different professional audiences is presented by Pfleeger and Menedez [PM00]. Neither does the transfer model by Gorschek et al. [GWC+06] consider employing professional education if seminars in companies do not lead to industrial pilots. In this paper, an approach for university-driven professional learning is proposed to facilitate the introduction of new industrial control software development technology.

This research is specific to the AUKOTON MDE approach [RK07; VHK08; VHK09; VSP+10]. Since this technology is not mature enough for full scale industrial pilots, eight R&D professionals from industrial companies were invited to university premises to learn and use

AUKOTON MDE and UML technologies in factory process control engineering. During the event, empirical material was collected to support the following research questions:

1. What is the role of user guidance in the context of other factors impacting the professional learning, and subsequently industrial adoption of AUKOTON MDE?
2. What other issues must be solved before user guidance solutions can complete the technology transfer?

Qualitative empirical material regarding participants' experience and impression on industrial applicability was collected. Grounded theory [SC90], a method for analyzing qualitative material, was used to identify the role of user guidance in the context of other factors impacting the professional learning, and industrial adoption of AUKOTON MDE. In addition, to analyze the technology transfer process we utilized the SECI model [NT95].

This paper is organized as follows. Section 2 covers related research and introduces the AUKOTON MDE approach. Section 3 describes the research arrangements and explains the use of grounded theory and SECI model. Section 4 presents the results of the above analysis. Section 5 concludes the paper by answering the research questions.

2 Related research

In this chapter we introduce both the target MDE of this study and some other research projects which relate to the study presented in this paper.

2.1 AUKOTON approach

This chapter describes the AUKOTON MDE approach. AUKOTON is a joint project of Aalto University School of Science and Technology, Tampere University of Technology (TUT), and VTT Technical Research Centre of Finland. The project focuses on producing a new approach in automation and control application development. The approach utilizes UML (Unified Modeling Language) [Uml] and Model-Driven Architecture (MDA) [MM03] by Object Management Group (OMG) [OMG] techniques, which have not yet been accepted into the industrial mainstream in the industrial automation domain. The AUKOTON development process consists of three main development phases in which the requirements, functionality, and target platform-specific details are modeled.

The simplified AUKOTON approach is presented in Figure 1 in which it is compared to the MDA approach. The process begins with the import of the requirements which have been produced in earlier development phases, such as production process design and instrumentation design. From this point onward, development occurs within the AP tool [VHK08; VHK09], which is an open source university prototype of a control application development tool. The concepts of the requirements model, as well as other models utilized in the development process, are defined in the UML Automation Profile [RK07]. The outcome of the requirements modeling phase is a complete requirements model. The requirements model is then transformed into a skeleton of a platform independent model (PIM). The transformation is fully automated and it does not require any user input.

In the next phase, the PIM is enhanced and elaborated to specify the functionality of the system according to the requirements. That is, the PIM is further refined to model the system in significant detail but without platform-specific features. As the PIM is completed, it is transformed to a platform-specific model (PSM) in user assisted transformation. The target

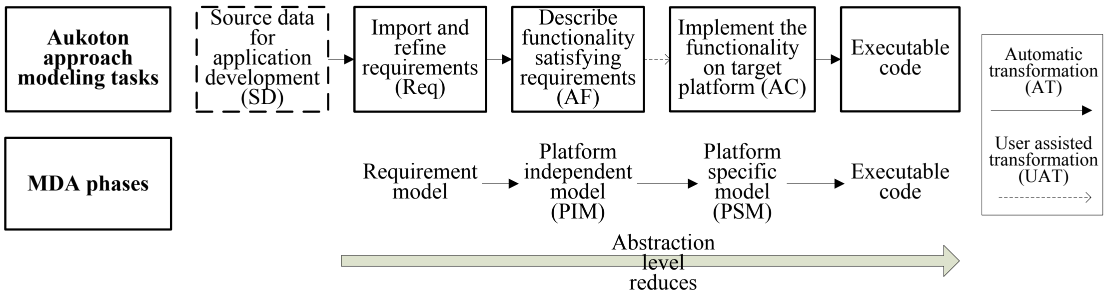

Figure 1: AUKOTON approach compared to MDA. Reproduced from [MM03; VHK09].

platform is chosen and appropriate platform-specific features are applied on the PIM elements transforming them platform-specific. The constituted PSM has sufficient detail to permit automatic generation of function block code using the library of the chosen target platform. In this study the target platform was the standard IEC 61131-3 PLCopen XML format.

2.2 User guidance

According to Lange [Lan06], a fundamental issue of UML is the lack of formal semantics and the fact that UML does not specify how it ought to be utilized. While this leads to defective models he proposes an approach in which the UML models are extended with the information of possible defects that are identified with a rule set. These rule sets can be seen as a form of guidance. Similar approach has been proposed by White et. al [WSN+08] in which the Object Constraint Language is used to guide users towards a correct solution. These approaches were considered too narrow in our study since we are viewing guidance of MDE approach with a somewhat broader learning perspective. A study by Baker et al. [BLW05] points out several issues relating to the adoption of a model-driven engineering approach including inexperienced teams and an undefined MDE process. They propose that best results are usually obtained when MDE is gradually deployed and matured. From the guidance point of view it ought to direct the organization to find its own best practices while providing them.

During the AUKOTON project, guidance was generated for the development approach [Rau09]. The guidance covers mainly the modeling concepts defined in the UML Automation Profile, though broader example cases and other practices were also provided. Interactive guidance was added to the AP Tool in the form of wizards and cheat sheets [HH06]. The purpose of an interactive guidance was to provide the user with advanced guidance and support methods and to investigate their implementation on the Eclipse platform [Ecl].

3 Methodology

This study is carried out along with a study that is concerned with the industrial adoption potential of the new control system design technique (AUKOTON) including, for instance, development process, modeling concept, and tool usability studies. The research arrangement limits the available methodologies. Surveys were not utilized since they require considerable a priori knowledge of the phenomenon under study [Tra01]. Since the technology is not sufficiently mature to be piloted in delivery projects in a company, it is not possible to apply fully the case study [BGM02] and action research [SGD05] methods.

Since methods mentioned above are problematic, professionals were invited to participate in a one-day project using the AUKOTON MDE environment on university premises. Student experiments have been used in the field of empirical software engineering to quantitatively evaluate customizations to UML, such as stereotypes and decorations describing non-functional component properties [BW02; KSW04]. The method in [KSW04] could have been modified to support an experiment in which our industrial participants develop a control application with the AUKOTON MDE environment and with a tool chain that is currently in industrial use. However, the development times and errors would greatly reflect the participants' familiarity with the tools and the maturity of the tools.

Qualitative methods were chosen, due to the lack of existing knowledge base for the phenomenon under study [Urq01; Tra01], which in our case is the role of user guidance in industrial adoption of MDE. Qualitative material is collected from eight industrial professionals from four companies participating in a one day technology assessment event held on university site. During the development process, qualitative material was collected using participatory observation and (structured) interviews. The arrangements are based on our experience with similar one week events in 2005-2006 [SSP+06; SCK+07].

In the assessment event, the participants used the AUKOTON methodology and tools to develop a small control application in the PC-class of the university. The assignment involves going through all the parts of the AUKOTON process, thus, providing foundation to acquire experiences and material on all the phases of the development. The event began with introduction to the AUKOTON approach and a demo of the tool chain to be utilized. The actual assignment began with a short introduction to the process for which the application was developed in the event. Then the participants utilized the AP tool (at the moment the only tool supporting the UML Automation Profile, and thus, used regardless of its immaturity) to develop a control application for a simple water heating process.

The participants were provided with work instructions, guidance developed for the process, and tools; they could also request the assistance of researchers participating in the event as technical support persons. As the researchers provided support on problem situations, they also collected empirical material on the problems users encountered during the assignment. Another source of empirical data is interviews. Participants were interviewed directly after each development phase and after they had completed the project. The interview questions concerned the development phase the participant had recently accomplished. This approach promotes the relevance and accuracy of the material since the participants were able to recall better what they had done during the development phase. This kind of reflection also promotes learning.

3.1 Using of grounded theory and SECI model

Since user guidance for industrial acceptance of MDE approaches in the industrial automation domain is a phenomenon lacking an established theoretical base, grounded theory (GT) was considered applicable [Urq01]. Grounded theory was originally developed by Glaser and Strauss in 1967. After that they both refined the method. In this paper we utilized the methodology developed by Strauss and Corbin [SC90; Jär04]. The grounded theory analysis consists of three types of coding processes: *open coding*, *axial coding*, and *selective coding*. The usual ways to collect material are interviews and observation.

Nonaka and Takeuchi, on the other hand, introduced in 1995 the SECI model which is a well-known theory for organizational knowledge creation [NT95]. SECI comes from words *socialization*, *externalization*, *combination*, and *internalization*. These modes are sequential with each mode depending on the outcome of the previous one. SECI is a spiral that can be traversed several times to create broader and deeper knowledge. We utilized this model together with grounded theory analysis to give our results appropriate perspective for learning.

The *open coding* phase of GT is a process in which researchers analyze the material. It includes two important analysis methods: the comparison of material issues and making questions. In the beginning of analysis we coded our material. In our case we first read the material through many times and looked for interesting statements and wrote them on post-its. We marked every statement with a source information (note number and/or interviewee's initials) so it was easy to go back to the material and see the context of statement when needed. We searched the statements using the SECI model as a main guideline. After finding the relevant statements we made a large poster (approximately size A0) on which we organized the statements into preliminary categories and subcategories.

The *axial coding* process of GT consists of procedures which are utilized to connect categories established in the open coding phase. By repeating this process, generality is improved as the nascent theory is challenged and refined against a broader set of empirical material [Urq01]. After the axial coding, the *selective coding* occurs. In this phase researchers try to find out one core category (or theme) which integrates all categories formulated during axial coding.

The axial and selective coding phases were closely related to each other in our analysis process. In our study we first searched new statements using the SECI model as the main guideline. This approach gave us an idea about the factors impacting learning and industrial adoption. After that, we considered the categories in the light of new statements. On another large paper we reorganized these categories many times considering several points of views, such as SECI model and AUKOTON methodology. As the result of this, many categories were changed or removed. In the end, the following three main categories were obtained: *the written support of work*, *design tool*, and *the challenges of process control engineering.* They are introduced in the next chapter.

4 Results

This chapter presents the analysis results obtained. In the tables a statement from participant is given with the design phase it relates. The abbreviations of the phases are described in Figure 1 (*GNR* = statement considering the process/approach in general).

4.1 The written support of work

First we shall discuss *the written support of work*. This category consists of two subcategories: *traditional guidance* and *advanced guidance*. In this paper the *advanced guidance* represents guidance and design support features embedded in the design tool (e.g. AP Tool). These kinds of advanced guidance forms are, for example, wizards and cheat sheets [HH06]. The category came together from participant comments considering or promoting advanced guidance methods in general. A statement by an interviewee (Table 1: 2) implies that the wizards, on one hand, provide means to externalize knowledge into models that are developed during

Table 1: Statements related to the written support of work.

Ref.	***Phase of development:*** **interview statement**	***SECI***
1)	*REQ*: (Requirements modeling) surely increases work, but it might be lucrative to focus on the requirements of the application. It would enable focusing on what is most important for customer and other interest groups.	**E**
2)	*GNR*: The wizards were great and eased completion of complex and tedious tasks.	**E**
3)	*GNR*: There could be need for (advanced guidance) in some marginal tasks, but probably not in the actual design chain.	**C**
4)	*AC*: Only most important information is visible on blocks of DCS system. Connection may be omitted if ports are invisible.	**I**

MDE based development. On the other hand, they provide means to understand the development approach and therefore support the internalization of the approach. One possible utilization target for wizards was mentioned in (Table 1: 4). A wizard that forces a user to go through each visible and invisible element reduces possibility of omission of a connection, and thus, enables user knowledge externalization to the model under construction.

The *traditional guidance* represents traditional means to provide guidance, such as user manuals including example cases and best practices. This category came together from an observation note that indicated low utilization rate of advanced guidance methods and a statement in (Table 1: 3). The participant cannot see a use for advanced guidance methods, which therefore might be unsuitable for MDE adoption process - at least in the field of process control engineering. Traditional guidance can also be utilized to focus the MDE approach to the requirement phase of development (Table 1: 1). Design process descriptions should emphasize and rationalize the requirement definition phase, and thus, help users to externalize the requirements model more precisely.

4.2 The challenges of process control engineering

This category includes observations which seem to be the most essential challenges in learning and using a new design tool, such as the AP Tool. The category consists of three subcategories: *domain-specific tasks*, *UML for process control engineers*, and *task-specific challenges*.

The subcategory of *task-specific challenges* represents design tasks which are especially challenging for process control engineers. Such challenges are, for example, the modeling of the prioritization of interlocking (Table 2: 5) and set point value description (Table 2: 8). The interlocking modeling is a problem of externalization. An engineer has to find a way to express the interlocking with the concepts available. To support the adoption in this context the MDE approach must provide suitable description concepts for the task and suitable guidance, such as example cases, to which the designer may refer. The statement (Table 2: 8) describes a problem of combination. According to the interviews, the current process control engineering practices lack requirements modeling phase similar to AUKOTON and MDE approach, yet the same information content must be supported by both. Thus, the combination of current and MDE practices must be supported.

The second subcategory is the *UML for process control engineers*. Especially among more experienced process control engineers UML is unfamiliar (Table 2: 9). From the MDE

Table 2: Statements related to the challenges of process control engineering.

Ref.	***Phase of development:*** **interview statement**	***SECI***
5)	*AF*: More complex scenario would be hard to model, (for example) interlockings with priorities.	**E**
6)	*GNR*: UML should not be visible, but hidden from process control engineers. They want to operate with control concepts. Domain-specific graphical presentation instead of UML specific. Process control engineers do not need UML.	**E**
7)	*GNR*: At first library that servers our (the company's) tasks, tailored for company needs. Design requirements of machine automation differ from continuous processes.	**C**
8)	*REQ*: Forming set point values is usually the most difficult phase. How one determines the right set point value?	**C**
9)	*GNR:* UML is quite unfamiliar environment for many experienced process control engineers.	**I**

point of view this is not critical, since MDE does not have to rely on UML [SVB+05]. However, in UML based MDE approaches, such as AUKOTON, the presence of UML graphical notation was here considered as an obstacle to industrial adoption. The users must internalize the concepts of UML and be able to combine them with familiar concepts to be able to utilize the MDE approach effectively. One way to handle this problematic situation is to hide UML from process control engineers (Table 2: 6). A visual language built on the top of UML, using notations familiar to process control engineers, is needed. The possibility to relate to professional experience via visually familiar constructs can support internalization of the AUKOTON approach for users who are not ready to learn UML.

The third subcategory under this category is *domain-specific tasks*. This subcategory represents those frequently occurring challenges encountered by process control engineers unrelated to any specific design task. A major requirement for industrial MDE implementation in process control engineering emerges from the modeling concepts (Table 2: 7). Though UML Automation Profile or other similar UML based profile try to be extensive, companies need specific libraries that suit their specific needs.

4.3 Design tool

The *design tool* category consists of two subcategories: *tool presentation challenges* and *tool flexibility*. The *tool flexibility* considers tool usability from externalization and combination point of views. According to (Table 3:11), the AP Tool does not provide for the participant familiar means to describe interlocking, which complicate the externalization. To support the MDE adoption the modeling needs should be identified, for example, through user feedback of the pilot project, and considered in the modeling language and tool. Moreover, as stated in (Table 3: 10), restriction of user externalization in modeling work could provide better results especially in the early stages of MDE adaption.

The *tool presentation challenges* category considers the presentation form of the tool. As stated in (Table 3: 19) the current user interface implementation of AP Tool is not adequate for industrial usage, and thus, it would be challenging for process control engineers to internalize the tool utilization even with suitable user guidance. Some specific issues are stated in statements (Table 3: 17, 18). Another kind of issue of AUKOTON and MDE approach emerges in (Table 3: 13, 15). The MDE approach may lead to development phases that are too similar, which may lead to problems if users neglect some of the phases. Training and guidance should rationalize the purpose of each phase, for example, by combining them with current engineering practices which, however, differ from AUKOTON practices (Table 3: 14). Especially the requirements modeling phase must be emphasized in guidance since in current industry practice control application development begins from the PIM level of AUKOTON process (Table 3: 16). Thus, introducing requirement modeling in current control engineering processes will help adoption of the AUKOTON approach in the future.

Apart from the tool presentation issues, the AUKOTON or MDE adoption also requires knowledge combination. Currently separated documents (Table 3: 12), must be combined under single data model utilized in AUKOTON and other MDE approaches. Data captured in several proprietary diagram formats used in industrial practice, such as control, regulation, and interlocking diagrams (see [VSP+10]) are all modeled in a single model in the AUKOTON MDE process.

Table 3: Statements related to the design tool.

Ref.	***Phase of development:* interview statement**	***SECI***
10)	*GNR:* User possibilities should be restricted according to what can be done in each (development) phase. Making of wrong things should be prevented.	**E**
11)	*AF:* (Interlockings) with many limiting values activating only in certain states or conditions of process (would be difficult to model). (The AUKOTON approach is) suitable for modeling simple and straight forward interlockings.	**E**
12)	*AF:* (In current practices) one moves from process design to basic design and produces regulation, interlocking, and control diagrams with appropriate texts. How does one get from this kind of approach to the approach of AP Tool?	**C**
13)	*AF:* Data content of requirements and automation functions (PIM) modeling phases are so similar that they could be one with process control engineering friendly concepts.	**C**
14)	*GNR:* The phases (of AUKOTON approach) does not correspond a typical (process) control engineering process.	**C**
15)	*AF:* In this transformation (from requirements to automation functions (PIM) model) no extra value was gained. The concepts could have been process control engineer friendly in that case already in requirements (modeling) phase.	**C**
16)	*AF:* The (automation functions/PIM) phase would in practice be the level, from which a control application engineer begins to implement the software.	**C**
17)	*AF:* (The presentation) should be more plain language, e.g. interlocking connections do not indicate what they do.	**I**
18)	*GNR:* It was hard to understand the concepts of the model, e.g. in tool outline, and the connection between diagrams and the model tree.	**I**
19)	*GNR:* Not even with a little training (the approach) could be utilized (in practice) for process control engineers. Graphical presentation does not meet current standards.	**I**

5 Discussion and conclusions

The research presented in this paper has addressed two themes. Firstly, we studied the role of user guidance in the context of other factors impacting professional learning, and thus, industrial adoption of AUKOTON MDE technology. Secondly, we were interested in the role of user guidance in the technology transfer process of UML and MDE technology into the factory process control engineering domain. This section concludes the paper by addressing the research questions 1 and 2 (see chapter 1) in sections 5.1 and 5.2, respectively.

The results of the study can be considered valid though the number of the participants and the length of the event were close to minimum. Though eight participants can not represent the whole process control industry, we managed to find certain issues and guidance needs for the AUKOTON approach with potentially valid for MDE approaches in general. Also the length of the event (one day) is not enough for participants to fully internalize the AUKOTON approach and the tool. However, it provides participants with enough insight to these techniques so that they can reflect the techniques against current practices they utilize in their work.

5.1 The role of user guidance

All of the problems presented in section 4 were encountered in a professional education situation, but some of the problems are not educational challenges. In the broader problem context of industrial adoption of AUKOTON MDE, it is difficult to distinguish between:

- development needs of the AUKOTON process, data model, tool, and notation, and
- educational challenges that may be facilitated with better user guidance

Since it is not possible for interviewees to make this distinction without resorting to leading questions, grounded theory was used identify the educational challenges that can be addressed with better user guidance.

The AUKOTON data model should be upgraded to support additional domain concepts, such as complicated interlocks (Table 2: 5; Table 3: 11). Also, the AUKOTON development process, which is directly supported by the data model, has phases that either do not directly correspond to industrial practice (Table 3: 12, 14) or are simply seen as unnecessary steps (Table 3: 13, 15). These issues require improvements to the data model and process, and cannot be solved only by user guidance.

A key development phase in current industrial practice that could be upgraded by the existing AUKOTON approach is the interface between process engineering and factory process control engineering; industrial participants were unable to understand the early phases of the AUKOTON chain in terms of their company practice (Table 3: 12, 14), but acknowledged the possibility of obtaining a more efficient process by adopting the AUKOTON requirements phase. Since current industrial practice does not have an activity that corresponds well with the AUKOTON requirements phase, professionals are not able to learn this by relating to their experiential knowledge. The latter statements make it clear, that even after updating the data model, additional user guidance is needed before factory process control engineers are able to understand and apply the approach.

User guidance can bridge the gap between industrial tools and new MDE tools and notations. However, guidance cannot be the sole solution: the notation should be changed to hide the unnecessary UML notation (ensuring not to discard essential concepts) from professionals (Table 2: 6, 9), so this is an issue which requires profound changes in visually representing the control concepts. Specific comments on the information content of diagrams were given (Table 3: 17), and attempting to resolve such issues by guidance is possible (Table 1: 4). The higher level structure of the underlying data model is a definite challenge for learning (Table 3: 18, 19). As this difference is related to the fundamental properties of MDE and Eclipse, there is a great need for user guidance to overcome this problem.

5.2 The technology transfer process

The second perspective of our research problem is identifying the opportune time for employing user guidance solutions in the entire technology transfer process; the issues related to guidance, data modeling, tool support, and notation identified in the previous subsection need to be addressed *in the correct sequence.* This has been investigated by applying the SECI model for organizational knowledge creation.

An example of immediate development needs is the support for interlocks with priorities (Table 2: 5) and multiple activating conditions (Table 3: 11). This has been analyzed as an externalization problem, because the knowledge already exists in tacit form among experienced professionals. However, another statement regarding interlocks has been coded as an internalization problem (Table 3: 17); this is not contradictory because it concerns the support for simple interlocks already present in the AP tool. When the former externalization problem is solved by data modeling and tool support, the possibility of a similar internalization problem, such as with the simple interlocks, should be anticipated by user guidance.

A serious issue that emerged from this study is that the AUKOTON development phases and related diagrams are not going to simply replace current industrial practice. Interviewees made it clear that AUKOTON development phases and data model concepts must be obviously related to the current industrial development process, and that AUKOTON needs to adopt terms, and possibly change the development process phases, in order to be sufficiently familiar to professional factory process control engineers (Table 3: 12, 13, 14, 15). These are all categorized as combination problems, since knowledge bases created and externalized in the AUKOTON project and numerous industrial projects need to be reconfigured to a mutually understandable and satisfactory knowledge system. A user guidance-based solution to the issues in the subsequent internalization mode of the SECI spiral (Table 3: 17, 18 and 19) will be contingent on the solution to the former combination problem.

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