Abstract: For successful and efficient development of unified modeling framework and software process model (SPM) for MES a new approach is needed. In this paper a modeling framework and SPM that integrates UML profile for system engineering SysML, ANSI/ISA-S95 standard and MES-ML modeling language for MES modeling and specification is presented. The proposed approach is illustrated with a real industrial Pick and Place Unit. Finally some conclusions are made.

Keywords: MES, UML, SysML, ANSI/ISA-S95, MES-ML

1. Introduction

Manufacturing systems are becoming more and more complex and there are many working groups whose research activities are directed in finding new modeling approaches for managing this complexity and for development of software process model (SPM). MES are combined, information, process-oriented and event and time activated software systems which main purpose is to link the automation layer to business planning and logical layer (ERP) [1]. One of the major challenges facing manufacturing today is ability to accurately express the information from multiple disciplines - mechanical, electrical and software engineering used of Manufacturing Execution Systems (MES). Another challenge is connected with the development of unified modeling framework for modeling of the important views of MES components using different modeling languages and standards.

The engineering and specification of MES is an interdisciplinary process which integration requires a modeling language able to represent software, hardware and their interactions. The rapid progress of computer technologies leads the possibilities for development of new methodologies, methods and approaches suitable for development of software and hardware in industrial systems. Some of the most promising and challenging approaches are these of Model Driven Development (MDD) and Model Driven Engineering (MDE) [2], where the systems are presented as models that conform to meta-models, and the model transformations are used to manipulate the various representations. Model Driven Architecture (MDA) [3] is a remarkable MDD initiative of Object Management Group (OMG), consisting in transformation of different platform independent models towards executable applications. In the core of MDA are the open standards - UML, MOF, XMI, etc. UML [4] does not specify a methodology for model driven software or system development but aims to provide an integrated modeling framework, covering structural, functional and behavior descriptions.

The currently available MES, based on traditional approaches, have monolithic architecture, are not flexible enough and have a limited scope. Due to the difficulties in their configuration and adaptation to specific needs, they do not meet the requirements of modern industry. The main trend to overcome these shortcomings is the use of new, advanced software process model (SPM) for MES development.

The main aim of the proposed paper is to suggest an approach for development of unified modeling framework and SPM for development of the important views of MES components and coupling their established modeling notations, based on the combined use of UML profile - SysML and ANSI/ISA-S95 standard models.

The paper is organized in 4 parts. After the introduction, in part 2 the related work about existing approaches for development of MES is discussed. Part 3 of the paper presents the proposed approach for development of SPM for MES is described. A case study concerning an application of the suggested approach for a real industrial unit is presented in part 4. Finally some conclusions are made.

2. Related work

MES engineering is an interdisciplinary challenge and requires cooperation between plant engineers, MES engineers, plant manager, production manager, IT engineers, solution developer, etc. The development and implementation of MES is a difficult task and the main challenges facing the field of MES are associated with the need of unified modeling framework and SPM that can be used to represent and execute such type of systems. The modeling techniques in the field of MES can be categorized in three basic groups – using of standard models, terminology and consistent set of concepts provided by ANSI/ISA-S95 standard [1, 5, 6]; using of MDE and MDA based approaches [2, 3, 4, 7] and set of approaches based on MES process modeling [8, 9].

2.1. Approaches using ANSI/ISA-S95

ANSI/ISA-S95 standard provides standard models, terminology and a consistent set of concepts for defining the interfaces between an enterprise’s business systems and its manufacturing control systems, and the activities of manufacturing operations management [1]. The suggested functional enterprise-control model is composed of 12 classes of different set of functions as shown in fig. 1. The information flows between the different functions are defined and categorized in three main areas: information required producing a product, information about the capability to produce a product and information about actual production of the product. A general activity model for all these categories is proposed, with the purpose to identify all possible data flows within manufacturing operations. As shown in fig. 1, eight main activities are defined: detailed scheduling, dispatching, resource management, tracking, definition management, data collection, execution management and analysis.

The object models of these functions are depicted using the Unified Modeling Language (UML) notation methodology. An extended approach based on ANSI/ISA-S95 series of standards integrates ontologies in order to achieve interoperability of the internal and external systems.

2.2. MDE and MDA based approaches

The UML [4] as a general purpose modeling language and an open standard supports the MDE and MDA. It does not specify a methodology for software or system design but aims to provide an integrated modeling framework, covering structural, functional and behavior descriptions. The UML notations support the development
of various diagrams that reflect different aspects of the system in order to capture the full complexity in the phases of detailed analysis and system design. Different object-oriented approaches based on UML and its profile for system engineering SysML [10] for development of control systems, which are applicable in different industry areas, are investigated. Detailed description and analysis of the different suggestions may be found in [11, 12]. The approach for MES modeling, based on SysML provides either an interaction between software components of MES and software and hardware components of the manufacturing system or possibilities for abstract and detailed modeling of MES activities.

2.3. Approaches using MES process modeling

The modeling techniques in this group can be categorized into three sub-groups: approaches for MES process modeling using traditional process modeling languages, approaches for MES process modeling using process decomposition and approaches for MES process modeling using hybrid techniques. Various modeling languages and notations are used for modeling of interdisciplinary processes in MES, such as Business Process Modeling Notation (BPMN), Business Process Execution Language (BPEL), and SysML. The BPMN standard offers a number of structural elements, which are missing in other technologies and the information for MES specification is spared among multiple co-workers who have different view for technical and business process, know different details about the processes and have different requirements. BPMN is insufficient for modeling of complex systems but enables to present MES system as a collection of separate processes (which represent the MES functions), and so it is possible to model these processes separately under one large model [13, 14].

In [15] M. Witsch and B. Vogel-Heuser suggest a modeling framework that different important views for MES specification by coupling their established modeling notations. The main contribution of this framework is the integration of a technical system model, a production process model and an MES functional model with their interconnections and dependencies by a formal link model. MES-ML proposes a graphical MES modeling language. The technical system model represents the static technical systems that perform MES functions. This model either could be on the abstraction level of an entire plant, or detailed to atomic function units depending on the needs. The second model is the production process model, which represents the manufacturing systems in MES. The authors propose to use UML activity diagram or flow chart as the modeling notation.

3. Short description of suggested approach

The existing modeling approaches in the area of MES are not sufficient to satisfy the users and system requirements and for development of the important views of MES components. MES are not flexible enough; they have a limited scope and monolithic architecture and may not be reused in new manufacturing applications.

The success of UML and SysML in unifying many different object-oriented approaches and the graphical modeling language support of MES-ML to the required engineering process of MES led to the idea of their combined use for development of unified modeling framework and software process model for MES components. Supplementary a separation of functions/activities of business processes from production processes by using of ANSI/ISA S95 standard models and terminology is undertaken.

The proposed model-driven approach is shown in fig.2. The basic cycles for task flow development process included in the proposed methodology, such as – requirements analysis, system functional analysis, architectural design and hardware/software specification are the stages from Harmony SE based methodology for software development processes, described in details in [11, 12]. The suggested approach uses different kinds of ANSI/ISA S95 standard models, modeled through SysML modeling constructs.

The first step in the development of MES using the proposed approach is creating on UML/SysML profile extended with new predefined stereotypes based on MES-ML modeling notations. According MES-ML the stereotypes are divided in several groups representing MES functional model activities, MES functional model events, MES functional model data objects and getaways and MES functional model connecting objects, swim lines and artifacts. To each stereotype an icon from MES-ML modeling notations is assigned.

The development process of the MES requirements and performance analysis function is divided into two main steps – define the concrete customer functional requirements and selection of MES functions represented through the Requirements Diagram (RD) and Requirements table (RT); and MES functionality definition using Use Case Diagram (UCD) and Block Definition Diagram (BDD). The performance analysis function is based on the follow steps – analysis of the MES domain to define the environment of the MES, analysis of the MES structure and manufacturing system and analysis of customer requirements and specification. BDD is used to perform analysis of the MES domain and the MES structure and manufacturing system and in order to present customer requirements RD, RT and UCD are used.

The description and analysis of MES processes and the definition of the interfaces between an enterprise’s business systems and its manufacturing control systems, and the activities of manufacturing operations management are sub-stages from next stage in the proposed methodology - architecture design. This stage includes the design of ANSI/ISA 95 models using BDD which are customized through the MES-ML stereotypes and design of the different views for MES system - technical system model, a
production process model and MES functional model modeled with Block Definition Diagram, Internal Block Diagram and Activity Diagram customized through the MES-ML stereotypes. In order to model the physical structure of the manufacturing control system (technical system model), BDD is used. The processes in the manufacturing systems (production process model), Activity Diagrams in different level of decomposition are used. The functions of MES embedded in interacting IT functionalities and systems can be modeled in MES functional model using activity diagram separated with swim lines presenting respectively the ERP, the MES and the process control system functions.

4. Case Study

To show some of the advantages of the suggested approach, a real industrial Pick and Place Unit (fig.3) constructed by Technical University Munich [16] is used. The PPU consists of a stack (1), working as a work piece input storage, a conveyor (2) working as a work piece output storage, a stamp (3) for stamping work pieces and a crane (4) for transporting work pieces by picking and placing them between three working positions – for black, white and metallic work pieces. The PPU may work in various different manifestations called Scenarios.

Fig.4 shows the UML/SysML meta-model of Production Operation Management functions according ANSI/ISA-95 [1] modeled using Papyrus plug-in of the Eclipse platform. The production operation management model is extended with product definition, product capability, product schedule, product performance, operation definition, operation capability, operation schedule and operation performance models presented like blocks. The meta-models of the Quality operation management function, Maintenance operation management function and Inventory operation management function may be modeled according their equal UML models.

Fig.3: Pick and Place unit

Fig.4: Meta-model of Production Operation Management functions

The operation schedule (fig.5), operation definition (fig.6) and operation performance models (fig.7) for PPU are presented using BDD. The operation schedule model for PPU (fig.5) consists of blocks named according ANSI/ISA-95’s model “PPU-Request”, “Requirement”, “Equipment Requirement” and “PPU-Material”. The information needed for model elements is presented as attributes with appropriate data type and constraints defined using OCL (Object Constraint Language). The attributes in block “PPU-Request” show that the plant execute Scenario 0 [16], type of operation is production, start and stop time of the process. The block “Requirement” contains information about earliest start time and latest end of the process. The required equipment for execution of Scenario 0 is Micro switch, Motor, Vacuum switch, Monostable Cylinder, Turning table, Stack, Crane, Ramp and Binary Sensors are defined as attributes in block “Equipment Requirement”. The information about material is assigned with attribute named “WP”, presenting the number of work pieces for PPU.

In fig.6 the operation definition model for PPU is shown. The model consists of blocks with names “PickUp&Place”, “Operation Material Bill”, “PPU”, “Operation Definition Dependency”, “Parameter Specification”, “Equipment Specification” and “Material Specification”. In block “Operation Definition Dependency” the operations dependency according ANSI/ISA-S95 specifications g dependency types: B can not follow A; B may run in parallel to A; B may not run in parallel to A; start B no later than T (Timing Factor) after A start; etc. are defined. Timing factor is also defined as constraint in block “PPU” and attribute “Duration”. The operation definition constraints are assigned using OCL. The type and number of required equipment is defined in “Equipment Specification”.

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Fig. 7 shows the operation performance model for PPU which consist from blocks named “PPU-Operation Response”, “Response”, “Equipment Actual” and “Material Actual”. Due the possibility to use metallic or plastic (black and white) work pieces in block “Material Actual” two attributes – WP color and WP material are defined.

Fig. 6: Operation definition model for PPU

5. Conclusions

The paper presents an approach for development of unified modeling framework and SPM for modeling of important views of MES and their components. The UML/SysML profile is extended and at the same time restricted with different stereotypes from MES-ML and ANSI/ISA S95 standard models. The benefits of using this approach are summarized as follow: development of open, flexible and reusable components, faster specification of MES functionality, improvement of capabilities for requirements definition, etc.

The proposed approach is partial realized for modeling of a real industrial Pick and Place Unit. The meta-model and the models of Production Operation Management functions are created.

The future research activities are concentrated mainly on applying the suggested approach to continuous and batch systems as well as application of the suggested approach in industry.

6. References

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