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IMPLEMENTATION AND ENHANCEMENT OF A GRAPHICAL MODELLING LANGUAGE FOR FACTORY ENGINEERING AND DESIGN

Carmen Constantinescu
Fraunhofer Institute for Manufacturing Engineering and Automation – IPA, Stuttgart, Germany
Carmen.Constantinescu@ipa.fraunhofer.de

Günther Riexinger
Fraunhofer Institute for Manufacturing Engineering and Automation – IPA, Stuttgart, Germany
Guenther.Riexinger@ipa.fraunhofer.de

ABSTRACT

The optimal design and permanent adaption of factories guarantees sustainable success and competitiveness in a global economy. Thus factory engineering is a key issue to be addressed. In order to support the engineering of factories a generic and extensible Reference Model for Factory Planning has been developed. The Reference Model is comprised of systemised planning phases and their corresponding planning activities. In this paper different concepts and languages to model the factory planning reference process during the Factory Life Cycle, are presented. Based on the requirement analysis, considering the functionalities of the existing modelling languages, a suitable graphical notation is selected. Furthermore the implementation in the phase of equipment and workplace planning is presented. The requirement of future enhancement of the graphical modelling notation is illustrated and a corresponding roadmap is introduced.

KEYWORDS

Factory Engineering and Design, Reference Model for Factory Planning, Factory Life Cycle, Graphical Modelling Languages

1. INTRODUCTION

To achieve sustainable success and competitiveness in a global economy, factories need to be able to face all the challenges with optimal designed production systems. These challenges and requirements arise from global markets, growing customisation of products with short life cycles and new adaptive production technologies. Factories and Production Systems need to be designed with the focus on sustainable and adaptable production systems (Bullinger et al, 2009).

As a consequence, the factory planning frequency and design complexity increases. Planning task and their influencing parameters get more and more complex and need to be approached with holistic optimisation of the process chains and factory planning sequences. Furthermore a considerable effort is needed, to coordinate all the information and data exchange between the responsible engineers and planners involved in a factory planning project. A holistic and multi-scale factory engineering and design reference process is needed, to support factory and process planning along the whole Factory Life Cycle. Thus, the generic and extensible Reference Model for Factory Planning was developed to support the design and engineering of factories (Constantinescu and Westkämper, 2009).

In this paper the scope and concept of the Reference Model for Factory Planning is illustrated and different concepts and graphical modelling languages to model the factory planning reference process during the Factory Life Cycle, are presented. Therefore, the modelling languages are evaluated considering the requirements and needed functionalities of the Reference Model. An implementation example in the phase of “Equipment and Workplace Planning” is given and new concepts for the future enhancement of the employed graphical modelling language are presented arriving from current research on scenario-based evaluation of factory planning processes and the use of the Reference Model.

2. SCOPE AND CONCEPT OF THE REFERENCE MODEL FOR FACTORY ENGINEERING AND DESIGN

This section addresses the scope and concept of the Reference Model for Factory Engineering and Design concerning factory and process planning. One objective of the Reference Model for Factory and Process Planning is to support planners and interdisciplinary teams in different planning phases with generic factory planning steps and activities. Several research works approached the concepts, purposes and tasks of factory and process planning and provide guidelines for the factory planning process e.g. Aggteleky (1990), Chryssolouris (2005) or Grundig (2009). According to these fundamental planning concepts and Factory Life Cycle phases proposed by Westkämper (2008), the fundamentals of the Reference Model for Factory and Process Planning have been established.

The systematised and structured planning phases that are shown in Figure-1 are the foundation of the Reference Model. All phases and activities required as standard and mandatory for the purpose of factory and process planning have to be implemented. The planning phases consist of corresponding planning steps and individual planning activities with inputs and output data objects. Furthermore, these planning entities and the identified relationships between the individual phases and planning steps support the management of factory data over the entire Factory Life Cycle and therefore the development of a holistic Factory Data Model (Constantinescu and Kluth, 2011).

Due to the individual, flexible and scenario-based nature of the factory planning process, the Reference Model has to be instantiated to cover the needs and requirements of a specific planning project and several types of factories operating in different industrial sectors. Thus, the main features and requirements characterising the Reference Model are:

a) The Reference Model has to be *generic*, to cover all the standardised aspects of factory planning and to provide the basic planning entities.
b) The Reference Model has to be *modular* to enable the reconfigurable and independent use of its factory planning phases, steps and activities.
c) Furthermore it has to be *extensible* and *open* to enable the implementation of additional data entities and further planning steps within its planning phases.

Moreover, the Reference Model has to be clearly structured and well-defined through the use of a graphical modelling method that covers all the requirements concerning the scope and concept of the Reference Model. Therefore, suitable graphical modelling concepts and languages are presented and evaluated in chapter 3. The Reference Model aims to be a common basis for planners and interdisciplinary teams involved in the factory design process. It supports the overall factory design process and brings benefits such as higher planning efficiency, higher planning quality and lower planning cost. Furthermore the Reference Model illustrates dependencies between the single factory design processes and its involved planning teams. In comparison to other state-of-the art factory planning approaches, a wider perspective of factory engineering and design processes with all its interrelations and information flows is described. Thus, different types of factories and industry sectors are able to instantiate and refine the Reference Model for their individual needs.

To provide additional benefits concerning the analysis of scenario-based and individually instantiated planning alternatives the Reference Modell for Factory and Process Planning need to be enhanced with additional factors or parameters. Thus, this paper presents a first approach concerning the enhancement of the employed graphical modelling language.

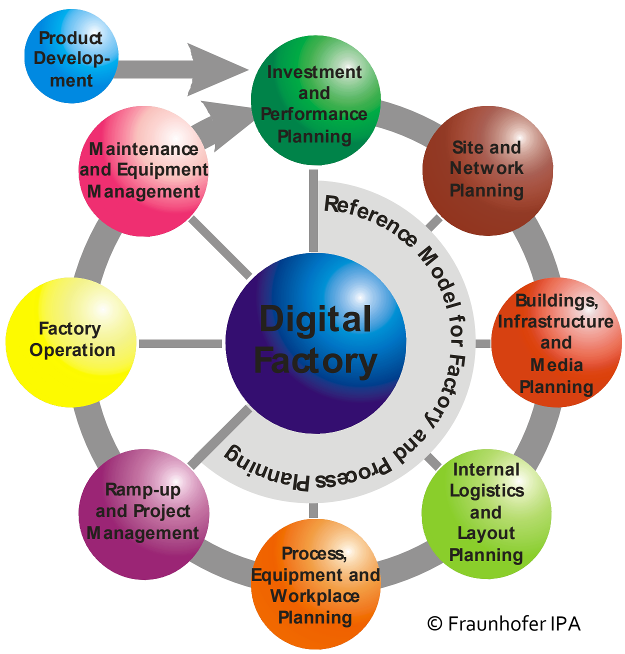

Figure 1 – Continuously Integrated Factory Engineering and Design with the Planning Phases of the Reference Model for Factory and Process Planning

2.1. PLANNING PHASES OF THE REFERENCE MODEL

The Reference Model for Factory Engineering and Design and its systemisation of planning phases and their corresponding planning activities refers to the "Factory is a Product" and the "Multi-scale Factory" approaches, which concentrate on the whole Factory Life Cycle and its phases (Westkämper et al, 2006). The focus of the Reference Model for Factory and Process Planning is on factory planning phases and its planning steps. Regarding the scope of the Reference Model these phases have been further structured in:

a) Investment and Performance Planning,
b) Site and Network Planning,
c) Bulidings, Infrastructure and Media Planning,
d) Internal Logistics Planning,
e) Layout Planning,
f) Process Planning,
g) Equipment and Workplace Planning and
h) Ramp-up and Project Management.

Each planning phase is composed of individual steps and activities, which can be related to other planning phases through the definition of the information exchange. There is no defined order for a specific planning sequence, instead the established planning phases can be situation-based arranged and individually adapted to specific planning needs. Thus, the overall planning phases and steps are as detailed as possible and as generic as necessary in order to be instantiated for different types of factory planning scenarios and industry sectors.

2.2. DETAILING OF THE PHASE: EQUIPMENT AND WORKPLACE PLANNING

The developed Reference Model will be applied in various factory engineering and design projects and planning scenarios. Thus, a short overview of the phase "Equipment and Workplace Planning" is given, as the implementation of the Reference Model for Factory and Process Planning is illustrated in this planning phase.

"Equipment and Workplace Planning" is closely related to all phases of the Factory Life Cycle. Information from earlier phases like logistics and layout design or process planning is crucial for the design of factory equipment and workplaces. Required production technologies are identified and established in accordance with the product requirements and production processes. Thus, the required production resources (e.g. machines, devices, tools …) are defined. Besides the functional design and configuration of machines, the dimensions and capabilities are defined according to the production operations and expected capacity requirements (Wiendahl, 2005). Furthermore, the capability and capacity of the production resources need to fulfil the planned production volume requirements (Aggteleky, 1990). In order to meet the needs for flexible configuration of production systems, the adaptability of planned resources has to be considered during this planning phase (Westkämper and Zahn, 2009).

To face these challenges, the classical methods of industrial engineering have to be used through innovative and efficient digital tools, which are employed within all phases of Factory Engineering and Design. These tools support the planning of the number and performance of individual machines for instance. Furthermore, the planning activities can be followed by simulations in order to optimise the machine parameters like setup times and the capacity utilisation.

Parallel to the equipment planning, the workplace has to be designed by taking into consideration ergonomic and safety aspects. The workplace is planned to ensure the optimal coordinated interaction of personnel and equipment under consideration of human capabilities and requirements (Eversheim, 2002). The focus is on ergonomic design of workplaces. The defined processes, equipment and environmental conditions (e.g. noise and ambient temperature) should be based on human characteristics (e.g. concerning anthropometry, biomechanics, physiology and psychology) and abilities (Schlick, 2010). Thus, digital human models can be used to ergonomically optimise and validate the planned processes and assembly sequences respectively (Schlick, 2009). Furthermore advanced planning methods and tools support the whole phase of equipment and workplace planning with manufacturing and assembly processes simulations.

3. MODELLING FOUNDATIONS: EMPLOYMENT OF GRAPHICAL MODELLING METHODS

Concerning the development of the Reference Model, concepts and languages to model the factory planning reference process during the Factory Life Cycle have to be evaluated and a suitable modelling method has to be selected. The evaluation is based on the criteria and requirements from: a) Scope, b) Clearness and Visualisation and c) Implementation of the Reference Model.

The modelling language should meet all the requirements on the scope of a generic, modular, extensible and open Reference Modell. Thus, the modelling language must be flexible if changes in the factory planning sequence are needed. Furthermore, the modelling language has to represent and visualise all planning phases, its factory planning process with corresponding input and output entities as well as the involved stakeholders (e.g. product designers, production planners, quality engineers,…). It should consist of structural elements, which provide a high degree of clearness with well-defined notation methods. Additionally, the modelled Reference Model should be able to be easily instanced and implemented in various industry scenarios and sectors.

Thus, in the following section four widespread graphical modelling languages and concepts are introduced and analysed regarding their applicability to represent the Reference Model.

The modelling methodology: "Integration Definition for Function Modelling" (IDEF0) as well as the related "Integration Definition for Process Description Capture Method" (IDEF3) are able, to model and describe process steps and actives of a factory planning scenario. These standards are a part the IDEF modelling method family and are based on the Structured Analysis and Design Technique (SADT). The IDEF standards have been established by United States Air Force within the Integrated Computer-Aided Manufacturing Programme (Clarkson and Eckert, 2005). The analysed IDEF languages provide useful methods and notations for the functional analysis and representation of processes. The process steps are being described in hierarchical structure diagrams with input and output mechanisms concerning the flow of information and resources. (Parnell et al, 2010).

Furthermore, the Event-driven Process Chain (EPC) modelling method allows the graphical modelling of business and factory planning processes. The main focus is on representing business processes concepts from a business perspective rather than describing the technical realisation of these processes. The EPC are part of the "Architecture of Integrated Information Systems" (ARIS) framework developed by Scheer (Weske, 2007). Business process and factory planning work flows can be represented in EPC flowcharting diagrams. EPC diagrams consist of graphs with events and functions that can be associated to information or resource objects and organisational units. EPC and IDEF diagrams consist of clear structures, but also could get very complicated if complex processes have to be represented. Furthermore, they are not very flexible if changes in the process sequence occur (Anderl et al, 2008). Thus, a different method to model and represent the factory planning reference processes during the Factory Life Cycle has to be selected.

Another very common standard of graphic based languages is the Unified Modelling Language (UML). It is an object-oriented modelling language that is used in the field of software engineering and managed by the Object Management Group (OMG). Concerning the graphical notations and modelling techniques, UML provides structure diagrams and behaviour diagrams. To represent the Reference Model for Factory and Process Planning, activity diagrams can be used to describe single steps of the factory planning process (Object Management Group, 2011b). UML activity diagrams are technically orientated and illustrate the network of process steps with their connections and data flows. UML 2.x diagrams are using petri-like semantics with a support of parallel executed systems and a wide scope of possible modelled situations. However, the involved stakeholders need experience in UML modelling to understand the activity diagrams for a business process model. Thus, a more business oriented modelling solution is required.

A graphical modelling notation, which focuses on the graphical representation and implementation of the business processes, is the Business Process Model and Notation (BPMN). BPMN is also published by the OMG and provides modelling solutions and flowcharting techniques, which are comparable to UML activity diagrams. The focus of the BPMN standard is to provide a graphical notation to specify and model business processes and whole process landscapes with relations between the single planning activities. (Object Management Group, 2011a) Furthermore, BPMN diagrams have a high clarity and are easy to understand for all stakeholders that are involved in the planning process. Thus, the graphical modelling method and notation BPMN was selected for the purpose of comprehensive modelling the Reference Model for Factory and Process Planning. The results of the evaluation are presented in Table-1.

Table 1 – Modelling Methods Analysis and Evaluation

	Scope	Clearness and Visualisation	Implementation
IDEF	+	-	-
EPC	+	+	+
UML	++	+	-
BPMN	++	++	+

4. MODELLING METHOD FOR THE REFERENCE MODEL: BPMN

The graphical modelling method "Business Process Model and Notation" (BPMN) and its functionalities is presented in this section. BPMN is published by the Object Management Group (OMG) as a standard for the modelling, implementation and execution of business processes. It is understandable by all business users, from the initial concepts and drafts of the processes, to the implementation of methods, tools and data models, that are needed to perform, manage, monitor or support business processes (Object Management Group, 2011a).

Business processes are modelled in Business Process Diagrams that are using graphical elements with the flowcharting technique. The main graphical elements of the modelling notation are Flow Objects with Events, Activities and Gateways as well as Connecting Objects with Sequence Flows, Message Flows and Associations.

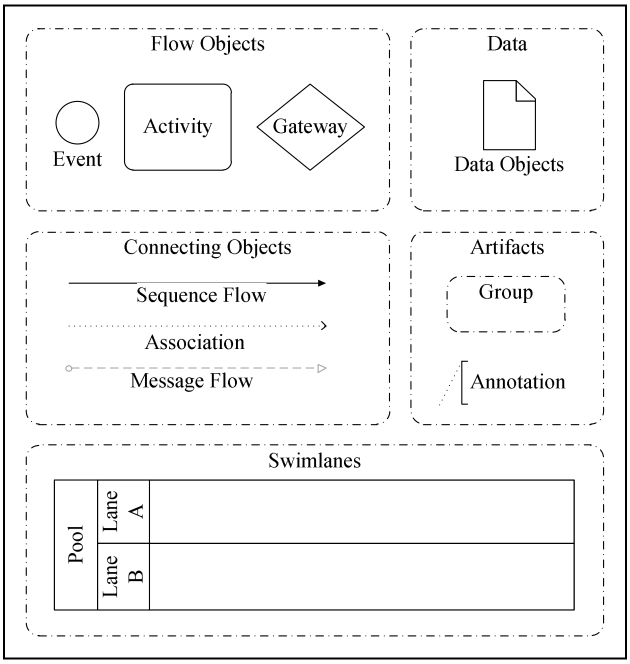

Figure 2 – Main Graphical Elements of BPMN

These elements are modelled within Swimlanes that represent the organisational structures or business stakeholders in Pools and Lanes. The flow of data and the associations to data entities is shown through Data Objects. Furthermore, Groups can be formed and Annotations can be made through Artifacts. An overview of these basic modelling elements is presented in Figure-2. The graphical elements of BPMN are specified as a standard visual language that all process modellers and stakeholders can understand and recognise. These elements and shapes are implemented within the Reference Model to compose the Factory and Process Planning Reference Diagrams of the established factory planning phases. Furthermore in version 2.0 of the BPMN standard new features like XML schemes for model transformation or the modelling of orchestrations and choreographies have been included.

4.1 MODELLING OF THE FACTORY PLANNING PROCESS WITH BPMN

For modelling the factory planning process within the Reference Model, Flow Objects are used as one of the main graphical elements of the Reference Model. Flow Objects constitute the factory planning process sequence with a start and an end event. Furthermore, the convergence or divergence within the process sequence is defined through gateways (Object Management Group, 2011a). The main gateways used in the Reference Model are: a) Exclusive Gateways (XOR) for modelling branching points where one process sequence can be separated in two or more alternatives and only one of them can be chosen, b) Inclusive Gateways (OR) for modelling branching points where two or more process flows can be split or merged and c) Parallel Gateways (AND) to divide a process path in two or more parallel process sequences.

Within the Reference Model, single process steps and activities are connected through Sequence Flows to define a process sequence. These Connecting Objects illustrate the order in which the factory planning processes are performed.

Data Objects are used to define input and output data entities of single planning steps as well as to provide information about the related planning phase of the required data for the process to be performed.

Furthermore, individual stakeholders, who are involved in particular planning activities, are stated and milestones are defined. Besides the use of Swimlanes also Groups are defined to cluster similar planning processes and therefore to give a simplified overview of each planning phase. In the following chapter 4.2 an implementation example is given.

4.2 IMPLEMENTATION EXAMPLE IN THE PHASE OF EQUIPMENT AND WORKPLACE PLANNING

BPMN is selected and employed as modelling method for the Reference Model as presented in chapter 2.1. Every planning step and activity as well as the corresponding relations have been implemented by using the BPMN. In this section an example of the implementation is presented for the equipment and workplace planning phase. The phase is structured in four main generic planning steps, which are shown in Figure-3.

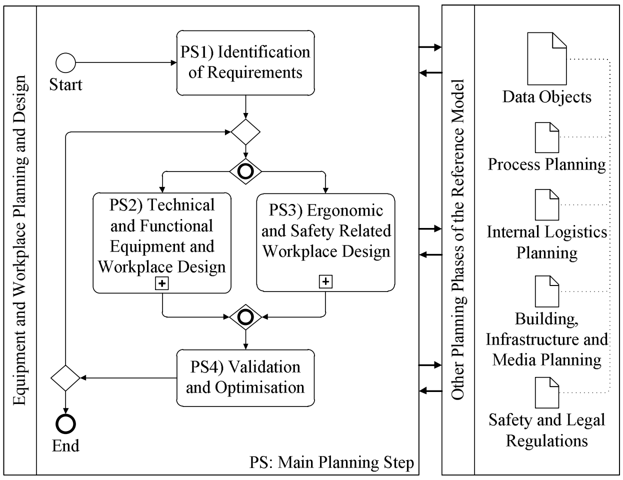

Figure 3 – Main Planning Steps of the Equipment and Workplace Planning

In the first planning step "Identification of Requirements", the process requirements and other general needs regarding Equipment and Workplace Planning are defined. Safety and legal regulations as well as production data consisting of layout, media process and logistic information is taken into account. The following planning steps are the "Technical and Functional Equipment and Workplace Design" as well as "Ergonomic and Safety Related Workplace Design". The used "inclusive" (OR) gateways specify, that the execution of planning steps can be performed in parallel or individually in a given sequence. After the last main planning step "Validation and Optimisation" a loop back can be performed. Within this planning step detailed evaluations or simulations are performed, and new knowledge could be taken into account, to refine the planned equipment and workplaces in an iterative planning sequence.

To present the implementation example with BPMN in detail, the planning step "Technical and Functional Equipment and Workplace Design" is illustrated in Figure-4. This generic example can be further detailed and instantiated on the specific requirements of any Factory Engineering and Design project. The planning step "Technical and Functional Equipment and Workplace Design" was chosen as an example planning step within the "Equipment and Workplace Planning" phase. It is composed of the following single planning activities:

a) Equipment and Tool Planning: This planning activity is closely related to process and layout planning. In this planning activity, the required production resources (e.g. machines, devices, tools …) are defined. The dimension and functional design of the production resources is planned, under consideration of their required capability and capacity. Furthermore all technological and economical requirements as well as aspects like maintenance and set-up have to be considered in this planning activity.

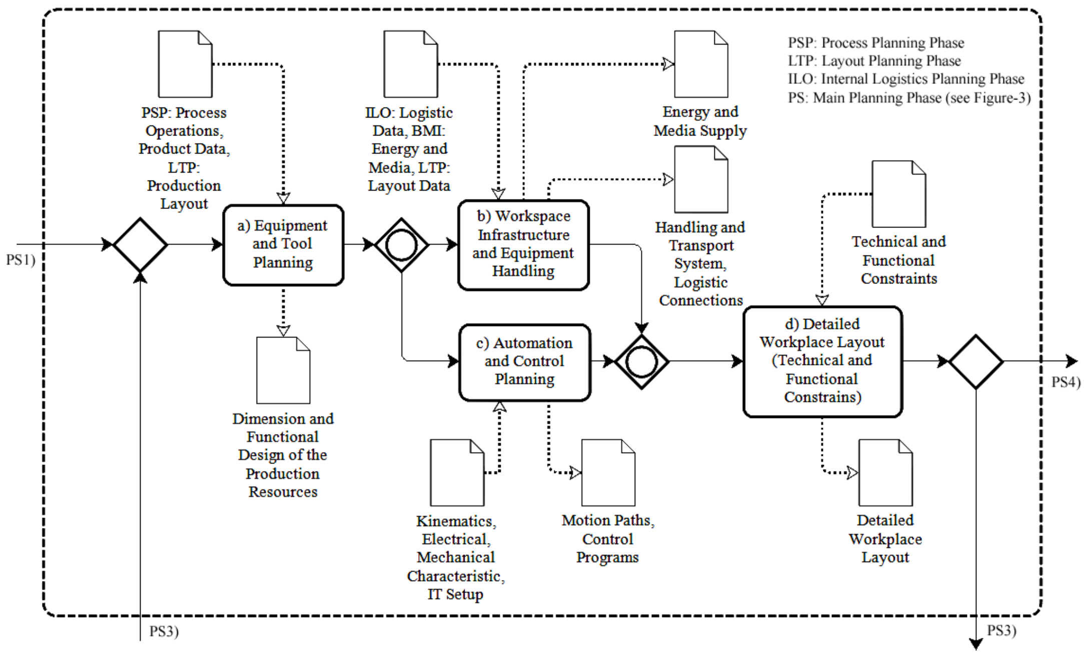

Figure 4 – BPMN Model of the Technical and Functional Equipment and Workplace Design

b) Workspace Infrastructure and Equipment Handling: Within this planning activity the Workspace Infrastructure is designed considering the connection to other components and to the internal logistic system as well as the supply and access to the energy and media network of the factory. Furthermore the equipment handling is planned in close relation to the phase "Internal Logistics" and "Buildings, Infrastructure and Media Planning". The handling and transport systems is defined in detail.

c) Automation and Control Planning: Within this planning activity, the machines are developed in close connection with other planning activities such as virtual commissioning and the ramp-up phase. Automated processes have to be designed and adjusted to the production needs and overall workplace design. Collision-free assembly sequences and motion paths have to be defined, concerning the development of complex robotics manufacturing zones.

d) Detailed Workplace Layout: The finalised detailed design of the workplace layout regarding all technical and functional constrains as well as the ergonomic and safety aspects from the planning step "Ergonomic and Safety Related Workplace Design" is established within this activity. Thus, the final definition and location of the production resources with the assigned work space and paths is defined.

5. REQUIREMENT FOR FUTURE ENHANCEMENTS OF BPMN

During the development and use of the Reference Model new requirements for further enhancement and application of the employed modelling method BPMN emerged. Factory planners and engineers have to evaluate different customised and instantiated planning processes and sequences. Therefore additional factors and economic aspects such as costs, time and quality have to be taken into account and integrated into the Reference Model. These additional factors or attributes are necessary to enable the evaluation of the factory planning process and to assess the effectiveness of a defined planning scenario (Schenk and Müller, 2010).

Thus, the extension of the selected BPMN standard and further enhancement of the corresponding modelling tools is recommend, as the integration of economic factors and requirement aspects have not been sufficiently considered within the BPMN standard and current tools. The BPMN standard 2.0 (Object Management Group, 2011a) provides guidelines and specifications for the extension of the method and notation as well as the implementation of additional modelling features.

There are approaches to incorporate quality requirements and economic factors to the BPMN standard and modelling tools, but these are not covering the specific needs and requirements of the factory planning process (Saeedi et al, 2010).

Furthermore, the planner must be able to manage factory planning risks such as design risks, to reach the factory planning objectives. These risks often result from unreliable or incomplete information on planning parameters (Weig, 2008). The aspects and parameters concerning risk assessment of different factory planning scenarios are also not supported within the current BPMN standard. Therefore, the necessary parameters and planning factors have to be integrated in the employed modelling method to enable the evaluation of factory planning requirements and the management of risks within the planning project and its single planning processes (Olson and Wu, 2008).

One approach to extend the BPMN standard is the assignment of customised factors and attributes directly to BPMN Flow Objects. The additional data entities have to be analysed and evaluated with individual and scenario-based calculation methods and tools as shown in Figure-5.

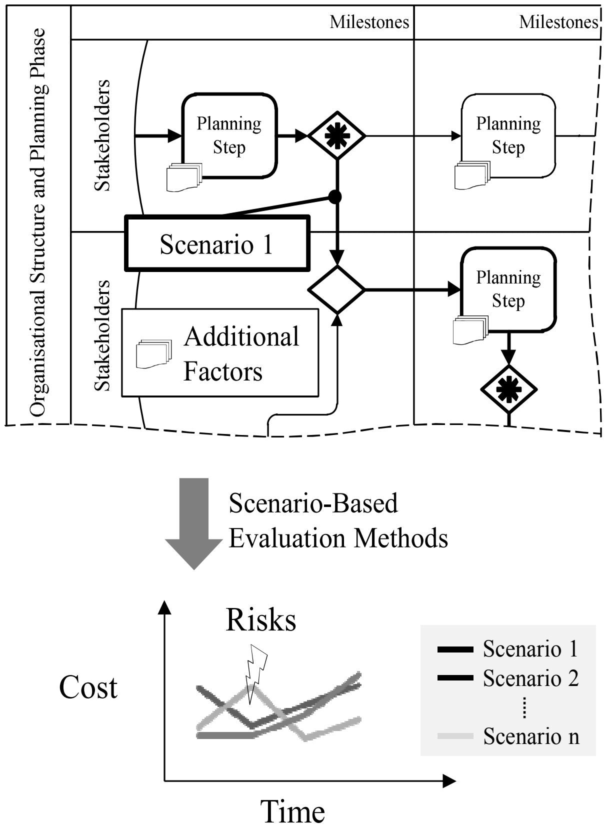

Figure 5 – Future Integration of Additional Factors and Scenario-Based Evaluation of the Reference Modell

Besides the extension of the BPMN standard, new and enhanced planning and evaluation functionalities have to be integrated in future BPMN modelling tools. In the next research steps new solutions will be developed to enhance and support the planning of factories and production systems as well as the scenario-based evaluation of factory planning processes.

6. CONCLUSIONS

This paper presents different concepts, standards and languages to model a factory planning reference process during the Factory Life Cycle. Therefore, the generic and extensible Reference Model for Factory Planning is illustrated. Different graphical modelling standards and languages are evaluated and the BPMN standard is selected and described in detail. To explain the employment of BPMN, an implementation example in the phase of equipment and workplace planning is given.

Concerning the limitations of the described graphical modelling notation BPMN, further enhancement for the evaluation of factory planning processes within the Reference Model is required. Thus, a first approach regarding the extension of the BPMN standard with customised factors and attributes directly assigned to BPMN Objects is presented.

As a result, the proposed extension of the BPMN standard and the further development of corresponding modelling tools will bring a significant enhancement to the evaluation and risk management of factory planning processes within the Reference Model for holistic Factory Engineering and Design.

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REFERENCES

Aggteleky B., "Fabrikplanung: Werksentwicklung und Betriebsrationalisierung - Vol. 2: Betriebsanalyse und Feasibility-Studie", 2nd Edition, Hanser, München, 1990, pp 465-476

Anderl R., Malzacher J. and Raßler J., "Proposal for an Object Oriented Process Modeling Language", *Enterprise Interoperability III: New Challenges and Industrial Approaches (I-ESA Conference 2008)*, 1st Edition, Springer, Berlin, 2008, pp 533–545

Bullinger H-J., Spath D., Warnecke, H-J. and Westkämper E., "Handbuch Unternehmens-organisation: Strategien, Planung, Umsetzung", 3rd Edition, Springer, Berlin, 2009, pp 26-27

Chryssolouris G., "Manufacturing Systems: Theory and Practice", 2nd. Edition, Springer, New York, 2005, pp 329-452

Clarkson P. and Eckert C., "Design process Improvement: A Review of Current Practice", 1st Edition, Springer, London, 2005, pp 74-76

Constantinescu C. and Westkämper E., "A Reference Model for Factory Engineering and Design", *Proceedings of the International Conference on Digital Enterprise Technology Digital Enterprise Technology (DET)*, Hong Kong, 2009

Constantinescu C. and Kluth A., "Flexible Connection of Product and Manufacturing Worlds: Concept, Approach and Implementation", *Proceedings of the 44th CIRP Conference on Manufacturing Systems*, Madison, USA, 2011

Eversheim W., "Arbeitsvorbereitung", 4th Edition, Springer, Berlin, 2002, pp 97-99

Grundig C.-G., "Fabrikplanung: Planungssystematik - Methoden - Anwendungen", 3rd. Edition, Hanser, München, 2009

Object Management Group (OMG), "BPMN 2.0", OMG documents BPMN 2.0, 2011a, Retrieved: 23.05.2011, <http://www.omg.org/spec/BPMN/2.0/>

Object Management Group (OMG), "OMG Unified Modeling Language, Superstructure", OMG documents UML Version 2.4, 2011b, Retrieved: 03.06.2011, <http://www.omg.org/spec/UML/2.4/Superstructure>

Olson D. and Wu D., "New Frontiers in Enterprise Risk Management", 1st. Edition, Springer, Berlin, 2008, pp 209-221

Parnell G., Driscoll P. and Henderson, D., "Decision making in systems engineering and management", 2nd Edition, Wiley, Hoboken, 2010, pp 40-49

Saeedi K., Zhao L. and Falcone P., "Extending BPMN for Supporting Customer-Facing Service Quality Requirements", *Proceedings of the IEEE International Conference on Web Services (ICWS)*, IEEE Computer Society, Miami, 2010, pp 616–623

Schenk M. and Müller E., "Factory Planning Manual: Situation-Driven Production Facility Planning", Springer, Berlin, 2010

Schlick C., "Industrial Engineering and Ergonomics: Visions, Concepts, Methods and Tools", Springer, Berlin, 2009

Schlick C., "Arbeitswissenschaft", 3rd Edition, Springer, Berlin, 2010, pp 949-1152

Weig S., "Konzept eines integrierten Risikomanagements für die Ablauf- und Strukturgestaltung in Fabrikplanungsprojekten", Herbert Utz, München, 2008, pp 53-78

Weske M., "Business Process Management", 1st Edition, Springer, Berlin, 2007, pp 158-169

Westkämper E., Constantinescu C. and Hummel, V., "New paradigms in Manufacturing Engineering: Factory Life Cycle", *Annals of the Academic Society for Production Engineering, Research and Development*, Vol. XIII/1, 2006, pp 143-147

Westkämper E., "Fabrikplanung vom Standort bis zum Prozess", *8. Deutscher Fachkongress Fabrikplanung*, Ludwigsburg, 2008

Westkämper E. and Zahn E., "Wandlungsfähige Produktionsunternehmen. Das Stuttgarter Unterneh-mensmodell", 1st Edition, Springer, Berlin, 2009

Wiendahl H.-P., "Planung modularer Fabriken: Vorgehen und Beispiele aus der Praxis", 1st Edition, Hanser, München, 2005