Proceedings of DET2011
7th International Conference on Digital Enterprise Technology
Athens, Greece
28-30 September 2011

DIGITAL FACTORY ECONOMICS

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ABSTRACT

Most factories already have a more or less adequate grasp on what a Digital Factory is, but hardly realise the possible benefits that an implementation may achieve. Still, especially for SMEs, the evaluation of situation based implementation scenarios of digital tools in the context of a Digital Factory is an insurmountable challenge and often keeps potential users from a further investigation. The main challenge is the lack of accepted and appropriate methods and tools to evaluate the economic efficiency, effectiveness and therefore the expected benefits of the employment of integrated digital tools. This evaluation needs to address a selection of digital tools and needs to be scalable to be able to evaluate different alternative implementation scenarios. This paper presents the foundations and the first steps aiming at the development of a scalable methodology for the evaluation and therefore the selection of suitable digital tools.

KEYWORDS

Digital Factory, Digital Tools, DF€, Economics, Process Modeling

1. INTRODUCTION

Due to the increasing globalisation of production in the last decade, many factories modernised or replaced their methods and digital tools used for factory planning and the continuous optimisation. Most of these systems have been heavily adapted and are now an integral part of the digital factory. Considering a life cycle of the methods and digital tools, replacing them is essential in the upcoming years (Buchta et al, 2009). Due to the crisis, these replacements often have been halted and the existing systems often are behind the possibilities, the currently available technologies may provide. With the end of the crisis factories are once again concentrating on the challenges they face, especially the increase in necessary interconnections for the information and data exchange as well as the amount of data that is generated now. Considering these challenges, keeping control of the constant planning tasks and at the same time, keeping the planning processes flexible and fast is difficult to achieve. One of the possible answers to get control of this complexity and address these challenges is the usage of methods and digital tools in the context of a Digital Factory. They aim at keeping the factory competitive, by introducing a new depth of control. There is a plethora of tools to choose from, all bringing their specific functions, risks and implications to the table. Selecting the suitable method or tool to fit into the existing systems and addressing the specific needs of one factory is difficult, therefore there is still a lot of potential to be realised, especially in small and medium enterprises (SME).

This paper presents the foundations and the first steps aiming at the development of a scalable method for the evaluation and selection of situation-suitable methods and digital tools in the context of a digital factory.

2. MOTIVATION

The planning processes in a factory are becoming increasingly complex. On the one hand the product world changes at an increasing pace, creating the necessity of flexible production systems. A flexible production system is defined by its capability and ease to accommodate changes in the system (Karsak and Tolga, 2000). It enables a production which is cost effective, but at the same time able to handle highly customised products (Gupta and Goyal, 1989). On the other hand the globalisation increases the complexity of the planning itself. With the analogy to the product life cycle, Westkämper et al (2006) stated the new paradigm “the Factory is a product”. This induced a holistic approach to the life cycle of a factory. The different phases of the planning processes have been ordered in the factory life cycle approach (Constantinescu and Westkämper, 2008). It divides the phases of a factory’s life into four groups, strategy, structure, process and operation (Figure-1).

Figure 1 – The factory life cycle management phases (Constantinescu et al, 2009)

The aforementioned groups are ordered and defined according to their granularity of the information used in the according phase. Inside those four groups, ten phases in total are identified to cover the whole life of a factory, ranging from the investment and performance planning to the operation and the final dismantling (Westkämper, 2008).

There is a plethora of different methods and digital tools available to offer support for these phases (Figure-2). The groups are created and scaled considering the increasing granularity of the data along the factory life cycle. The first phases are in the group “strategy”, generally supported by tools like manufacturing resource planning (MRP) or production planning and scheduling (PPS).

The second group “structure” covers the planning phases of the factory life cycle from the site and network planning up to parts of the process planning. The third group “process” details the information further and covers most of the process planning as well as the equipment planning. It also includes the ergonomy and work place planning. The group “operation” includes all detailed information and reaches from the ramp-up to the demantling and recycling. Some of these methods and digital tools are specifically designed to support very specific tasks in single phases, while others address a whole phase or even the combination of different phases. This creates a complexity in selecting the suitable methods and digital tools to address the challenges arising in a specific factory.

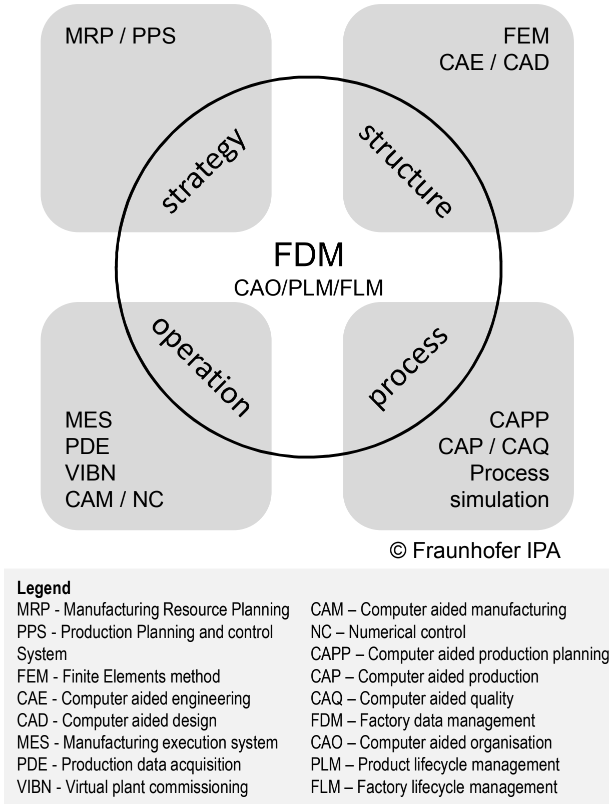

Figure 2 – Digital tools supporting the factory life cycle management (Westkämper, 2008)

A factor that is most of the time even increasing the complexity of the selection process are the legacy systems. Most of the factories do already use methods and digital tools at least for some of their planning tasks. These are called legacy systems and have to be considered in the selection. They increase the complexity as there are several possibilities on how they can influence a new selection. They can either be completely replaced, be improved to be able to handle new challenges (e.g. using new software modules or integrating new interfaces) or they can be integrated with new, complementary systems. They define the “As-is” situation, influencing the system selection through e.g. the existing data and the existing planning workflow. Considering interfaces to legacy systems can be crucial in order to ensure a smooth introduction, acceptance amongst the users and the long term usability.

The potential benefits of using methods of industrial engineering and digital tools in the context of a digital factory are not in question and acknowledged by most factories (Bierschenk at al, 2004). It is generally accepted that there are relevant potentials to be realised, but especially SMEs often stop their approach to these technologies when encountering the differences in trying to evaluate the potential benefits and select the ideal match for their specific situation. The methods and digital tools used for the planning of the factories have a huge impact on the value adding operation of a factory and their initial as well as their maintenance costs can be substantial. This induces, that a trial and error approach is not an option.

To synchronize the three goals of the factory planning activities – decrease of time, money and increase of quality – is at first difficult to see, using a digital factory. Considering the initial costs, showing the decrease of planning costs is most of the times not possible. Taking into account the whole product costs, including the allocated production and thus the production planning costs, however may change this picture. Avoiding unnecessary work and increasing the quality of the planning may be able to lessen the overall expenses even if the initial planning costs using the methods and digital tools of a digital factory may be higher than when being done manually. The general quality of planning is the harmonisation and optimisation of the process of production planning by considering e.g. the information management, the data and the seamless intregration of product development and production planning (VDI 4499, 2008). These two points, the difficult to assess suitable system selection and the sometimes complex cost situation, induce the need for a method to support the analysis, selection and introduction of suitable methods and digital tools for the factory specificly occuring planning tasks. This method for the “selection of the suitable methods and digital tools and the evaluation of their economics in a digital factory” will consider both, the integration and operation. It needs to be generic in order to be able to cover the very divergent planning phases. To be able to be used for SMEs as well as big international factories, it needs to be scalable. In a next paragraph, the most important used terms in this paper are clarified and confined. Economic efficiency in the general field of business administration is usually defined as the value of the output divided by the value of the input or as earnings divided by expense (Wöhe and Döring, 2010b). This definition focuses on the financial aspects. In the case of IT investments, only taking the financial aspects into account is most of the time not sufficient, as some of the benefits that the IT creates are very difficult to quantify and therefore to measure. This is especially the case, if not only singular digital tools are considered, but a plethora of tools in the context of a digital factory (Bracht et al, 2011). Therefore, in this paper, we use the more open definition of economics as costs, divided by benefits (Vajna et al, 2009), as shown in equation-1.

$$economics = \frac{cost}{benefit} \qquad (1)$$

The benefit as denominator implies a quantification of the benefits, which can be very difficult especially when trying to cover complex coherences like they exist in the field of methods and digital tools in the context of a digital factory. The term “digital tool” is a varying one. The term is limited here to the methods and tools specific to the factory planning. A digital factory usually covers the factory operation as well, but in this case it is not explicitly taken into account, as the field of digital tools there is vast and cannot be considered in sufficient depth. The method *DF€* approached in this paper, needs to be generic and is therefore applicable to the factory operation as well, if the data basis is generated. Digital tools in this approach will not be reflected on the scale of specific software (e.g. Siemens NX), but on the system scale. In our approach, the considered system scale is the classification, e.g. CAD, CAQ, CAM.

The Fraunhofer Institute for Manufacturing Engineering and Automation (IPA) has the “Grid Engineering for Manufacturing Laboratory 2.0” (GEMLab 2.0) available, which is the implementation of the grid-flow-based approach to a holistic and continuously integrated factory engineering and design. It uses a combination of commercial and self developed tools, integrated into the Grid Engineering Architecture through a standardised service. For its validation, an example product was designed, on which a continuous factory planning and optimisation scenario is based. This scenario includes all required factory planning steps (Constantinescu et al, 2009). In this paper, this basis is used to imagine an example scenario, where in the existing GEMLab, the digital tool used for the process planning step is wished to be updated or replaced. This is used as a hypothetical case to clarify the steps of the *DF€* method presented in chapter four.

3. STATE OF THE ART

The state of the art for this approach is structured into three parts. The first part is the confinement of the considered methods in this state of the art. The second part shows the state of the art in evaluation methods for economics. The third part is dedicated to the method developing systematics and languages needed for the approach *DF€*.

There are two key aspects that may be seen as basic properties of every evaluation method:

- *The time frame*: It can either be ex ante or ex post, depending if the evaluation is done before or after the investment has taken place (Wöhe and Döring, 2010a).
- *The subject*: The evaluation can be either partial/singular or a portfolio/selection of investment objects (Adam, 1999).

In the case of the method to be approached in this paper, a portfolio consisting of several methods is the object of evaluation.

The methods for the evaluation of economics in general can be divided into two groups (Schabacker, 2001):

- Comparative calculations, which compare if actions without investments, e.g. changes in a production process, are expedient.
- Investment calculation, which try to evaluate if investments in a certain matter are expedient.

In this case, investment calculations are relevant, as the method *DF€* is about investments in methods and digital tools in the context of a digital factory. The method needs to be specified in respect to the evaluated time frame and the object of evaluation. Investment calculation can be divided itself into several types of methods. Three approved and established types are:

- Static investment calculations: Static investment calculations are based on average costs and revenue over one defined period of time. All input is gathered for one call date. The differing value of money depending on the time scale is therefore not considered. They are the most common type of investment calculations, as the effort for the data acquisition is usually lower than with the other investment calculation types (Perridon and Steiner, 1995). Typical static methods are e.g. the payback period rule, the comparative cost method and the ROI reporting (VDI 2216, 1994).
- Dynamic investment calculations: Dynamic investment calculations take into account the changing value of money over time. They cover several periods of time, considering the costs and expenses for each and putting it into relation to the according cash value and the generated revenue. Therefore, it takes into account the timing of the cash flow and its differing value over time (Perridon and Steiner, 1995). The effort for dynamic investment calculations is significantly higher than for the static investment calculations, due to the information needed for every accounting period. Typical dynamic methods are e.g. the net present value method, the annuity method and the method of actuarial return (VDI 2216, 1994).
- Cost-benefit-analysis: This analysis is a comparison of objects or different alternatives for a decision, based on purely financial aspects. It takes into account the comparison of the discounted investments in the future. The evaluation scales of the costs and benefits as well as the extent of the considered factors cannot be objectively defined (Venhoff and Gräber-Seissinger, 2004; Schabacker, 2001).

These three types of investment calculations are entirely focused on financial aspects. Therefore, they are at best only partly able to support decision taking if there are substantial effects of the investment which are not financal. In the newer business management approaches, which lead to the development of more specialised methods taking into account not only financial aspects but to mix them with other, but quantifiable aspects. A very commonly used method here is the value analysis or scoring model. It creates a comparison of alternatives with quantified non-financial factors. It enables the user to compare complex alternatives taking into account his predefined weighting of the considered factors. There are different methods to approach a replicable weighting, which can be applied here (e.g. paired comparison). Even if the procedure becomes intricating with an increasing number of factors, it is a very common method. The result, the sum of the weighted values for every factor, is the ordinal order of precedence (Zangemeister, 1976a). This implicates that the result is not suitable to be put into relation with e.g. the total costs or the expected proceeds, which often precludes its use for an investment decision. Additionally, it is possible to integrate a statistical confidence into the values of its factors. This allows an inclusion of risks (Zangemeister, 1976b), but highly increases the complexity of the method. There are additional approaches to the investment evaluations that include non financial factors. One well known approach is the balanced scorecard. Its consideration of non financial factors is restricted to a causal connection to financial goals (Kaplan and Norton, 1996; Wöhe and Döring, 2010). For several years, the investments necessary in the IT have been increasing (Renkema and Berghout, 1997). Several authors have evaluated the existing/shown methods and mostly concluded they are not sufficient (Renkema and Berghout, 1997; Hirschmeier, 2005). This is even more the case, if the evaluated investment is for a specialised field. To tackle these evaluations, specialised evaluation methods have been approached. Relevant for this paper are methods in the field of evaluating IT investments for production planning methods and digital tools. There are methods, aiming to address very specific evaluation challenges. One example here is the guideline VDI 2216, aiming at "Introducing strategies and economical benefits of CAD Systems". It is used to estimate the economics ex ante and to address the benefits from the employment of CAD systems. As the title suggests, the term benefit is limited here to easily quantifiable, financial benefits. A verification of the estimated economics is included. The method covers a small, very specific and limited part of challenges that are similar to the ones to be addressed here (limited to CAD and the product construction). Therefore typical effects that occur in a digital factory are not covered, e.g. the synergies of different methods and tools using a common data pool (VDI 2216, 1994). There are similar guidelines, covering a specific type of software. One example is the guideline VDI 2219 for EDM/PDM systems (VDI 2219, 2002). Based on these guidelines, an approach to evaluate the introduction and use of digital tools in the product planning is the benefit asset pricing model (BAPM). This method is considering the implementation and operation of new technologies and especially digital CAx tools. The method is specialised on tools for the product planning and therefore does only partly cover the production planning. The, in the production environment, important synergy effects are only touched, not covered in detail. These effects are significant in the field of the production planning in the context of a digital factory. Additionally, BAPM is used not to evaluate a group of methods and digital tools but for a single selection (e.g. a specific software tool) and does not cover the dependencies and interfaces. To evaluate methods and digital tools in the context of a digital factory, it is therefore not sufficient. There are other approaches addressing the measurement of factors relevant in the economics that sometimes are not easily quantifiable. An example would be the measurement of the flexibility, which influences the economics mainly in the operation of the planned factory (Alexopoulos et al, 2011). An approach directly in the field of evaluating methods and digital tools in a digital factory is the method DigiPlant Check. In this method, the expected benefits of introducing a digital tool are estimated in a workshop (Schraft and Kuhlmann, 2006). The selection of the workshop attendants has a great effect on the results of the estimation, making the result subjective and not repeatable. There are currently no suitable methods to evaluate the benefits as well as the costs of methods of industrial engineering and digital tools in the context of a digital factory.

For the approach presented in chapter four, the necessary state of the art in relevant modelling notations is reflected to support a selection. The presented modelling notations are considered and chosen taking some key properties into account:

- *Simplicity*: The analysis of the current situation of the evaluated factory is not directly generating value and therefore needs to be as simple as possible. Needing to learn complex new languages or systematics in order to analyse the existing situation would hinder or even prevent the success of a method for economic evaluation.
- *Scalability*: The methods as well as the language need to be able to easily scale to analysis challenges in different sizes. This scalabilty is two fold. On the one hand, while sometimes a complete representation of existing planning processes of a factory is needed, other factories will only want to analyse parts of their existing infrastructure. On the other hand, the modelling needs to be scalable taking into account the depth of consideration. It needs to be able to consider every last detail of a planning process as well as on the overall processes and e.g. their ranking.
- *Visualisation*: The created model needs to be easily readable. The more complex the existing planning processes are, the more important is the verification of the model to ensure its realism and actuality. To be able to easily include the affected planning staff, the visualisation needs to be human readable.
- *Interchangeability*: The model created during the situation analysis in the beginning needs to be transferrable into the other steps, even if different languages are employed there. A common interface for exporting and importing already created models, is key to keeping the necessary effort down.

The modelling notations that are considered for a selection are:

- Unified Modelling Language (UML),
- Event-driven process chain (EPC), and the
- Business Process Model and Notation (BPMN).

The UML is an object oriented, graphic based business modelling language. The notation is available online in an extensive documentation. It has no focus on any specific area and a modularised approach is allowed in the specifications. This modularisation may lead to interchange problems, if two instantiations use a different set of notations. In order to circumvent such problems, a set of compliance levels has been created (OMG, 2011a). To model a factory planning process, activity diagrams can be used. As a graphical notation without any specific focus, the vastness of possibilities is shown in the wide range of available symbols. This makes the notation difficult to learn completely and possibly difficult to read. Actitivity diagrams do not offer a detailed description of a business organisation unit together with materials and information that is used in each of its functions.

The EPC originates from configuring ERP systems and from improving the existing business processes. It is not a complete notation language, but an ordered graph of events and functions. There are free tools available to create EPC graphs, which as such are very intuitive to read. In contrary to a UML activity diagram, there are hardly restrictions to the connections that can be displayed together in one graph. This implies the difficulties that arise when trying to display complex planning processes: Due to the complex and numerous interconnections, the graphs become hard to handle. On the other hand, it is a fast and intuitive procedure to draw an EPC.

BPMN is a commonly used notation if complex business processes are modelled. It is based on a flowcharting technique, where business processes are easily modelled along work flows. It is able to handle very complex planning processes and due to very clear rules for the visualisation, it is human readable. It is able to scale according to the targeted information depth of the model (OMG, 2011b). The notation is available on the internet and there are numerous tools around to simplify the modelling process. It is possible to export BPMN diagrams into XML to provide a common interface.

4. APPROACH

The approach *DF€* is comprised of five steps. These steps, their dependencies and their sequence are depicted in Figure-3. They are explained in detail in this chapter and then clarified using the example scenario described at the end of chapter two.

The first step of the *DF€* method is the "Target definition". First of all the desired type of the project e.g. a new planning of methods and digital tools or the replacement or optimisation of the existing landscape is defined. There are several key aspects of the project that are specified, like the timeframe, the financial borders and planning phases that shall be covered. In order to measure the outcome of the implementation at the end, a range of KPIs and their expected changes are defined here. Additionally, expected case specific benefits can be defined here. Valid targets also include strategic alignments (e.g. "integrate product and production data management"). Specific key aspects can be fixed here as well, if there are aspects that cannot be changed (e.g. due to restrictions by clients or law). The result of this phase is a definition of all relevant requirement specifications and of the relevant KPIs. In the example scenario of this paper, the goals for the replacement of the process planning digital tool are defined, e.g. maximum introduction costs and hardware restrictions.

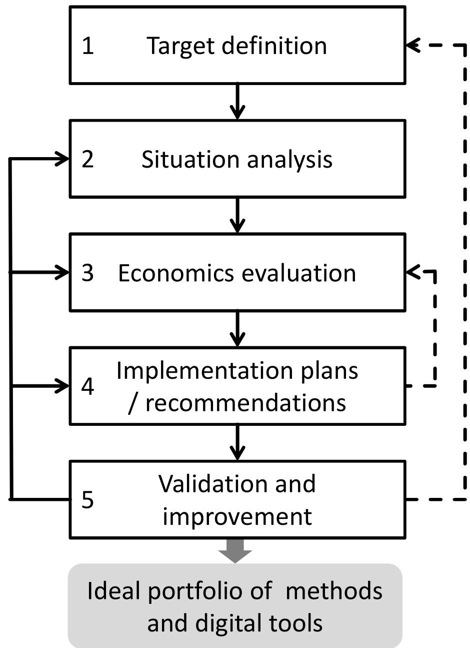

Figure 3 – Steps of the DF€ approach

The second step is the "Situation analysis". Here, the existing factory planning processes are analysed in detail. This begins with the identification of the affected departments. The existing planning processes per department are then analysed. The planning processes are modelled as depicted in Figure-4 using existing reference models for the factory planning processes as a basis (Constantinescu and Westkämper, 2010). Their interconnections are then analysed in detail. They are then displayed to enable a verification of the created instantiation of the planning process model by the according departments, ensuring the accuracy and realism of the created model. The model is supplemented by a model of the data and information, considering four aspects: Who provides it, who uses it, who has rights on changing it and where is the master data stored. This model is created as an instantiation of the factory data reference model. Afterwards, the model of the planning processes is detailed including the used methods for planning process.

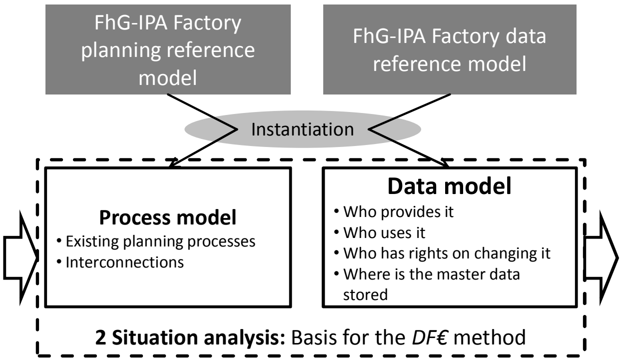

Figure 4 – Models in step 2 "Situation analysis"

The possible modelling languages are analysed in chapter two, where one or a combination of several can be used here. Additionally the used digital tools are listed, including their version, the license and the hardware they are running on. This list of digital tools is then classified according to the groups of digital tools, shown in chapter two. A connection between the model of the information and the list of digital tools complete the model of the factory planning. The result is a model or map of the "As-is" situation. The detail of the model or map is adjusted to fit the goals, set in step one of the *DF€* method. If the goal only affects certain departments or planning steps, the model is considered complete if these are covered. It may be necessary to map planning processes even if they are not directly related to the field or department that the set goals are centred on. This is the case, if the used information in the specific non relevant phase is relevant to the considered planning processes or methods and digital tools used there cover one of the targeted aspects of the planning process. All steps of the *DF€* method scale accordingly. The model or map provides a basis for the identification of the planning processes suitable for an evaluation. This is necessary, as a complete evaluation could be unnecessarily extensive. The model or map is analysed to select points of action in accordance to the base library, the evaluation method uses. This ensures a timely execution and realistic implementation propositions. The result of step two is a map of the "As-is" status of the planning processes, as well as a list of possible points of action. In relation to the example scenario, the existing process planning and adjacant steps are modelled, including employed interfaces, data and information. They are then analysed and a pre-selection is made. In order to continue the thought experiment of the example scenario, we assume here the identified action point is the process planning.

The third step "Economics evaluation" is the core component of the *DF€* method. Based on the suitable planning processes identified in step two, scenarios are created, each differing in the employed portfolio of methods and digital tools. An additional scenario is created, mirroring the current "As-is" situation of the factory to be analysed. This is the reference point for the comparison of the economics. For each scenario, the implicated costs are calculated. These costs can be split into the initial costs, e.g. licensing fees, training costs, hardware acquisition costs, and the running costs, e.g. service costs, hardware running costs. Their quantification is calculated based on the scenarios, taking into account the existing infrastructure and its costs models. The benefit is then determined, based on the case specific list of factory specific relevant benefits, defined in step one. To determine the benefit, a specialised method is derived based on the specific requirements of the digital factory environment. These benefits include soft factors as e.g. ease of usage as well as hard factors e.g. specific decreases in planning time. To achieve a overall quantification for a comparison that is mainly considering relevant factors, the expected changes of target KPIs are calculated based on the data basis of the method *DF€*. Using the expected costs and benefits, a valuation factor is calculated. The result is a quantified value for every scenario including the "As-is" situation. This factor is the basis of the selection of the first version of the ideal implementation goal. The third step of *DF€* is depicted in Figure-5.

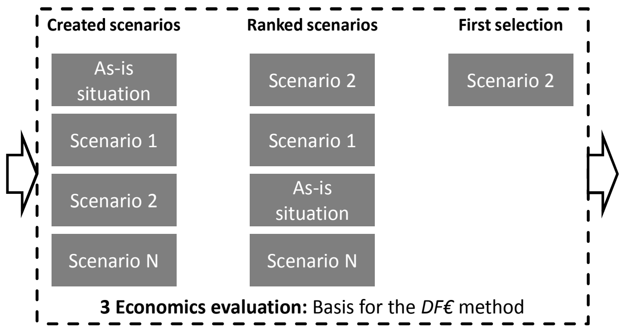

Figure 5 – Scenarios in step 3 "Economics evaluation"

Applying this step on the example scenario, a list of substitute digital tools for the process planning steps is generated, each one is evaluated and the one with the best evaluation value is selected.

Using the specific implementation goal from step three, the implementation itself is planned in step four. This step shows the typical challenges that arise when implementing the specific choice of methods and digital tools. These challenges are then evaluated if they might apply in the specific evaluated case and are valued by their possible impact on the implementation process. Taking into account these foreseeable challenges, a step by step implementation plan is created. Using the process planning model, created in step two of the *DF€* method, this implementation plan is adapted to reduce the disturbing impact on the production and its planning during the implementation and migration to the new scenario. In case the expected challenges are very significant or impossible to overcome, an iterative loop back to step three is created, to include this information into the evaluation and selection of the ideal scenario. This optional iteration is depicted in Figure-3 as a dashed arrow. At the end of step four, the user has created a step by step implementation plan including a list of possible and inevitable challenges as well as plans on how to overcome these. In the example scenario, step four generates an implementation plan, taking into account foreseeable challenges that might arise with the specific new selection of a digital tool for the planning process. For the example scenario, such a challenge could be a non functional information transfer into one of the adjacent planning phases.

Step five of the *DF€* method is the validation of the implemented scenario. The gained experience here is input into

- step two in case of too extensive or incomplete input from the situation analysis,
- step three in case of a miss in fulfilling the defined KPIs as predicted in the evaluation,
- step four in case of new or different arising challenges during the implementation.

This feedback is depicted in Figure-3 as arrows on the left side, going into the according steps. It is created through applying the *DF€* method in industry cases and the latter verification through comparison with the situation as it was beforehand. Another source of experience is the existing experience of partners. The feedback is directly included into the basic libraries of the *DF€* method and as such improve the results for the iterative following evaluation. If the implemented selected scenario is not able to be measured by the KPIs defined in step one of the method or if it is not possible to achieve or measure the set goals, an optional feedback into step one enables the user to adapt or even expand the set KPIs and goals. As this usually changes the shape of the project, this step should only seldomly be necessary and is therefore depicted in Figure-3 as a dotted arrow. Using the example scenario, step five is the validation of the integrated new digital tool. The new implementation is used with a former planning order, and the results are compared against the goals set in step one.

5. ROADMAP

Due to the complexity of the approached challenges, the upcoming activities are of special interest. The next steps will be the design of the steps one to four of the *DF€* approach.

For the first step, a list of KPIs needs to be developed and checked together with industry in order to be complete, descriptive and realistic. A ruleset will be created to give guidance to the creation of realistic targets for the method, to ensure the applicability of the evaluation results.

For the second step, a method and a tool to describe the planning processes will be found. A modelling notation or a combination of several will be used to supply the basis for the selection of points of action. A method for this selection will be created, basing on the experience, gained by the usage of numerous tools and industry cases.

The economic evaluation method in the third step needs to be carefully designed, taking special consideration for the implementation of experience gained by the usage of the method as a whole.

The implementation plans and recommendations to be developed in step four are in a field where research is extensive. The existing work in the field will be classified and checked for its applicability to factory planning, especially considering the complex situation of a Digital Factory. Most likely, the existing research will need to be extended extensively. It is cruicial for the realism of the given plans and recommendations to base this research on actual industry cases.

The libraries, methods and tools created for step one through four, will then be combined and tested intensively for their applicability on real world scenarios. This will include ex ante evaluations as well as the verification of already existing work.

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