Challenges for the Provision of Process Data for the Virtual Factory

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Abstract. During practical simulation projects, the required model data must be imported from existing data bases. The focus is to keep the amount of effort required to a minimum. The main issue is the provision of process data in particular concerning work operations that require timing and resources to be accounted for. This task is comparatively easy in the field of parts manufacturing as the operations are sequential in nature. However, with assembly processes requiring interlinked operations, this task turns out to be considerably more complex. A detailed discussion of differences between the relevant process data and the relevant time data required for simulation is followed by the illustration of two examples showing how the interface problem can be solved for the export of sequential and interlinked process data to a simulation procedure. The difficulties which usually arise during such a project and future approaches to the problem are also discussed.

Keywords: Time management, Process data, Simulation, Modelling, Virtual factory, Interface, Data export.

1 Time Management Views on Production Processes

1.1 The Need for Time Management Data

The volume of time management data required for the tools used in the virtual planning of production systems is dependent on the complexity of the respective production processes. This data is used to generate planned processes and resources which are modelled through simulation procedures as realistically as possible or to illustrate them in the form of animations using the tools of the virtual factory concept [1]. The requirements for providing the respective time management data increase with the complexity of resources to be modelled. If it is only required to simulate material movements or mechanical manufacturing processes, it is usually sufficient to use kinematically determined time data which can be defined through the use of formulae.

W. Dangelmaier et al. (Eds.): IHNS 2010, LNBIP 46, pp. 46–56, 2010.

This method cannot be used if the processes are carried out by people instead of machines, due to the fact that the cooperation between machinery and personnel resources must be reflected within the time data [2]. Time data concerning the work object are often also required, for example when surfaces need drying time or when adhesive needs time to set.

1.2 The REFA View Concept

For decades, the concept of different views on production processes has been a well-known part of the REFA methodology. REFA focuses mainly on the views on the person, the means of production and the specific work task or order ([3], pp. 20). REFA focuses to a lesser extent on the work object and only very little on work information ([4], p. 12).

The process types resulting from the different views and the corresponding types of time data must be taken into consideration when virtual factory tools are used to model the complex interaction of all resources involved as well as mechanized or automated production processes. The REFA view concept states that only some process types or types of time data can be used as input data required to simulate and animate processes ([5], p. 12-98) compared to other types of time data derived from the same resource that constitute output data in the form of simulated production process results (Fig. 1).

One typical example can be seen in the transition of a manufacturing order between two machines (Fig. 2): when the first work process is completed, the order must first wait for transportation to the next step, where it will generally then be placed in the queue for the next machine. Although it is possible to determine in advance the

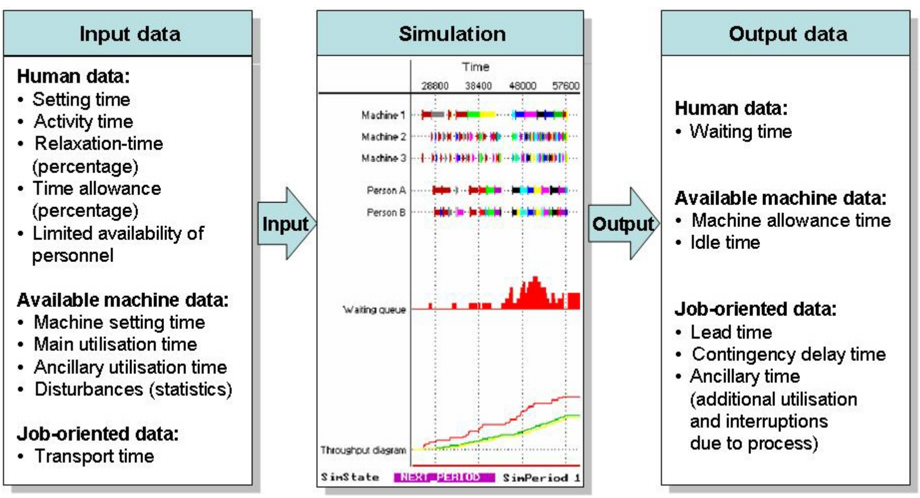

Fig. 1. Input and output data of organisation-centred simulation (following [2], p. 14)

transportation time to a good level of accuracy with deterministic methods and use the data as an input value for the model, the two waiting periods are a result from simulation of the dynamic production process with all its resource limitations.

Consequently, the common approach to this problem, which consists of the simplification of material handling processes through the use of global values for the transition time data (see e.g. [6], p. 319), leads to simulation errors. However, the time decomposition described in this article, what REFA refers to as the 'intermediate time', has not yet become a standard of the REFA methodology ([7], pp. 8).

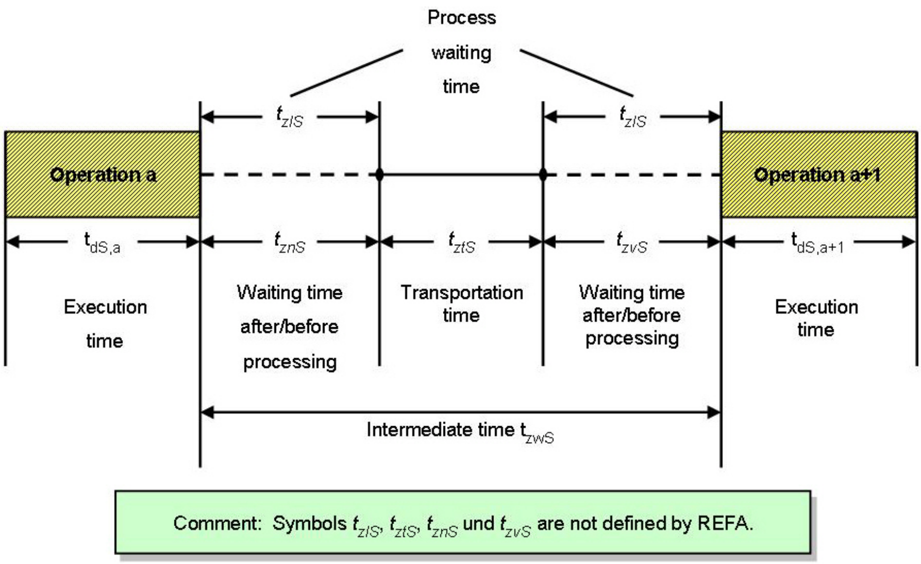

Fig. 2. Decomposition of intermediate time (acc. to [7], p. 9; following [4], p. 17)

1.3 Deterministic and Stochastic Modelling of Time Data

The REFA methodology supports analysis and subsequent modelling of production processes under the assumption that the time data are deterministic, and therefore, are not subject to any fluctuations. With regards to work processes that must be performed by people, this assumption implies a simplification which can lead to overly optimistic results. However, it is known that processes performed by people should be assumed to be stochastically distributed. This distribution is generally not symmetric with expectation values and measure of statistical dispersion such as in normal distributions and uniform distributions but takes the form of skewed distributions such as gamma distributions or beta distributions.

The assumption that human operation times are stochastically distributed is backed by the fact that the time data required for planning are often not available at all, or are of poor quality. The assumption of beta distributed operation times ([8], pp. 620; [9], pp. 814) linked to the *PERT* method (*P*rogram *E*valuation and *R*eview *T*echnique) since the beginning of the network technique ([10], pp. 545) provides a solution that is suitable for real life application. Especially projects within the service sector have shown that corporate partners involved in joint simulation projects find it relatively easy to estimate the parameters required for beta distributions, i.e. the optimal and pessimal values, the mean or the mode [11].

In manufacturing and logistics required time data often may be represented as statistical distributions, which simplifies process modelling as it is then not necessary to allocate a deterministic time value to every single process of an order. Experience shows that industry tends to consider this as a "band-aid solution" and is more inclined to change to a deterministically defined order programme. The latter also represents the only viable solution if the simulation model is to be examined for validity through the use of historical data ([12], pp. 111).

2 Modelling Sequential and Interlinked Production Processes

2.1 Provision of Time Management Data

So far this article has been limited to stating the need for time modelling for individual operations. It is also necessary to model the logical sequential interdependencies between operations within a work order. This does not only raise the question of how these relationships between different operations are to be modelled, but also of how the resulting abundance of data can be imported from existing databases with minimum effort.

This problem is discussed below and is illustrated by the example of incorporating sequential and interlinked processes from existing data bases into a simulation procedure. As the target system, the *FEMOS* simulation procedure developed by the Institute of Human and Industrial Engineering (ifab) of Karlsruhe Institute of Technology (formerly University of Karlsruhe) is used (see [13]; alternatively see *OSim* [14]). This procedure resorts to the traditional graph-based modelling of processes. The import of time management data from existing data bases is illustrated using the example of completed projects. In the case described, the data had to be imported in order to handle the abundance of data within the specified project timelines.

2.2 The Export of Sequential Process Data to the *FEMOS* Simulation Procedure

The example discussed in this chapter describes the export of sequential process data from a company's proprietary enterprise resource management system (ERP) to the *FEMOS* simulation procedure (see also [15]). In practical projects of today, the problem is on how to create an interface between two data bases while keeping the required effort to a minimum (following [16], p. 54). The challenge involves importing existing data from a production planning and control system (PPC) or from a more comprehensive ERP system, to a simulation procedure in very little time.

Applications from the virtual factory concept tend to be based on high-performance, decentralised applications combined with centralised data management. This approach reduces both the effort and the time required while avoiding the risk of information loss. However if there is no centralised data management, then there must be an interface between the different data bases. In order to facilitate this, some manufacturers have included an export data option. Siemens PLM Software simulation tools, for example, offer interfaces in the form of text files, object files, excel sheets and data base interfaces as well as XML format interfaces that allow the import of data ([17], pp. 259).

However, for the project discussed in this article this was not an option. The project was initiated when the production of precision parts had to be relocated to a new building. In order for production logistical, staff-related and economic targets to be met, production had to be restructured. One of the main objectives included a reduction of the machinery by approximately one third and a significant production area reduction of approximately 50 % while retaining the permanent staff. Other objectives involved an increase in flexibility due to the expected batch size reduction and a major reduction in manufacturing order lead times.

Manufacturing was subdivided into sequential machining steps performed by cutting processes such as turning, drilling, and grinding. Additional steps consisted of special machining processes, and the cleaning of the manufactured parts. The complete machining cycle consisted of between 5 and more than 30 individual steps. Fig. 3 shows the production of two sample parts, including the machining steps, in the form of nodes of a sequential graph.

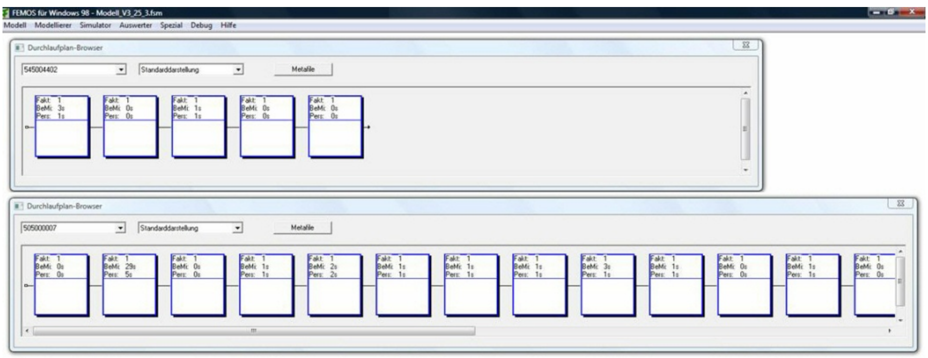

Fig. 3. Operation sequence for manufacturing a precision part in *FEMOS*

The layout of the operating equipment was previously based on technology requirements instead of being targeted towards the process, i.e. the machining steps. Only rarely was it possible to machine a complete order at the same machining centre – an option which was meant to be utilised more following restructuring, i.e. after the reduction in production area and the intended reduction in lead times.

As it was not possible to predict the target achievement rate of possible restructuring measures by using conventional planning methods, a simulation project was initiated to evaluate potential planning solutions. The evaluation should be based on the assumption of a new production programme stretching over several months. It soon became obvious that the manual entry of required model data would take longer than the intended duration of the project, meaning that an IT solution was required for data import.

The *FEMOS* simulation procedure was used for the project. In addition to the evaluation of planning solutions through the use of common production logistics indicators such as lead time and service ability, *FEMOS* offers other evaluation options. For example, staff-related indicators such as work load, and economic indicators such as personnel costs, manufacturing costs and net present value can be determined from the results of a simulation study.

The requirement that entries of the order-specific data needed to be highly detailed added complexity to the project. When the simulation model was validated against a real order programme from the existing production system, it became evident that the lower level of detail of the data caused excessive deviations between the simulation results and the actual situation. The reason for this was that during the specific period that was looked at, orders were often temporarily discontinued for order sequencing reasons because high-priority rush orders had to be completed first.

The existing *FEMOS* text interface was used to export data from the company's ERP system (Fig. 4). This interface was particularly suitable due to its ability to be easily adapted to the ERP system data format. Therefore, it was possible to link the ERP system and the simulation system within a week.

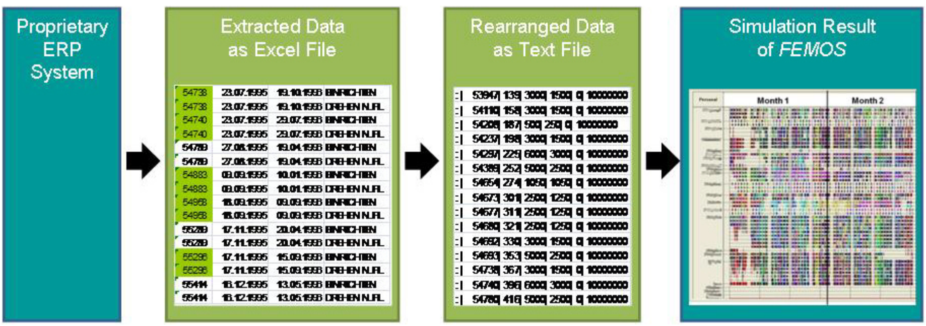

Fig. 4. Concept for exporting sequential orders from the ERP system into the *FEMOS* simulator (fictive data)

With the exception of some inconsistencies within the existing data, the export of the machining sequences was shown to be relatively easy, which resulted, in part, from the fact there were no fork nodes or join nodes to be modelled by the net graph. The following example describes such a case from a different project.

2.3 Export of Interlinked Process Data to the *FEMOS* Simulation Procedure

Problem Statement. The second project involved an order sequence simulation for an extensive production programme of one-of-a-kind products (for the operations research solution for this problem refer to [18]). The process data was available in the form of net graphs from the *MS-Project 2003* procedure. The production programme encompassed a total of 41 products and approximately 4,500 operations. The production system consisted of 30 different types of operating equipment with a total of 41 machines and manual work stations. The initial solution provided a makespan for the whole production programme of approximately 1 year. The simulation-based improvement of the sequence finally led to a makespan of approximately 8 months. For reasons of confidentiality, the details of this production programme cannot be disclosed.

The intention was to achieve an automated export of net graphs from *MS-Project* to the *FEMOS* simulation procedure in order to reduce the modelling effort required. This data then needed to be completed with the project data that was either not modelled in *MS-Project,* or that was not contained in the MS-Project representation. Furthermore, the basic data regarding personnel and operating equipment also needed to be exported. Finally, the graphs had to be verified as the data basis could not be considered error-free according to the *FEMOS* modelling requirements.

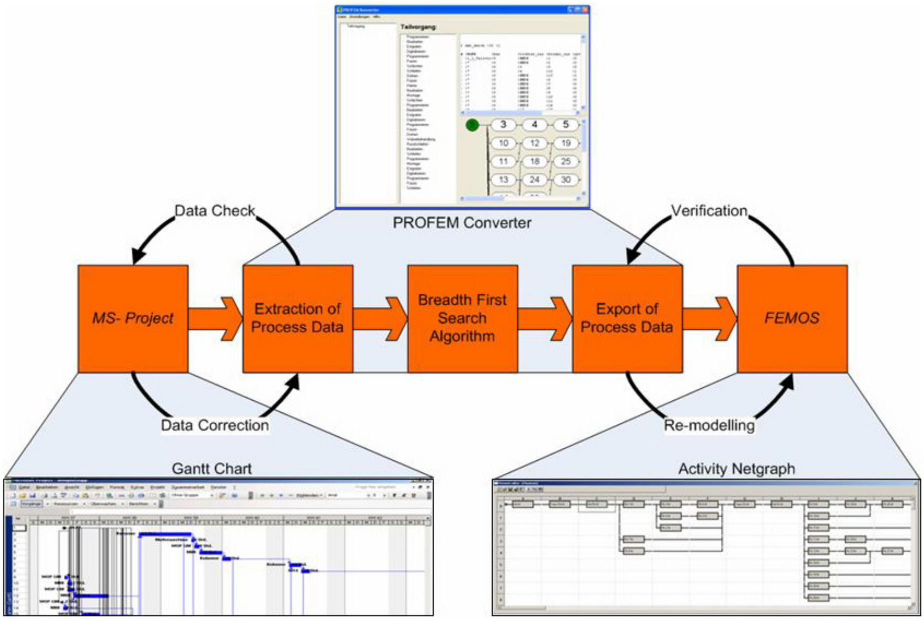

Fig. 5. Interface for exporting process data from *MS-Project* to *FEMOS*

Following this approach, the interface problem was subdivided into the three sub-aspects extraction of data from MS-Project, interface algorithm programming, and data import into *FEMOS* (Fig. 5). Three possible solutions were highlighted for the implementation of the required algorithm:

- Implementation using a stand-alone programme which reads the data in the *MS-Project* MPP file format, converts the data and then exports the data in the *FEMOS* FSM file format.
- Implementation of an import filter for *FEMOS* which creates the database for the simulation procedure from the MPP file format.
- Use of an add-in programme for *MS-Project* which exports the data in the FSM file format.

Given that the *MS-Project* file format is a proprietary binary file format that has yet to be disclosed, the implementation of the two scenarios using this format for the exchange of data would require considerable effort and the use of complex reverse engineering techniques. Consequently, an add-in programme for *MS-Project* was chosen, the so-called *PROFEM* converter. The original data is accessed via the component object model interface (COM) of *MS-Project*, which means that the MPP file format can be evaded.

Extraction and Completion of the Basic Data. The different approaches by *MS-Project* and *FEMOS* for the modelling of a work system had to be considered for the extraction of the process and resource data. *MS-Project* follows a strictly resource-oriented approach which means that every operation is allocated to the resource earmarked for it. Depending on the respective bottleneck, that resource could be either operating equipment or the personnel required to perform the operation. *FEMOS* in turn, breaks down the work system to be simulated into the element categories "operation", "personnel type" and "workplace type" which are interlinked via matrices. The relations between the element categories, i.e. "ability", "responsibility" and "feasibility" are modelled within these matrices (Fig. 6).

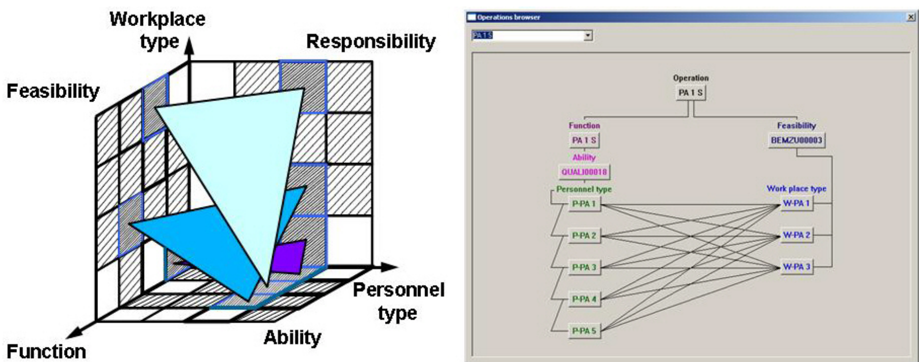

Fig. 6. Concept for modelling qualifications and its representation in *FEMOS*

In order to use the more generic approach of the *FEMOS* simulation procedure, the "resources" from *MS-Project* were integrated into the *FEMOS* personnel list and workplace list. The element categories were assigned to one another via a 0-1 allocation within the matrices. Subsequent examinations of the dynamic behaviour of the work system considering multiple qualifications or backup machines could only be performed through manual remodelling in *FEMOS*. Due to the missing subdivision in *MS-Project*, the time data of each operation had to be allocated to both the relevant operator (as order time) and to the operating equipment (as occupation time) in *FEMOS*, and had to be subsequently modified as required.

Remodelling and Verification of the Net Graphs. Also, the basic data of the orders that had to be simulated was derived from the *MS-Project* database and was modelled in *FEMOS*. This aspect of the interface problem involved the export of the net graphs of the individual production orders modelled as Gantt charts in *MS-Project*. Due to the *FEMOS* modelling approach it was required to arrange and link the individual operations in a planar way, i.e. two-dimensionally and without intersections. The operations were arranged through the use of a breadth-first-search algorithm [19] that runs through the graph breadthways. The nodes found are added to a two-dimensional grid, and nodes that have already been placed are moved around to comply with the requirement of having a non-intersecting graph.

The data base was insufficient to ensure that all net graphs would allow for planar arrangement and would be error-free in accordance with the *FEMOS* modelling approach. Therefore, the model was subjected to a verification process which identified typical modelling errors and eliminated them by inserting additional dummy operations. The verification process also identified and highlighted graphs that were unsuitable for planar arrangement. These graphs were either remodelled manually or were modified in the *MS-Project* database in such a way that it would be possible for them to become planar through the use of the respective algorithm.

Efficiency of the Export Procedure. The above-described software-based solution to the interface problem reduced the modelling effort considerably. The exemplarily performed manual modelling of parts of the production programme showed that without the interface, the complexity of the sequencing problem with all its operations, operating equipment, work stations and individual products would have required modelling times that would have been unacceptable for the project and would have required a qualified employee fulltime.

The add-in programme for *MS-Project* reduced the time needed to create the required model data to just a few minutes. Only minor specific interference with the modelling process was required in the form of manual modifications of the output data. The reduction in modelling effort was the decisive factor that enabled the implementation of a comprehensive design of simulation experiments against different scenarios within the specified project duration.

Consistency of the Process Data. During the conception and implementation of the interface programme, several core challenges relating to automated modelling from an *MS-Project* database were identified. The most important aspect was data inconsistency in *MS-Project*. The lack of restrictions for a user who enters data into the programme often poses an obstacle to the automated export of data.

Simple deficiencies such as typing errors can inadvertently lead to the creation of an additional operating resource requiring manual elimination from the database that would be time-consuming. Also, non-standardised designations in *MS-Project* made by different users can lead to the incorrect modelling of the work system. Therefore, it is indispensable to work according to a standardised and error-free designation system when entering and maintaining the original data and to thoroughly check the data prior to its export.

3 The Need for Further Developments

The interface programmes developed here for specific applications represent individual solutions that are targeted towards specific data sources and to the *FEMOS*

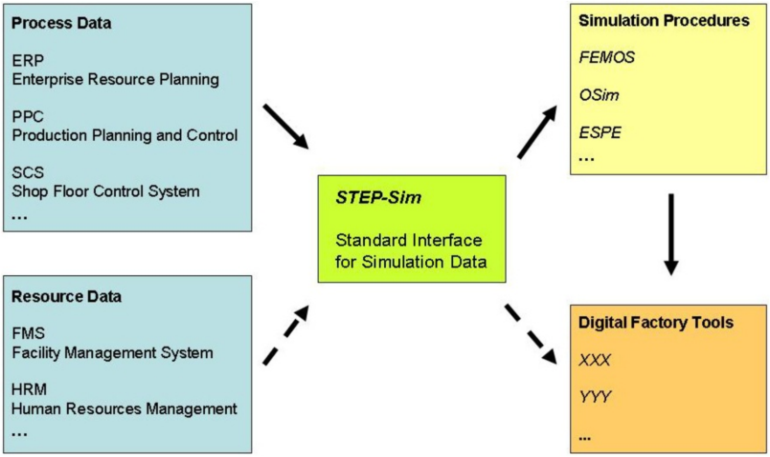

Fig. 7. Concept for a standardized interface for exporting process data into simulation procedures

simulation procedure as the target system. Therefore, no conclusions can be drawn concerning their portability to other applications. However, it can be stated that the modelling work required for complex problems is unacceptable without such an interface, specifically if actual production programmes are to be simulated.

The common approach of resorting to stochastically distributed times and arrival intervals for comprehensive process data, and of generating orders of a production programme stochastically even if they have a network-like structure (see e.g. [20], pp. 67; [21], pp. 185; [22], pp. 531) is not always an appropriate solution, as can be seen from the example of sequencing for one-of-a-kind products. Furthermore, partners from industry often refuse to accept such an approach because they prefer to see the effects that structuring measures have on actual orders.

The existing problem of importing process data from ERP and PPC systems will continue to exist in the future and will require the creation of individual solutions for interface programmes. As a future solution, the definition of standard interfaces is requested to allow for the provision of at least a basic pool of process data for simulation applications through the use of IT (Fig. 7). The interoperability of applications is supported by the fact that the modelling principles of both application areas are often based on net graphs. Data interfaces like *STEP* (*St*andard for *E*xchange of *P*roduct Model Data; [23] [24]) show that such a solution is feasible in principle. There can be no doubt about the fact that this would increase the use of simulation procedures and would include a huge savings potential for project implementation.

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