The Necessity of Using Semantic Models for Configuration*

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Abstract

The subject of this paper is the integration of configuration of material flow systems and material flow processes in the area of material flow plants. It will be shown the using of knowledge representation for the configuration process of matertial flow plants. Furthermore the necessity of an new quality in representation is illustrated. The described configuration process is very complex. In different to the conventional process the configuration is understand as a process that can be described by steps, loops, and versions, at which the unit of synthesis, analysis, and evaluation is of decisive meaning.

The principal objective is the integration of configuration of material flow plants in an extended model-based configuration concept. This can be represented by semantic models. Such an integrated concept offers the ability of systematically treating the necessary interrelations of the different models of material flow systems and material flow processes and achieves a more effective overall configuration process.

1 Introduction

The configuration of material flow plants is a problem of mechanical engineering in the special field of material flow and logistic. The material flow plant consist of the logistic system (technical material flow system and controlling system) and the logistic process (material flow process and controlling process). The following characterized configuration problem relates to the material flow system, the material flow process (physical process), and the controlling process (logical process). In the sequel the summary of the physical and the logical process is designated as material flow process.

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The configuration problem of this domain is a common development of the technical material flow system and of the material flow process. Configuration steps and configuration decisions influence the modelling of the material flow system during the modelling of the material flow process and vice versa. An integrated view on these two aspects is required in order to handle the interactions, to describe all interdependencies, and to fulfill the requirements of the configuration task. Possibilities of an integration of different aspects and models are described in [CBRR90, GKNO96, Lan94, Had95].

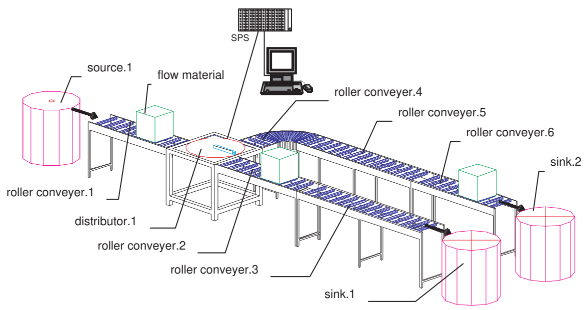

Figure 1: Example for a simple material flow plant

Current configuration concepts are insufficient in the way that they do not support or represent the procedures and the connections of the configuration of material flow plants in a comprehensive form. Up to now there is no possibility to record the connections between the material flow system, the material flow process, and the material flow control in a simple and integrated form. Another problem is the insufficient possibility to assess (sub-)solutions of the configuration. The described problem is to be led back, that the configuration concept is limit up in most kind to synthesis functions, where by part-whole relations find special regard [Gün93].

Further it is introduced an approach of using semantic models as an extension possibility and as a possibility for an integrated model description. **p**redicated **U**nit-**R**elationship-Models (**pUR**-Models [DT94]) will be used for the representation of semantic models.

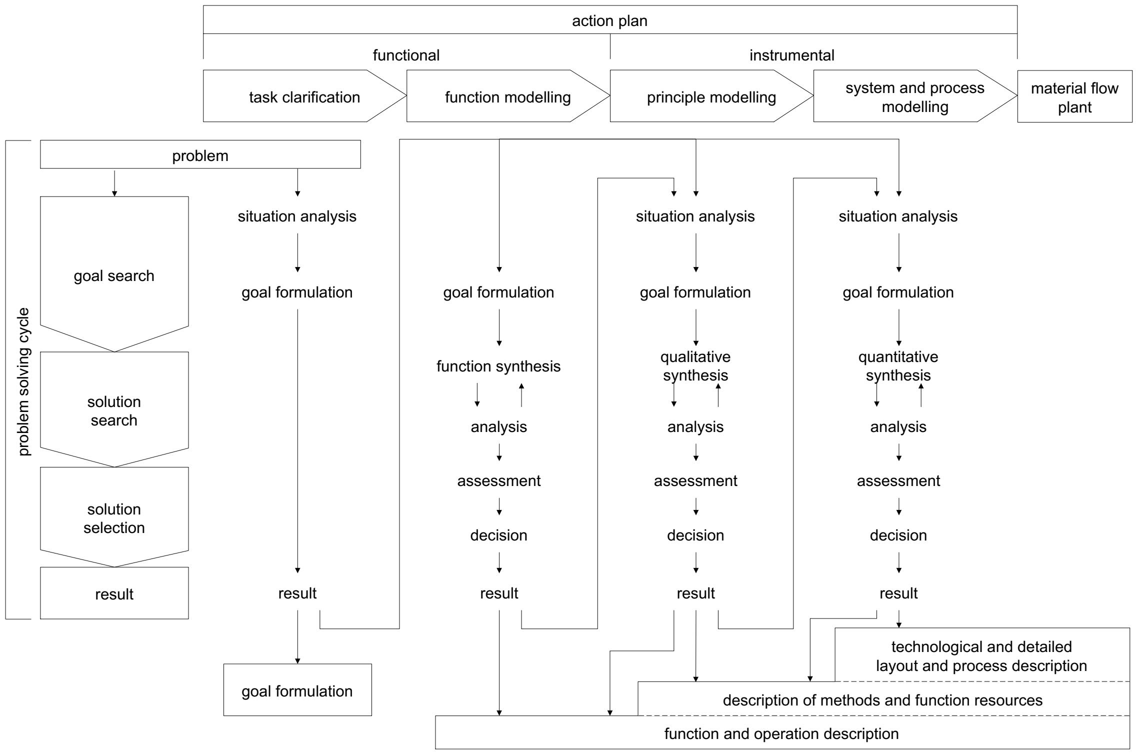

Figure 2: Action plan and problem solving cycle according to [Kra90]

A small parcel distribution plant is described as an example of the mentioned configuration problem. The plant distribute parcels according to a simple criterion (figure 1).

2 Configuration of Material Flow Plants

The configuration problem of material flow plants can be described as an evolutionary process of steps, iterations, variants, and versions with different degree of model abstraction of the material flow plant. Moreover the configuration process is generally separated into several phases. The phases of developing models can be divided into functional, principle, and system/process phases (see figure 2). A sequence of phases is defined by an action plan and by a problem solving cycle. A set of rules, control knowledge, and other methods of synthesis and analysis are associated with each phase. The steps of the process are models of different abstraction level which build up on each other by generalization/specialization.

During the solution development there is a permanent change of analyzing and working steps with synthesizing and assessing steps. At the same time the knowledge problem and the views on the models are changing. First of all it is looked for suitable and fitting solution elements. After this the elements must be tuned that they fulfill the demanded total function.

The used configuration techniques are heterogeneous and depended on the kind of knowledge problem, on the reached degree of the solution, and on the kind of the available information. The techniques contain methods for synthesis and analysis models and methods for a selection of model components with different detail. Further the management of model versions and variants must be possible. The methods of analysis describe simple determinate and complex stochastical calculation models in form of analytical formulas.

Existing model states can be analysed by statistical models of process simulation. Analytical methods support the establishing of

- suitable versions and variants,
- solution properties,
- conditions for the work of solutions, and
- consequences, which are shown through the solutions.

Furthermore assessments and views of versions and variants are realizable by state management and by interactive work. Because of that the complexity can be reduced.

The development of models is characterized by permanent changing of view and between abstraction levels and through a step by step increasing of information during the problem solving process. The solution development is influenced through the common configuration of the material flow process and of the material flow system.

3 pUR-Models as Formalism for Modelling

A possibility for representing semantic models are **p**redicated **U**nit-**R**elationship-Models (**pUR**-Models [DT94]). Brodie [Bro84] defines semantic models as a scheme which describes the following properties of an universe of discourse (UoD):

- The static properties of an UoD are described by fixing objects, properties of objects, and relationships between objects.
- The dynamic properties of an UoD are described by assigning operations to objects, properties of these operations, and relationships between these operations.
- Integrity rules about objects (static conditions) and operations (dynamic conditions) are described by additional requirements and admissible states or state transitions of the considered mini world.

pUR-Models fulfill all these requirements. They represent objects, their attributes, belonging targets, and constraints on three levels: object level, attribute level, and assessment level.

Real objects of an UoD can be represented as object units. There exist units which describe one real world object or object set units which describe a set of equal real world objects. In pUR object units are expressed by boxes with small lines and object set units by boxes with big lines (see figure 3).

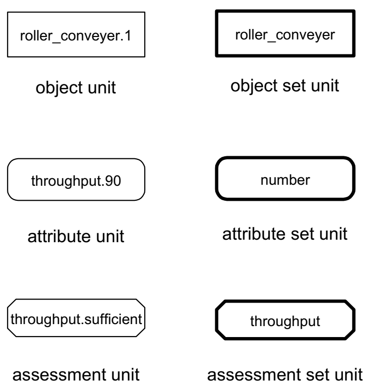

Figure 3: Object, attribute, and assessment units

The properties of objects can be described on the attribute level. For each object (object units or object set units) attribute units could be modelled. They are represented by boxes with rounded corners (figure 3). The assessment level is characterized through assessment units which are expressed by boxes with sloped corners (figure 3).

Furthermore pUR allows to model space and time relations (see figure 4). This relations describe relationships between object units, attribute units, or assessment units themselves, or between the elements on the three levels. For an example see figure 5. This pUR-Model describes a material flow plant. Every plant has an attribute *throughput*. If the *throughput* of the plant is greater than *900* than this plant fulfills the requirement for an sufficient *throughput*.

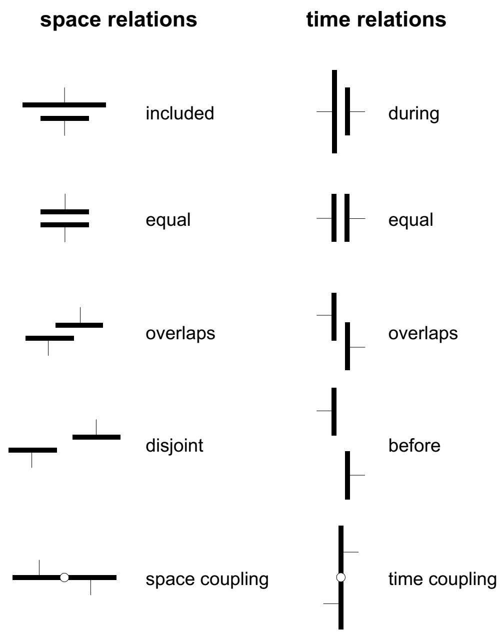

Figure 4: Space and time relations

With pUR it's also possible to model combinations of time and space relations, e. g. an inclusion (the space relation *included*) which exits only for a determined time.

Through the summary of similar real world objects in object set units the abstraction concept of classification is representable. Furthermore the abstraction concepts of aggregation, association, and generalization/specialization could be modelled (figure 6). In an easy way constraints can be represented by description of an UoD on three levels (object, attribute, and assement level).

4 Model-based Configuration

The configuration of material flow plants is a problem of model based configuration, whereby models are of decisive meaning. In different to [Tan91] and [KBN94] the configuration is not only a problem of design rather of technical system planning. The configuration is understand as a modelling process of a material flow system and a material flow process. Basis of a systematic configuration is a corresponding configuration process with a structured and overlapping procedure. Thereby suboptima of solutions will be avoid and an approach at a main solution ensured.

The result of the configuration process is a detailed description of different models of material flow system and material flow process. In the sequel this description defines the requirements on the controlling system and the controlling program. Especially

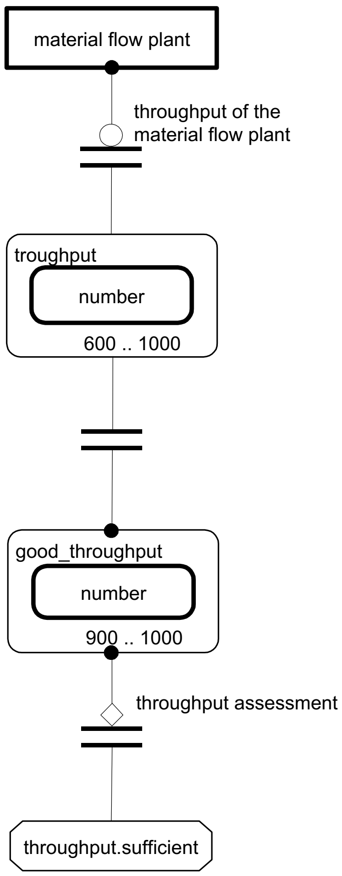

Figure 5: Connection between object, attribute, and assessment level

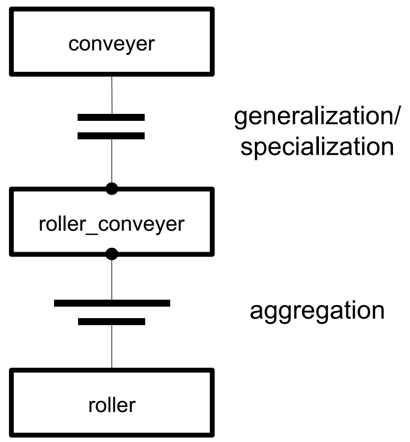

Figure 6: Example for aggregation and generalization/spezialization

the complexity of the domain material flow plant requires an integrated model development. In particular the integrated model description will be used for the representation of solutions and for the check of the solution variants and versions in the different phases of abstraction and granularity. A similar approach of integrated modelling is shown in [GKNO96]. The goal of this approach is the integration of action planning and configuration in the area of planning of flexible assembly systems.

The advantages of an integrated model description are

- a better combination of different subsolutions (e.g. in the area of material flow systems and of material flow processes),
- the improvement of data consistency,
- a better transparency of models,
- an expressive common model description,
- the ensurence of flexible and suitable models with an uniform concept, and
- the development of problem adequate model views.

Today all known configuration concepts are restricted to single-stage configuration problems. In this context single-stage means that the solutions of configurations are developed at one step of abstraction with existing configuration objects (see e.g. [CGS+90, SW91, Gün93, Som93, Lan94, GKNO96]. This does not agree with the requirements which appear during the configuration of material flow plants in the area of mechanical engineering. In this process the focus of interest is the development of integrated models of the material flow plant. The resulting models are the solutions to the mentioned configuration problem (see section 2).

Different models on different hierarchical abstraction will be developed in the configuration process. There are correlations between the models which depend on the special configuration task. During the problem solving process there is an information extension step by step which is supported by methods (see section 2). In the configuration process used methods are case based and ambiguous, therefore it is necessary to develop a variety of different solutions (proper configurations) and a flexible and variable assignment of different methods. The methods can not assigned to a special task of configuration (see also [Gün95]). The common development directions are present through the specific configuration task, the function order, and the configuration steps (figure 7). To simplify the further work it is useful to model the process for the primary working function, the functional, principle, geometrical, and process oriented aspects of the material flow plant, first. The complexity of the configuration process can be reduced by determining the primary functions (as described above) followed by extra functions and help functions. An orientation on primary functions can be described as a opportunistic procedure of configuration. Another possibility of reducing the complexity can be achieved by modularisation. This means there is a reducing on interfaces between subsystems and objects. Furthermore are used rough constraints in context with object interfaces. In this situation interfaces are predefined and can not change. This kind is often used in the configuration process of material flow plants. Another aspect is the assumption that some subsystems and objects (components) and there properties are known in order to carry out a proper configuration.

In the first step of developing the configuration models a simplified view is taken on the formulation and on given relevant constraints and objectives. The formulation describes with the given initial state and the desired final state the material flow objects and their transformations. The functional/operational model is a specified formulation for the selection of technical elements (functional ressources). Functional/operational models will be represented mostly by graphs. The nodes represent functions/operations und the edges represent relations between nodes. The edges also characterize the flow process. On functional/operational models operate process chains and simple mathematical and analytical operations. Then suitable functions and fitting solution components (technical elements) are added to the principle model. This model allows to describe and to compare technical and technological information. In the third and last step this principle model must be tuned to fulfill the required plant function (system and process). Result of this step is the system and process model.

In this configuration process the focus of interest is the development of models, which are of different granularity and application and, of course, are problem adequate. The level of granularity can be characterized through models on different stages with various details. The granularity or abstraction level can change permanently during the process of configuration. The resulting models are the solutions to the mentioned configuration problem. The resulting models can be also of different granularity and are the proper configurations of the plant.

The basic operations of the configuration process which have to be realized by different configuration methods are

- synthesis:
  - *generation/elimination*
    The generation corresponds to the generating of a new component, a solution, and/or a partial solution. The inverse operator for the generation is the elimination, which is used for the deletion of a component.
  - *classification*
    Classification stands for the acquisition of a set of different objects with equal type. The objects are described by homogeneous properties and equal possibilities.
  - *aggregation/decomposition*
    With the bottom up approach aggregation objects/models will be assigned to another complex one. The decomposition corresponds with the top down approach and break an complex object/model into it's simple one's.
  - *generalization/specialization*
    Generalization assigns an object/model to a general class and specialization is the invers operation.
  - *association*
    Association describes relations between objects/models.
  - *combination*
    Combination is used to arrange subsolutions of variable complexity to a solution.
  - *substitution*
    With substitution an object/partial model will be replaced by another one.
  - *selection*
    Is used to select an object which will be used in the configuration process.
  - *transformation*
    Transformation is used for a stepwise refinement of partial solutions that means for representation of increasing the information. Transformation describes the elaboration process.
  - *specification*
    The specification is used for the refinement of a model. This refinement determines additional system attributes.
- analysis:
  - *evaluation (assessment, decision)*
    An assessment is undertaken through a judgment by potential (sub-)solutions thereby particular points of view and features. The choice contains the decision of a (sub-)solution from a final (sub-)solution set.
  - *interpretation*
    When interpreting connections are evaluated, whereby these lead to determined results.
  - *testing*
    The testing serves the consistency and correctness of structure and flow of the plant and the completeness of a configuration.
  - *situation analysis*
    The formulating of goals serves to complete, to structure, and to capture goals of the resulting material flow plant and subaspects as well as goals of the configuration procedure.
  - *simulation*
    The discrete-event simulation is used to determining and analyzing the models and controlling strategies of the material flow process.

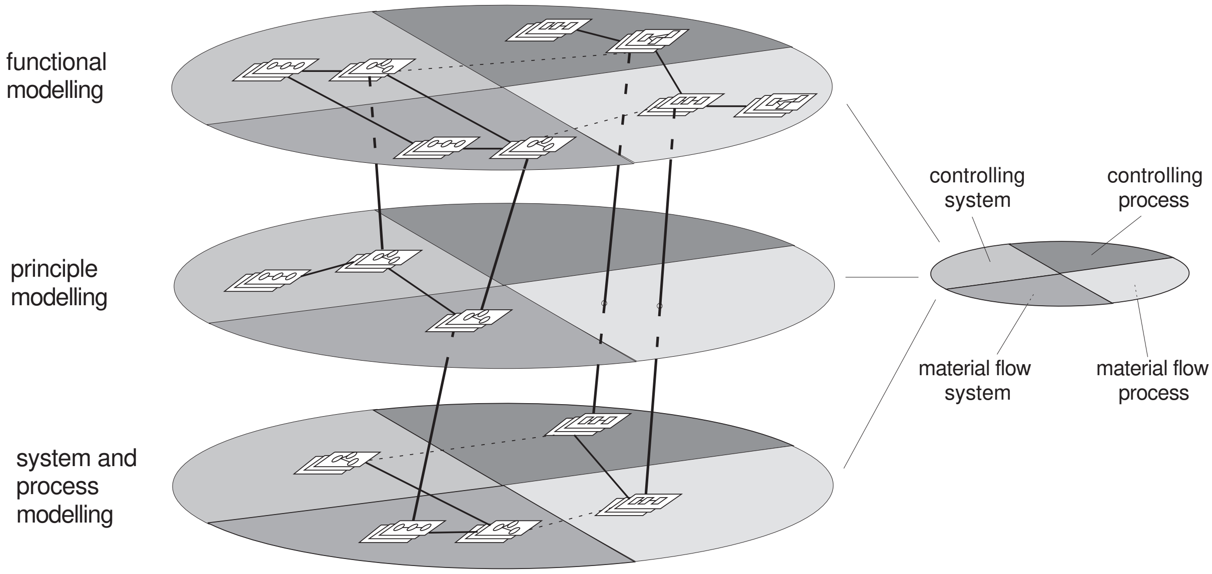

Figure 7: Modelling Space for configuration of material flow plants

The models can be described by versions and variants. Now the configuration of a model on one level can be isolated from the others, but also integrate with models on another level in a larger context. The evaluation of the system model can furthermore result in a replacement of one or more components. But, this replacement is only permitted when all information about possible predescessors, successors, and the function properties are preserved. To guarantee this there exist relations inside the model, between model modules and part models, and also between different models (figure 7).

The possibility to combine and translate models using mapping relations is an important criteria for their efficiency and effectiveness. Therefore the description of the models must be unique, interpretable, detailable, manipulable, and analysable. Using the appropriate abstraction concepts it can be guaranteed that the mapping relations are correct.

A multi-aspect-modelling, which is possible through space and time structures, allows to describe static and dynamic models in an integrated representation. With the integrated representation, connections can be expressed between resource (object), system, process, and flow material. Furthermore it is usable for the creation of jointly realizable structures by an uniform concept.

5 Knowledge Representation with pUR

Because of the necessity of permanent changes to the model view and the resulting complexity, emerges the demand on using an extended model based configuration. Such an extended configuration concept can be presented by semantic models. The knowledge representation is based on an object oriented hierarchical model concept called **p**redicated **U**nit-**R**elationship-Model (pUR-Model) [DT94].

With pUR-Models it's possible to represent the whole configuration knowledge. pUR describes the knowledge in a hybrid form. Hybrid means in this context that different categories of knowledge and their combinations can also be represented through pUR-Models. In particular the solutions of the configuration process are also pUR-Models. The knowledge representation implies component and system models, the belonging discriptional, and controlling data as well as the configuration knowledge.

In [KB90] the different knowledge forms is structured. Refer to the contents of the knowledge it's distinguished between problem solving dependent and problem solving independent knowledge. Refer to the representation it's distinguished between formal and informal description. pUR-Models allow and support a formal and an informal knowledge representation in form of diagrams or pictures (see [DF96]). During the configuration process of material flow plants three different categories of knowledge must be handled: domain knowledge, problem solving knowledge, and dynamic model knowledge.

The domain knowledge describes the specific properties and the combinations of these properties in the area of material flow plants. The classification of material flow functions in a taxonomic representation, e.g. transport functions and distribution functions, the relations between material flow components, e.g. the connection between a component and a material flow subsystem, and a part-whole representation for components are described through the domain knowledge. Consequently domain knowledge is a part of problem solving independent knowledge.

Further the problem solving knowledge characterizes the procedure of the configuration process. It describes, how the configuration problem can be solved. This knowledge is also a part of the problem solving independent knowledge.

The following characterized dynamic model knowledge belongs to the problem solving dependent knowledge. Therefore dynamic model knowledge contains the whole solutions and describes the history of the configuration process.

The goal of modelling is to configure and to define a material flow plant. The plant must fulfil the requirements and can be described through a conceptual model description. This description contains the complete form of the plant, which implies structural and functional completeness (see [SG91]). Structural completeness is fulfilled if all objects of the structure are defined and all values of their properties (attribute values and layout relationships) are determined. A description is functional complete if all requirements of the configuration task are fulfilled. Functional completeness expects the consistency of model description but not expects structural completeness.

The pUR paradigma offers a straigth-forward method to represent relationship concepts. Adding temporal relations, fundamental dynamic dependencies can be described. pUR-models are rated - predicated - by adding relations and data with which you can e.g. model constraints. Constraints are used for representing and evaluating of interdependencies between objects. They may refer to objects properties or to the existence of objects. A basis for using of constraints could be the 3-step constraint model of [Gün92]

- the claim of existence and non-existence constraints,
- to fade in and to fade out of constraints, and
- relaxation of constraints.

Furthermore the pUR-concept is applicable for recording the process of solution by model based elaboration and for an integrated description of different modelling aspects.

As mentioned earlier, the configuration solution are defined by models. During the configuration process the models are refined, perfected, and adapted. The transformation of a partial model into a new one by executing a configuration method is called *elaboration* [CGS+90]. The elaboration characterizes the different relationships between models on various development or abstraction levels and on one level (see figure 7). An elaboration tree can be built during the configuration process. The nodes of the tree characterize the models and the edges of the tree describe the model transitions or the working states. The resulting elaboration tree represents the complete history of the configuration process. "It stores the necessary information for 'intelligent' backtracking in case of conflicts, and for an explanation module" [Gün93]. So it's possible to document and to understand the problem solving process.

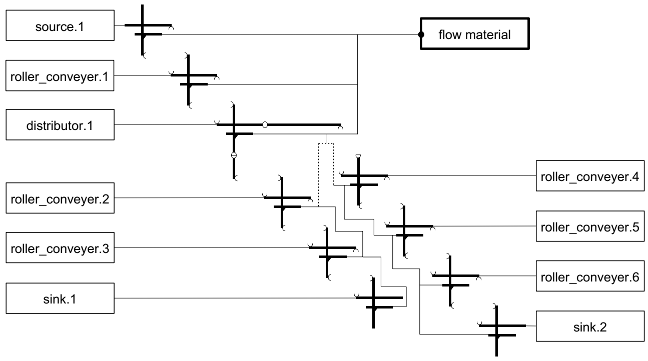

Figure 8: Structure and transport direction of a material flow plant

Another advantage of the model-based configuration with pUR is the practicability of an multi-aspect modelling (see also section 4). Multi-aspect modelling means that different facts can be represented by one pUR-Model. A different consideration of the integrated model description provides different aspects (views). Such views represent e.g. structure oriented and flow oriented properties. A view does emerge through fading out of all relevant properties, whereby an own subaspect model is defined. For example, a consideration of this structure oriented subaspect model can lead to a simulation model [DT96]. The model in figure 8 describes the solution of a configuration task (for the example see also figure 1). The structure of the material flow plant and the transport direction of a flow material can be derived from this one pUR-Model. So it's possible to describe many facts and relationships with few pUR-Models. The objects represent in case of system view components, technical functions, and ressources. In case of process view objects are general operations, work processes, and actions (see also section 4). The relations represent the structure relations between the objects and subsystems. They represent also the flow of material and the flow of information.

An additional example for the multi-aspect modelling is represented in figure 9. The controlling process of the material flow plants is described in this figure. This pUR-Model contains also information or aspects about the structure of the material flow plant which is shown in figure 1.

Finally is to remark that the models can be simplified by hiding of irrelevant properties or aspects.

6 Conclusion

In this paper an outline of a model-based configuration concept with pUR-Models was described. The meaning of the introduced concept for model-based configuration in the domain of material flow plants is the creation of an integrated description form. This integrated representation form allows to define problem adequate model descriptions. By using of inte-

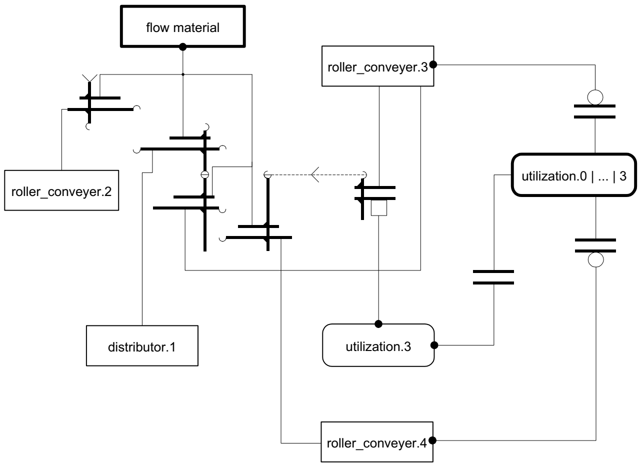

Figure 9: Controlling of a material flow plant

grated representation it is possible to realize a general computer aiding and a reduction of necessary model developments during the configuration process of material flow plants.

CAD-oriented configuration techniques in the domain of material flow plants (see [ZRW96]) were the starting point for the development of a model-based configuration concept with pUR-Models. A first approach for using pUR-Models was described in [RWS96]).

The introduced method was validated on a simple example (see figure 1). In future works the validation of complexer plants must be realized. Simultaneously a concept for mapping of a pUR-Model to an object-oriented scheme or to a relation scheme will be defined. The final goal is the prototypical development of a model-based configuration tool for material flow plants using pUR-Models.

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