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Modelling Smart Label-Supported Production Processes

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Abstract

Control of dynamics and complexity of logistic systems will continue to gain in importance in the future. One possibility to cope with this challenge is the concept of autonomous logistic processes that counts on using sophisticated smart labels. This article addresses the issue of requirements to a method for modelling autonomous logistic processes as well as the development of the method. It will give an overview to the created modelling and view concepts.

1. Introduction

Today enterprises are exposed to an increasingly dynamic environment. Last but not least increasing competition caused by globalisation more and more requires gaining competitive advantages by improved process control, within and beyond an enterprise. One possibility to face increasing dynamics is autonomous control of logistic processes. This shall allow more robust processes in spite of growing environmental as well as internal complexity. This paper presents the idea of autonomous logistic processes and focuses on a concept for modelling such processes. First section 2 gives a short overview to the concept of autonomous logistic processes. Main section 3 discusses process modelling under the paradigm of autonomy and introduces important aspects of our modelling method. The paper is concluded by a short summary and an outlook to future work.

2. Autonomous control of logistic processes

Autonomous control in the context of SFB 637, the research project this work is based on, means processes of decentralized decision making in heterarchical structures. It requires the ability and possibility of interacting system elements to autonomously make goal-oriented decisions. The use of autonomous control aims at achieving a higher robustness of systems and simplified processes achieved by distributed handling of dynamics and complexity due to greater flexibility and autonomy of decision making. Focus of the SFB lies in the areas of production and transport logistics, so the system elements, making their decisions autonomously, are the logistic objects themselves [1].

In order to enable logistic objects to be intelligent they have to be provided with smart labels. While today's RFID (radio frequency identification)-chips have very limited capabilities in respect to energy, range, storage capacity and especially information processing [2], near future shall bring highly evolved smart labels that can provide resources alike micro computers to logistic objects. Nowadays RFID is already widely used in industry for identification matters and several visions for future applications exist [3].

With respect to shades of autonomous control, different scenarios are possible, depending on which logistic objects are provided with smart labels and the functionalities they offer. This determines to what extend the logistic objects are able to make decisions. Considering the kind of decision-making by autonomous and therefore potentially intelligent logistic objects, transferring control decisions to goods, machines, storages and conveyors is obvious. Besides scenarios, where only one of the kinds of logistic objects has the ability to autonomously make decisions, arbitrary combinations are possible, depending on whether objects of the respective group are rather autonomously controlled or not. Different logistic objectives can be assigned to the different groups of objects. For instance the objective of a high utilization can best be assigned to machines, while the objective of due date deviation can best be assigned to a good. Concrete goal values are only achieved by the interaction of many logistic objects. Often conflicting goals of different objects have to be balanced, e.g. by negotiation. This leads to an increased coordination and communication effort compared to hierarchic forms of finding a decision. The more objects and groups of objects are involved in such a communication and make their decisions autonomously, the more important this point becomes. The number of possible communication relationships roughly grows quadratic in the number of participating objects. With 10 communicating objects there are 45 possible relationships, having 100 objects already leads to 4950. These numbers make clear that communication has to be limited to objects in the immediate spatial and/or logic neighbourhood as otherwise control strategies can only hardly be scaled to problems of a realistic size. Broadening the scope to inter-organizational processes makes things considerably more complicated. Not just due to an increased number of participants, in the general case they also have to account for non-cooperative behaviour of the participants. In such scenarios the absence of a higher-level instance in a heterarchical organization, that could resolve a goal conflict, further complicates things. All these points have to be considered designing a control strategy and for modelling such a system.

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3. Modelling autonomous control

Requirements to modelling
In this section requirements to models are formulated from which requirements to methods for model construction can be deduced directly. First the Guidelines of Modelling (GoM) [4] are shortly illustrated followed by more concrete requirements for the domain of autonomous control of logistic processes.

Relevance: The guideline of relevance considers the problem adequacy and tractability of model construction that are highly dependent on the constructing engineer's perspective.
Correctness: The guideline of correctness addresses the syntactic and semantic correctness of a model.
Economic Efficiency: The guideline of economic efficiency points out the necessity of economic advantage for modelling projects.
Systematic Design: In order to reduce complexity the guideline of systematic design provides a description of different views of the domain and availability of a view spanning metamodel. A common practice differentiates between static and dynamic views.
Clarity: The Guideline of clarity bears on clearness of models for different users.
Comparability: The possibility of comparing different models has to be guaranteed, which is of particular importance in target/actual comparisons.

For more details to these general requirements refer to [4]. Furthermore the modelling method has to contribute to the following more concrete requirements adjusted to the specific domain.

User orientation: A user-oriented view of model quality is an important principle of the guidelines of modelling. In particular the clarity guideline summarises subjective impressions like understandability, clearness and expressiveness. That subjectivity calls for identification and subsequent consideration of potential model constructors and users. First of all the prior existing qualifications and expert knowledge have to be considered.
Application area orientation: Strongly connected with user orientation of models is application area orientation. So the correspondence of model adequacy and model requirements concerning problem solving has to be addressed. The application area of the modelling method to be designed is defined by the logistics context and the autonomous control paradigm.
Efficient model construction: This requirement results from the guideline of economic efficiency. Here in particular basic building blocks and predefined modules matter for easing and acceleration of model construction. Reference models or scenario comprehensive autonomous control configurations play an important role as well.
Application integration: A heterogeneous use of constructed models also results from the guideline of economic efficiency, which is expressed by the requirement of application integration. In the following there are some exemplary fields of application.

- The design of the logistic system is based on the constructed models. The hardware configuration of the real system can be designed, for example a selection of RFID systems with dedicated performance characteristics can be done.
- On the basis of the logistics system design an economic efficiency estimation concerning an implementation of the system is possible. Benchmarks of different alternatives might also be done.
- The model built shall be a basis for a simulation model, which allows a better evaluation of system properties.
- Use of models in process management eases controlling and continuous improvement of the logistic processes, for example by nominal/actual value comparison.
- Logistic systems increasingly call for software support, for whose design the built models are the basis. In particular in connection with autonomous control this aspect becomes more important.

It becomes obvious, that these guidelines of modelling result in partly conflicting requirements to a model or a modelling method. For instance the objectives of user orientation and application integration are conflicting. Conflicting goal relationships can also be identified within the Guidelines of Modelling. These conflicts have to be identified and balanced. Another difficulty in connection with the Guidelines of Modelling is that it is not obvious how to operationalize them. Therefore they work more as general orientation that helps to systemize concrete rules for modelling.

Beyond the aspects mentioned above the decisive characteristics of autonomous control have to be considered in a model. These characteristics are at least: heterarchic organisation, decentralised decision making and the interaction of autonomous system elements.

Decentralised decision making: The ability of logistic objects to make decisions is an elementary approach of autonomous control. This requires in principle the ability to make a decision, the goals pursuit as well as the parameters and inputs that have to be present in a model.
Interaction: The term interaction describes the ability of the autonomous system elements to mutually influence each other, resulting in the functionality of the whole system. In a model the representation and layout of the interactions has to be possible, e.g. by

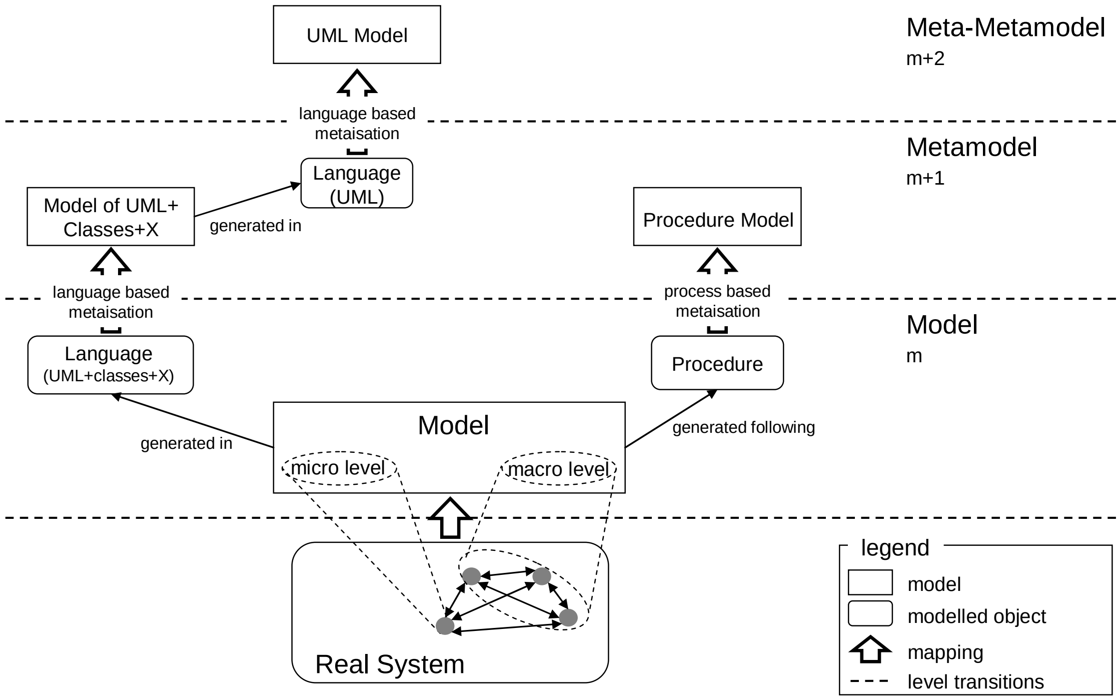

Figure 1: Overview of the modelling concept.

the illustration of communication respectively coordination mechanisms.

Shades of autonomous control: The different possible shades of autonomous control of a system, which result from different levels of the abilities of logistic objects, have to become clear constructing and using a model.

Modelling Concept

Before the next part gives further details of the modelling method and the view concept behind it, we will give an overview of the modelling concept on an abstract level (see figure 1). The figure shows different modelling levels, from the mapping of the real system at the bottom to the model level as well as from the modelling layers to their respective meta-levels. The distinction between model to meta-model is the same as between the real system level and the model level: the higher level contains explicitly the elements that can be used to model the level below. This means the meta-model-level specifies the elements that can be used to model the system on the model level. Speaking of “elements” this refers only to one aspect of the level transition, the specification of the modelling language. This aspect is called “language-based metaisation” in contrast to “process-based metaisation” which shows the modelling procedure to be used on the level below.

On the lowest layer of figure 1 the (real or thought) system to be modelled can be found. This system will be modelled, shown by the lowest layer transition. Additionally the distinction between a macro- and a micro-level in modelling is indicated. Details regarding this point can be found in the next section. The created model on one hand was created in a certain modelling language and on the other hand created following a certain modelling process. Therefore the layer transition from the model to the meta-model-layer distinguishes between language-based and process-based metaisation (for more information on metaisation refer to [5]). Explicit representation of the creation process leads to the depiction of a procedure model for modelling. This procedure model is the subject of further research and not detailed in this paper. The procedure model will be represented using natural language and the process of its creation is not of particular interest to us thus nothing is shown in the figure on the meta-meta-model layer regarding the language- or process-based metaisation of the procedure model.

Concerning the branch of language-based metaisation and the transition from model- to meta-model-layer, the modelling language respectively modelling notation is explicicated. Our modelling notation will be based on version 2.0 of the Unified Modelling Language (UML). In addition to that the modeller will be supported by pre-defined domain-specific classes and logistic-specific process-parts and process-templates. Furthermore subsequent research work will determine if an extension of the UML notation is useful to better show certain aspects of the logistic system. These extensions of the modelling language are indicated in the figure by the “X”.

This (language-based) meta-model again is depicted in a certain way. At this point the distinction between language- and process-based metaisation could be made again, but only the first is of interest here. To represent the modelling notation, as a means for semi-formal modelling, UML will be used. To depict the fact that also this modelling language has to be specified somewhere, the top-layer shows the “model of UML”, being the UML specification (see [6]). Relative to the modelling we aim at, this specification is on the layer of a meta-meta-model, strictly following language-based metaisation.

Concepts of views

Creating process models usually leads to a high degree of complexity. A view concept serves as a means to reduce the complexity constructing a model [7] which is also reflected in the guideline of systematic design (see subsection Requirements to modelling). Based on the requirements mentioned above a view concept for modelling of autonomous logistic processes is proposed, whose views are depicted in figure 2. A fundamental distinction can be made between a static and dynamic model. The static model describes the structure, the dynamic model the behaviour of the modelled system, according to the basic classification in UML [6] that is also appropriate here.

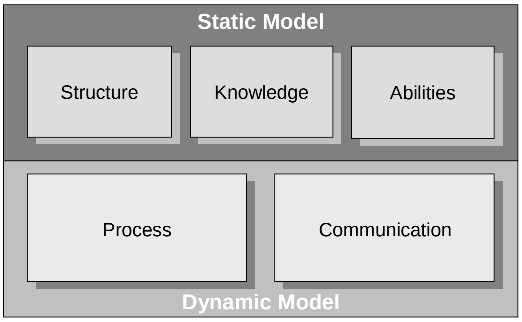

Figure 2: View concept.

The structure view that shows the relevant logistic objects is the starting point. The basic elements for this view are UML class diagrams. Besides objects and classes the structure view can show relationships between them, for instance in the form of associations or inheritance relationships.

The knowledge view describes the knowledge, which has to be present in the logistic objects to allow a decentralized decision making. This view should comprise spatial and temporal aspects. For relatively simple views UML-class diagrams are sufficient, while for more complex connections, for instance to show the just mentioned temporal aspects, a dedicated knowledge representation language has to be used [8]. Nevertheless it remains to be investigated, in how far the increase in expressiveness is bought by additional complexity in using it. This seems especially useful with respect to the intended use of the modelling method by a process expert.

The ability view depicts the abilities of the individual logistic objects. Processes of a logistic system need certain abilities, which have to be provided by the logistic objects. These abilities are supposed to be seen as abstractions of problem types occurring in reality.

The process view depicts the logic-temporal sequence of activities and states of the logistic objects. Here the objects' decision processes can be modelled. The process view plays a central role connecting the views of the static model and depicting the behaviour of logistic objects, so far only viewed statically. The notation elements used for this are activity diagrams as well as state diagrams. These two diagrams are also proposed in business process modelling using the UML [9].

The communication view presents the contents and temporal sequence of information exchange between logistic objects. Depicting the communication is especially necessary to depict the interaction of autonomously deciding, otherwise only loosely coupled objects to model their interaction [10]. To display the communication UML-sequence diagrams showing their temporal progression as well as class diagrams to display communication contents are supposed to be used.

In addition to the dynamic and static model just described we distinguish a macro and micro perspective. This distinction is also used in methods for software agent development [11]. The macro view describes the interaction between the autonomous logistic objects. To some extend, it shows an external view onto the system, its elements and their relations and interactions. On the contrary the micro view describes the actions within the autonomous logistic objects. For the micro-level especially the process, knowledge and ability view are relevant, while all views proposed are relevant for the macro-level. This means that the micro-macro perspective is orthogonal to the views shown in figure 2. Nevertheless not all views use both perspectives to the same extend.

As an example for the static model and to clarify the described modelling concept figure 3 shows a part of the classes available to the modeller. He can build instances of the existing classes as well as adapt and/or expand the class model. This means that the diagram is a modelling basis that can be adapted for concrete scenarios if necessary. The figure shows some relevant classes and the most important relations between each other. For clarity reasons there are no multiplicities included in the diagram. As central classes commodity and resource can be identified. To create the collection of domain specific classes [7], [12] and [13] were used as references. The models presented there were used in context of information system development and are now adapted to our requirements.

Commodity represents a concrete logistic object in a material flow, e.g. an individual end-product, while commodity type is used when a commodity shall be

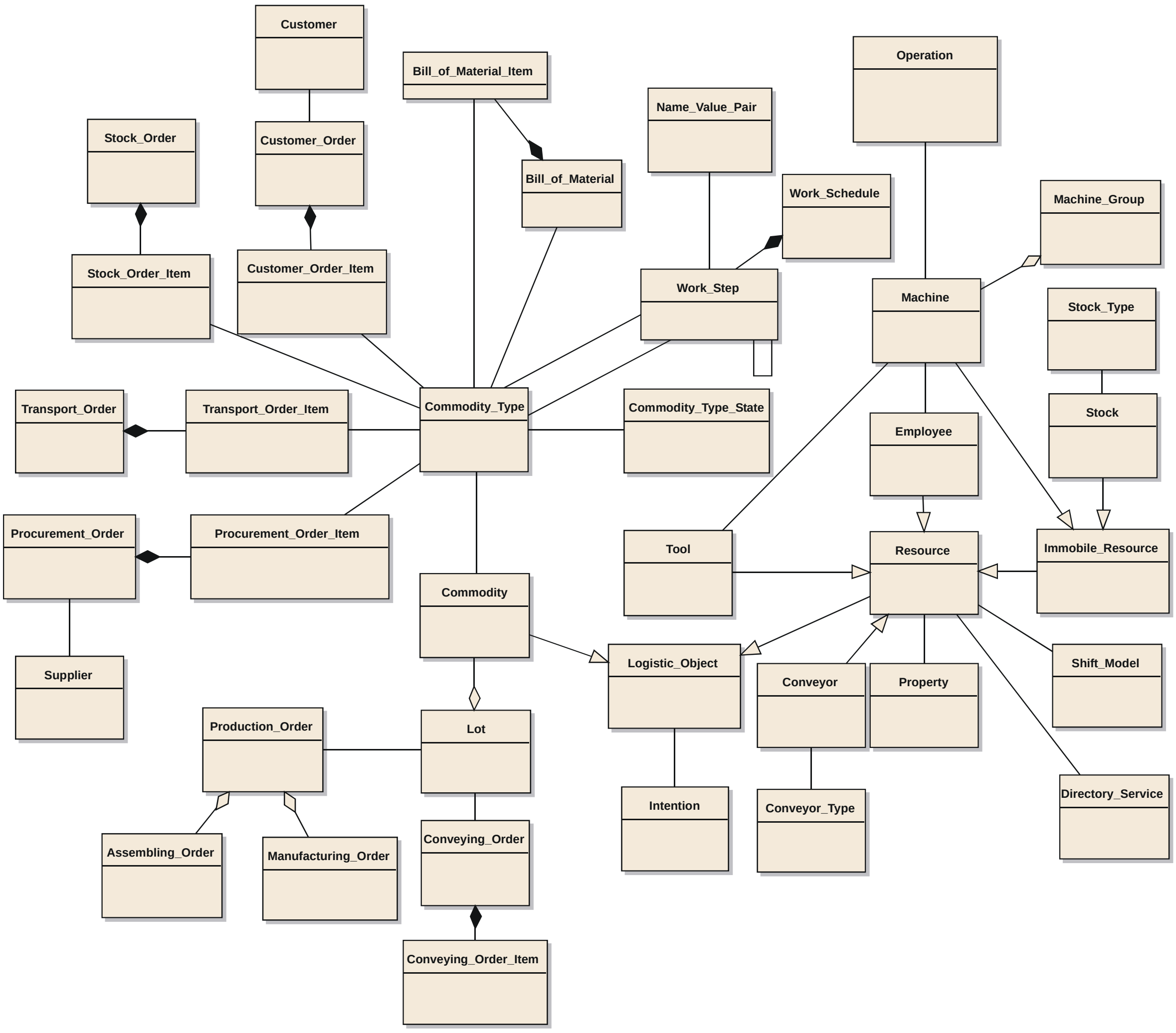

Figure 3: UML class diagram of the relevant logistic objects

referred to anonymously. A commodity type might be a type of end product, intermediate product or raw material. Resource represents a common basic class for physical and more static components of a production. Specialisations of the resource class are machine, tool or stock. Both commodities and resources are potential autonomous cooperating entities, having the abilities of autonomously controlling their behaviour.

As an example for the dynamic model figure 4 shows an exemplary sequence diagram as part of the communication view. The example is rather simplified and concentrates just on commodity-machine communication although availability of conveyers must be considered in a resource selection process. The diagram shows a machine object and a commodity object. The exchanged messages are shown chronologically in vertical direction. The commodity requests a machining process answered by the machine with a quote. After the machine has selected a quote (the selection itself with its criteria and algorithms may be modelled in the micro level process view) the chosen machine is booked by the commodity, the others are informed about the quote cancellation. In figure 4 this is modelled by a combined fragment of the type “alternative”.

The presented example also shows some deficits of the UML 2.0 standard with respect to modelling

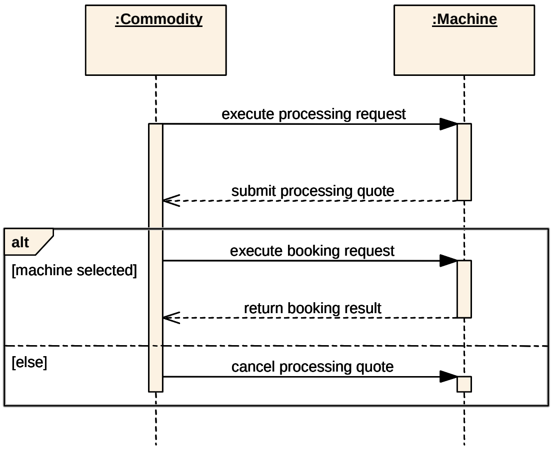

Figure 4: UML sequence diagram machine selection

autonomous logistic processes. It is not one commodity communicating with one machine, but one commodity communicating with multiple machines. On the other hand the "maschine selected"-part of the alternative fragment is only executed with one machine. For reasons of clearness this should be modelled explicitly. One possibility to assure clearness could be an extended notation similar to cardinality which is proposed for software agent modelling with UML using specific extensions [14].

4. Conclusion

This paper addressed the topic of modelling autonomous logistic processes. Therefore after a short definition of autonomous control in the context of logistics, requirements to modelling were defined first. After that the concept of our modelling method was presented, first giving a rough overview, then detailing certain aspects of it such as the view concept.

Further research will further detail some aspects of the concept and will be concerned with the development of a procedure model. Finally our work will result in the development of a software tool, specifically tailored to support our modelling method comprised of the notation and procedure model as far as possible. With the help of this tool a process expert (e.g. a logistics expert with only little background in computer science) will be supported in modelling and designing autonomous logistic processes.

5. Acknowledgement

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