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Autonomous Supply Net Coordination

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Abstract
Enterprises have to survive in an increasingly dynamic environment. To achieve this, a good ability to master their business processes beyond the borders of their own enterprise is inevitable. Autonomous control of logistic processes is proposed as a means to reduce dynamics and complexity and currently investigated by a large, interdisciplinary german research project. This paper presents approaches to the modelling of autonomous logistic processes and extends them to processes of a supply network using a supply net scenario derived from an industrial research project.

Keywords:
Coordination, Decision making, Modelling, Supply Nets

1 INTRODUCTION

Today enterprises are exposed to an increasingly dynamic environment. Last but not least increasing competition caused by globalization 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 complexity. This paper presents concepts for modelling autonomous logistic processes and an approach to transfer the idea of autonomy to coordination in supply networks. Firstly section 2 gives a short overview to the concept of autonomous logistic processes. Next section 3 discusses process modelling under the paradigm of autonomy. In Section 4 presents an overview to process coordination methods in supply networks being proposed in literature and being considered for implementation of autonomy. Section 5 describes a real supply network-based scenario from machine building, which is used to display order coordination against the background of autonomy by a plan by exception approach. The paper is concluded by a short summary and an outlook to future work.

2 AUTONOMOUS CONTROL OF LOGISTICS 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. With respect to shades of autonomous control, different scenarios are possible, depending on which 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 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.

3 MODELLING AUTONOMOUS CONTROL

3.1 Requirements to modelling

In this section there requirements to models are formulated from which requirements to methods for model construction can be deduced directly. First the Guidelines of Modelling (GoM) [1] are shortly illustrated followed by more concrete requirements for the domain.

General Requirements: Guidelines of Modelling (GoM)

Relevance – The guideline of relevance considers the problem adequacy and tractability of model construction that are highly dependend of the construction 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 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.

Concrete requirements to modelling

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 consequent 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 concerned. 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 may play an important role, too.

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 process model built might 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 [1]. These conflicts have to be identified and balanced.

Specific requirements from autonomous control

In a model the decisive characteristics of autonomous control have to be considered. These characteristics are: 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 the illustration of communication resp. coordination mechanisms. Shades of autonomous control - the different possible shades of self control of a system, which result from different levels of the ability of logistic objects to autonomous control, have to become clear constructing and using a model.

3.2 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 [2] which is also reflected in the guideline of systematic design. Based on the requirements mentioned above a view concept for modelling of autonomous logistic processes is proposed, whose views are depicted in figure 1. 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 [3].

The static view to show the relevant logistic objects is the starting point. The basis 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.

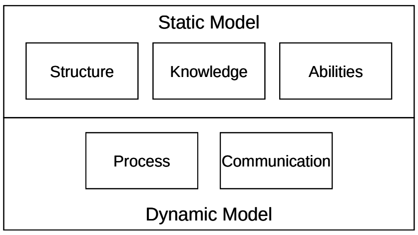

Figure 1: View concept.

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 spacial 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 [4]. 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

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objects, so far only viewed statically. The notation to use for this are activity diagrams as well as state diagrams [5].

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 [6]. 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 [7]. 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.

4 COORDINATION WITHIN SUPPLY NETWORK MANAGEMENT – SELECTED BUSINESS PROCESSES WITH SPECIFIC DEMANDS

Within the scope of operative supply network management exists a wide range of complex business processes, which basically are spanning various enterprise boundaries. Furthermore they often require very specific coordination procedures in terms of their controlling. Especially within operative supply network management it is the first and foremost goal to fulfil the customers' orders regarding the key criteria fulfilment time, amount delivered and due date concerning the completion of the final product.

From the perspective of the final producer, often the term original equipment manufacturer (OEM) is used, he basically has to make contact to various suppliers on many layers of the supply net, either directly or indirectly through 1st-tier or 2nd-tier suppliers depending on the type and quantity of the customers orders, respectively the complexity of the final product. Often the OEM does not even know the suppliers to his final product, which may be operating for example on the 4th or 5th layer of the supply network from his point of view. Furthermore the different suppliers themselves may as well be integrated into different other supply networks. Moreover the different participants involved within the selected supply network try to reach an efficient capacity utilization and a low level of stockage. This indicates classic goal conflicts, which may possibly be resolved by deploying new approaches.

A beneficial approach to better understand complex systems in general (here supply networks) can be identified with cybernetics, as the meta-science of steermanship in biological as well as in technical or economic systems [8]. Cybernetics basically describe the control and dynamics of large scale and complex systems by deploying and integrating aspects of several other sciences like adaptive control theory, general systems theory or mathematic game theory. These aspects support, for example, the adaptation and specific further development of adaptive control theory (here e.g. in the context of plan-by-exception and bi-directional change-propagation) to improve the identification as well as the design of autonomous, distributed control entities from the applications point of view (here supply network management). In this context the benefit of deploying a cybernetics approach would be to change the fundamental design of such a complex and dynamic system as a supply network, in order to achieve a self-stabilizing system, which ought to return to a stable general system state after being destabilized by a wide range of possible disturbances (e.g. production down times, information distortion, drop out of an allocated supplier).

In this context figure 2 displays a range of possible types of customer-supplier relationships. This paper basically addresses the sector of the complete supply network (top, right), which will be demonstrated on the basis of a real world scenario from the machine building industry further down.

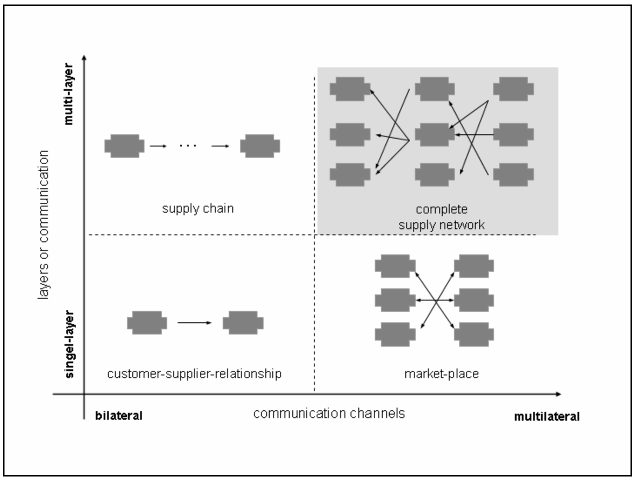

Figure 2: Range of possible customer-supplier-relationships.

Within literature currently about four different, enterprise spanning business processes have been identified, which seem to be appropriate for an autonomous coordination of customer orders.

Therefore it can be distinguished between the following enterprise spanning, business processes, which are analysed within this section of the paper:

- Available to promise (ATP) [10],
- Capable to promise (CTP) [10],
- Plan-by-exception [13],
- and bi-directional change-propagation [13].

Plan-by-exception and bi-directional change-propagation are built up upon the ATP- and CTP-processes and supplement them.

The ATP-process primarily serves to determine reliable delivery dates concerning the customer orders (final products) all along the supply chain for example of a certain part or module of the final product (e.g. related to 1st-Tier up to n-Tier), which is part of the overall supply network. This process considers and includes all disposable inventories in the calculation of a delivery date along the viewed supply chain, for example even those which have been produced and stocked or purchased in the past for expected customer orders based on imprecise forecasts [10].

The CTP-process follows the ATP-process and extends it by considering and including the available production capacities in the calculation of a delivery date along the viewed supply chain. These available capacities on the production resources, are as well as the inventories widely and asymmetric distributed at the different suppliers along the viewed supply chain, which are aligned to fulfil the customers order [10].

The ATP- and CTP-process are basically classified as so called short-term planning processes, for example within the classification scheme of the supply chain planning

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matrix (SCP) (figure 3) [14]. The supply chain planning matrix describes a fundamental, hierarchical arrangement of planning information systems within the field of supply chain management [14]. Within [14] the SCP has been stated more precisely how ATP-process is combined with demand fulfilment, whereas the CTP-process is rather related to production planning or scheduling respectively. By taking a close look on this classification, one will realise that the supply chain planning matrix describes a strict hierarchical classification approach of planning information systems, which is basically the opposite of the heterarchical, distributed and loosely coupled set of autonomous control entities for the coordination of customer orders described above. The possibility of autonomy on the level of the logistic object, like for example the parts or modules as core elements of the "physical" order, as well as the object related container systems or means of transportation (e.g. pallets) are not taken into account. Furthermore from the production data acquisition (PDA) point of view, for example on the basis on new, advancing technologies like RFID (Radio Frequency Identification), the build up of potentially complete and closed chains of information (e.g. automated data feedback loops, respectively pass on of the finish of production, assembly or dispatching steps) without any loss of information are not taken into account.

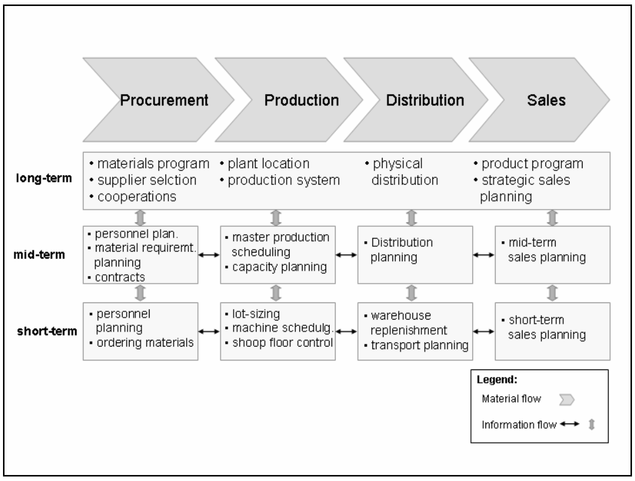

Figure 3: Overview of the supply chain planning matrix adapted from [14].

A different approach has been introduced with the so called task-model (figure 4) for supply chain information systems [12]. Within this task-model the ATP- and CTP-processes are summarised under the common headline availability- and feasibility-checkup. Possibly a function called configure to promise (CoTP), which comprises the configuration of the product due to customers preferences, supplements these two processes (ATP & CTP), within a holistic order promising process [12]. The order promising process itself offers a lot of potential to be supported by a wide range of simulation tools (e.g. on-line). These may allocate the relevant suppliers including their available production capacities, as well as calculating the over-all throughput time (here order fulfilment time) under consideration of forwarding time. Some selected aspects will be discussed within the next section by taking the paradigm of autonomous logistics processes into account.

Furthermore regarding the coordination of the distribution and fulfilment of components of the customers orders (e.g. parts and modules of the final product) in between the enterprises of the supply network, the concepts plan-by-exception as well as bi-directional change propagation [13] are very interesting in terms of autonomous logistic processes. Plan-by-exception basically focuses on the relief of the planner from the routine activities, in favour of challenging, exceptional circumstances.

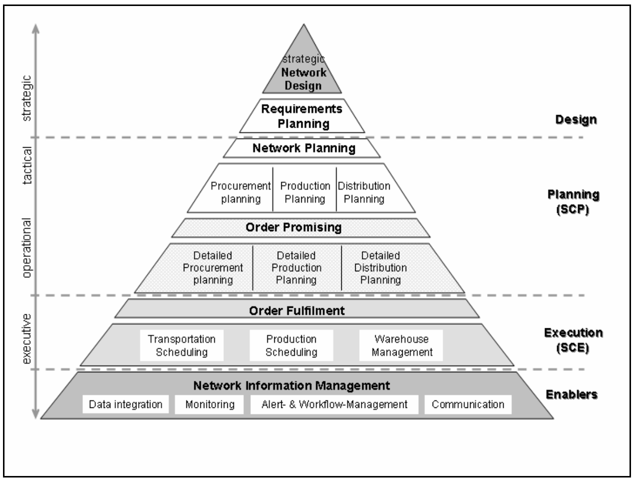

Figure 4: Task-model for supply chain information systems adapted from [12].

This concept basically requires a broadly enhanced application of "intelligence" (e.g. methods from the artificial intelligence field) already on the level of the logistic objects (e.g. purchased and supplied parts and modules, means of transportation), to implement the idea of autonomous logistics processes in an automated way. The plan-by-exception process [13] comprises a multi-sage ATP- and CTP-process to calculate a reliable delivery date, including the following steps:

- Identifying potential problems,
- Identifying the causes,
- Running through alternative scenarios,

as long as it takes to allocate and to reserve the available, disposable inventories or production capacities on the different levels of the supply network in order to fulfil the customers order (here a final product). So far this concept is just drafted for the internal view of a participating enterprise within the supply network without any further integration of other partners. In the future it can be extended by deploying more sophisticated coordination mechanisms (e.g. game or decision theory), for example within the research activities related to autonomous logistics processes. But it has to be considered that it will take extensive capabilities concerning the abilities of integration of information and communication systems (ICS).

Within the context of the plan-by-exception process the bi-directional change propagation is another logistics planning process, which is very interesting under the focus of implementing autonomous logistics processes. For example a local drop-out, due to a potentially wide range of failures (e.g. machine break-down, break-down of the means of transportation), will be examined, which before has already been allocated as disposable production capacity for a certain customer order within the CTP-process. The bi-directional change propagation initiates a new calculation and updating of the production schedule on the local level and furthermore propagates respectively communicates the results (e.g. drop-out, new customer due date) up and down along the affected area of the supply network. Concerning the affected area the produced lot sizes and purchased order quantities are adjusted, for example through substitution by other parts or modules, furthermore through changing of order sequences (including customer delivery dates) if possible.

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Taking these processes (plan-by-exception, bi-directional change propagation into account) one can easily recognise, that for example workflow-systems (e.g. workflow software modules within ERP-Systems) are an absolute must as enabling information technology, as well as widely agreed standards (e.g. data formats), all along the supply network. But the currently available workflow-technology is neither enabled, nor do exist commonly agreed standards and procedures all along a supply network to perform these processes. This as well supports the idea of a fundamental paradigm shift to modelling and running autonomous logistic processes.

5 EFFECTS OF THE PRODUCT ATTRIBUTES ON THE SUPPLY NETWORK AND THE LOGISTICS PROCESSES

Within the following section the theoretic coherences of the previously described logistic business processes, which are relevant in the context of developing and modelling autonomous logistic processes, will be discussed and demonstrated on the basis of a real world supply network scenario of the machine building industry [15]. Furthermore the most important aspects concerning the mapping of the product attributes, in terms of the product structure, onto the structure and geographical distribution of the supply network, will be presented.

The selected supply network scenario of the machine building industry originates from an industrial consulting project and has been prepared by the authors for the further use within basic research projects. The consulting project has been conducted at a well known European producer of industrial pump sets (e.g. for the chemical or food industry). The producers of these pump sets are operating globally and basically produce their pump sets make to order respectively due to just arrived and confirmed customer orders. Furthermore There exists a range of other special requests related to the final products (pump sets), depending on the different branches where they are deployed. For example the chemical industry has special requests concerning galvanic corrosion. Figure 5 displays the industrial scenario. The scenario comprises three vertical layers starting with the OEM-, followed by the 1st-tier and finally the 2nd-tier supplier layer [16]. The final product – pump set – is built up of the pump itself, here are two different pump types available with very different characteristics concerning delivery height as well as the sort of fluid to be conveyed, furthermore an electrical motor as gear to the pump, a coupling as physical connection between motor and pump, as well as a cover plate for the coupling and a base plate.

The two different types of pumps can not be substituted and are manufactured and assembled to customer ordered pump sets at two different production sites (business units). The electrical motors can basically be easily substituted by each other and therefore present a kind of redundancy within the product structure, which is a pre-requisite for the development and modelling of autonomous logistics processes.

As figure 5 displays there are eleven suppliers on the 1st-tier level and twenty suppliers on the 2nd-tier level. Through a calculation of this scenario one can easily see that there is a total of twelve different product configurations on the basis of specified customer orders concerning the final product – pump set – possible, where each of them reflects a certain configuration of the supply chains within the supply network [16]. Figure 5 displays as well that all the modules and components of the pump sets are manufactured all over Europe.

This pan-European distribution and basic redundancy is an excellent basis for the introduced bi-directional change propagation in terms of the rescheduling of a customer's order.

Regarding the industrial scenario (figure 5) the option of flexibly substituting an electrical motor on the 1st-tier level can be viewed as an example for a multiple sourcing strategy of the OEM. This ends on the 2nd-tier level, where concerning the supply of parts there is only a one to one relation (e.g. E-Motor GB → metal housing GB, and so on).

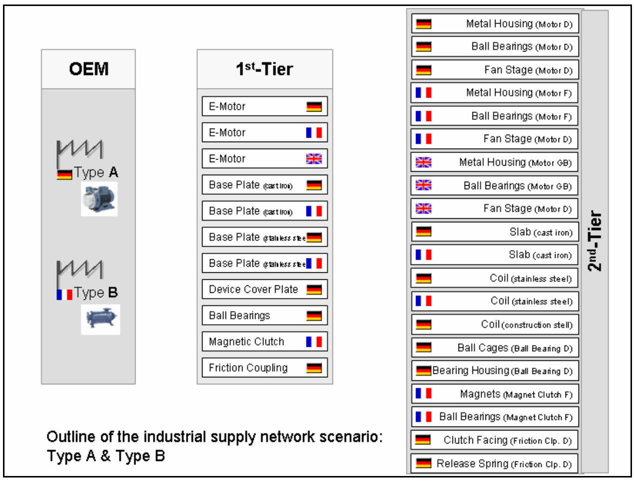

Figure 5: Outline of the industrial scenario.

This allows a good application and study of the plan-by exception process, for example if a certain electrical motor supplier is requested within the customers order of a pump set, but the production capacities needed or parts of the suppliers are not available on time, which leads to a reallocation of an electrical motor supplier including his suppliers on the 2nd-tier level. This concept has already been implemented by deploying agent-technology, by considering some of the drafted aspects of autonomous logistic processes [16] on the basis of a multi-agent system architecture for distributed intelligent information systems described by Huhns and Singh. It deploys a range of different types of agents (e.g. User-, Broker-, Execution-, Mediator-agents), which represent among others machines, stocks respectively buffers and customers [16].

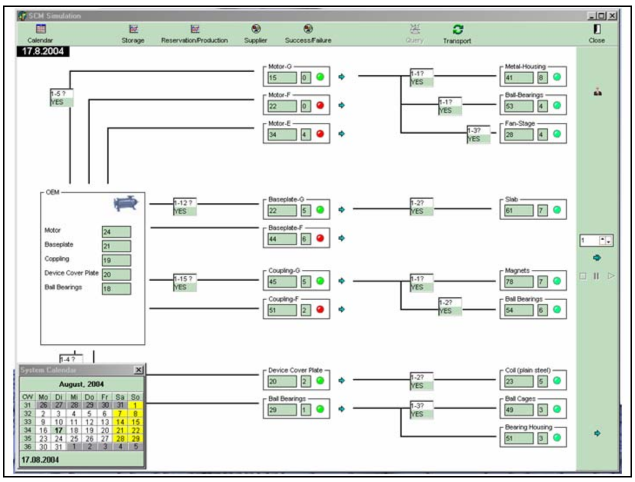

Figure 6: GUI of the multi-agent simulation tool.

A range of extensions under the focus of designing intelligent logistic objects in terms of concrete components or modules are part of the ongoing research activities regarding the modelling concepts introduced above, for example on the basis of the concept of active objects as a part of the UML 2 (Unified Modelling Language), before a further extension of the so far achieved agent-based solution.

The currently implemented logistic process, which is an extended and reimplemented concept compared to [16], are triggered with the product configuration either by an customer or a sales engineer, where a bill of materials as outcome of the product configuration are mapped onto the supply network (figure 6). Concerning the decisions about the relevant alternatives within the plan-by-exception and the bi-directional change propagation processes, currently a kind of prioritisation on the basis of stated customer preferences (e.g. most preferred e-motor comes from France followed by Great Britain) during the product configuration are being used (figure 7).

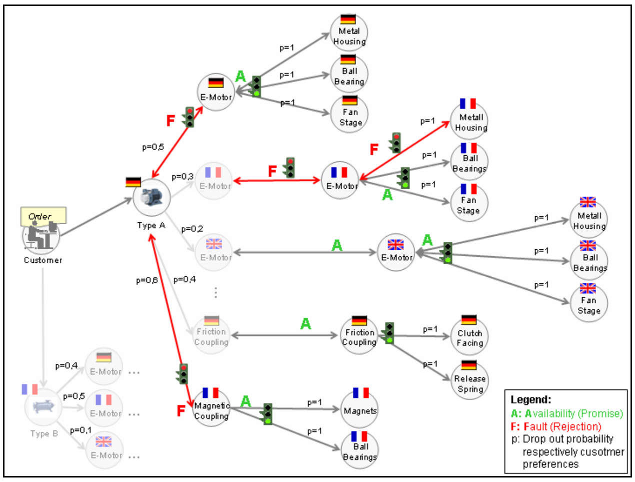

Figure 7: Principal process flow of the coordination of customer orders.

If a basically feasible customer order has been accepted and initiated, the ATP- and CTP-processes introduced further above are executed multiple times until the customers order has been either confirmed by all relevant suppliers on the 1st- and 2nd-tier level (e.g. concerning an electrical motor), or due to an unplanned respectively random disturbance (e.g. drop out of a 2nd-tier supplier), it triggers the plan-by exception and the bi-directional change propagation via messages. This will provide a possible solution to the OEM to still fulfil the customers order in due time. Furthermore only acceptable product solutions for the customer are provided based on the once entered preferences for certain product attributes and components. If the chosen preferences by the customer have been exhausted and there are any configuration options left, the possibility of configuring a feasible product bundle, which might still fulfil the customer requirements, in terms of the selected basic attributes as well as the logistic key figures (e.g. product quality, remaining delivery time) will be open and thus free to decide for the OEM [16]. Since the basic idea of supply chain respectively network management is a cooperative coordination and fulfilment of customer orders according to their requests, the authors belief that in terms of an autonomous and heterarchical processing, new coordination approaches will be needed. As demonstrated within figure 7 a coordination approach considering customer preferences as a first attempted can be very useful.

In order to reallocate new suppliers without available respectively exhausted customer preferences and under consideration of constrains like time overrun, lower product (e.g. component) quality, which may be expressed through a lower preference of the OEM, as well as higher assembly or higher transport costs, mechanisms which implement cooperative behaviour or coalition forming seems to be appropriate. These aspects can be expressed through deploying for example cooperative game theory, where the players (here OEM, 1st-tier and 2nd-tier suppliers) typically make binding commitments, as opposed to non-cooperative game theory, in which they cannot [19]. Currently typically a range of different types of market mechanisms (e.g. Dutch or English auctions) have been implemented [20], which requires a free market as prerequisite, on the basis of freely negotiable product prices (e.g. ebay, stock exchange), which is basically not the case if one considerers a supply network of cooperating enterprises, where the prices are mostly fixed within cooperation treatise. Cooperative game theory in fact is viewed as a rather reduced-form theory, which focuses more on the outcome rather than on the strategies to achieve the outcome (e.g. Pareto equilibrium), a method which is sometimes the modelling of the complex resolution process which is too complicated [21]. Cooperative games often allow the players to maybe split their gains (e.g. to foster or encouraging the cooperation) from cooperation by making side-payments transfers between themselves, which might change the payoffs. Furthermore it generally incorporates commitments and side-payments via the solution concept (mechanism design), which can become very elaborate [22].

Concerning the attempt of applying cooperative game theory, within the context of the ATP- and CTP-processes, it can be basically distinguished between a sequential and a simultaneous connection establishment [23].

Taking these aspects into account, a sequential cooperative game can be modelled exemplarily by considering the following aspects [23]:

- An exogenous order above all players is given (here via the mapped product structure onto the supply network).
- All pairs of players within the sequence are requested to establish a connection or not to do so.
- A connection will only be established if both players (enterprises) are willing to do so.
- If the first pairs of players have established a connection the others are requested to do so and so on until all willing players have been connected.
- Concerning the concept of sequential games the newly established connections cannot be dissolved right away.
- The sequential game terminates if a connection structure, in this case equally to the configured product structure, has been successfully achieved.
- Hence everyone will receive his payoff.

Furthermore the most important thing is to derive the appropriate game strategies (e.g. goals), including the pool and the allowed combination of strategies, for each player, which is in close relation with the design of the coalition and payoff functions of each player. Like already mentioned above this elaborates very fast. Nevertheless it is worth to be explored and it is a part of the ongoing research activities concerning the further development of the theoretical basic principles related to the introduced industrial supply network scenario.

6 SUMMARY

Recapitulating it can be noticed that not really the apprehension of the introduced logistics business processes is the key issue, but in fact their enterprise spanning realisation, as well as their consistent design and modelling. The characteristics identified above and concepts concerning the modelling of the grade of autonomy within the autonomous logistics business processes are currently developed within the collaborative research centre (CRC) 637. As a first attempt they shall meet the concerns of the pointed out paradigm shift, by explicitly integrating the logistical objects themselves, like product components and modules, means of transportation and containers or boxes, into a strictly object oriented modelling approach.

7 ACKNOWLEDGMENTS

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Some of the topics discussed and presented in the context of the industrial supply network scenario (especially section 4 and 5) are extended results of the finished research project **agent-based reactive control of supply chains,** which has been funded by the DFG under the reference no. Scho 540/8-1.

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