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Scalability Effects in Modeling Autonomously Controlled Logistic Processes

Challenges and Solutions in Business Process Modeling

Bernd Scholz-Reiter, Daniel Rippel, Steffen Sowade

Modeling of autonomous logistic processes requires detailed knowledge about logistic systems and about the design principles of autonomous control. The Autonomous Logistic Engineering Methodology incorporates both types of knowledge in varying degree in order to guide logistic process experts through the modeling process. Although the methodology enables modeling of any autonomous logistic process, two important challenges affect the methodology's scalability in case of large logistic scenarios that consist of several organizational independent companies. This article analyzes both consequential challenges, namely the increase of a system's complexity and the lack of obtainable information. It presents two logistic scenarios of different scale and discusses the selected challenges in detail. In addition, the article suggests a new type of model visualization and a set of collaboration mechanisms allowing to overcome of these challenges.

Introduction

Today's logistic systems become more and more complex. In this situation, high fluctuations in customer demand and unforeseen events decrease the predictability of their behavior and increase their dynamics and vulnerability. While classical production planning and control systems are reaching their limits in order to deal with these effects, autonomously controlled logistic processes are a possible solution [6]. This concept aims to increase a logistic system's robustness and flexibility by distributing planning and control competencies to logistic objects, e. g. to commodities, half-finished goods, resources, and orders. Autonomously controlled logistic processes rely on the logistic objects' local decisions and lead to a positive emergence of the overall system's behavior [6].

Logistic process experts face the tasks to design, model, and evaluate autonomous processes in order to apply autonomous control in logistic systems. This development process includes the specification of logistic processes, logistic objects' abilities, decision-making strategies, as well as a definition of an overall system in form of a logistic scenario. In order to guide logistic process experts through the development process, a modeling methodology called Autonomous Logistic Engi-

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neering Methodology (ALEM) is being developed [20]. The methodology's applicability and its advantages have been demonstrated at the example of production logistic scenarios like shop-floor manufacturing systems [7]. Beyond that, the advantages of autonomous control obviously increase with the growing size of a logistic system, due to an increasing number of decision alternatives in its running processes as well as during the system's design process. Consequently, a decentralization of planning and control mechanisms in larger scaled logistic systems results in an increase of flexibility and robustness. For example, supply chains, production networks, or virtual enterprises constitute more complex scenarios than simple manufacturing scenarios. They cover a variety of logistic objects, each having a wide range of decision alternatives.

An increase in a logistic system's size and complexity influences the amount of information to be modeled in ALEM. Hence, an interesting question is, if and how this increase affects the modeling process and the ALEM model consequently. ALEM might have to deal with two challenges caused by scalability that emerges during the design and modeling process.

First, ALEM's bottom-up modeling approach requires a detailed modeling of the logistic processes and their components. In large scaled scenarios, this might come along with a low comprehensibility of the models and might face modelers with additional challenges in modeling, testing, enhancing and error tracing.

Second, modelers face the task to obtain all information that required for a detailed model of all logistic objects' abilities, knowledge, processes etc. However, such information might be considered as private and might be unavailable for a specific modeler. This is in particular true during the modeling of large scaled logistic systems which involve a variety of organizational independent entities. Their internal information might not be revealed to the modeler. Hence the question arises, if and how these issues affect the modeling process and its results.

Therefore, this article investigates both challenges as they emerge from the application of ALEM to large scaled logistic scenarios. Thereby, it illustrates techniques and methods in order to cope with them. First, the article presents the paradigm of autonomous control and the corresponding modeling methodology ALEM. Afterwards, it discusses organizational, technical, and personnel issues by making use of two logistic scenarios. The first scenario represents a manufacturing system, while the second illustrates a supply chain. At last, the article sketches approaches to deal with these challenges and limitations.

The Autonomous Logistic Engineering Methodology – ALEM

Hülsmann and Windt define autonomous control as "processes of decentralized decision-making in heterarchical structures. It presumes interacting elements in nondeterministic systems, which possess the capability and possibility to render decisions independently. The objective of Autonomous Control is the achievement

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of increased robustness and positive emergence of the total system due to distributed and flexible coping with dynamics and complexity." [6].

In order to enable autonomous control, selected logistic objects are equipped with the abilities to manage information, to process information (decision-making), and to execute decisions. The heterarchical interactions of these objects form autonomous processes. Although it is impossible to predict the overall system's performance, simulation studies demonstrate positive effects of autonomous control on the system's performance, e. g. in terms of logistic goal achievement, flexibility, and robustness ([14], [16], [4], [12]).

In order to enable logistic process experts to develop and evaluate autonomously controlled logistic systems, the methodology ALEM is being developed. It is designed to provide logistic process experts with tools and methods, to develop autonomously controlled logistic processes. Hence, it has to satisfy four essential requirements [17]:

General requirements: A modeling methodology has to consist of a notation, a procedure model, and of a fundamental structuring which provides orientation during the modeling process.

User orientation: A modeling methodology has to be suitable for its users. ALEM focuses on logistic process experts. Therefore, it has to exploit well-known and standardized methods for process modeling in logistics.

Domain orientation: A modeling methodology has to be specific to the domain of application. In case of ALEM, this domain is threefold and consists of logistic systems and logistic process modeling, as well as of the paradigm of autonomous control.

Model-usage orientation: Created models and parts of them have to be useful in subsequent steps of a development process. Hence, they have to provide essential information about the system in scope, in order to enable its deployment in real world applications.

In order to satisfy the general requirements, the ALEM methodology provides a view concept and a procedure model, described in the next subsections. The notation, applied by ALEM, closely conforms to a subset of the Unified Modeling Language (UML), in order to satisfy the user orientation requirement. The UML is a well-known and standardized language that is widely used in the areas of software development (e. g. [2], [9]), knowledge representation (e. g. [25]) and process modeling (e. g. [10]). Therefore, it is likely that a potential user of ALEM already had contact with this notation [20]. ALEM extends the UML-Notation by some domain specific diagrams to address the needs of a modeling methodology for logistic systems [8] [20]. For example, these additional diagrams cover the structure of products, which are manufactured within a modeled scenario [21]. ALEM follows a bottom-up modeling approach, in order to satisfy the domain requirements on autonomous control. This modeling approach focuses on the logistic objects' abilities and their processes for decision-making. This focus directly results from the definition of autonomous control. The ALEM methodology spans four major steps of a system's development cycle (Figure 1) in order to satisfy the model-usage orientation requirement: First, the methodology supports logistic process experts in specifying the logistic processes and the scenario. Second, it supports simulation to evaluate the models. Third, the methodology provides tools and concepts to configure the infrastructure that is necessary to enable the autonomous processes. Finally, the methodology provides means to perform a cost-benefit analysis on its models. Furthermore, the high level of detail, encompassed by ALEM, enables an easy development of an agent-based system out of ALEM models [18].

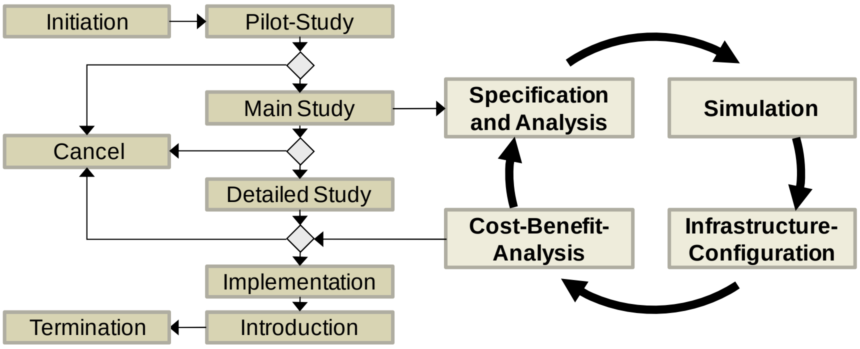

Figure 1: System Development Cycle

ALEM – View Concept

The ALEM view concept [19] distinguishes between five semantic views (Figure 2). These views either describe static or dynamic features of the model. For example, static features define which intelligent logistic objects exist within the modeled scenario, their knowledge, and their abilities. Dynamic features cover the logistic objects' processes and communication protocols. Each view may contain aspects referring to either the micro or the macro perspective. Elements within the micro perspective, like decision-making strategies, are object-internal. In contrast, the macro perspective describes object-external elements, such interaction protocols. The semantic views distinguish between structural features (structure view), knowledge aspects (knowledge view), actions which can be performed by the logistic objects (ability view), processes (process view) as well as between communication protocols and message contents (communication view).

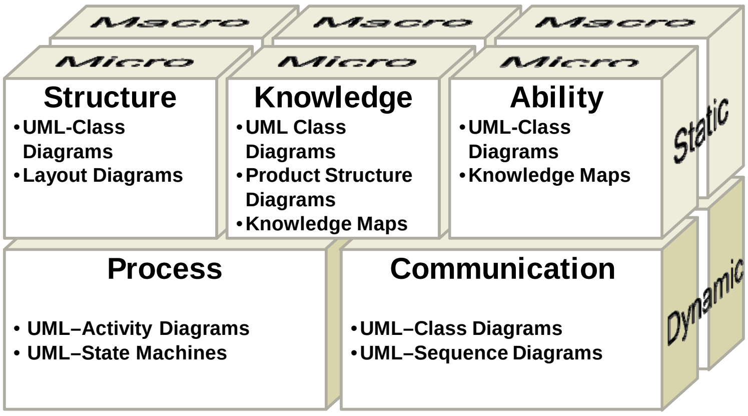

Figure 2: ALEM - View Concept [19]

The structure view contains structural features of the modeled system. It defines all present logistic objects, as well as relationships between them. In addition, this view includes the spatial layout of modeled scenarios.

The knowledge view covers all aspects concerning knowledge and objectives. UML-Class diagrams represent the logistic object's knowledge in form of attributes. The logistic objects' objectives are defined in UML-Class diagrams. Additionally, this view incorporates product structure diagrams [21] and knowledge maps. Those maps assign knowledge, modeled within the distinct diagrams, to logistic objects.

The ability view uses a UML-Class diagram in order to represent fundamental abilities that logistic objects can perform. Knowledge maps assign these abilities to logistic objects.

The process view makes use of UML-State Machines and UML-Activity diagrams in order to represent the behavior of logistic objects. It incorporates object internal as well as system-wide processes. State machines describes logistic objects' life cycles, while activity diagrams cover complex chain of single activities.

The communication view contains UML-Class and UML-Sequence diagrams. UML-Class diagrams define the content of messages, which are exchanged by logistic objects. Sequence diagrams depict communication protocols.

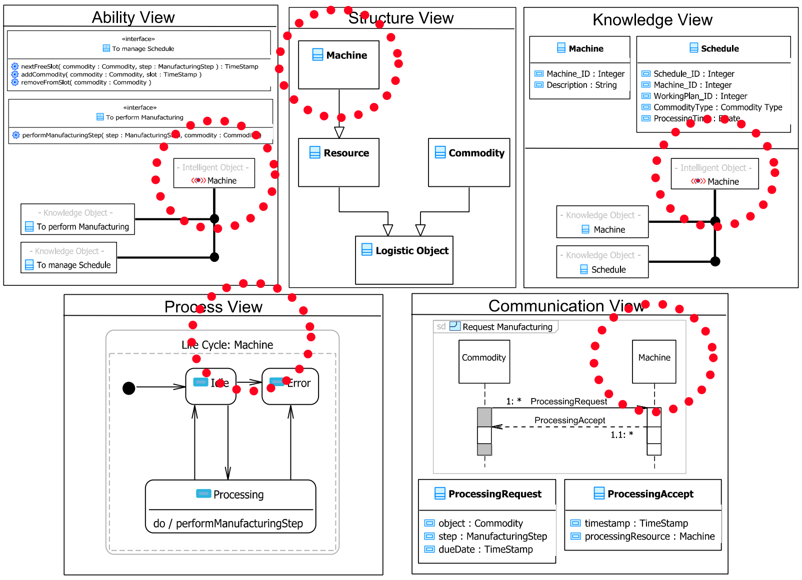

Figure 3: Interconnectivity of ALEM-Diagrams

The different views' diagrams are interconnected, through knowledge maps or by direct assignment. In addition to the links indicated as circles in Figure 3, state-machines and activity diagrams refer to other activities, state-machines, communication protocols, or abilities. This modular modeling approach allows reuse of already present model elements. For example, a set of abilities can be assigned to several logistic objects. The possibility to remove assignments, without removing the modeled element poses another advantage of this modularity.

ALEM – Procedure Model

The ALEM Procedure Model [7] closely conforms to the view concepts semantic views (Figure 2). It covers eight steps and follows a bottom-up modeling approach. Feedback loops are allowed between the different modeling steps. Figure 4 presents the procedure model and depicts possible interdependencies between its steps. For example, logistic process experts have to ensure that required knowledge is available to logistic objects, if he designs a communication protocol.

The first step incorporates a definition of the logistic system's objectives for each logistic object. For example, these could be high utilization, low throughput times, or low costs. The second step is the definition of a system's structure. In this step, logistic process experts define which logistic objects will be present in a system as well as their relationships towards other logistic objects. As a third step, the experts' model all abilities, which contribute to a logistic process, and assign them to the logistic objects, defined in the second step. Examples for such abilities are a machines ability to manage its production schedule autonomously or to perform manufacturing steps on commodities. The fourth step includes modeling of complex activities, carried out by the logistic objects. Fifth, logistic process experts design the decision strategy of each logistic object. In the sixth step, they model and assign required knowledge to the logistic objects. In order to enable the logistic objects to render the modeled decisions, the experts design communication protocols that ensure the availability of information at decision-making objects. For example, a commodity, that decides which machine to select for processing, requires knowledge about processing times, as well as about the next free time slot on a machines schedule. Finally, the last step makes use of the modeled logistic objects, in order to instantiate a specific scenario of the described system in which autonomous logistic processes take place.

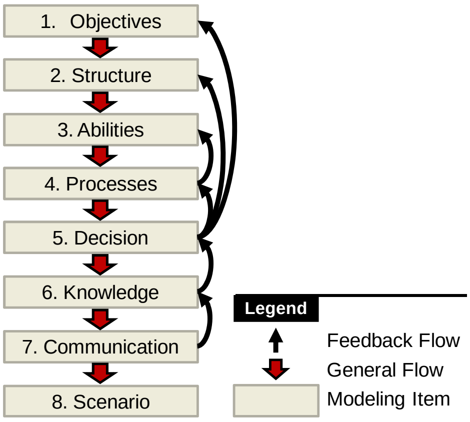

Figure 4: ALEM - Procedure Model [7]

ALEM has been applied exemplarily to production logistic systems (e. g. [7]). In order to examine implications of larger scaled logistic processes and to the ALEM methodology, the next section briefly introduces two example scenarios of different scale and describes their properties with respect to modeling.

Scenarios

This section introduces a flexible flow-shop manufacturing system and a value supply chain scenario. Both scenarios sketch the modeling processes as well as difficulties logistic process experts face during modeling. Building upon these problems, the following section identifies scalability-related limitations on the ALEM methodology.

Flexible Flow-Job System

Today, flow-shop systems are widely used and usually employ different production and/or assembly stages. Commodities pass each stage in a sequential order given by their product and manufacturing structure. According to Allahverdi et al. [1], flexible flow-job systems use parallel machines on each stage. For reasons of illustration, this article's example flow-job scenario utilizes the minimum of two production stages, each with two equal machines in parallel (Figure 5). For instance, two turneries form the first stage and two sawmills represent the second stage.

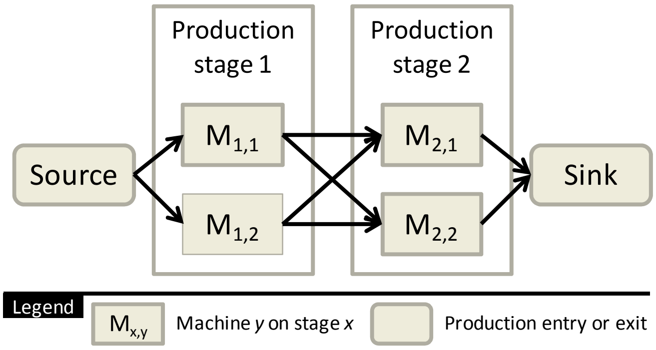

Figure 5: Flexible Flow-Job Scenario

In order to apply autonomous control to this flexible flow-job scenario, logistic process experts have to describe the desired autonomous processes. Commodities (e. g. raw materials) enter the production system according to production orders. These production orders either originate from external sources, like customers, or arise from internally activities, e. g. for warehousing. With respect to the ordered products' structure and the objectives associated with the type of order, the commodities proceed through the production stages. On each stage, the commodities select the most suitable machine, according to their objectives. Therefore, they request information from the parallel machines on the next production stage and make their decision. This process reoccurs for each production stage, until the final product finishes manufacturing.

In order to model these autonomous processes, logistic process experts first identify those logistic objects that will make and carry out local decisions. In this case, these objects are at least commodities and resources, i. e. machines. Orders may be included as intelligent objects if desired [23]. Following the ALEM bottom up modeling approach, the experts model the objects' abilities, processes, and knowledge, as well the data exchanges between them. Building upon this basic model of the system, the experts design decision-making strategies, -functions, communication protocols, and include additional, knowledge, required for decision-making. After modeling the desired system, logistic process experts evaluate the model and refine it if needed.

Supply Chain Scenario

While value networks or chains cover all activities that increase a product's value, i. e. manufacturing and transportation, as well as management activates within and around those organizations related to the product [11], supply chains span the part of a value chain that focuses on the delivery process of products and commodities, as well as on the partners involved.

The supply chain example employed in this article originates from a case study conducted in the apparel industry [22]. The case study covers production of garments, their transportation to distribution centers, as well as their shipping to customers. The considered supply chain spans one manufacturing plant, one reloading center, three distribution centers, and several customers. Ships or airplanes perform transportation between manufacturing plant, reloading center, and distribution centers. Motor-trucks serve the customers on the last hop. In each case, different subcontractors perform the transportation task (Figure 6).

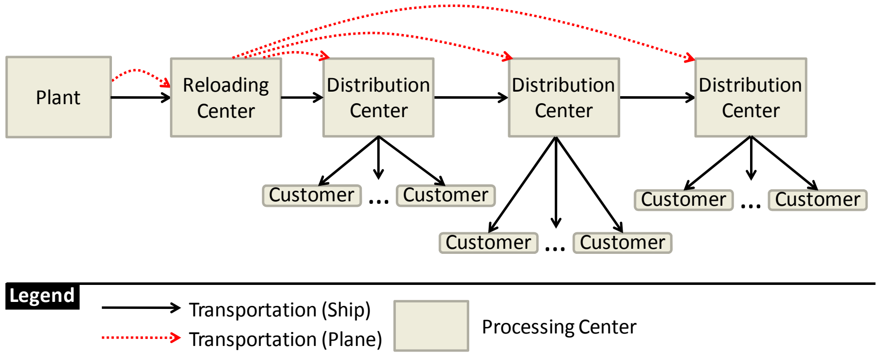

Figure 6: Supply Chain Scenario

In contrast to the manufacturing scenario, the desired autonomous processes are more complex within this scenario. They cover manufacturing, different transportation activities, as well as distribution and order assignment. Concerning manufacturing, the decision-making objects are as well commodities, (half) finished goods, and machines. The autonomous processes are quite similar to those described within the last scenario.

In addition to these processes, the garments are able to arrange themselves to badges, e. g. packages, palettes, and containers, in order to prepare transportation or distribution. Therefore, the garments coordinate each other, to identify conforming delivery dates and destinations across orders. The case study dealt with autonomous processes, which enable those garments to satisfy customer orders dynamically, by reference to the number of ordered variants as well as to the garments' spatial location and the orders priorities. In order to achieve such dynamic behavior, the (badges of) garments decide on their own to decompose into smaller badges or even to single garments in distribution centers, as well as they recombine themselves as demanded in a customer order.

The third activity covered by this supply chain scenario is transportation. According to the badges' or their respective orders' objectives, transportation devices, e. g. planes, ships, trucks, and trains, are selected autonomously. These transportation devices constitute additional decision-making objects, as they perform routing decisions on behalf of their own, or even on behalf of the (badges of) garments' orders.

In order to apply autonomous control to the described supply chain, logistic process experts have to model all decision-making logistic objects, including their knowledge, abilities, decision-making strategies, processes, and data exchanges. Thereby, the organizational independence between manufacturing companies, transportation providers, and distribution center operators leads to difficulties in modeling of all processes and objects in an integrated view. Logistic process experts, belonging to the manufacturing company, are unlikely to have insight into a transportation provider's processes, inventory, and decision-making strategies and vice versa. This organizational independence further complicates the development of logistic objects that are involved in all of the supply chain's activities.

Complexity Induced Challenges

An increasing size of the scenario confronts logistic process experts with various challenges. These challenges emerge from the handling of the models and of the methodology. The ALEM methodology contrasts classical process modeling methodologies in its structure. It focuses on the single objects and their partial contributions to the overall process. Therefore, ALEM does not provide a general overview over the overall process, but only provides modeling capabilities for those partial processes of the logistic objects involved. Moreover, the increasing complexity complicates the tasks of creating, analyzing, and modifying ALEM models for logistic process experts.

Local Process Modeling

One major challenge is ALEMs focus on single objects' processes. In contrast to classical process modeling, there exists no general overview, depicting all the process' activities, regardless of which logistic object executes the activities. A set of diagrams, each referring to single objects' activities and decision processes, represents a manufacturing process. In order to acquire an impression of the overall process, logistic process experts have to search manually through different diagrams identifying main activities and protocols. The other way round, the bottom up modeling approach requires logistic process experts to model the intelligent logistic objects' activities and decision-making strategies first, before combining them to processes that are more complex. This bottom-up way of modeling requires a different understanding of those processes interactions, which is contrastive to the practice of classical process modeling.

One possibility to cope with this challenge could be the introduction of a process design perspective into ALEM's macro-process view. The respective diagrams would consist of the overall processes main activities, each assigned to a particular type of intelligent logistic object. The assignments indicate which intelligent logistic object performs a specific activity. Transitions could describe information passed between activities. If different intelligent logistic objects perform linked activities, a communication protocol is required, in order to convey incorporated information or decisions. Figure 7 presents a possible example for such an overview.

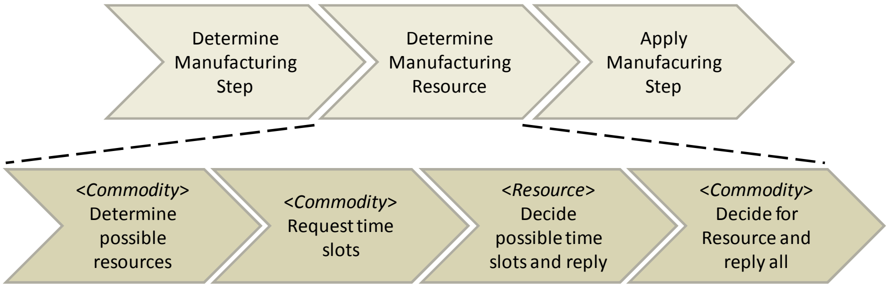

Figure 7: Process Overview with Refinement

The lack of a general overview as well as a high number of single processes, leads to additional challenges regarding the creation, analysis, and modification of ALEM models. With an increasing size of a logistic system, the number of decision-making objects and processes increases likewise. On the one hand, this prolongs modeling and testing of the ALEM models. On the other hand, the variety of decision-making functions and activities requires careful modeling to avoid errors.

Model Creation

The required effort in creating an initial model increases, as logistic process experts have to describe all intelligent logistic objects involved in autonomous logistic processes. Moreover, this task is complicated by the possibility of objects that

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are of the same object class, but apply different decision-making strategies and abilities. In case of modeling two distinct manufacturing plants, commodities are likely to apply different decision strategies when selecting resources. In particular, supply chains involving a company and its suppliers' processes, abilities, or objectives can differ, although similar objects proceed through both companies. Moreover, abilities may be distributed differently between intelligent logistic objects of distinct plants. In such cases, ALEM requires modeling of those objects as individual intelligent logistic objects, although they are of the same type. Consequently, the complexity of ALEM models can increase dramatically by extending the logistic system under consideration. Besides the increasing number of intelligent logistic objects to define, the effort grows to create a scenario representing the complete system. Due to the enlarged system, there exist more intelligent logistic objects, like commodities, resources or devices, that have to be created and set-up during scenario creation. For logistic process experts, it can be difficult to retain an overview over the objects abilities, knowledge, and processes, as well as over the complete scenario and all instances of logistic objects.

Model Modification

Applying modifications to existing models poses additional challenges to logistic process experts, when the model's size increases. Modifications become necessary when resolving errors, or if experts redistribute knowledge or abilities. In the context of the supply chain example, logistic objects take part in several activities. Each object stays active for a longer period with a growing number of successive activities. Within the shop-floor example, the autonomous objects only have to pass manufacturing. Within a supply chain, the objects additionally pass several transportation, as well as packaging and repackaging stages. Due to the growing number of processes, modifications to a single object's abilities, communication, or decision-making strategies may affect different processes and thus other logistic objects. With an increasing scale of the systems under consideration, the interconnectivity between logistic objects grows. Consequently, a modification may affect a greater number of intelligent logistic objects.

Estimating the impact of local modifications to a single intelligent logistic object, regarding the overall processes, becomes more difficult with a system's growing size. For example, modifying a communication protocol in order to reduce the amount of transmitted information can speed up some processes, while leading to a lack of information in others. The redistribution of abilities or knowledge within a model provides a particular challenge. Redistribution might be necessary, if logistic process experts plan and evaluate autonomous business processes. On the one hand, the original model could require specific information at one logistic object, which cannot be obtained in a real world counterpart. On the other hand, logistic process experts might experiment with different autonomous

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system architectures in order to estimate the suitability of specific configurations for a particular system. Modifications regarding an object's abilities or knowledge have to incorporate the overall process' structure. In case of a logistic process expert optimizing the supply chain example's manufacturing process, he has to ensure, that modified logistic objects still possesses all abilities to perform transportation and distribution as well. Furthermore, he has to validate, that his modifications do not decrease the performance of other processes.

Modifications to the object's knowledge or abilities impact the object's processes and communication protocols. If knowledge is redistributed to another intelligent logistic object, communication protocols might have to be redesigned. The same accounts for objects' abilities. In case of modifying an intelligent logistic object's abilities, it might become necessary to design new processes and protocols in order to maintain a model's functionality.

The ALEM-Procedure Model provides support for the task of modifying existing models. The procedure model's feedback loops could be interpreted as validation links, if interpreted in a bidirectional way (compare Figure 4). As an example, modifications to a logistic object's knowledge require validation of communication protocols; modification to an object's abilities requires validation of its processes, decisions, knowledge, and communication. In addition, the modeled scenario has to be validated in all cases. Another way to support logistic process experts in modifying an existing model would be the application of automated validation tests. At least on a syntactical level, such tests could identify other segments of the model, which would be rendered inconsistent with the modifications. Amongst others, communication protocols could be tested on modifications to an intelligent logistic object's knowledge, in order to validate if all knowledge, which should be transmitted, is still present at the object. On changes to an object's abilities, its processes could be validated to identify those processes that formerly included the modified ability.

Model Testing

The great variety of objects and activities prolongs the time until a model can be tested. Further, the duration of simulation runs increases with a growing scenario size. Moreover, testing becomes complicated due to the increasing amount of interactions between involved autonomous objects. From a logistic process expert's point of view, the behavior of an overall system becomes more and more non-deterministic with a growing number of interactions and processes. Additionally, the non-determinism of some autonomous control strategies (see for example [15]) reinforces this effect. In the context of testing and analyzing the model, non-determinism leads to difficulties in recreating particular situations of interest for the purpose of simulation. In order to test specific situations, logistic process experts have to model them directly as scenarios. Therefore, logistic process experts

have to create a scenario that exactly matches the conditions of the desired situation, involving all objects internal states and positions. With an increasing size of the scenario, more and more objects may be involved in such situations.
A related challenge emerges, if logistic process experts observe undesirable behavior in the overall system. In such cases, they have to isolate those logistic objects, and activities from which the behavior originates. With a growing number and interconnectivity of objects and activities, this task requires a deeper insight into a system and its objects' history, with regard to information handling and decision-making. For example, a logistic object's wrong decision could result from a miss-specified decision function or from the use of outdated or wrong information. One decision function may be a good choice in some situations, while failing in other situations. In case of an object using outdated information, logistic process experts have to evaluate, if the object itself did not properly update the information, if it did not request updated information, or in the worst case, if other objects provided outdated information. In this case, logistic process experts have to analyze additional logistic objects, to identify an error's cause. Once logistic process experts identified the origin of an error, he has to modify and reevaluate the model. Therefore, he has to recreate those situations, in which the object decided wrong.

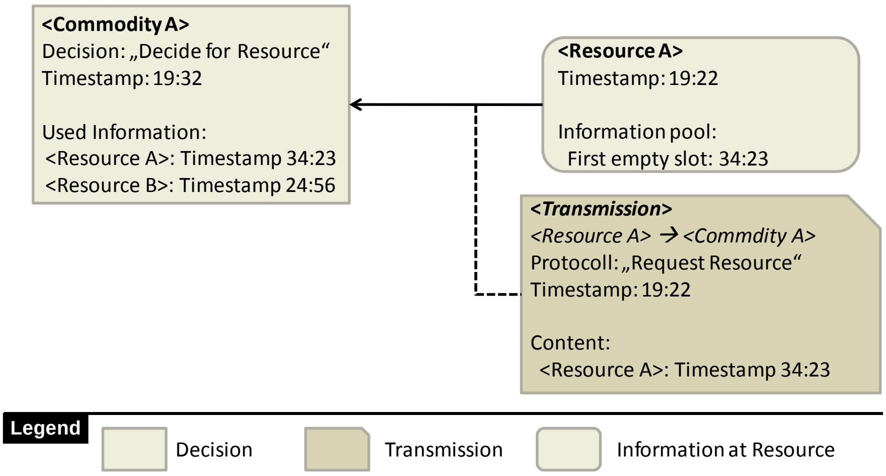

Figure 8: Example for Information Tracing

One possibility to cope with this challenge would be the integration of a detailed, simulation-based logging functionality. During simulation runs, a logging component records all decision related information the objects make use of. In addition, it records all information sent and received by the objects. Using this information, logistic process experts can track all information used in particular decisions to their origins (Figure 8). In particular, if several logistic objects transmitted one particular information, a logging component could identify and visualize the information's route from the decision in question to its source. By se-

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lecting a decision, the logging component depicts all information used to make the decision, as well as the information's origin and transmission history. Additionally, the logging component could facilitate the creation of specific scenarios, as the state of each object becomes observable at any point in time.

Organizational Independence

Logistics employs several processes in production, assembly, and transportation in order to produce and deliver goods for industrial and end consumers. Usually, different companies perform the processes, due to their high degree of specialization in procuring specific products and services basing on their technological and economical capabilities and resources. They are organized in form of supply chains, production networks, or virtual enterprises.

In this sense, the involved companies are organizationally independent of other companies that participate in such networks [3]. For instance, Figure 6 illustrates an apparel supply chain with independently operating processing centers and transportation links. In this case study, one company owns the plant and the distribution centers displayed. However, various service providers operate the reloading center and all the transportation links [24].

Due to their independence, companies within one supply-chain are unlikely to unveil their internal processes and objectives to their partners in detail. Instead, they specify their demand in form of orders that describe requested goods and services in qualitative and quantitative properties, like dimensions, material, quantity, due date, and location. Thus, independent companies basically interact via contracts and a supply chains' activities consist of sub-processes, which belong to different partners. However, the manufacturer in the case study is likely unable to influence succeeding transportation processes after handing cargo over to transportation provider. He regains control on delivery at the target location.

As introduced in the case study, participating companies in such networks are assumed to operate economically independent [3]. They hide their internal operational and organizational structure as well as keep other important business secrets, like politics and strategies. The companies follow their own objectives without accountability for a partner's behavior and do not have power to direct other partners' internal processes or structures. Furthermore, their independence proceeds in the methods, standards, and tools used by them internally. Each of them models their part of the supply chain for their own. Nevertheless, functional dependencies can correlate with technological constraints and vice versa, e. g. if a process requires a specific predecessor that is offered only by few other companies.

In addition, supply chains, production networks, and virtual enterprises form large logistic networks and induce a high level of complexity into the modeling process. In general, complexity is understood as the quantity of systems elements

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and their relations to each other. The model complexity of the mentioned networks is higher than in case of a single manufacturing plant when assuming the networks consist of several interlinked plants in any case. Autonomous logistic processes lead to additional complexity at the systems elements design and in the dynamic behavior of the overall system [26]. However, the collaborative complexity does not result from the pure amount of system elements, but from the specifics of the interaction processes that are required for inter-company cooperation. The system elements, logistic objects, have to be equipped with components that enable decision-making. Dynamic characteristics of the system emerge from fluctuations of quantitative and qualitative parameters in space and time domain. For example, the fluctuations can be distinguished by their linearity, directness.

The ALEM modeling methodology uses a view concept in order to cope with an overall models' complexity. This model complexity results from the amount of elements that need to be modeled, from cooperation-induced issues, the lack of a global overview about a logistic business process, as well as the difficulty to determine the emergent behavior of systems while being under construction. Although the ALEM view concept provides seven distinct dimensions on a model, it excludes illustrations of the overall model to designers, process managers, or single logistic objects, as well as an overview about all information of a selected logistic object. Further, a collaborative view is currently not part of the ALEM methodology. This view can be useful, in order to oversee processes spanning large value networks, supply chains, or virtual enterprises.

Summarizing the Problem Areas

An integration of distinct, independent organizations into one logistic system induces several challenges towards modeling of the overall autonomous business processes by independent modelers with the use of the ALEM methodology. ALEM has to be enhanced and modified in order to guide a modeler through the design and evaluation processes in case of supply chains, production networks, or virtual enterprises.

The first problem area results from a lack of overview about foreign systems, e. g. their system elements, processes, and objectives. Secrecy of such crucial company information leads to barriers for the information exchange, which thereon affects the whole modeling process. Logistic process experts can only obtain a comprehensive view on the overall process on an abstract level. However, the ALEM methodology requires modeling of all sub-processes contributing to the overall business process. Logistic process experts face the challenge to model the supply chain partners' sub-processes as detailed as possible, while specific information is unavailable. For the supply chain example provided, logistic process experts of the manufacturing organization can easily model manufacturing and reloading processes. Processes taking place within a distribution center can be obtained in full detail, as the centers and the manufacturing plant belong to the same organization. In contrast, the manufacturing organization cannot obtain and model transportation processes, as subcontractors carry out these activities independently.

The second problem area bases on limitations introduced by the ALEM modeling process. At the moment, the methodology does not include collaboration mechanisms for creation and design of highly autonomous decentralized logistic business processes. Instead, the modeling process is described with the inherent assumption of modeling one logistic business process at a time at one location by a single modeler instance. Logistic process expert are able to model autonomous logistic processes, as long as they take place at the company that is under control of the modeler. This modeling approach works fine if modelers have access to all necessary information. However, the modeling approach leads to a lower detailed model, if segments of large logistic systems belong to different, organizationally independent companies, e. g. supply chains, production networks, or virtual enterprises whose members model their internal process structures themselves. ALEM lacks of collaboration mechanisms for modeling and evaluation of autonomous logistic business processes in a decentralized way by different modelers.

Improvements for Collaborative Modeling with ALEM

As a consequence of the problem areas derived previously from the organizational independence of companies, ALEM has to be modified in order to allow collaborative modeling of autonomous logistic business processes in large value chains. For this purpose, the methodology requires adaption of suitable mechanisms for collaborative modeling, for example interfaces for interconnecting submodels, for the exchange of model components between different ALEM-T instances, and for distributed simulation capability.

The modifications have to support the complete system development cycle: specification, infrastructure configuration, simulation, and evaluation. Further, it has to allow modeling the complete model locally distributed, at different times, and by different modelers or organizations. The latter issue means that the collaborative modeling method has to be able to cope with different rules and processes as well as operational and organizational structures. In this sense, the methods should provide inter-organizational collaborative modeling [13].

The literature proposes several requirements and mechanisms collaborative modeling methods have to comply with, e. g. model viewers which display a model differently for each modeler [5] [13]. Further, the complete model has to be exportable into a common file format in order to present it at different places. A version control system is required, which allows a comparison of different model versions and backtracking. A user profile manager handles access rights of the users and a commentary function allows users to place asynchronously notes at the model workspace. However, most important is a mechanism that is able to split models into sub-models and to merge them later [5]. Autonomous logistic processes require the following additional capabilities in order to circumnavigate the described problems:

- Spatial and temporal distributed modeling and simulation
- Multi-user and multi-organization modeling
- Parallel and partial modeling of the logistic process and simulation run execution
- Capsulation of model elements and sub-models
- Standardized Interfaces between sub-models
- Exchange of sub-model an model information
- Exchange of simulation data
- Synchronization of model parts
- Quality assurance functionality (Syntactic, Consistency, Semantic)

Further, a new collaborative modeling view is required. This view is adjusted to a specific users' scope in terms of his spatial and organizational location and represents the model in this context to him. Additionally, a new central model overview is proposed which shows the semantic and possible emergent behavior of decisions within sub-models. It reduces the modeling complexity of value networks.

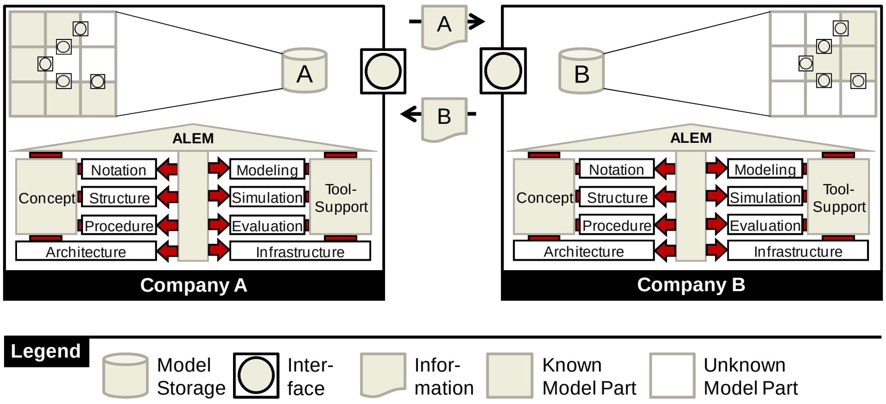

Figure 9: Multi-ALEM-Framework

Besides the new views, several other technologies help to master the challenges. Figure 9 presents exemplarily the exchange of sub-model information between different companies, which use the ALEM methodology. It shows the interfaces between both ALEM frameworks as well as between the known and unknown sub-models at each company. In Figure 9, company A knows six of nine sub-model elements, while company knows only three of them. Both companies are either able to exchange information about the sub-models content in order to learn more details of the overall model, or they exchange sub-model interface information. In the latter case, companies model their part of the logistic process independently. The sub-model interface hides other sub-models. The respective company notices them as black box.

The interfaces that enable interaction between different sub-models and ALEM frameworks processes clearly have to state required and available information. While designing the overall process, each partner defines the information that is required for entering a process and that is provided on exit of a process. Known model elements appear as white boxes, while unknown model elements and their behavior are handled as black boxes.

Summary and Outlook

This article investigates challenges towards modeling autonomously controlled logistic systems, with regard to the scalability of the ALEM modeling methodology. It identifies two major sources of challenges: Challenges which emerge from the increasing complexity of the systems, as well as challenges originating from the organizational independence between different organizations participating in the autonomous processes.

The complexity, induced by an increasing amount of objects, processes, and decision-strategies makes it hard for logistic process experts to maintain a general view on all of a system's aspects. Furthermore, with an increasing size, modelers become hardly able to estimate the total effect of local modifications towards the overall system and to determine how parts of a model contribute to a specific behavior in the overall system. Thus, the effort for refining and testing of a model increases. These difficulties occur in particular in case of miss-specified model elements or if error tracing is required. Moreover, an increasing number of objects, processes, and decisions prolong the time that is necessary for model refinement, error tracing, and simulation. The more complex a system is, the more time consuming are these tasks. Last but not least, logistic objects interact frequently with each other and react to random environmental events. Thus, results of simulation runs become more and more non-deterministic from an experts point of view and impede uncomplicated testing of a specific system behavior.

Other major challenges emerge from the organizational independence of companies involved in large value networks, like supply chains. Due to a logistic process expert's limited view on partners' or subcontractors' processes, he might not be able to create a model covering the complete system in all details. Differences between partners' control and information management strategies can prevent logistic process experts to obtain required information. For logistic process experts, this results in a chance either to neglect useful information, which could be obtained by the logistic objects, or to expect information, which is not passed or collected by a partner. In addition, the ALEM – Procedure Model assumes a central modeling of a highly decentralized system. It will work fine in case of a small system that is under control of the modelers company. However, this approach might fail in case of larger systems, such as supply networks. The question is: How to model a decentralized autonomous system in a decentralized way across economically independent partners?

Both issues picture different challenges of ALEM's ability to scale up with a systems complexity as well as with its diversity in organizational manner. The paper presented first approaches for each challenge class that will be under investigation in future research.

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