# Modelling of Requirements and Technical Enablers as Precondition for the Configuration of the Infrastructure of Autonomously Controlled Logistic Processes

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**Summary:** Todays companies face increasing complexity and dynamics in their processes, which lead to problems for centralized decision making in logistic process control. Thus, autonomously controlled logistic processes are proposed to overcome the induced negative effects. Logistic objects employ additional infrastructure components providing decision making and execution abilities to solve process control tasks on their own. However, the infrastructure configuration task is rarely addressed in literature. This paper sketches a concept for the collection and modelling of requirements and infrastructure components of autonomous logistic processes. It presents application requirements and infrastructure components in textual form being organized in a tabular requirements catalogue.

**Keywords: Knowledge Management, Adaptive Control, Logistics, Modelling.**

## 1. Introduction

Growth of complexity and dynamics are known as global megatrends and are an immediate result of an ongoing increase of the world's population, which leads in a system theoretic view to more complex and dynamic (social, economic etc.) systems [1]. Forthcoming, complexity and dynamics of logistic processes increase within and between companies, as well [2, 3]. In consequence, central provision of information and central decision making for purposes of logistic process control becomes increasingly difficult [4].

Hence, autonomous control concepts are proposed for logistic process control in order to overcome the megatrend-induced negative effects, which interfere and impede logistic process flows. Involved logistic objects are equipped with abilities for decision making and execution, enabling them to solve process control tasks locally by themselves [5].

An implementation of an autonomous control system varies in its elements and behaviour according to a given application scenario [6, 7]. In this sense, autonomous process control systems have to fulfil application specific requirements, e.g. in terms of control rules, logistic objects and infrastructure that is required to operate autonomously controlled logistic processes.

Previous work introduced new control methods, a modelling methodology, an infrastructure configuration procedure model and a functional classification for infrastructure components [8, 9, 10, 11, 12]. However, there is a lack of work addressing the process to configure the infrastructure of autonomously controlled logistic processes. This configuration process can be understood as part of the system development process to which the specification of requirements is a precondition for a systematic system development. „ […] The main task for the construction [and the configuration] of an infrastructure is the aggregation of all [required technical] partial solutions in a single system without conflicts. " [13] (translated from German). Hence, identification and modelling of application specific requirements and of infrastructure components of autonomous process control systems are first steps for the configuration of a scenario specific autonomous control system infrastructure.

This paper aims to outline a conceptual approach for collection and modelling of requirements and infrastructure components of autonomous process control systems. As an intermediate result, the paper presents an exemplary list of application requirements and infrastructure components.

The remainder is structured as follows. Section two outlines the knowledge based configuration concept describing the demand for infrastructure and the supply of technical enablers. Section three presents requirements for the configuration of the infrastructure of autonomously controlled logistic processes. The fourth section exemplarily describes relevant infrastructure components as technical enablers. Section 5 presents two parts of a combined tabular requirements catalogue. The last section projects subsequent research demands.

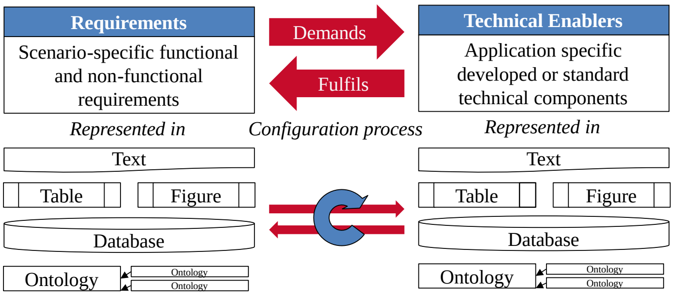


**Figure 1.** Knowledge based configuration concept.

## 2. Knowledge based configuration concept

An infrastructure for autonomously controlled logistic processes has to employ those technical components, which are able to fulfil all functional and non-functional requirements of a planned logistic scenario. Thus, knowledge about scenario specific requirements and corresponding components is essential for the infrastructure configuration process. For this reason, this paper proposes the development and use of two opposed knowledge bases. The first one shall hold requirements of an autonomously controlled logistic process towards its infrastructure. The second knowledge base shall specify available infrastructure components that can fulfil these requirements. Configuration or matching processes connect both knowledge bases and assign particular components to specific requirements, i.e. they can select appropriate technical enablers (Figure 1).

**Table 1**. Generic demand side requirements (exemplary).

| Requirement class | Description |
|---|---|
| Functional encapsulation | Control system functions shall be defined independently from each other within the Autonomous Logistics Engineering Methodology. |
| Adaptability | Hardware and software components must be changeable in state of operation and when idle. User interfaces shall allow observation and intervention of autonomous control systems to change components. Software shall be platform independent und reusable. |
| Interaction and cooperation | Autonomous logistic objects shall be able to collaborate in order to achieve their individual objectives. Their control system infrastructure must cope with the resulting communication efforts. |
| Mobility | Mobile autonomous logistic objects need to have access to required infrastructure services, no matter of time and location. |
| Context awareness | Autonomous logistic objects have to recognize and to interpret their own and their environments state continuously. |
| Decentralisation | Control system infrastructure components can be deployed at different areas. They have to be modular and combinable with other components in order to increase the abilities and functions. |
| Embedment | Control system infrastructure has to be integrated into logistic objects and structures to supply them specific abilities or services. Their inner structure remains invisible for a user. |
| Robustness | Infrastructure services have to be available in all cases. |

**Table 2**. Technical demand side requirements (exemplary).

| Requirement class | Description |
|---|---|
| Combination of technological abilities | Autonomous logistic objects require a combination of abilities, e.g. for data acquisition, processing, and exchange, for the higher-level activities communication, identification, locating, decision making, decision execution and power supply. |
| Information processing | Components processing input to output data by use of algorithms according to their functionality and quality, e.g. a microprocessor. |
| Communicatio n | Components designed for information exchange of a specific data volume, duration, distance between sender and receiver, energy needs, transmission reliability and consistency, for instance. |
| Interfaces | Use of different technologies and technical components, as well as stakeholders, requires suitable physical and logical interfaces between functionally enabled objects and human stakeholders. |
| Power supply | Autonomously controlled logistic objects require a power supply being available no matter of their speed or position in a logistic system to perform their specific functions. |
| Intelligence | Logistic objects require prescribed behaviour and objectives in order to assess information and to execute decisions according to a logistics' systems state. |
| Time behaviour | Autonomous logistic objects have to synchronize material and information flows that have different runtime behavior in a logistic process. They must react on-time to changes in a logistic system and its environment. |

The first knowledge base contains requirements of a planned autonomously controlled logistic process. They can be derived from the theory of autonomous control and from case studies in terms of control approach, architecture and application scenario [12], as well as from related system concepts, e.g. multi-agent systems and Internet of Things. The functional and non-functional requirements represent a demand with specific properties that has been derived from an autonomous logistic process. A fully and consistent satisfaction of all requirements under all side condition is necessary for a proper implementation of an autonomously controlled logistic process.

The second knowledge base sketches available technical components and describes them according to their functions, properties and interdependencies. They are grouped under the term "technical enablers". Selected technical enablers have to meet the functional and non-functional requirements of an autonomously controlled process. All available components being appropriate to a set of requirements serve as supply of corresponding functions and properties.

The knowledge bases can be in form of texts using natural language, in form of structured tables and figures for better visualization, as well as in form of databases and ontologies. The last option allows easier modelling of interdependencies and enables support of information technology during the subsequent configuration process. The systematically built knowledge bases of classified requirements and technical enablers narrow the solution space for selectable infrastructure components during the development of autonomous logistic processes and simplify the configuration process. Although, specification of configuration mechanisms are not in scope of this paper, queries in databases and ontologies as well as market based coordination mechanisms are possible candidates for driving the configuration process.

## 3. Demand Side Requirements

Identified requirements have been divided in four categories. Generic and technical requirements refer directly to a demand for autonomous control specific components of a particular infrastructure layer. Economic requirements subsume monetized cost-benefit-life-cycle-aspects. Protection and safety requirements are relevant as well, e.g. control systems must be protected from interference by malicious software. Requirements have been derived from a demand-oriented point of view on an autonomous control system and focus on generic and technical requirements (Table 1) as well as technical infrastructure component requirements (Table 2).

## 4. Supply Side Technical Enablers

Technical enablers must be integrated in logistic objects in order to provide them specific functionalities [14]. They can be categorized in functional classes and are characterised by a set of attributes. Instances of these classes are technological infrastructure components, e.g. a microcontroller using control algorithms to process sensor data into control information.

Microcontrollers contain components for storage, processing and exchange of information and for monitoring and controlling processes. Functional, performance, and operating parameters are criteria for their selection. Performance parameters are e.g. system clock, execution time for defined algorithms, cycles per instruction and operations per second. Functional properties are e.g. bus width, extent of instruction set, size of address space for data and programs and size of cache memory. Operating voltage and power consumption are operating parameters. Further criteria can be the physical dimensions of a controllers' housing and compliance to standards, like electromagnetic compatibility.

## 5. Tabular Requirements Catalogue

Both knowledge bases can be described in tables, holding the characteristics of all demanded and available infrastructure components, in order to organize them in a structured manner (Table 3 & 4). The infrastructure functions act as organizing scheme. Requirements are expressed in natural language. The column "Relation" notes positive complementary (a:), negative limiting (b:), and mutually dependent relationships (c:). The table includes concept names that serve as base of an ontology development for subsequent work.

Table 3 exemplarily shows requirements for the class "communication technology" dealing with data transmission and is structured in transmitting and receiving requirements. Further, the requirement for consistency of transmitted data leads to a demand for protocols. Additional infrastructure requirements that must be satisfied by integration of corresponding components into an autonomous control system can be derived from the perspective of technical enablers.

Table 4 exemplarily shows characteristics that must be fulfilled by microcontrollers. These are infrastructure components employing stored decision algorithms to generate control information from received data. Storage of algorithms in a microcontroller depends on the design of the control system. Hence, it is an optional requirement. The concept "microcontroller integration" has to be fulfilled with respect to embedded and networked system aspects. Microcontrollers have a specific data bus width, which is one of many criteria for selecting a microcontroller.

## 6. Outlook

Subsequent research is needed to model the requirements in a formal ontology and to validate them. Further, the feasibility of this approach must be demonstrated in the configuration process by querying the presented tables and the planned ontology in order to select infrastructure components for an exemplary autonomous logistic process scenario.

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**Table 3.** Generic and technical demand side requirements (exemplary).

| Infrastructure class | Reference to | Requirement | Type | Priority | Relation | Concept name |
|---|---|---|---|---|---|---|
| **Communication technology** | Decision process | Has the ability to exchange data between logistic objects. | Functional | Obligatory | | Data exchange |
| | | Has the ability to transmit data to a logistic object. | Functional | Obligatory | | Data transmission |
| | | Has the ability to receive data to another logistic object. | Functional | Obligatory | | Data reception |
| | Communication | Data must be consistent during a communication process. | Qualitative | Obligatory | c: Protocol | Data consistency |
| | | Data exchange requires rules represented in protocols. | Qualitative | Obligatory | a: Data consistency | Protocol |

**Table 4.** Technical enabler supply side requirements (exemplary).

| Infrastructure class | Reference to | Requirement | Type | Priority | Relation | Concept name |
|---|---|---|---|---|---|---|
| **Microcontroller** | Infrastructure function | Microcontroller stores decision algorithms. | Functional | Obligatory | | Algorithm storage |
| | | Microcontroller stores intelligent software. | Functional | Optional | c: Cache size | Software storage |
| | | Microcontroller processes received data. | Functional | Obligatory | | Data processing |
| | | Microcontroller executes decision algorithms. | Functional | Obligatory | | Algorithm execution |
| | | Microcontroller generates control information. | Functional | Obligatory | | Control generation |
| | Embedded system Networked system | Microcontroller is integrated in an objects’ infrastructure. | Condition | Obligatory | | Microcontroller integration |
| | Selection criteria | Microcontroller has data bus width. | Qualitative | Obligatory | | Data bus width |