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Ontology-based Forecast of the Duration of Logistics Processes in One-of-a-Kind Production in SME

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ABSTRACT

Due to severe global competition, the project management process for one-of-a-kind production must aim for better risk management and higher efficiency. Despite being critical in order to forecast the duration of logistics processes, intra-enterprise knowledge, historical data from past projects as well as simulation models are not sufficiently utilized in today´s practices. To improve the project planning for one-of-a-kind production, a systematic modeling concept and a technical solution approach are developed, which are based on logistics reference processes and an ontology, as a major part of the overall systematic. This paper focuses on the development of the basic structure of the ontology. A use case applies the ontology within a project management toolset to highlight the potentials for process duration forecasting in project management.

KEYWORDS: ontology · forecast · duration of logistics processes · one-of-a-kind production · methodology toolbox · project management

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1. INTRODUCTION

Today, companies must do their business in a global competitive environment and are integrated into well-organized value chains. In addition to the maximum utilization of production facilities, timely completion of orders plays an increasingly important role, especially for small and medium-sized enterprises (SMEs) within the supply industry [1]. Moreover, the requirement for timely completion of orders also applies to companies manufacturing one-of-a-kind products. Therefore, the competitiveness of the value chain requires efficient and effective manufacturing, including logistics processes from raw material to customer-specific products. A company's overall success is determined by an efficient design of its value creation processes, a reliable and precise scheduling and therefore by a valid planning process.

Referring to [2] and [3], customized engineering and construction of one-of-a-kind products like machines, large-scale plants or ships differ significantly from stationary series production due to product-, process- and logistical-specific constraints. Additionally, the planning, construction, transport, and commissioning of these products are subject to several uncertainties, which should be considered in the planning process by a realistic estimation. When determinig process durations in one-of-a-kind production, only a limited number of assumptions can be directly derived from previous projects. In some cases, expert knowledge from previous projects cannot be transferred at all. Interactions between one-of-a-kind products and their logistics processes can be modeled (see e.g. [4-6]), but the project planner is not able to apply them to new projects, because of the unpredictability of disruptive factors. Therefore, additional time buffers are often added during the planning process, which leads to higher costs for the customer. This may represent a competitive disadvantage for the planning SMEs, since a weak planning process leads to a weaker market position. While the scope of this paper focuses on the specific requirements of SMEs, this problem is not

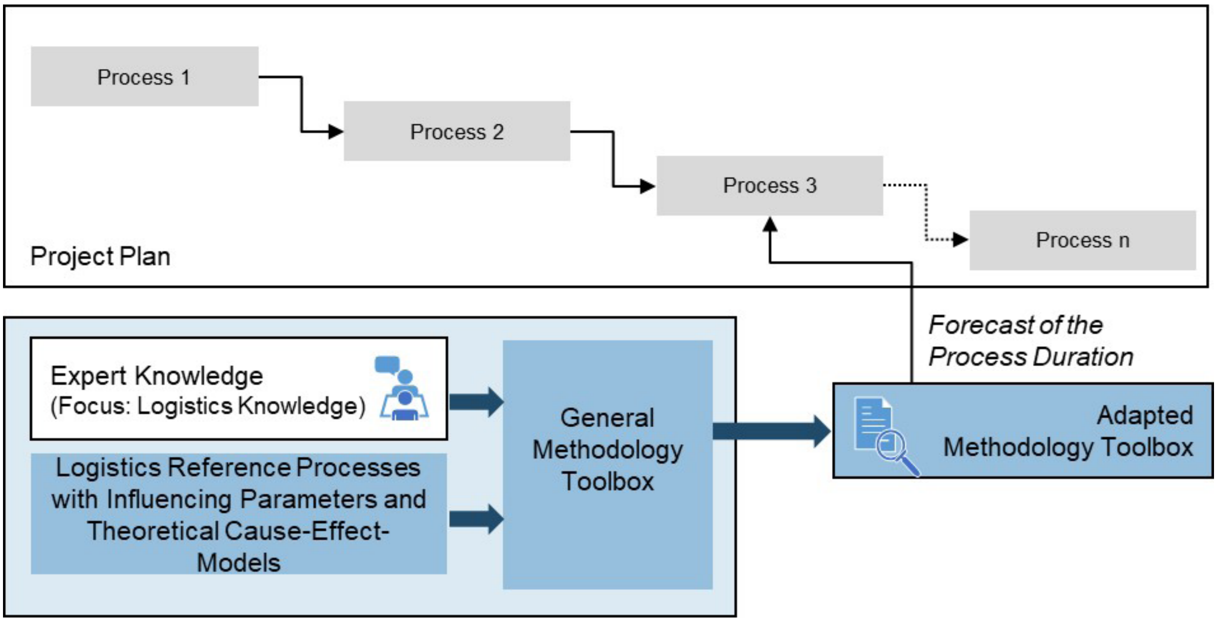


Figure 1: Overview of the developed methodology

exclusive to them, larger companies also suffer from the same deficiencies.

To date, there is no methodology that supports reliable forecasting of logistics processes with the challenges listed above. Necessary data to forecast logistics processes is difficult to collect due to the customized nature of one-of-a-kind products. Thus, one-of-a-kind production has a project character, as manufacturing always differs from previous individual products. The experience knowledge from previous projects has to be consolidated into a suitable form, in order to be applicable to future projects. Therefore, a methodology is developed to forecast the duration of logistics processes in addition to the given project management tools already used. This methodology includes a general methodology toolbox based on logistics reference processes and expert logistics knowledge. Later, a case-specific application of the general methodology toolbox is used to forecast the logistics process duration in a specific company (see Figure 1).

The elaborated approach for the improved forecasting of logistics process durations is based on a knowledge model. This model was developed in collaboration with and evaluated by SMEs, and as a result is geared towards manufacturing SMEs. One central element of this solution approach represents an ontology as part of the general methodology toolbox, which on one hand serves as a structure for the collection of the company's knowledge according to their specific products, processes, and customers. On the other hand, it serves as a technical infrastructure for the developed prototype for estimating a specific process duration based on the provided specifications.

This paper describes the development of an ontology-based forecast of logistics process durations. In the second section necessary foundations of ontologies are discussed and in the third section the methodology toolbox is described. The fourth section of this paper explains the development of the ontology as part of a general methodology toolbox and the process through which it becomes an adapted methodology toolbox by being applied by a specific company. The fifth section provides an insight into the ontology-based forecasting of logistics process durations within an applied use-case in the context of the research project's evaluation, followed by a conclusion in the final section.

2. RELATED WORK

As already introduced, project planning assumptions for customer-specific constructions, usually implemented through one-of-a-kind production, cannot be derived reliably from previous projects to determine process durations in most cases. High customer specificity and complexity do not permit the transfer of standardization in the product business; thus, each logistics process requires an individual planning with manually estimated effort for each step, which poses a challenge for SMEs.

A definition of *logistics processes* is deduced from the two terms *logistics* and *process*. [7, p. 11] defines logistics as the scientific study of planning, designing, and controlling the flow of materials, people, energy, and information within companies and in company networks. The task of logistics is to ensure that the right goods (according to type and quantity) are delivered in the right condition (e.g. undamaged) at the right time (e.g. at the agreed time) to the right place (correct delivery address given by customer) at minimum cost [8]. [9, p. 30] defines a general process as a set of interrelated or interacting activities that use inputs to achieve an intended result. Following [10], a logistics reference process comprises a systematic and generally valid description of a defined logistics process with its characteristic properties relevant to a given specific logistics task. To structure the logistics reference processes within the general methodology toolbox, they are classified based on the transformation types (see [11-13]): transportation, handling, picking, storage, (un-)packaging as well as information and communication processes.

Reliable time management and scheduling are important in global competition, especially for SMEs. However, a reliable forecast of logistics process durations is not possible yet. [14] as well as [15] already propose different approaches to improve the estimation of project durations via knowledge extraction or the collection of real-time data for specific individual cases, but they do not refer to logistics process durations in one-of-a-kind production at all. The solution approach discussed in this paper focuses on estimating logistics process durations via knowledge extraction. In contrast to other estimation methods (see e.g. Case-based Reasoning [16], Constructive Cost Model (COCOMO) [17], Multiplication Method [18], Comparison Methods [19], Factor or Weighting Methods [20], Analogy Method [21], Indicator Method [22]), this paper explicitly uses qualitative knowledge, i.e. empirical knowledge, as the knowledge base for estimating the duration of logistics processes. In particular, the knowledge base combines the logistics knowledge of experts from several projects.

Logistics knowledge in the context of logistics planning is not uniformly defined in the literature (derivation of the term logistics knowledge in [23]). In this paper, it refers to knowledge about transforming objects, resources, structures, management, data, and environments. According to the planning principles of [8], logistics process planning should be future-oriented, systematic, methodical, dynamic, iterative, flexible (capable of change, if necessary), adaptable, accurate, unambiguous, continuous, economical, complete, and traceable. Logistics planning can be very complex and therefore requires, for example, knowledge to formulate planning goals and tasks and to define the approach.

The major challenge of complex planning tasks is to make existing expert knowledge reusable, e.g. experience of experts about methods, models, planning results or procedures (see in this context for example [24-28]). Knowledge is based on information; it is created in an “enrichment process” [29], which according to [30] is represented as a “knowledge staircase”. Knowledge is derived from information; the use of stored information leads to a pool of knowledge with the certainty that with each use new data flows in and thus new knowledge is added iteratively. The implicit experiential knowledge [31, 32] refers to cause-effect-relationships and has a personal character; it belongs primarily to the individuals of an organization. This knowledge is difficult to document and communicate, since it relates to individual activities, obligations and skills as well as personal life experiences. With the help of scientific-empirical methods, such as surveys, the empirical knowledge of experts, which is available in implicit form, can be acquired and collected so that it is available in explicit form. In a survey, an experience-related question is systematically prepared and described to the experts with the help of relevant information [33]. In empirical social research, the three basic methods of information collection include questioning, observation and content analyzis (for more information see [34, 35]). If the required knowledge about the problem is not yet available in a suitable form, questioning is often used as an empirical research method to generate the necessary information and subsequently develop the required knowledge from the obtained information [34]. The resulting knowledge that is thus available in an explicit form can be modeled.

An essential prerequisite for the use of explicit available expert knowledge is its structuring and provision to guarantee quick access for the users. From the point of view of the information economy, the task is to establish a balance between the supply of information and the demand for information, i.e. to make the expert knowledge available to a defined target group in the present context [36]. Particular importance is given to the management of information resources: information sources (e.g. reports, hand recordings, interview results) are turned into a constantly maintained and reusable information resource by information modeling (e.g. structuring, representation, storage, verification and the creation of physical, and intellectual access to information), whose contents can ultimately be used to generate user-oriented information offerings.

In the context of information modeling, the structuring and representation of information and knowledge are of central importance in order to enable efficient handling of information. In this regard, metadata describes formal and content-related properties of information. From the perspective of educational psychology, the “Munich Model of Knowledge Management” [37] describes a procedure in form of an analogy to the aggregate phases of water: The transition of everyday knowledge, used in daily conversation and action (gaseous), via initial systematization and provisioning in the form of a common, controlled vocabulary, e.g. as a thesaurus (liquid), to a semantically rich knowledge model within a knowledge domain in the form of an ontology (solid). The authors in [38] describe the steps up to this point in terms of a “semantic staircase” on which the semantic content and the formal expression possibilities increase with each (evolutionary) step [39 in 40, p. 93]. The starting point for knowledge modeling is a glossary, a list of terms with their respective natural linguistic descriptions. A taxonomy is a hierarchy of terms in a subject area e.g. from a glossary; it maps super- and suborder relationships and represents inheritance relationships [32]. With a thesaurus, terminological relations (e.g. synonyms, homonyms, equivalence relations) between terms can be represented in addition to a taxonomy [36]. "Topic Maps" is the name of a semantic technology, standardized according to the International Organization for Standardization (ISO). It is used for the representation of knowledge and the linking of the represented knowledge to relevant information [40]. The linking of knowledge to information generates content relationships.

An ontology, like it is developed in this paper, represents the most complex form of knowledge-mapping in IT. While in a philosophical context an ontology denotes the "doctrine of being", in computer science it describes the "formal definition of concepts and their relationships as a basis for common understanding" [41, p. 286 f.]. The most used definition of ontology in relation to computer science originates from [42], see also [43]: "An ontology is an explicit specification of a conceptualization". Ontologies should improve or facilitate communication between computer applications, between computer applications and people, but also between people [41]. According to [40], an ontology is a description of the use of common symbols and concepts (syntax) and a common understanding of their meaning (semantics). It includes a classification of concepts in form of a taxonomy, an interconnection of terms via associative relations, and rules and definitions that determine which relations are meaningful and permitted. Ontologies formally represent knowledge of a domain to be reused independently of programs. They describe concepts and their relationships within a domain of knowledge and support machines in interpreting content on the web instead of simply presenting it and thus leaving all networking activities to humans [38].

Ontologies distinguish according to their degree of specialization, their level (e.g. the specialization of the subject matter of the concept) and the nature of the concept itself [36, p. 137; 44]. The level view differs between top-level ontologies (also upper, or generic), which describe general knowledge, domain ontologies, task ontologies, and application ontologies. Furthermore, three types of ontologies can be classified: terminological ontologies, information ontologies, and knowledge ontologies. Well-known examples of realized ontologies are WordNet [45], a large lexical database of the English language, and SUMO (Suggested Upper Merged Ontology) [46], which represents terms of different knowledge domains and complements WordNet by linking them. For other examples of ontologies see [47]. Initially, the goal of developers was to use ontologies to create a normative model for a domain, so that a proprietary description of knowledge was sufficient. However, at present several ontologies coexist even for one domain, so that the function of an ontology is less the correct description of reality and more the support of a correct interpretation of a given dataset [48]. This also applies to the field of production and logistics, where initial domain and application ontologies have been developed mainly in the context of research work (see [49-52] for more details).

As a result of this development, the exchange between ontologies as well as the sharing of ontologies through standardized modeling languages and via appropriately designed interfaces is becoming increasingly important. The Resource Description Framework Schema (RDFS) [53] defines a standardized language (syntax and formal vocabulary) in which ontologies are formulated. In addition to RDFS, several other ontology description languages exist, such as DAML+OIL [54], whose direct successor OWL (Web Ontology Language) [55] builds on RDFS and represents today's standard for formulating ontologies (see [40, 56]).

In specific terms, editing tools such as Protégé® [57] or OWLGrEd [58] support users in creating ontologies. The tools provide an overview of an existing ontology in the form of appropriate visualizations, e.g. for the representation of taxonomies and relationships, support in manipulating the ontology using applicable forms, and logical verification of the ontology. The server Apachi Jena Fuseki [59] offers the possibility to make an OWL described ontology available for SPARQL requests (SPARQL Protocol and RDF Query Language [60]) on the web via HTTP (Hypertext Transfer Protocol). Thus, a direct use and a simple integration of knowledge in the form of ontologies in existing applications, in this case in tools for project planning, are possible.

3. THE METHODOLOGY TOOLBOX

In the context of a long-term research project in the field of information systems, the development of a methodology often bases on the design science paradigm. The three-cycle view of design science research (DSR) is presented in [61] and addresses the relevance, design and rigor of the developed artifact. Thereby, the included literature review according to [62] corresponds to the relevance cycle, the conducted interviews according to [34] correspond to the rigor cycle, the construction of the ontology according to [63] and [64] and the case study for evaluation according to [65] correspond to the design cycle. In addition, the research described in this paper uses the "design science research method" according to [66], which is divided into six phases. The research entry point for this paper is thus a problem-centred initiation. In the first activity the problem and motivation are identified through an expert interview. To get objectives for a solution, a review of the state-of-the-art is performed in activity two. In activity three the ontology design

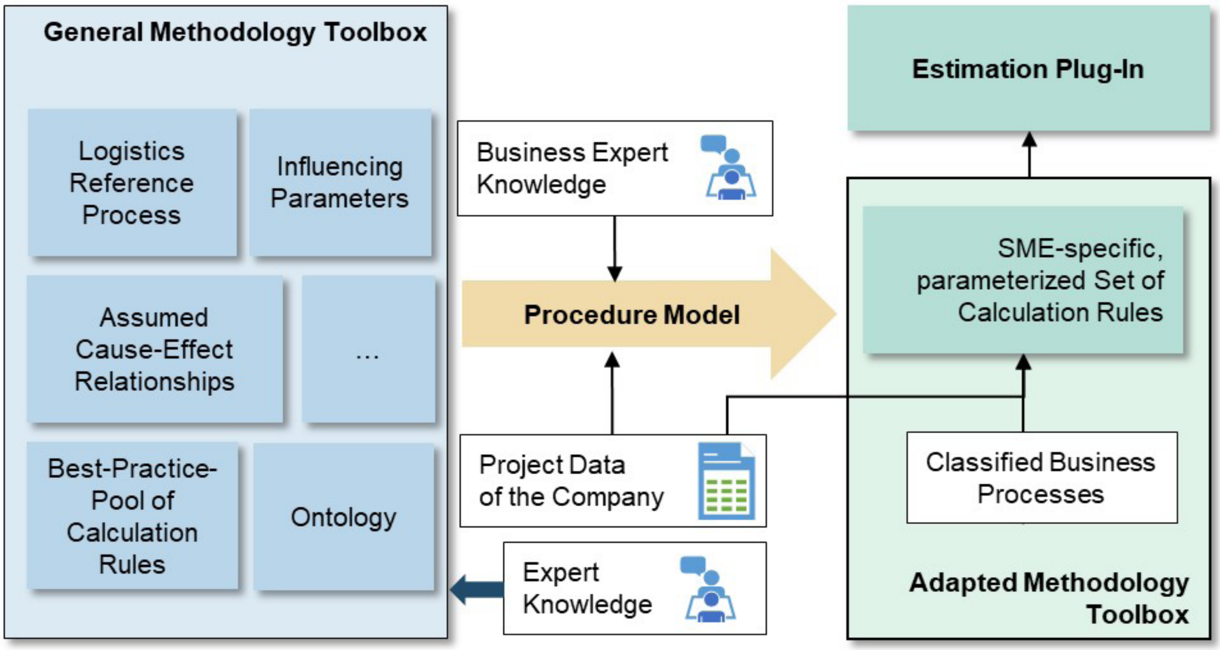


Figure 2: Interaction between relevant parts of the methodology

is developed to represent the acquired knowledge. Subsequently, the artifact demonstration and evaluation in activities four and five is done using semistructured expert interviews to gather expert opinions. The final activity consists of the communication of the research results to the relevant interest groups. The structure of the following content is based on this DSR method.

The related work points out the necessity for further research to improve project planning of one-of-a-kind productions. To support SMEs, a methodology to estimate the duration of logistics processes was developed based on an elaborated general methodology toolbox. The method construction, consisting of design activity, technique, design results, role and metamodel, is based on [67]. In this paper, parts of the methodology toolbox, the application of which in turn represents a part of the methodology, are discussed. For further information, see [68]. Figure 2 gives an overview and shows the interaction between the relevant parts developed within the methodology: a general methodology toolbox and a procedure model that customizes the general methodology toolbox to a company-specific adapted methodology toolbox. The adapted methodology toolbox includes relevant company-specific rules to estimate logistics process durations and give the results back to the project plan via an estimation plug-in.

The general methodology toolbox comprises the management methods for externalizing and systemizing expert knowledge, as well as processing techniques. The uncertainty of the obtained estimations is statistically quantified so that the proposed methodology provides an accurate forecast of the duration of logistics processes in the context of project planning. It is based on logistics reference processes of one-of-a-kind productions, influencing parameters as well as quantifiable interdependencies of these influencing parameters; the results are briefly presented below for the understanding of subsequent work.

Logistics reference processes: The logistics reference processes are described in a reference model for mapping logistics processes in one-of-a-kind production based on the Supply Chain Operations Reference (SCOR) model, see Figure 3. The SCOR model has been established in practice with the aim of making activities and services comparable and assessable, and thus creating a common understanding of the processes of the entire cross-company process chain [69]. The reference model developed here is based exclusively on logistics processes within the company boundaries of one-of-a-kind production-based manufacturers in SME. It is divided into three levels: process landscape, process classification and process description. On the third level, the individual logistics processes (e.g. transport, handling, picking) in each area, which were defined on the second level, are described in detail in their temporal-logical sequence. In order to increase the general validity, accuracy and completeness of the reference model, it is evalutated by three companies. For this purpose, value stream analyses are performed for a representative product and transferred into a Business Process Model and Notation (BPMN) model.

Influencing Parameters: Based on a delphi study [70] with 14 experts, a total of 91 parameters with a potential influence on the duration of logistics processes (e.g. such as length, weight, material specifications of components, capacity of the technical or human

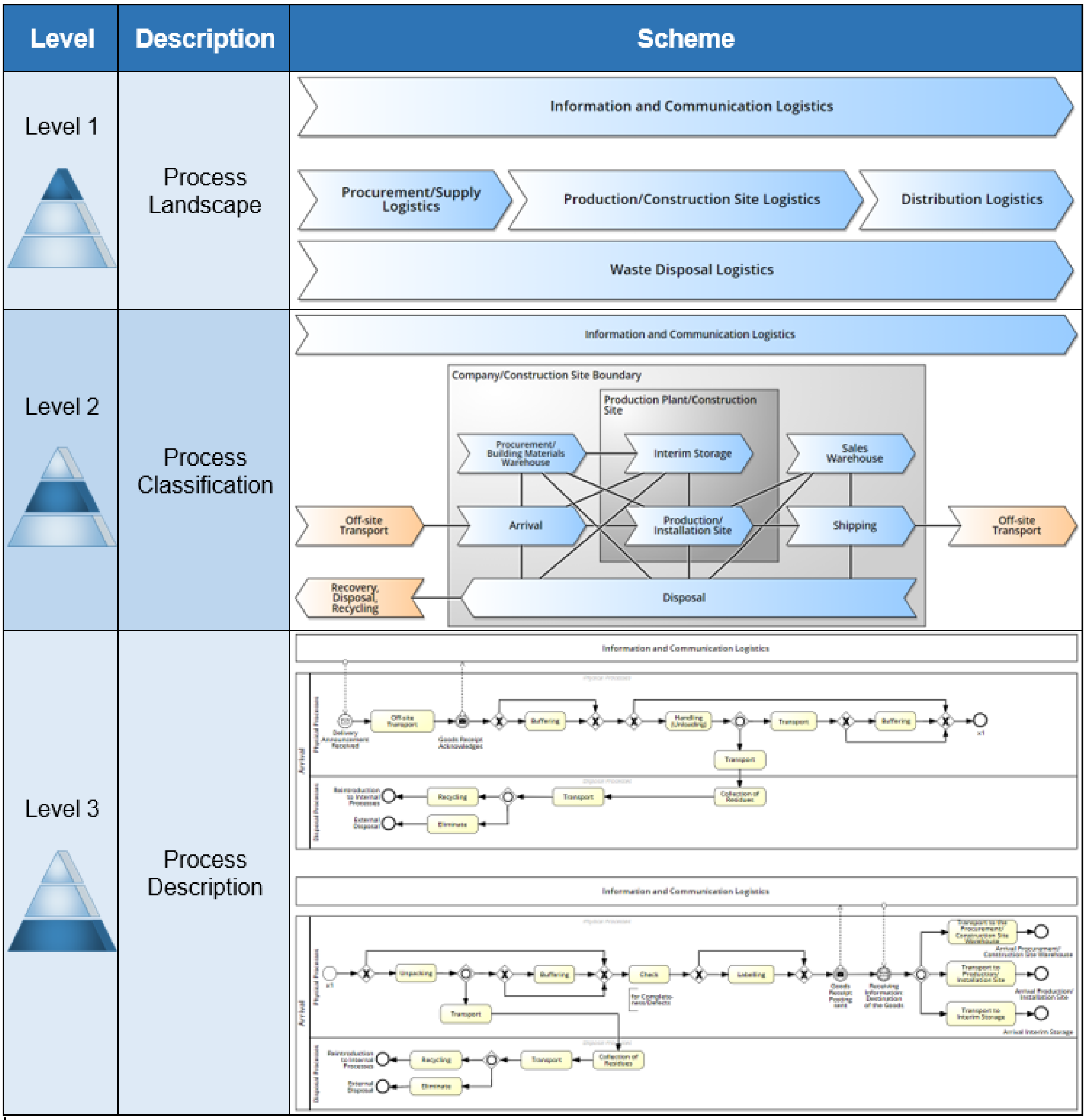


Figure 3: Levels of detail of the reference model (own representation based on the SCOR model)

resources) could be identified. Thereof, eleven very important influencing parameters affect the duration of logistics processes: number of different objects, availability of the object, degree of staff utilization, responsibilities in the process, media discontinuities in communication, efficiency of the personnel, priority of the task, digitalization of information exchange, sequence of processes, compliance with targets and quality of control of the process. The 91 identified parameters from the literature and the delphi survey are assigned to the following six categories [71]:

1. Transformation Object: Transformation objects undergo a spatial (transport), temporal (storage), sort-based (picking) transformation, a transformation of the service level (packing) or an interface transformation (handling) in the logistics process.
2. Resource: Resources include the operating resources, work equipment, work aids and the necessary personnel required for the process.
3. Structure: The structure of a process includes the process-internal structure as well as the technical communication structure (organization of information technology).
4. Control: The control coordinates and regulates the process by means of rules and control regulations.

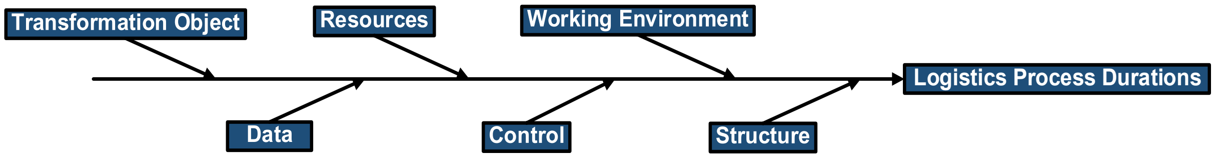


Figure 4: Cause-effect diagram

5. Data: The data required for the execution of the process is collected, processed and stored within a process.
6. Working Environment: The working environment (hereafter referred to as the environment) has an external effect on the process.

Assumed Cause-Effect-Relationships: To show causality relationsships, all 91 identified influencing parameters and their interdependencies are derived and combined in a theoretical cause-effect-model, also known as fishbone diagram or Ishikawa diagram after the inventor (for the Ishikawa diagram, see [72]). The named six categories listed by [71, p. 52] are used as the main fish bones (see Figure 4) of the diagramm.

Best-practice-pool of calculation rules: For the prediction of process durations, calculation rules are determined based on the expert knowledge gained and summarized in a set of rules. The determined calculation rules are divided into three types: binary function (influences the program schedule), scalable function (influences the process duration), and mathematical function (influences the program schedule according to the exclusion procedure like the scalable function and predicts a specific time with the help of mathematical formulas).

Ontology: Finally, the entire knowledge structure is formally combined in an ontology to make the extracted knowledge reusable and available for machine exchange. The development of the ontology is described in detail in section 4.

Summarized, the research results are combined in the general methodology toolbox: Logistics processes of one-of-a-kind productions are described in a logistics reference model with 91 identified influencing parameters and classified in the six categories available for logistics processes. They are integrated in presumed cause-effect-relationships and administered in the form of an ontology, as well as a best-practice-pool of developed calculation rules.

During the development of a demonstrator, the research results (logistics reference process model, cause-effect-relationships, best-practice-pool of calculation rules, Ontology) are embedded in a project planning context. This enables their usability in the operative project management process for estimating the duration of logistics processes in new projects. The methodology toolbox is evaluated with the help of an executable demonstrator.

4. DEVELOPMENT OF AN ONTOLOGY FOR A KNOWLEDGE-BASED FORECAST

To represent the researched knowledge structures of the general methodology toolbox, an ontology is used to forecast logistics process durations in one-of-a-kind productions. To check whether ontologies already exist for the logistics domain, a systematic literature review is carried out [62]. In the literature analysis, the databases EBSCO and Google Scholar are used. A first search by keywords ("ontology AND Logistics" as well as "ontology AND company logistics") in English and German with no time limit delivers a hit count of 219 articles at EBSCO and 887 articles at Google Scholar (48 articles only selected with keywords in the title). The abstracts of the remaining publications are subjected to a rough screening by examining whether the focus is within the logistics domain and what the goal and intended use of the ontology is. Publications that demonstrate the development and subsequent use of an ontology in the context of logistics were considered. Finally, 17 articles are selected for further analysis, to check whether the ontologies at hand are suitable for use.

The result of the literature analysis is that, despite increasing popularity, the use of ontologies in the logistics domain is not yet widespread. It is also striking that most articles deal with ontologies for information exchange and data integration between different systems or supply chain partners. [73] pursue the goal of a smooth exchange of documents in the logistics domain with the construction of their ontology, e.g. to ensure transport invoices or transport requests between different systems of the supply chain partners. The concepts used there and in the other articles (if presented at all) thus do not refer specifically to a description of logistics processes. Only [74-76] include logistics processes, but do not fit into the issue addressed in this paper. The ontology approaches provide clues how to classify some domains and which methods can be used for the construction of an ontology, but the ontologies created are not suitable here. Existing ontologies rarely meet the specific requirements of a new application and therefore need to be extended and adapted [48, p. 162], since the ontologies of the different works have been created for a specific purpose and are therefore difficult or impossible to transfer to other problems. Because of this issue, there is a need to develop a new ontology concept. The use of an appropriate process model for an ontology design that includes all activities required for the construction of an ontology is necessary to develop a consistent ontology and to ensure an efficient development [77, p. 3].

Several methods for designing an ontology exist in the literature [63, 64, 78-80], the approaches are analyzed for their use in the ontology design (see Table 1). With the help of the evaluation criteria *general validity*, *completeness*, *depth of detail*, *simplicity* and *tool support*, the methods are evaluated for the addressed problem. The selection of the criteria is explained below:

General validity: The general validity is one of the fundamental requirements imposed on the preliminary ontology development model. A method that is generally valid and independent of the application domain expresses the maturity of the ontology development process [81, p. 61].

Completeness: The criterion of completeness requires a method to consider and represent all relevant aspects of the ontology development process. This means that all necessary activities, beginning with the initial situation and up to the final design of the ontology, are described in sufficient detail [82, pp. 30].

Depth of detail: The depth of detail criterion describes the extent to which the methods specify the modeling activities, decisions, and proposed techniques [83, pp. 4-3].

Simplicity: Simple models are more flexible, easier to understand and easier to implement. Therefore, simplicity represents a further requirement to the method and/or the process model. This is because the content should be understandable and unambiguous for everyone (including non-technicians) and especially for end users [82, p. 32].

Tool support: The examined methods are to recommend an appropriate tool (similarly to Protégé®) for the development process, which supports the modeling steps and thus makes an easier application of the process model possible. This increases the comfort as well as the efficiency of the ontology development process at the same time [82, p. 33].

All methods divide the modeling process of the ontology into different sections or phases. These sections are partly iterated and cyclically run through in a given order. Only the method according to [63] describes a process emerging during the development without a strict specification of the sequence. All methods begin with the delimitation of the application scope as well as user groups and through that produce an application specification. Apart from the method described in [78], the knowledge in all process models is well structured, informally documented and thus a natural-language concept model is developed. This is then continuously refined and evaluated until it is fully formalized and implemented in an appropriate representation language. In summary, the evaluation shows that it is noticeable that the individual activities of the methods are presented in varying degrees of detail or are even missing in part. [79] and [80] are evaluated as rather incomplete. On closer inspection, the individual implementation steps in [64] are described in detail, whereas activities such as evaluation and documentation are completely missing. Regarding the requirement of simplicity, the method according to [79] stands out as relatively complex and difficult to understand due to its formal design approach. Moreover, this method represents a rather application-specific approach, which makes transferability to new development projects difficult. In contrast, the other methods are universally valid and thus application independent. Except for [79] all authors refer to the necessity and/or use of a software development environment and recommend appropriate tools for it.

Predominantly, the methods according to [63] and [64] are selected as an orientation for the ontology modeling approach. According to [63], a subdivision into technical phases and supporting activities is made.

Table 1: Results of the evaluated methods for designing an ontology

Criteria	[78]	[79]	[63]	[80]	[64]
General validity	Application independent	Application dependent	Application independent	Application independent	Application independent
Completeness	Complete	Rather incomplete	Complete	Rather incomplete	Incomplete
Depth of detail	Low	Medium	Medium - high	High	High
Simplicity	Simple and understandable	Rather complex and difficult to understand	Simple and understandable	Simple and understandable	Simple and understandable
Tool support	Reference to Ontolingua	No recommendation	Recommendation of required functions, free choice of tools	OntoEdit	Protégé

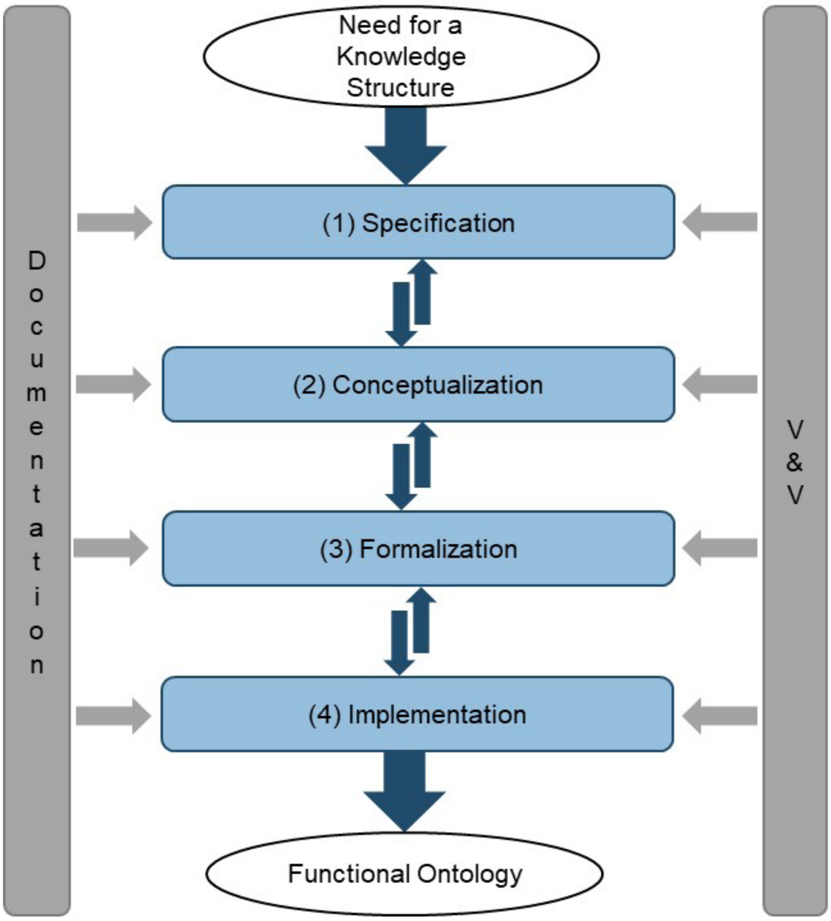


Figure 5: Process model to create an ontology design

The four steps (1) specification, (2) conceptualization, (3) formalization, and (4) implementation represent the technical phases of the ontology development process As supporting activities, documentation as well as verification and validation (V&V) are performed in each phase (see Figure 5). Additional phases that include project and resource planning or post-development care and maintenance of the ontology are not considered here. The following further explains the development of the ontology and its structure in detail, in order to facilitate deployment of the devolped ontology within companies.

Step 1: Specification

The knowledge scope is the domain of logistics in one-of-a-kind production, in order to plan the duration of the logistics processes in projects with higher accuracy. To fulfill this purpose, the ontology must hold certain information and provide answers to queries relevant to planning. The user of the ontology will be a project manager who will schedule the time duration of logistics processes in his projects through an appropriate end-user application, e.g. a planning tool. The scope of the ontology is limited to the description of the logistics processes, as well as the influencing parameters and the representation of interrelationships between the parameters. Also the specific relationships between the logistics processes and their respective influencing parameters are contained. The ontology should describe, for example, which logistics processes make up the process of arriving goods, and which resources are used to handle each transformation object in what way. Furthermore, the influencing parameters linked to logistics transformation objects are mapped and the mutual relationships between parameters and objects are shown.

Subsequently, a list of competency questions has been created (e.g.: Which parameters influence the transformation object? Which parameters influence each parameter?). They not only limit the effort for the creation of the ontology but represent questions that should later be answered by the functional ontology. Thus, they also serve to check the ontology for correctness and completeness [48, pp. 160]. Finally, the information generated in this phase is recorded and documented in a corresponding requirements specification.

Step 2: Conceptualization

The following conceptualization is done step by step. At first, a basic terminology is created containing the basic vocabulary of relevant terms. The logistics reference model and Ishikawa diagram presented in section 3 are used and analyzed as knowledge sources for this purpose. They provide a basis for the description of a class hierarchy. The knowledge is then structured and linked with simple statements, e.g. a pallet is a work aid, a work aid has geometric properties, dimensions are geometric properties, length is a measurement, etc.

In the next step, the statements contained in the catalog are grouped with respect to their relationship to each other and examined with respect to their composition. This serves the subsequent structuring of the knowledge. Nouns, verbs and adjectives are grouped into separate columns to provide a better overview of the statement composition. The terms identified as nouns then represent possible classes or, in some cases, instances of the ontology. The verbs represent inheritance relations, property relations, or other relations. Adjectives describe special properties in the form of instances. This assignment of object types is subsequently stored in an extended collection of terms.

The verbs *is* and *has* indicate inheritance relations, i.e. a taxonomic relation. The verb *is*, for example, connects the arguments or objects *pallet* and *work aid* with each other and implies that the pallet is a subclass of the class work aid. The verb *has* expresses that this relation can be about characteristics or properties of an object like "the vehicle has a length". This structure is represented visually and is defined as lightweight ontology.

Using the example of the class *category*, which is declared as a superclass, the detailed structure is described below (see Figure 6). Six specific categories are declared as subclasses in the next level: transformation object, resources, structure, management, data, and environment. Furthermore, the subclass resources is divided into further subclasses: staff, work equipment, work aid, and storage. These can include company-specific objects that are specific objects in the ontology (individuals). For example, the specific transformation objects "sheet metal" or "tube" are individuals of the subclass transformation object. The same applies to the subclass work equipment, see the specific work equipment objects forklift 1, forklift 2 and forklift 3.

The relations between the subclasses must also be taken into consideration. The logistics reference model defines which logistics processes possibly take place in which area. In addition, relevant categories are assigned to each logistics process, i.e. the category storage is important for the warehouse process but irrelevant for the transport process (see Table 2). The parameters are already assigned to the six categories (see section 3), so this assignment must also be considered in the ontology concept.

Selected relations are exemplarily illustrated with the subclass *work equipment* and two relevant influencing parameters (IP) "IP_{24}: max. transport load" and "IP_{23}: speed" (see Figure 7). This is just a simple example to illustrate the application of the ontology. The subclass *work equipment* is related to both parameters IP_{24} and IP_{23} ("hasParamValue"). If a new piece of work equipment is added, it should be represented through

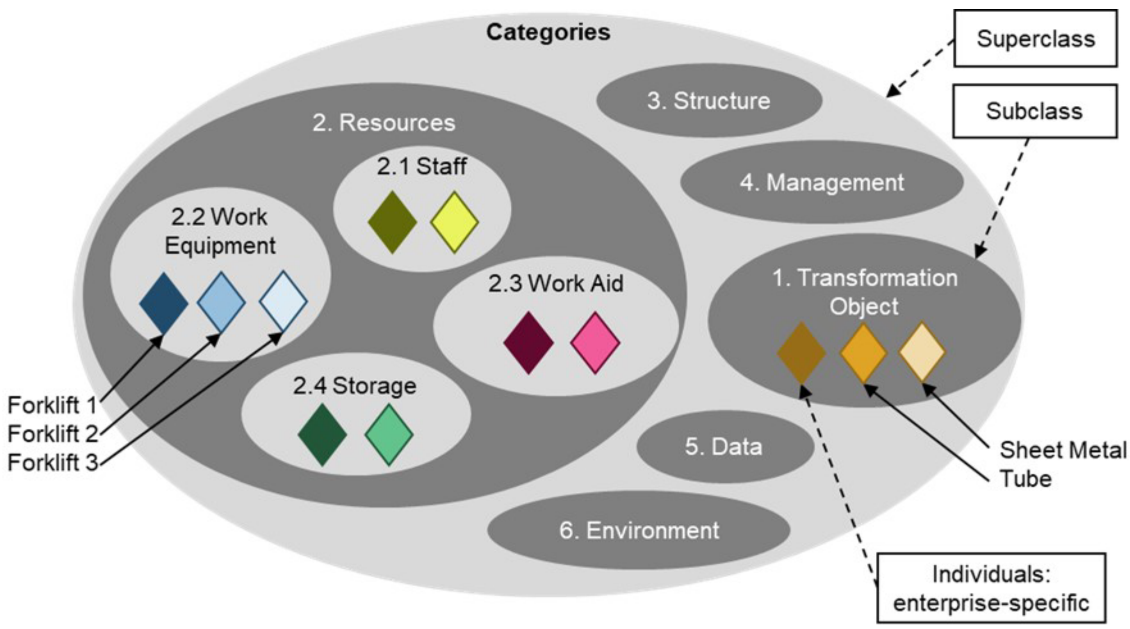


Figure 6: Ontology concept I

Table 2: Allocation of the logistics processes to the various company divisions

Logistics Process \ Company division	Arrival	Procurement Warehouse	Interim Storage	Production	Sales Warehouse	Goods Issue
Transport	X	X	X	X	X	X
Buffer	X	X	X	X	X	X
Packing/Unpacking	X					X
Handling	X					X
Store		X	X		X	
Picking		X	X		X	

a new individual of the subclass work equipment, like the two objects forklift 1 (dark blue) and forklift 2 (light blue) in the example. The two forklifts inherit the relationship to the relevant parameters from the subclass work equipment. "IP_{24}: max. transport load" holds individuals representing the parameter values for each instance of the subclass work equipment to store object parameters independently. The same applies to the parameter "IP_{23}: speed". The units of each value are also defined beforehand in the ontology to ensure homogeneity across the stored values. All individuals representing parameter values belong to the class "ParameterValues". In this example, these individuals only include values from technical data sheets of the forklifts. It is also possible for an individual to hold a selection of possible attributes of an object (such as the shape of a product) or value ranges to be entered by experts (such as performance).

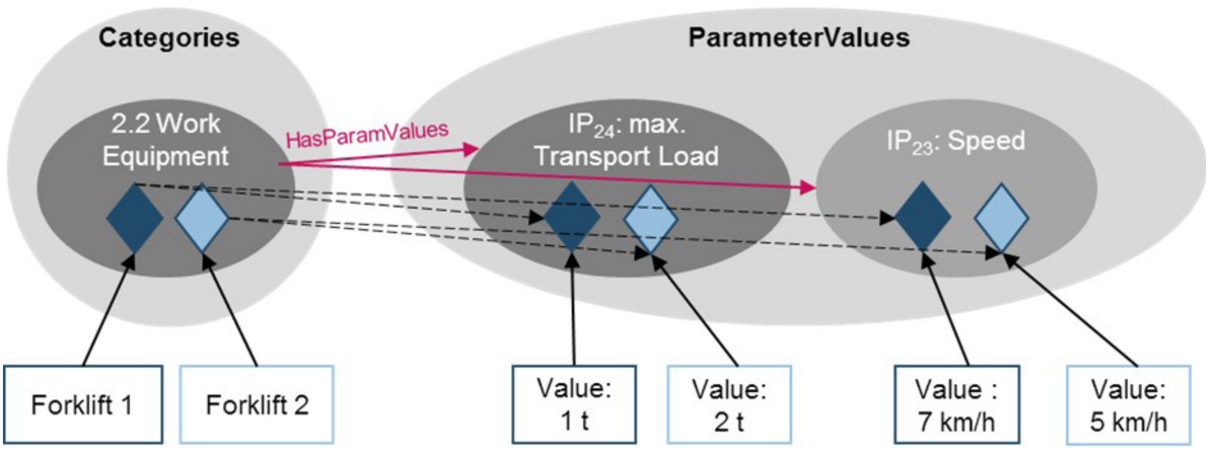


Figure 7: Ontology concept II

So far, the ontology concept allows the query of knowledge about specific areas for specific processes. The next step in the development of the ontology consists of the integration of the interrelations between the influencing parameters. For this, a new superclass "ParameterTypes" is required to store all parameters as individuals (see Figure 8), to define relations between them. Contrary to "ParameterValues", this class stores a unique pre-defined individual representing an abstract parameter for each parameter type, to take object relations between them into account. These individuals are associated with the parameter values of each object through the property "typeOfParameter". Finally, the corresponding cause-effect-interactions between parameters are modeled through the object properties "causeOf" and "consequenceOf", with one being the inverse function of the other.

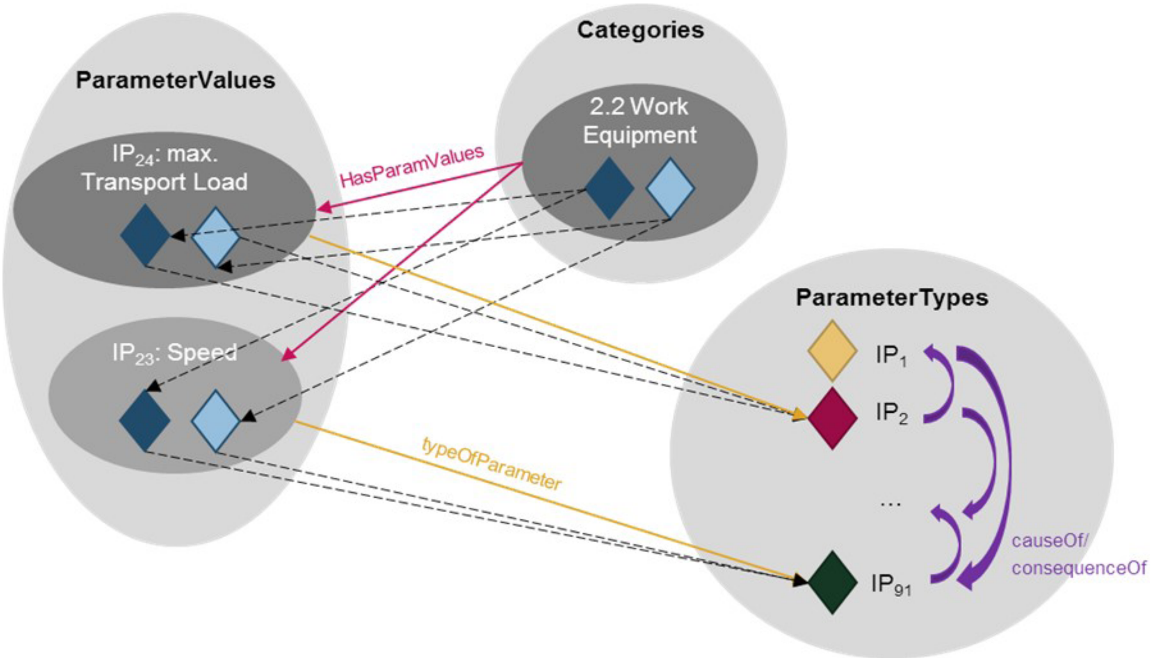


Figure 8: Ontology concept III

Step 3: Formalization
The formalization phase is listed in the process model but takes place in the background. Because the tool Protégé® is used for the creation of the ontology, the explicit coding of the informal knowledge into a formal description logic is not necessary, since this occurs in the background during implementation in Protégé®.

Step 4: Implementation
The ontology is implemented within the framework of the project in the development environment Protégé®. The described class hierarchy, the relations and the axioms (restrictions) formalize the knowledge, so that a knowledge structure is created that allows the user to query said knowledge. The ontology concept is shown in Figure 9 using the visualization tool OntoGraf. The blue section shows the class areas with its subclasses, the orange section contains the superclass logistics processes with its respective subclasses, the green section holds the categories of transformation objects with its subclasses and the red section represents the superclass "ParameterValues" (identified influence

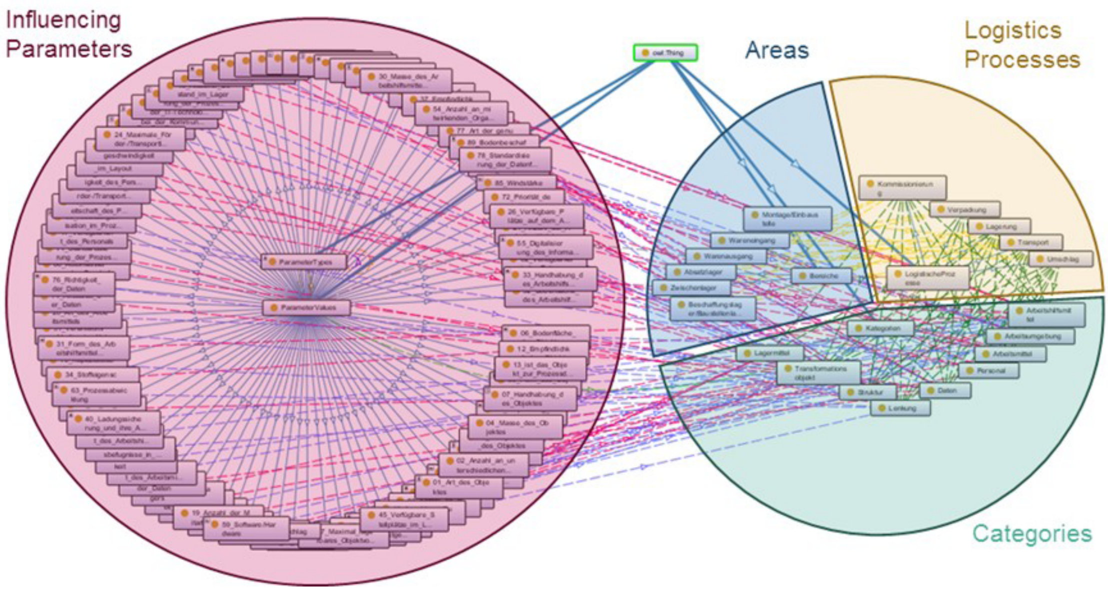


Figure 9: Ontology – basic structure

parameters) with its subclasses, which are connected through object properties with the individuals contained in the class "ParameterTypes".

The structure to organize expert knowledge for the targeted retrieval of information in the application of the methodology for the forecast of logistics processes is completely available in the ontology. The use of expert knowledge for the forecast of a logistics process duration is done by calculation rules (see section 3). Only basic calculation rules are defined for the general methodology toolbox. First, a distinction must be made whether the rule is a specific calculation of a logistics duration or a secondary condition that influences the calculation. For example, the physical rule for calculating a transport duration is $t_{transport}$ = s/v with s = distance between source and sink and v = speed of the work equipment. However, in order to determine the speed of the work equipment, a suitable work equipment with a specific speed must be selected based on its and the work aids' capacity, depending on the goods to be transported. The secondary conditions in this case are:

$$[\kappa\,(WA) < \kappa_{max}\,(WA)] \Leftrightarrow [\sum_{i=1}^{n}(m_i) < m_{max}\,(WA)]\ \&\&\ [\sum_{i=1}^{n}(V_i) < V_{max}\,(WA)]$$

$$[\kappa\,(WE) < \kappa_{max}\,(WE)] \Leftrightarrow [\sum_{i=1}^{n}(m_i) < m_{max}\,(WE)]\ \&\&\ [\sum_{i=1}^{n}(V_i) < V_{max}\,(WE)]$$

with κ = capacity, κ_{max} = maximum capacity, m = mass, m_{max} = maximum mass, V = volume, V_{max} = maximum volume, && = logical AND, WE = work equipment and WA = work aid

These basic calculation rules can also be retrieved from the ontology. However, in order to allow individual company-dependent situations to be considered in the calculation of a logistics process duration, these basic calculation rules must be converted into company-specific ones.

In order to guarantee a functional ontology, the supporting activities *documentation* and *V&V* are of high importance (see Figure 5). The documentation takes place in parallel to the four steps of the process model. In particular, the conceptualization is recorded in a high degree of detail and serves as a basis for discussion of the development process in meetings. The documentation of the implementation process includes information about the responsible person or team for each task, its description, goal(s), prerequisite(s), priority, and degree of fulfilment. This proves to be advantageous for the implementation in Protégé®, so that the project team always knows the current processing status.

The validity of the ontology is proven by continuously checking the correctness of the entries. Four methods are used for this purpose:

OntoGraf: The OntoGraf graphically displays the ontology. Thus, classes, subclasses, individuals, and their relationships are traced and discussed in the project team. The OntoGraf allows a graphical examination of the completeness and structure of the ontology and serves primarily for early verification.

OWL-Reasoner: With the help of an OWL-Reasoner, the consistency of the ontology is checked. By characterizing ObjectProperties, the activation of the Reasoner displays processed knowledge that has been gained from logical conclusions and inference. Inconsistencies between the target and the actual state are detected and corrected by using this tool.

DL Queries: During the implementation of ontology in Protégé®, the functionalities of the ontology are already checked, and errors detected through simple queries. With the help of a DL Query (Description Logic Query), the developer searches for classes, subclasses and individuals and checks their completeness. The relationships between the classes and individuals are thus tested regarding their defined conditions. In particular, the ObjectProperties "causeOf" and "consequenceOf", which describe the interaction between the influencing parameters, are checked.

SPARQL queries: SPARQL queries are carried out in their own query language, which is derived from the database language SQL (Structured Query Language). The query results are returned in an XML format (Extensible Markup Language Format). By activating the Reasoner, queries that are more complex are executable using the SPARQL queries. Only by checking the ontology with the SPARQL queries it can be ensured that an ontology fulfills the required functionalities for the addressed problem, since inverse relations are also considered by activating the reasoner.

At this point, the development of the ontology to represent the knowledge structures researched for the general methodology based on expert knowledge is completed. Furthermore, the general methodology toolbox using the ontology with a general knowledge structure must be adapted to a company-specific methodology toolbox with a company-specific ontology. To adapt the general ontology into a company-specific ontology, the general ontology is additionally extended by company-specific data stored in Microsoft Excel® lists. The intention here is merely to demonstrate that company-specific data must be maintained from a database into the generally valid ontology, Microsoft Excel® is used for simplicity's sake. The companies usually manage the data in information systems such as Enterprise-Resource-Planning or Manufacturing Execution System. The specific knowledge available in the ontology is accessed through SPARQL queries.

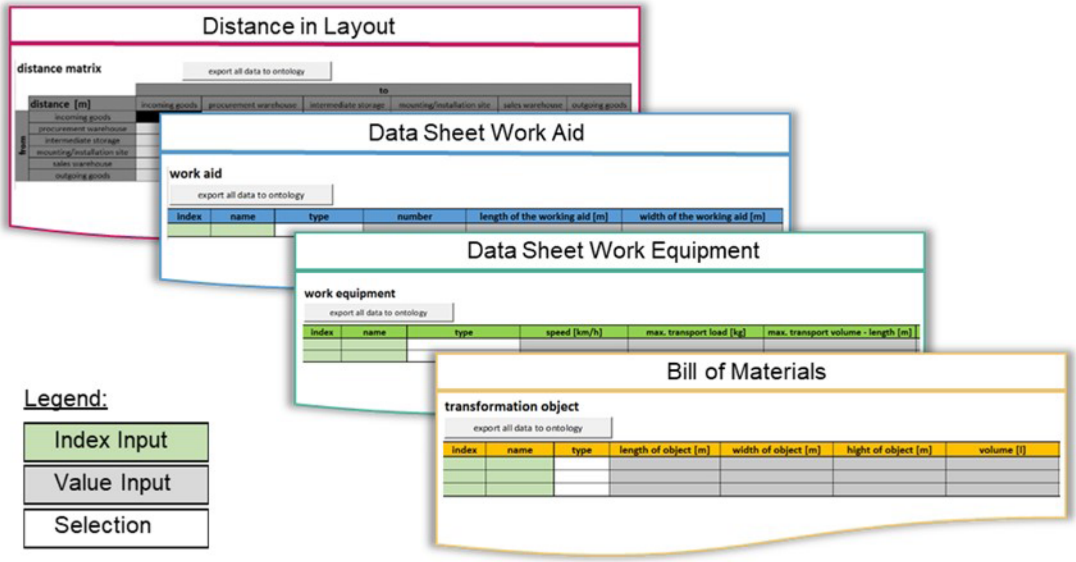


Figure 10: Excerpt from the Microsoft Excel® lists

The following describes the structure of the Microsoft Excel® lists and the transfer of data from Microsoft Excel® lists to the ontology carried out using a macro to enable a semi-automated process.

The basic prerequisite for estimating a process duration based on expert knowledge is the necessary storage of structured enterprise data, in this demonstration in Microsoft Excel® lists (see Figure 10). For functionality, the lists “bill of materials”, “data sheet work equipment”, “data sheet work aid” and “distance in layout” must be maintained with corresponding data from the enterprise. Each row in the Microsoft Excel® lists represents an object to which specific properties are assigned. The required completeness and quality of the data should be emphasized. In order to be able to guarantee this, it is indispensable to know the sources of the data and, if necessary, to define and check the quality when storing the data in enterprises’ databases. Master data maintenance is extremely important in this context to fill the Microsoft Excel® lists successfully.

In addition, basic calculation rules stored in the ontology must be transferred into company-specific calculation rules. Influencing parameters cannot be assigned to logistics processes in the same way for all companies, so the assignment must also be done in the preparation phase. In the basic structure of the ontology there is only an assignment of influencing parameters to the categories, but not to the individual logistics processes. Thus, it is already known that category 2.5 “storage” influences the storage process but not the handling process. Which specific influencing parameters in an individually considered company influence a logistics process must also be recorded in Microsoft Excel® by an expert. Referring to the example below, the basic calculation must be extended to company-specific calculation rules, such as

$$t_{transport} = s/v * \prod_{i=1}^{n} f(IP_i)$$

with t = transport duration, s = distance between source and sink, v = speed of the work equipment and $f(IP_1)$ = factor due to influencing parameter 1 or $f(IP_2)$ = factor due to influencing parameter 2

The factors consider disturbing or promoting influences on the duration of logistics processes and can be derived based on the information provided by the expert in the company.

The entered data in the Microsoft Excel® lists are automatically transferred into the developed general ontology with the help of a macro, and a new version of an example input file Ontologie.owl is saved under the name Ontologie_Export.owl. The data flow of the participating components “lists” and “ontology” is represented graphically in Figure 11. In this example, three new objects are created (green) by entering the index. Certain object properties, in the example for the middle object (T005_sheet_metal_neu), are selected in grey. These are defined by entering values, such as length, width and height (red), or by specifying values that are selected from suggestions (blue). The expert has entered the value of these parameters in the explained Microsoft Excel® lists. The specification of other parameters that cannot be determined in this way is done during the selection in the application to forecast a logistics process duration (orange).

The process to store company-specific data in the general ontology is done in a way to reuse expert knowledge. Furthermore, the company-specific ontology with retrievable knowledge can be connected to a custom-developed plug-in for Microsoft Project®. It should also be noted that the plug-in was designed for Microsoft Project®, as this is the only project

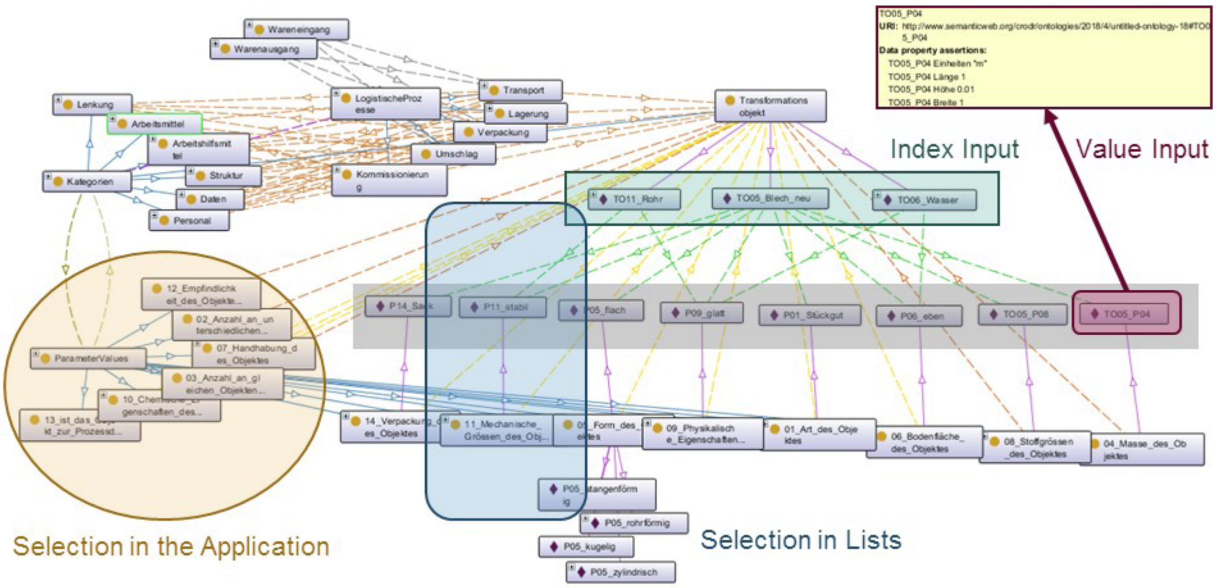


Figure 11: Ontology – data structure

management software used by many SMEs. Further development for other project management software is possible. The plug-in includes all steps to estimate the forecast of the duration of logistics processes. SMEs decide whether to use the ontology locally, in their intranet, or on the Internet by using a Fuseki® server. The plug-in uses the Fuseki® environment to send SPARQL queries to the ontology. The plug-in receives an XML-based output according to the query sent, which the Fuseki® server passes on (see Figure 12). The feedback from the ontology is ready to be used for the forecast.

The ontology-based process to forecast the duration of logistics processes is explained in the following section using an example of a SME.

5. EVALUATION OF THE METHODOLOGY FOR AN ONTOLOGY-BASED FORECAST BASED ON A PRACTICAL USE CASE

In this section the methodology will be evaluated using a practical use case (see [65]). The general methodology toolbox provides a framework that specifies all necessary methods, interactions of influencing parameters and data structures, but practical application in a company is only possible with the help of company-specific calculation rules. For this reason, the evaluation of the methodology is done based on a specific use case with individual framework conditions and restrictions,

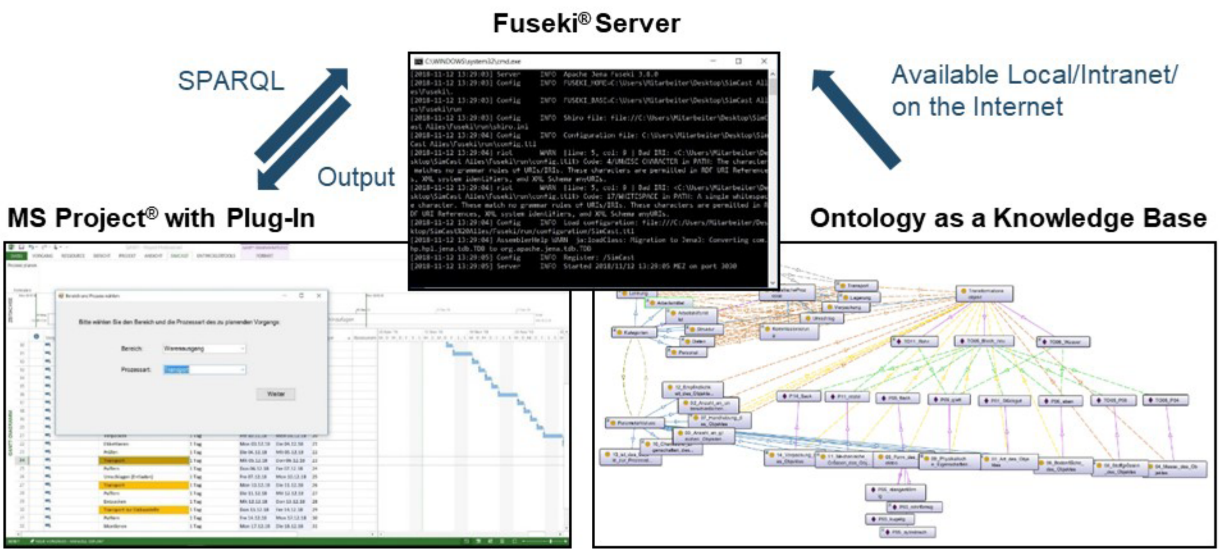


Figure 12: Access to the knowledge structure

and individual calculation rules are derived. Based on the example, an improvement of project management using an ontology-based forecast of the duration of logistics processes is examined. In the following, the individual framework conditions of the use case are described first, followed by the preparation for the application of the method and the actual application of the method. Finally, the evaluation of the method is presented.

Individual framework conditions of the use case before applying the method:
For a company-specific process representation, the material and information flow in the company must first be documented. An established method in industry is the value stream method (see [84]). The value stream method is used exclusively for the purpose of describing a use case with all its internal processes (not only logistics processes) and does not include any application of the developed methodology. Figure 13 shows the material flow at a one-of-a-kind manufacturer. The one-of-a-kind product, a special machine for a customer, is finished as a final product in the final assembly stage in the form of a construction site production, tested, packed for shipping and delivered to the customer. Modules are assembled for the one-of-a-kind product, which are completed in advance as small series in the assembly department from picked parts from the warehouse. The internal manufacturing, in which commissioned raw material from the warehouse are punched, bent, welded and/or coated, supplies both the assembly production and the final assembly with material. Bulk material, which includes screws, for example, is made available to the (final) assembly using KANBAN control. The material (raw material, standard parts and project-specific purchased parts) is ordered from various suppliers depending on the stock levels and new customer orders. After delivery, the material is unloaded, checked and put into storage. The production is centrally controlled. Information, such as picking or assembly lists, is printed out from information systems and is used in the different areas. Information, for example from arrival or shipping, is entered manually into information systems. Process times are not automatically recorded. Forklifts do the internal transportation in the company, continuous conveyors are not used, which is typical for SMEs in mechanical and plant engineering.

If this company receives and confirms a new sales order, the corresponding project must be planned. A project plan is generated for this project in order to make a before/after comparison after applying the methodology for forecasting the duration of logistics processes. The activity list shown in Figure 14 represents a classic project planning in Microsoft Project® without taking internal logistics processes into account. Material procurement and scheduling of production and assembly are currently included in the project plan. In practice, other methods and systems, such as Enterprise-Resource-Planning systems, are used, but these are not relevant to the application of this method.

Logistics processes are necessary in the company, even if they have not been planned in detail up to now. For example, 25 % of the project costs are estimated as overhead costs for logistics at a flat rate. This means that logistics is covered financially, but the schedule is not planned with certainty. Planners avoid this, for example, by adding a one-day blanket buffer to the time required to carry out a transport between different workstations. When considering the total project lead time, large time buffers arise, due to imprecise planning of the logistics processes. The planner now uses the completed project plan for project controlling.

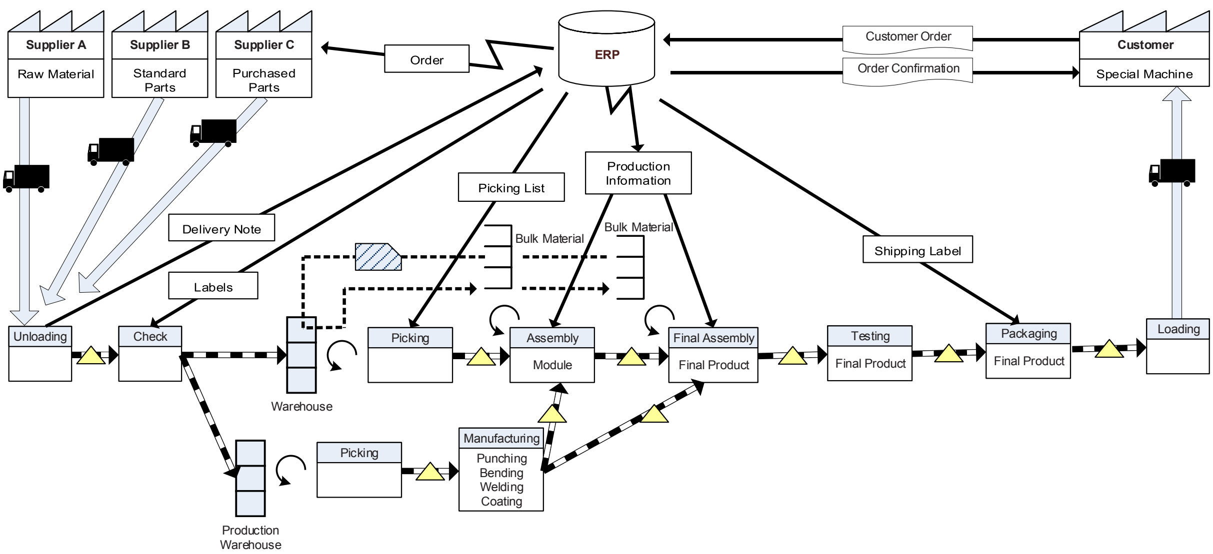


Figure 13: Company specific value stream (exemplary presentation)

Nr.	Process name	Duration
1	Customer Order	6 d
2	Order Confirmation	1 d
3	**Procurement**	**59 d**
4	Order S1	2 d
5	Provision of Raw Material (1)	1 d
6	Provision of Standard Parts (for B1)	1 d
7	Provision of Standard Parts (for B2)	1 d
8	Provision of Standard Parts (for M)	1 d
9	Delivery purchased Parts	28 d
10	Incoming goods Inspection	3 d
11	**Production**	**19 d**
12	Punching (1.1)	3 d
13	Bending (1.1)	2 d
14	Welding (1.1)	4 d
15	Coating (1.1)	10 d
16	Punching (1.2)	3 d
17	Welding (1.2)	4 d
18	**Assembly**	**25 d**
19	Assembly group B1	4 d
20	Assembly group B2	3 d
21	Final Assembly (Machine M)	14 d
22	Quality Control with Function Test	7 d
23	**Distribution**	**4 d**
24	Dispatch Preparation	2 d
25	Transport to the Customer	2 d

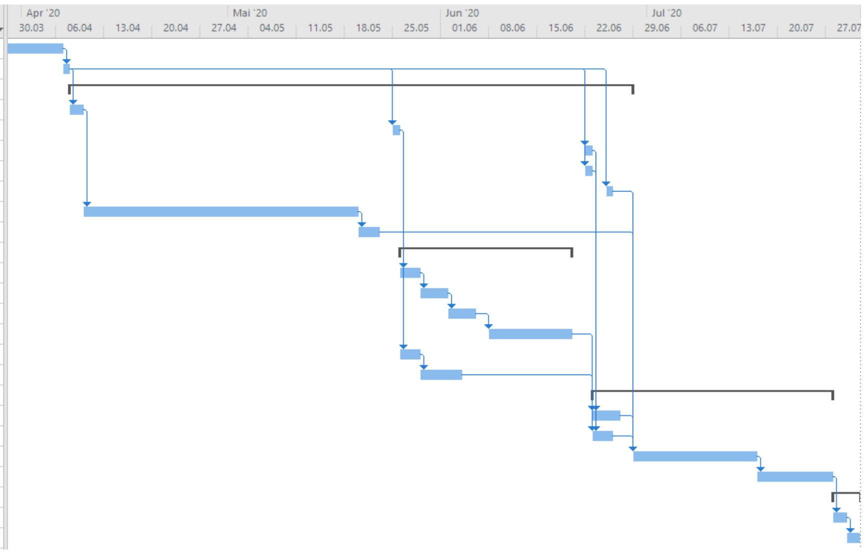


Figure 14: Company specific activity list and Gantt chart

The activity list is supplemented in Microsoft Project® by the corresponding Gantt chart. In parallel an activity node network is created using the precedence diagram method (see [85-88]). This now contains the complete and contradiction-free project flow from the planner's point of view. The critical path for the project is calculated using the graphical representation of the Metra-Potential-Method-based network (see Figure 15). The nodes with a buffer of "0" are critical because they do not allow the nodes to be moved without extending the project duration. The nodes are assigned according to the numbering in the activity list in Figure 14. Decisive on the critical path is above all node 9, the delivery of purchased parts; this also has the longest duration. The other nodes are not critical and can be shifted around their respective buffer. The critical path calculation is important for the planner in project management because it ensures a valid project plan. The further course of this example examines the arrival process; however, all processes must be formally described.

Preparation for application of the method:
The detailed description of the company's internal logistics processes is based on the logistics reference model (see section 3). The description of the process landscape (level 1) and the resulting process classification (level 2) are presented in more detail below to ensure a formal process description (level 3). Figure 16 shows the logistics processes in the areas "Arrival", "Production " and "Goods issue" of this example on a detailed level.

The arrival shown in the foreground in Figure 16 shows the part of the value stream of a special purpose machine manufacturer that extends from off-site transport to transport to production. In order to determine the calculation rules for the duration of logistics processes, which are necessary to apply the methodology, it is first necessary to determine the influencing parameters for every process step. For this purpose, the parameters determined in the delphi study, which were rated highest and thus the most influential, were used (see section 3). The parameters that influence

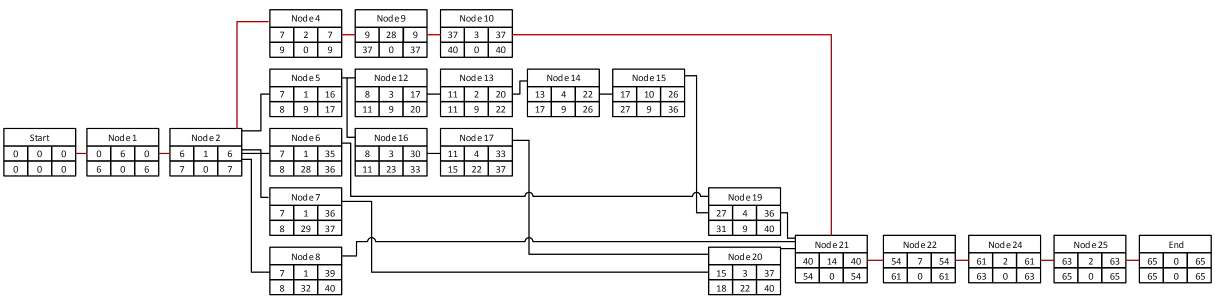


Figure 15: Metra-Potential-Method based network diagram

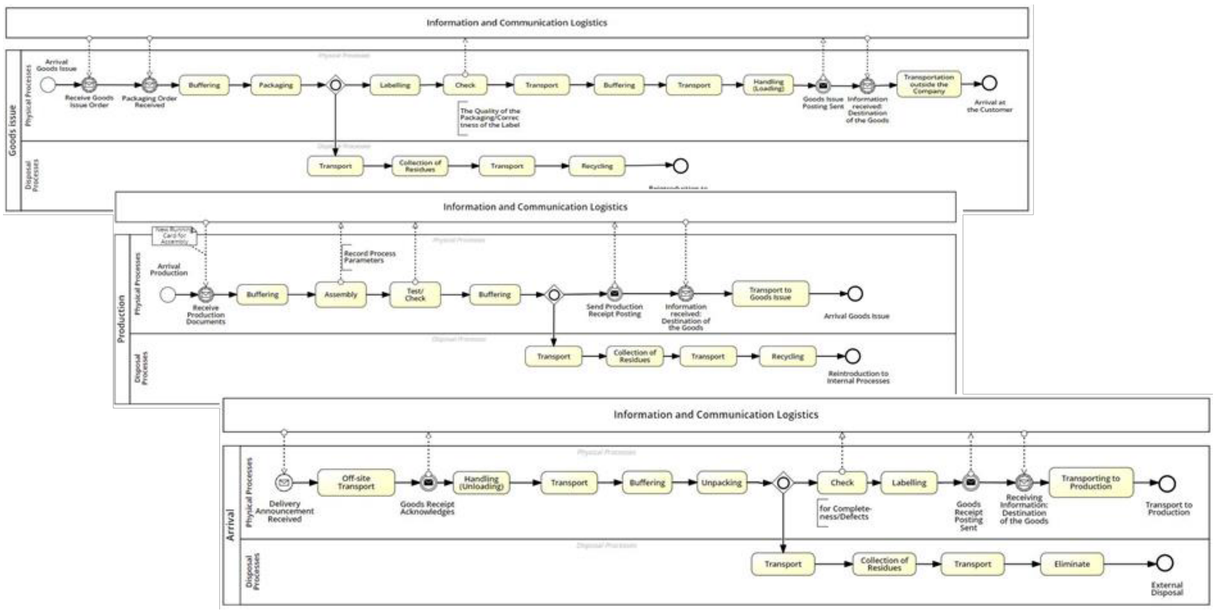


Figure 16: Process description level 3 (excerpt)

the logistics processes are assigned on a company-specific basis (see Figure 17).

The company-specific assignment leads to the derivation of the following rule:

The calculation of the duration of a transport process, for example, is based on the physical rule t=s/v with t = transport duration, s = distance between source and sink, v = speed of the work equipment (see section 4). Through the extension of the basic calculation rule in a company-specific one, the calculation is more precise, so the calculation also considers parameters influencing the logistics process. These improve the planning

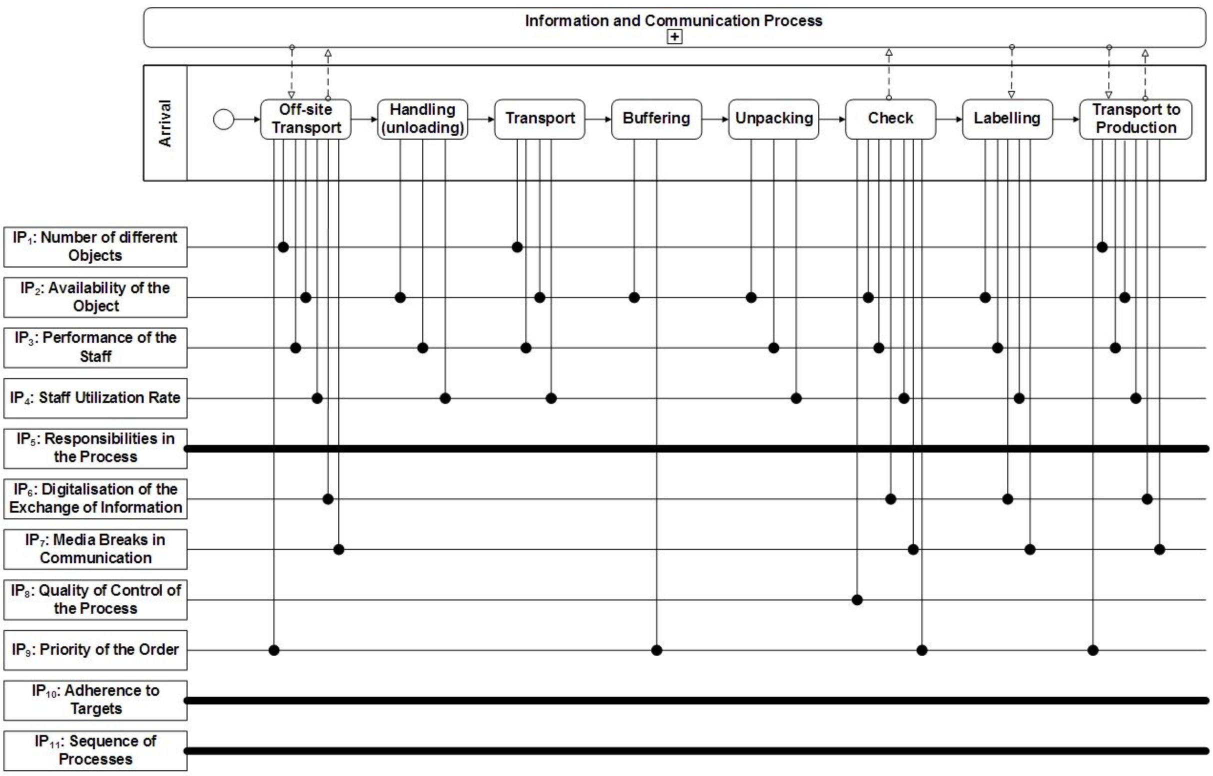


Figure 17: Allocation of the highest rated influencing parameters to the individual process steps in arrival

quality of the process and thus the overall project. Figure 18 shows that four influencing parameters (IP) are relevant when calculating the transport time in the here considered arrival area: number of different objects (IP_1), availability of the object (IP_2), performance of the staff (IP_3) and stuff utilization rate (IP_4). The company-specific adaption leads to the derivation of the following rule to calculate the transport duration in the arrival, considering the influencing parameters in Figure 17:

$$t_{transport} = s/v * \prod_{i=1}^{4} f(IP_i)$$

with t = transport duration, s = distance between source and sink, v = speed of the work equipment and

f(IP₁) = k, k∈N⁺

$$k = \begin{cases} 1: [\kappa\,(WE) < \kappa_{max}\,(WE)] \\ n = \max(z_1, z_2) \end{cases}$$

$$z_1 = \sum_{i=1}^{n} m_i \; div \; m_{max}(WE) + u \qquad \text{with } u = \begin{cases} 0: \sum_{i=1}^{n} m_i \; mod \; m_{max}(WE) = 0 \\ 1: \sum_{i=1}^{n} m_i \; mod \; m_{max}(WE) > 0 \end{cases}$$

$$z_2 = \sum_{i=1}^{n} V_i \; div \; V_{max}(WE) + w \qquad \text{with } w = \begin{cases} 0: \sum_{i=1}^{n} V_i \; mod \; V_{max}(WE) = 0 \\ 1: \sum_{i=1}^{n} V_i \; mod \; V_{max}(WE) > 0 \end{cases}$$

with κ = capacity, κ_{max} = maximum capacity, m = mass, m_{max} = maximum mass, V = volume, V_{max} = maximum volume, WE = work equipment, div = operator for whole number division, mod = operator for the remainder of the whole number division

$f(IP_2)$ = [0;1]
with 0 = not available; 1 = available

$f(IP_3)$ = [1/80;1/100;1/120]
with 80 = 80 % performance; 100 = 100 % performance; 120 = 120 % performance

$f(IP_4)$ = [1/80;1/100;1/120]
with 80 = 80 % capacity utilization rate; 100 = 100 % capacity utilization rate; 120 = 120 % capacity utilization rate

The missing influencing parameters “Responsibilities in process” (IP_5), “Compliance with objectives” (IP_{10}) and “Order of processes” (IP_{11}) are relevant for the smooth progress of the project. However, their influence cannot be calculated for a single process step, and they are not directly considered in the forecast of the duration of logistics processes but are indirectly incorporated into the overall project. They represent fundamental management tasks.

At this point all preparatory steps for the application of the methodology are completed. As explained in section 4, the company-specific information is stored in the ontology, which contains specific values of parameters and characteristics of parameters. The company-specific ontology is now available via intranet on the Fuseki® server. The selection of specific parameters takes place in the application. Subsequently, the forecast of the duration of logistics processes using expert knowledge is investigated in the following with the help of the developed demonstrator. All information is implemented in the ontology, so the project planning process can start.

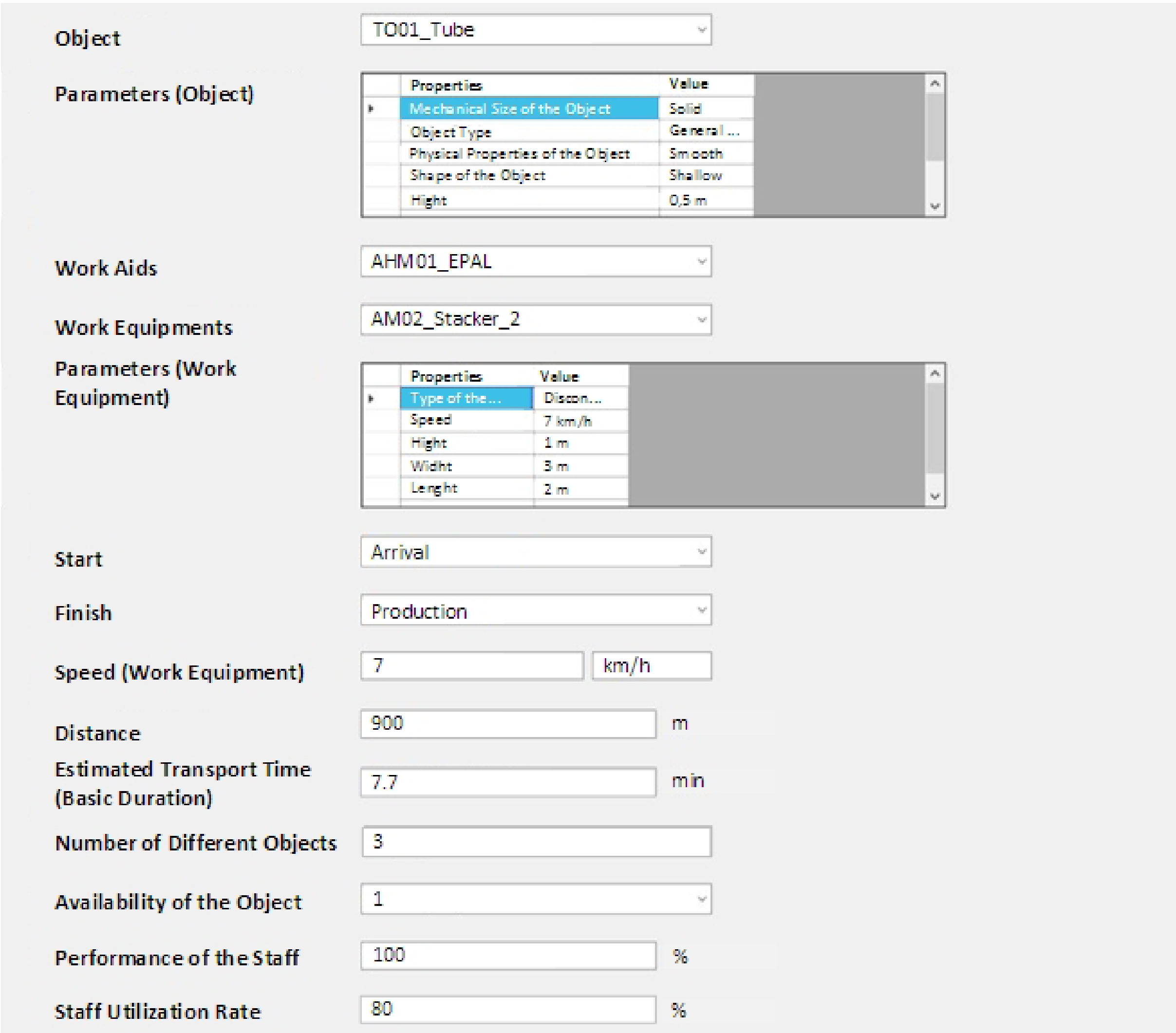
Application of the method:
The planning tool Microsoft Project® is started and the chosen process is marked. The project planner (called user in the following), using the demonstrator as a plug-in in Microsoft Project®, selects the entry “Process plan” in the menu bar and starts the estimate plug-in by clicking the menu item. Then the user selects the area (e.g. Arrival) and the process (e.g. Transport) to be planned and confirms his selection by “Accept”.

Depending on the selected logistics process, the categories available for each logistics process are queried. The following explained SPARQL queries are statically programmed in the plug-in for the application and validated in advance via the Fuseki® server. The example below shows the source code of a SPARQL query to filter categories that are important for a particular logistics process (see Figure 18). "Transport" is selected as the logistics process. The result of the query is an assignment of which categories (e.g. transformation object, staff, work equipment) are important for the transport. For example, the result contains the following assignment: The category "transformation object" is assigned to all five logistics processes (transport, transshipment, storage, picking and packaging). Only the logistics processes transport, handling and picking are assigned to the category "work equipment". The assignment is important because only parameters that fulfill this assignment are queried in the further course of the queries.

```
SELECT DISTINCT ?object
WHERE {
Transport rdfs:subClassOf ?description.
?description owl:onProperty ?property.
?description owl:someValuesFrom ?object.
}
```

Figure 18: SPARQL query (select categories)

On the following screen (see Figure 19), the user first selects the object to be transported. The selectable objects are already stored in the ontology in the preparation phase. Depending on the previous selection of range and process type, the objects "TO01_tube" and "TO02_metal_sheet" are available according to the database in the ontology. Certain parameters that are important to define the transformation object can also be determined using a SPARQL query. The result of this query is displayed in a table in the "Parameters (Object)" area under "Object". The query itself and its output are described below.



(to be continued on p. 21)

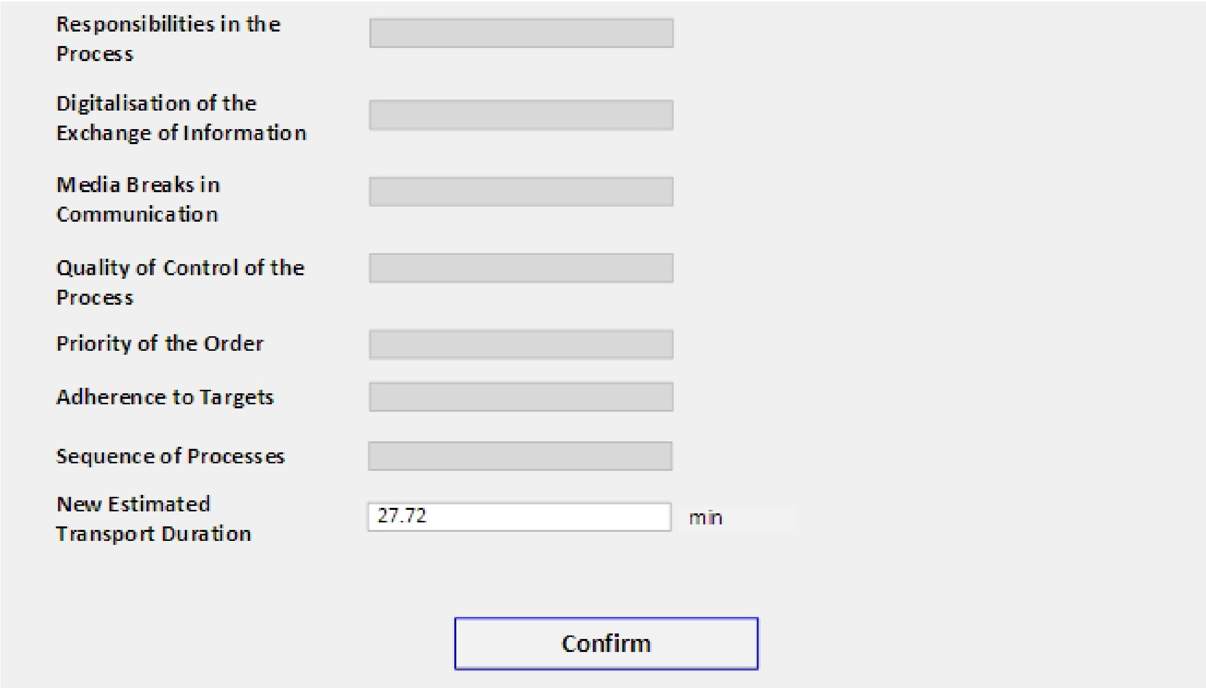


Figure 19: Determination of a process duration based on expert knowledge

The SPARQL query in Figure 20 selects parameters that are related to the category transformation object. The relationship is described as "parameterOf". The result of the query is used to assign categories to parameters. The transformation object is characterized by geometric properties, substance properties, and other properties that influence the selection of the work aid and work equipment based on their characteristics. The ontology is used to map and query these "branches".

```
SELECT DISTINCT ?a
WHERE {
?a rdfs:subClassOf Project:ParameterValues.
?a rdfs:subClassOf ?label.
?label owl:onProperty Project:parameterOf.
{?label owl:onClass Project:Transformationsobjekt}
UNION
{?label owl:someValuesFrom
Project:Transformationsobjekt}.
FILTER (?a != owl:Nothing)
}
```

Figure 20: SPARQL query (select parameters)

Depending on the selected transport object, the user must choose, dependent on the previously selected area, a work aid and, depending on that, appropriate work equipment. The start and finish areas are then selected manually. Now the user sees the speed of the work equipment depending on its properties. The distance is read from the "Transport matrix" list and transferred. Based on this information the transport duration (= basic duration) is determined.

Relevant parameters queried in the application from the company-specific ontology (Number of different objects, availability of the project, performance of the staff, staff utilization rate) now allow a more precise forecast of the duration by entering additional information. For example, in case of an 80 % staff utilization rate, a 20 % increase in process duration is predicted (see Figure 19). The example also shows that the performance of the staff has no influence on the duration of the transport process. Comparing the basic duration (7.7 min) with the new forecasted transport duration (27.72 min), the new forecasted transport duration is predicted more precisely based on the additional information. By selecting the "Confirm" button, the estimation process is completed, and the value accepted. The user has the possibility to consider additional influencing parameters and to perform more complex calculations in the plug-in due to the consideration of the large number of parameters.

To achieve a better understanding, Figure 21 shows the relation between the use of expert knowledge and the nessesary avaliability of data, and the ontology as well as its usage in the developed demonstrator (black arrows). It starts with the input of expert knowledge to build the general ontology. Through adaptation, a company-specific ontology is achived (blue arrows, applications). Then, the enterprise-specific ontology uses SPARQL queries to process the formalized expert knowledge, which includes the influencing parameters

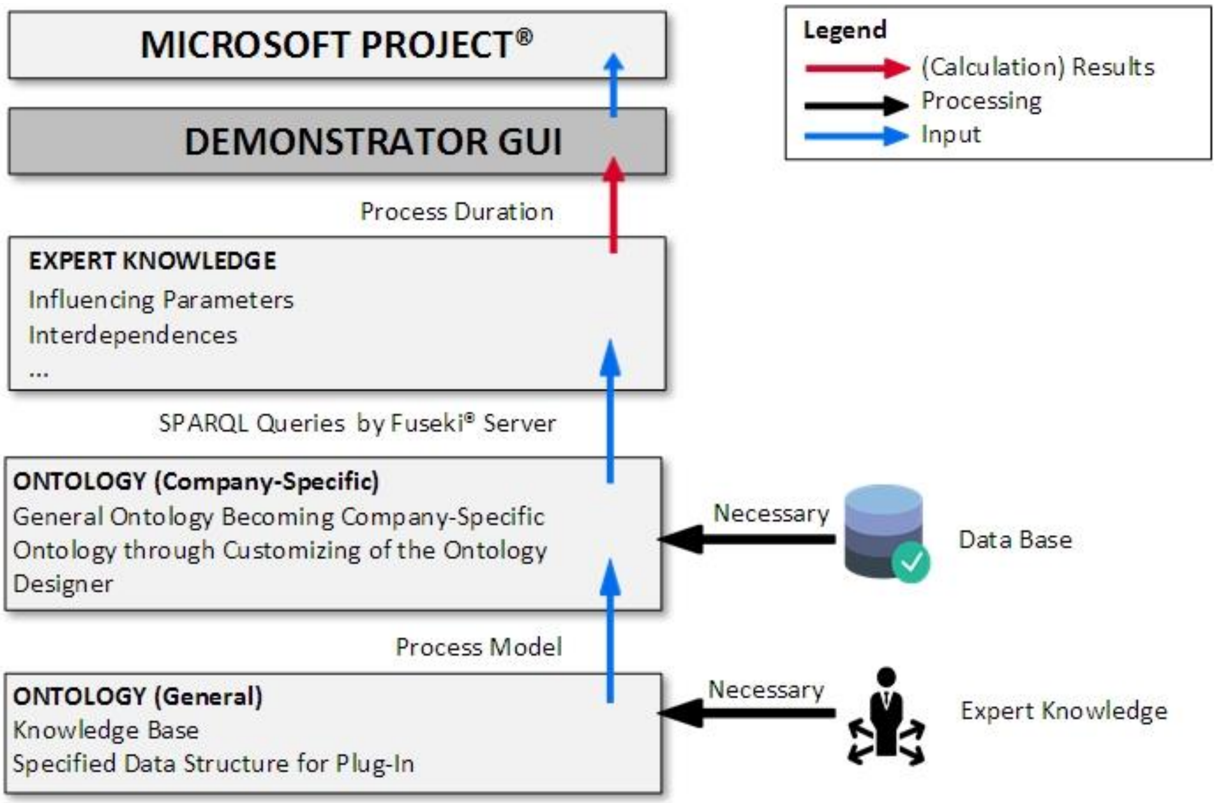


Figure 21: System architecture of the demonstrator

and their interdependences. To display this output (enriched with expert knowledge, red arrow) a user-friendly graphical user interface (GUI) represents the new calculations in Microsoft Project®.

Compared to Figure 14, the newly, more precize forecasted duration of the transport process is automatically adjusted in the Gantt chart in Microsoft Project® and labelled with an orange cell (see Figure 22). The duration of the other logistics processes in the arrival area is also forecasted using the demonstrator and marked with a label as well. This example shows a way to forecast the duration of logistics processes based on expert knowledge.

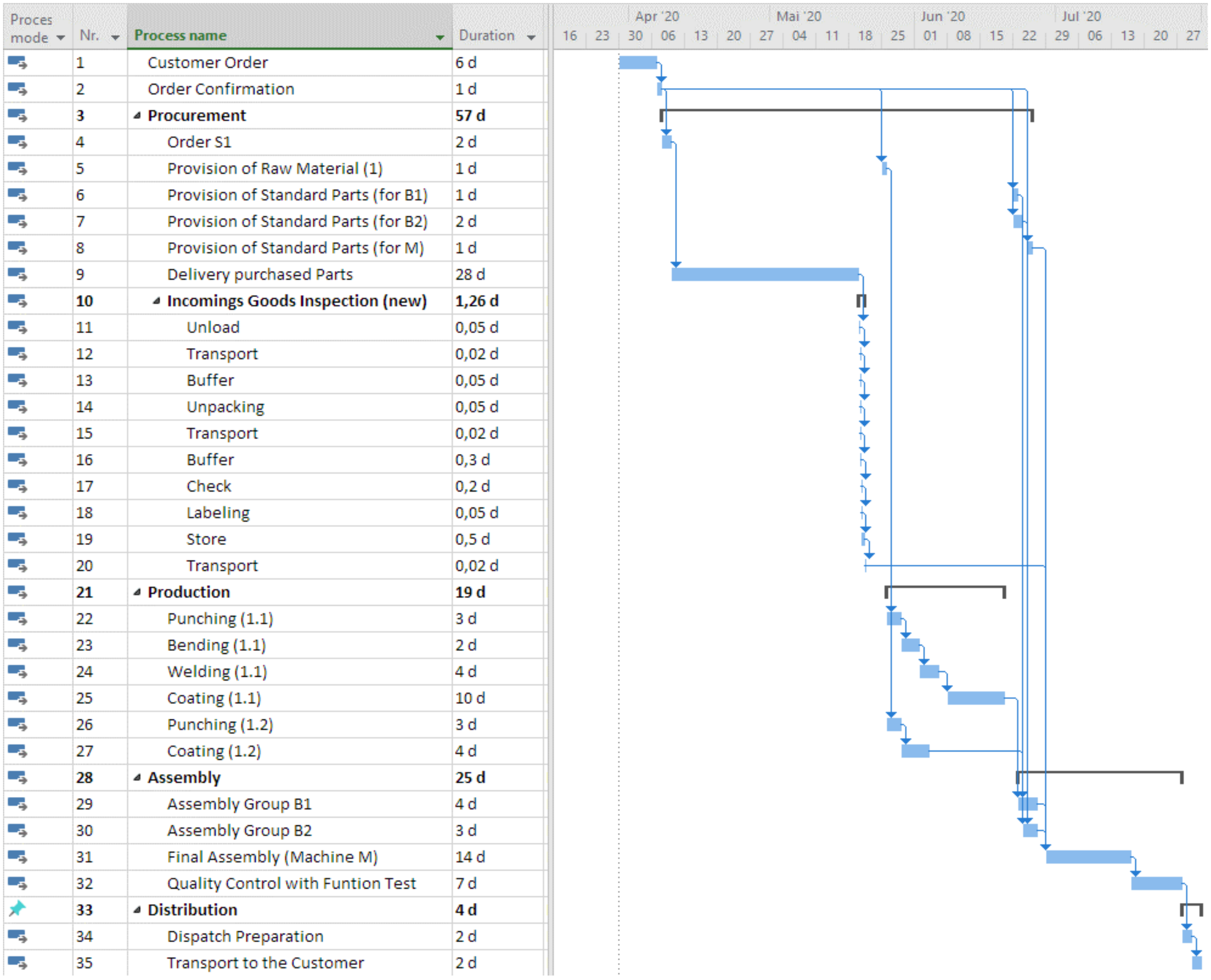
Previously, the process in the arrival area was only calculated reflecting the incoming goods inspection with a large time buffer. However, planning the individual logistics processes more precisely improves the project management. The project manager no longer needs the large time buffers, and instead has logistics processes planned in detail, which leads to a reduction in the overall lead time. Whereas the final assembly previously had to wait for project-specific purchased parts according to the project plan in Figure 14, now the internal processes do not lead to a delay at all. This means that final assembly can be carried out earlier and the machine can be delivered to the customer earlier.

In addition to the planning of the transport processes presented here considering the influencing parameters, all further logistics processes are to be planned in the same way, since the parameters that are in the ontology ensure transferability to the logistics processes assigned to the category.

Evaluation of the method:

A guideline for conducting individual interviews has been developed for the evaluation. This guideline focuses on checking the usability for SMEs in terms of plausibility, applicability, and relevance of the plug-in for their own company. This assesses the acceptance of SMEs for the use of the support tool in project planning. Most of the questions are rated on a scale of 0 to 10, where 0 stands for "does not apply at all" and 10 for "fully applies". If the expert cannot make a statement, the question should be answered with a cross at "no answer". In addition, the questions provide the opportunity for a brief justification of the decision. For a better overview, the quantitative results from the continuous recording scale are summarized in four groups of equal size.

A total of eleven fully completed questionnaires are analyzed as part of the evaluation. The respondents are working in leading positions, are familiar with the course of the project and the project results due to their participation in the project-accompanying committee and answer the questions from their practice-related point of view. Since the evaluation took place in the context of the overall project evaluation (see [68]), only three questions are presented and discussed below in the context of the ontology:



Proces mode	Nr.	Process name	Duration
	1	Customer Order	6 d
	2	Order Confirmation	1 d
	3	Procurement	57 d
	4	Order S1	2 d
	5	Provision of Raw Material (1)	1 d
	6	Provision of Standard Parts (for B1)	1 d
	7	Provision of Standard Parts (for B2)	2 d
	8	Provision of Standard Parts (for M)	1 d
	9	Delivery purchased Parts	28 d
	10	Incomings Goods Inspection (new)	1,26 d
	11	Unload	0,05 d
	12	Transport	0,02 d
	13	Buffer	0,05 d
	14	Unpacking	0,05 d
	15	Transport	0,02 d
	16	Buffer	0,3 d
	17	Check	0,2 d
	18	Labeling	0,05 d
	19	Store	0,5 d
	20	Transport	0,02 d
	21	Production	19 d
	22	Punching (1.1)	3 d
	23	Bending (1.1)	2 d
	24	Welding (1.1)	4 d
	25	Coating (1.1)	10 d
	26	Punching (1.2)	3 d
	27	Coating (1.2)	4 d
	28	Assembly	25 d
	29	Assembly Group B1	4 d
	30	Assembly Group B2	3 d
	31	Final Assembly (Machine M)	14 d
	32	Quality Control with Funtion Test	7 d
	33	Distribution	4 d
	34	Dispatch Preparation	2 d
	35	Transport to the Customer	2 d

Figure 22: Gantt Chart in Microsoft Project® using the demonstrator

Question 1: How do you evaluate the assistance that the duration of logistics processes is secured via calculation rules considering the determined influencing parameters?

Figure 23 shows the evaluation of the answers to question 1. Seven experts rate the assistance provided by using an ontology as (very) positive. They can imagine using the methodology to estimate the duration of transport processes more reliably by considering influencing parameters. Five experts evaluate the calculation rules as practicable with hurdles (value group 5-7.5). Possible reasons for this rating are the complex implementation and integration into the

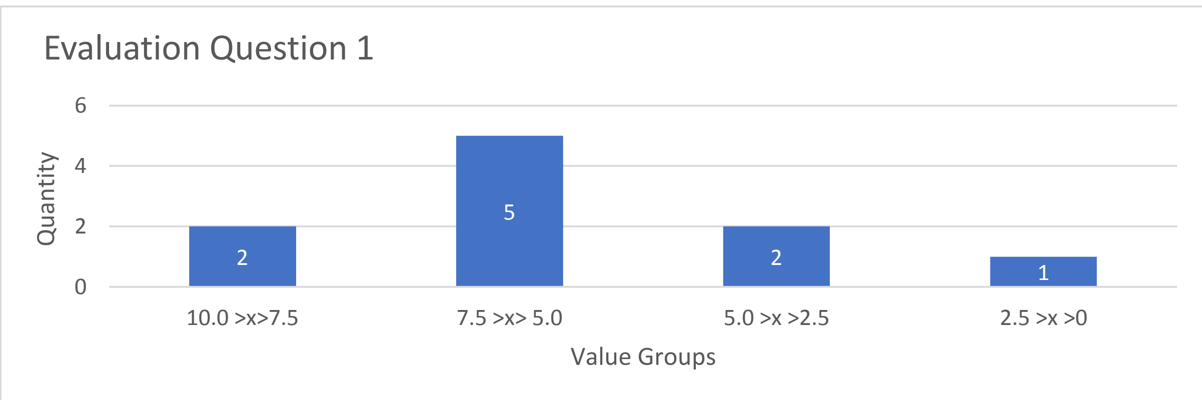


Figure 23: Evaluation question 1

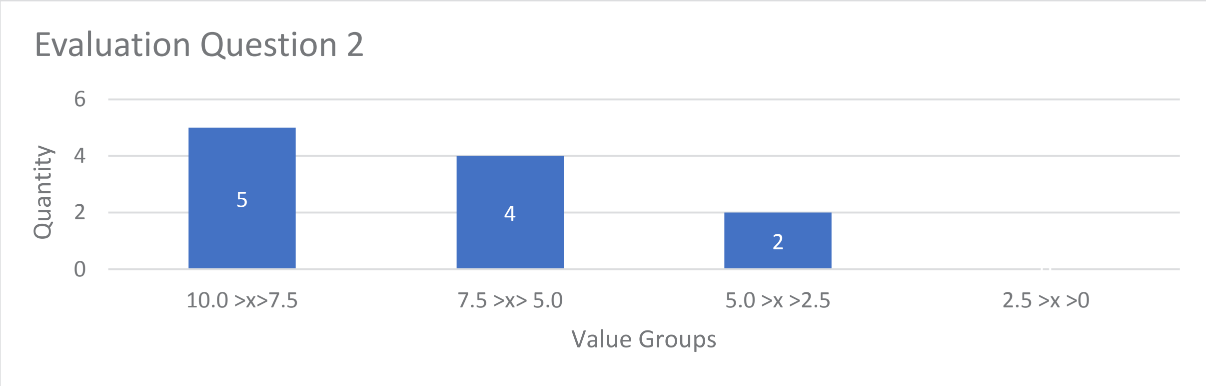


Figure 24: Evaluation question 2

existing IT infrastructure. However, the inclusion of the influencing parameters is considered very useful and does not pose a problem for the application. As a suggestion to improve the assistance given by the tool, the experts added that the results should be compared with practice in further use and thus "fine-tuning" of the influencing parameters would be possible. Since logistics processes only take up a very small proportion of the lead time, the wish is expressed at this point that the methodology could also be applied to other areas, such as manufacturing.

Question 2: Is the result transparent and comprehensible?

Figure 24 shows the evaluation of the answers to question 2. Nine out of eleven experts rated the presentation of the results as at least "positive". They mention that the results are mostly comprehensible, and for the most part even very transparent and comprehensible. Only one expert, in negative feedback to the evaluation question, noted that in the use case the path from data entry to the result was not transparent. Nevertheless, the remaining experts have confidence in the results due to the high level of transparency and can imagine using the calculation rules.

Question 3: Can you imagine acquiring and applying the know-how for customizing the company-specific ontology?

The evaluation of the answers to question 3 is shown in Figure 25. Six out of eleven experts cannot imagine the application of a company-specific ontology, four experts answer the question in the affirmative and one expert does not want to give any information. According to the experts, the main reason for the mixed feedback is the very high effort required for integration into the existing IT infrastructure and manual maintenance of the ontology. In addition, the high effort required for data entry is mentioned, but this is only demonstrated prototypically for the use case using Microsoft Excel® lists. The experts can imagine an application in principle as an assistance tool if there

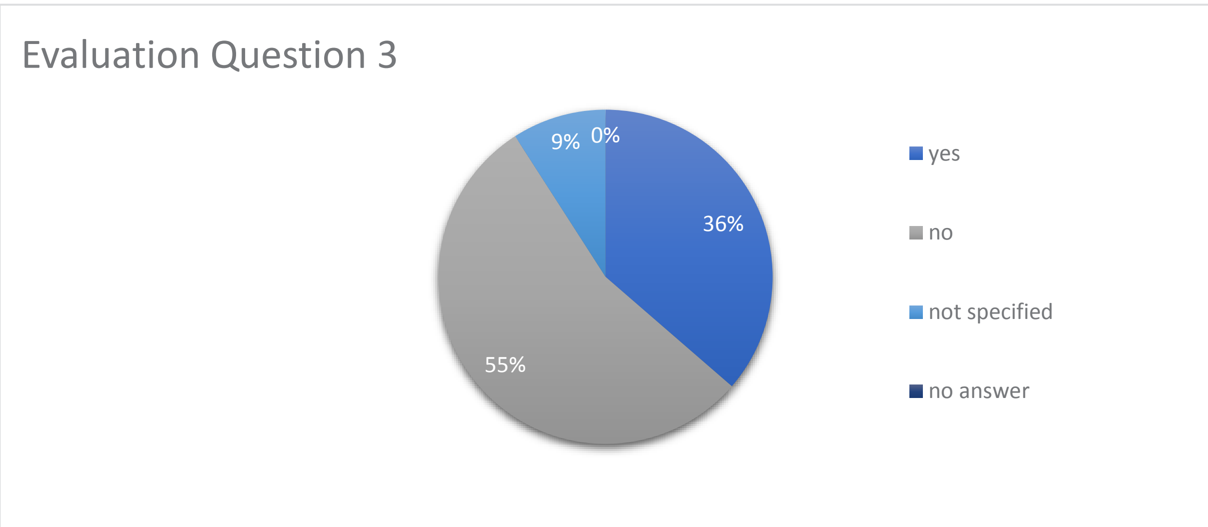


Figure 25: Evaluation question 3

were a higher degree of automation overall, e.g., for extending the ontology for continuous maintenance of current information, and if it would be possible to link it to existing information systems. The automatic adaptation into an existing IT infrastructure shows further need for research.

Due to its high complexity, the topic of ontology represents a high barrier to entry. As a result, there has been too little acceptance of ontologies in the commercial environment for them to be of interest or relevance to SMEs. In addition, the experts do not see the application of the methodology as suitable for SMEs, since SMEs often have a shortage of personnel and do not have specialists available with the necessary knowledge to use it. The ratio of benefits to costs cannot be assessed directly either, as the costs for various complex products are very different and are even considered impractical for products with extensive bills of materials. Nevertheless, the experts can in part imagine acquiring and applying the know-how for customizing the company-specific ontology if sufficient capacity is available in the company.

The evaluation results indicate that the methodology adds value to the planning of logistics processes and that there is interest in such a planning aid, but that the hurdles for implementation in SMEs are very high. In summary, the consistent application of the methodology promises an improved planning of the overall project duration. Improvement means that the process duration can either be reduced or increased, because previously unnoticed influencing parameters are included in the forecast. I.e., an increased process duration can also be considered as an improvement, as it is more accurate. The more accurate estimation leads to a reduction of time buffers in each individual process step and thus also in the overall project duration. However, the methodology can also be applied flexibly to individual company divisions and lead to improved planning reliability within these divisions. Consequently, the planning risk is reduced by increasing planning reliability.

6. CONCLUSION, OUTLOOK, AND LIMITATION

The paper points out the necessity to forecast the duration of logistics processes in SMEs with one-of-a-kind production and discusses a new methodology using logistics reference processes, and ontology-based knowledge descriptions. The research results and the use-case show the applicability and the advantage of forecasting the duration of logistics processes for an efficient project management. A critical reflection of the research results points to the necessity of a sufficiently large readiness for the application of the methodology in an enterprise, for the maintenance of the ontology as well as the necessary information and data. In order to be able to implement the adaptation of the methodology to a specific company, method and process knowledge is required, which must first be acquired in individual cases and thus leads to delays in the introduction and subsequent application of the methodology in a company. The implementation of the initial solution in a company requires effort and an extensive ontology adaptation in individual cases. However, the integration into the IT infrastructure of a company leads to an increase in automation of the planning process and thus to a reduction of manual planning activities. If the ontology is maintained during the project, the effort decreases with each estimate carried out in the plug-in and the benefit increases associated with a more precise estimation. The application of the methodology is also costly in the initial company-specific solution, but the method effort decreases in later applications. The estimation results obtained by applying the method offers the same or better quality as the planner's estimate. The application of the methodology enables an estimation based on a secure planning basis, in the form of the presented ontology. In addition, the ontology ensures that the information is permanently available, and kept permanently up-to-date through maintenance. Thus, the project planner will always be provided with up-to-date knowledge, even if the planning expert of past projects is not available in the company or has left the company. The knowledge stored in the ontology is also available to future planners. Without the ontology, the company runs the risk of (permanently) losing essential project and process knowledge when the planner leaves.

In addition to the use of in-house expert knowledge, the use of historical data from past production projects to forecast the duration of logistics processes in current and future projects is of course a relevant approach of the methodology. The available version of the methodology is largely based on the application of expert knowledge. The data-based planning support is taken up, conceptually developed, and implemented. The developed methodology can serve as a driver for data-driven determination of the duration of logistics processes in project management for SMEs, and for the integration of novel technological concepts in project management. Throughout the entire project duration, the authors are in close exchange with the companies. A company survey has shown that historical data can in principle be used to forecast the duration of logistics processes, provided it has the required granularity and validity. This can be ensured by operations for the collection of logistics data during a project of one-of-a-kind production with the use of technology solutions (e.g. solutions for data identification, data acquisition, data transmission or data storage), which are not yet sufficiently implemented in most companies. Especially a more widespread implementation of Industry 4.0 standards could improve the data availability considerably, and therefore lessen the effort needed in applying the proposed methodology.

The currently available historical data is not sufficient for the integrated application of the methodology but is essential for the planning and operation of one-of-a-kind production. Consequently, the next research steps must ensure functional and suitable data collection methods for logistics processes for SMEs with this kind of production. The necessary data analysis methods are already integrated in the methodology; the more mature the data collection method is in the future, and the higher the availability of historical data is, the more precise the method will be in determining data-based forecasts. Furthermore, the paper consequently proposes various avenues for future research regarding ontology-based planning support, more precise forecasts of the duration of logistics processes, based on a well-founded set of methods, and sensitization to the benefits that consideration and analysis of logistics data can bring to a company.

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