D23.4 OMSE Management Principles for Tangible Assets (Final Edition)

Document Owner:	Manuel Hirsch (DITF-MR)
Contributors:	DITF-MR, PoLiMi
Dissemination:	Public
Contributing to:	WP 23
Date:	31.03.2013
Revision:	1.0

VERSION HISTORY

NO.	DATE	NOTES AND COMMENTS
0.1	07.01.2013	REVIEW STRUCTURE OF DELIVERABLE
0.2	13.01.2013	IDENTIFY UPDATE CANDIDATES & DRAFT
0.5	12.02.2013	UPDATE 1
0.8	27.02.2013	UPDATE 2
0.9	28.03.2013	READY FOR REVIEW
1.0	30.03.2013	UPDATED FINAL VERSION

DELIVERABLE PEER REVIEW SUMMARY

ID	Comments	Addressed (✔) Answered (A)
1	Please check the text for references to previous versions of this deliverable and update the content accordingly.	Typos corrected
2	METHONTOLOGY is used to build the OMSE ontology. It is not clear how the five steps were performed when creating the ontology.	Methontology refers to an *iterative* procedure; in this deliverable only the outcome of the method, not each detail of the actual execution of this method is outlined. However, according to Methontology, Performance Questions were deduced, existing ontologies were analyzed and partly re-used, TAO was build up evolutionary, feedback from end-users and expert was gathered, and prototypical implementations were evaluated against respective requirements (derived from Performance Questions).

TABLE OF CONTENTS

TABLE OF FIGURES

TABLE DIRECTORY

LIST OF ABBREVIATIONS

MSE	Manufacturing Service Ecosystem
MSEE	Manufacturing Service Ecosystem - the research project
MSP	Manufacturing Service Provider
OMSE	Open Manufacturing Service Ecosystem
OWL	Web-Ontology Language
RDF	Resource Description Language
TaaS	Tangible asset as a Service
TAO	Tangible Assets Ontology
USDL	Unified Service Description Language

1. Executive Summary

In accordance with the MSEE DoW, this deliverable D23.4 is a straight forward update of D23.3, comprising additional details on MSEE's Tangible Asset Ontology (TAO) elaborated in course of WP23. As a matter of fact, this document reports on the feedback from both, scientific as well as industrial MSEE partners that has been evaluated and finally integrated in TAO within the last six project months.

The final version of TAO – as discussed in this document but provided as prototype in D23.6 – takes on the idea of distinguishing tangible assets in industrial Ecosystems according to their input-output features into *objects* (no input/output but used as input/output) and *transformations* (being composed of objects hand having objects as input/output). Each real world tangible asset can be represented virtually as instance of TAO. For example, a real sewing machine in partner Bivolino's ecosystem can be formally described by the concept of TAO:Asset:Factor:Transformation:Joining:TextileSewingMachine. Even though TAO is considered to be final in MSEE, the ontology is open to be extended in order to meet domain-specific requirements later on, e. g. in context of other innovation-related ecosystems.

TAO is applied as part of the virtualization process, which is outlined in D23.1/2. Thereby, real-world tangible assets within an enterprise can be transformed into Tangible Assets as a Service to be communicated and further elaborated on Ecosystem level. In contrast to (in-/tangible) products, tangible assets do not 'live' on market level, but on ecosystem and organisational level. A similar fact holds for Tangible assets as a Service, in contrast to services, they 'live' on ecosystem and organisational level, not on market level. Consequently, Tangible assets as a Service can be used to compose 'real' services on ecosystem level so that 'real' services expose Tangible assets as a Service to the ecosystem's market. Prototypical outputs of this composition and transformation are detailed in D14.1 and D23.5/6.

According to the DoW, the idea of D23.4 is to provide a final update of D23.3 in order to derive a single thus comprehensive and final reporting document. Consequently, D23.4 comprises both, some further detailed results of D23.3 as well as additional contributions:

The **Tangible Asset Ontology (chapter 7)** has been completely re-worked due to feedback gathered from scientific as well as industrial MSEE partners. As **linkedUSDL got changed** recently, the conceptual link between TAO and linkedUSDL has been re-viewed and confirmed **(chapter 5.3)**. Furthermore, a detail re-analysis of state of the art **management principles for tangible assets** on Ecosystem level has again been deduced and evaluated against our approach **(chapter 4)**. In **chapter 6.1** additional state-of-the-art tools (deriving from MSEE) are taken into consideration in context of **semantic modelling** for tangible asset management. **Chapter 6.2.3** represents the fact, that D23.6 will cover concrete means for providing **ad-hoc asset composition (in-/tangible assets) features**.

LESSONS LEARNED

The changes and additional contributions in this deliverable – in comparison to D23.3 – are due to some lessons learned within the last six month:

- Chapter 4: State of the art Management Principles for tangible assets on Ecosystem level (like Supply Chain Management) have been analysed with respect to system theory and service-orientation principles. As a result, the need for a more holistic management approach for tangible assets on ecosystem level has been deduced. A service-driven concept on how to enable tangible asset management has been derived and further elaborated towards a comprehensive management approach, suggesting transforming real-world tangible assets into their virtual representation by means of Tangible Assets as a Service.
- Chapter 5.3: Linked USDL got updated by SAP non-MSEE employees. In this context the USDL:Resource got temporarily deleted; even though MSEE used this concept as its connection point to link TAO:Assets to the linkedUSDL core ontology. This is of course crucial to the success of the TAO sub-ontology. Taking into account the nature of semantic models and ontologies, it is however common practice, that models do change according to evolving requirements. As SAP's perspective on resources in linkedUSDL changed, the respective semantic model got updated accordingly and published. MSEE being a part of the linkedUSDL community got informed about that change via online notification (triggered by linkedUSDL website). As common practice in open source development projects suggests, discussions started on how to proceed: is it better to go back to a further state of linkedUSDL where the USDL:Resource concepts was still valid, or is it MSEE's obligation to rework the TAO ontology in order to still fit into the remaining linkedUSDL core. Both options were valid alternatives. Due to the strong necessity to link USDL-Services to their components – namely resources, the USDL-Resource concept was finally re-activated in the linkedUSDL core ontology. No change in MSEE'S TAO was needed.
- Chapter 6.1: Additional sematic tools were analysed with respect to their capability to model, handle, share, and further elaborate semantic models within online communities. In this context two to-be developed MSEE tools were considered explicitly: the SLMToolbox (Hardis) and the LinkedUSDL editor (SAP). While the SLMToolbox seems to be well suited to re-use already modelled and virtualized tangible assets, the LinkedUSDL editor appears to be extendible towards a fully fletched TAO-Instance-Editor, allowing MSEE partners to directly fill in data on tangible assets in order to generate Tangible Assets as a Service in USDL-like notation.
- Chapter 7: Due to the fact that non-semantic state-of-the-art IT-tools as used in e. g. WP26 and SP3/4 are struggling with multi inheritances within TAO outlined in D23.3; TAO in D23.4 no longer consists of two parts, namely TAO-Sections:
    - Quality-Section
      Here abstract qualities or characteristics that can be associated with arbitrary tangible assets are collected and formalized.
    - Asset-Section
      Here generic knowledge on all tangible assets is expressed.

  but has been re-worked in order to provide a flat hierarchy with linear inheritance from a core concept, called *thing*. This is a major change, due to which already published Tangible Assets as a Service had to be re-worked and re-published.

2. Introduction

This deliverable represents the final version of the Open Manufacturing Service Ecosystem (OMSE) Management Framework for Tangible Assets (D23.3/4). The findings outlined in this document derive from work performed in task T23.2 of WP23, which is about Management of Tangible Assets. This volume further elaborates and updates an initial version of semantic model of tangible assets, namely the Tangible Asset Ontology (TAO), which is a core element of the OMSE framework for the management of tangible assets in Ecosystems. This second volume focusses on completing the framework and updating preliminary findings, taking into account input and feedback to/from the virtualisation process (T23.1/.2.), the instantiations experience supported by industrial partners in SP6 (T23.3) and results of other SP2 work packages – in particular WP22 Management of Intangible Assets, led by Polimi.

The main outcome of this deliverable is a comprehensive ontology on tangible assets for key resources within the manufacturing domain, covered by MSEE (incl. predefined domain-specific attribute-sets), enabling management of tangible assets in OMSE.

2.1. Objectives of D23.4

The main objective of task T23.2 is to conceptualize and describe an Open Manufacturing Service Ecosystem (OMSE) Management Framework for the **management** of tangible assets. Therefore, in this deliverable D23.4 a top level perspective on tangible assets is captured, answering the core question "how can tangible assets be handled, communicated and shared, promoted, and combined in Manufacturing Service Ecosystems". An iterative approach is considered, decomposing this question into concrete sub-questions like:

- "How can multiple tangible assets be combined?"
- "How to find an adequate substitute for a damaged tangible asset?" or
- "Which details about tangible assets to publish on community and Future Internet level?"

Answers to these sub-questions leads to a formal representation of tangible assets by means of a domain specific ontology including dedicated attribute sets and rules (see Figure 1). This ontology is considered to be a dedicated means for supporting effective management of tangible assets. The TAO ontological structures reflect the potential use of Tangible Assets as a Service (TaaS) for operational activities (e.g. scheduling in production chain, re-scheduling due to deviations and disturbances (delay, low quality, machine breakdowns)), for tactical activities (e.g. for Virtual Enterprise formation also from a STEEP point of view), and for strategic questions.

The ontology has already been applied and will be further evaluated in at least two other tasks, namely in T23.1 to facilitate the virtualization of tangibles assets as well as in T23.3 to apply OMSE in MSEE use cases. Also cross-links to WP22 complementary findings about management of intangibles are outlined in the following.

2.2. Structure of D23.4

After a short introduction to the scope of this deliverable in chapter 2, the envisaged development of a domain specific ontology for tangible assets in manufacturing is contextualized with regard to the Open Manufacturing Service Ecosystem (OMSE) idea, as outlined in chapter 3. Chapter 4 provided additional context on how management of tangible assets is enabled on Ecosystem level. The final OMSE framework provides conceptual, technological and knowledge requirements for effective and efficient management of tangible assets by means of applied semantics in chapter 5. Special focus will be laid in chapter 5.3 on already existing taxonomies[1] on tangible assets in literature. Valuable contributions of already existing taxonomies are integrated towards a comprehensive semantic model on tangible assets in manufacturing. This is an iterative process, as described in chapter 6. The main outcome of this deliverable is outlined in chapter 7, where details on the Tangible Asset Ontology (TAO) are provided. Finally, a short conclusion as well as an outlook on future activities is drafted in chapter 8.

2.3. Crosslinks to other MSEE Work Packages

There are strong relations between WP23 and WP22, both addressing management principles for intangible and tangible assets. This document is only focusing on semantically capturing tangible assets.

| D23.3/4 focus |

Task / Aspect	T23.1 Virtualisation of tangible assets	T23.2 Open Manufacturing Services	T23.3 Application in Use Cases
Focus ★	Tangible Assets -> TaaS	Tangible Assets -> Tangible Asset Management in OMSE	Service Spec. -> Service Offer (& Implementation)
Concept	Assets: Tangible assets as production factors in Ecosystems	Activities: Tangible Assets in Open Manufacturing Service Ecosystems	Actors: ★ MicroFirms in OMSE provide **exemplary TaaS** in MSEE
Method	**Virtualisation** ★ Method for TaaS (using Taxonomy)	Combination of virtualised assets in OMSE, Key Questions	Apply Virtualisation Method for TaaS in Use Cases
Model & Tool	USDL (extension) for TaaS	**Taxonomy** of ★ Tangible Assets incl. IPR, evtl. STEEP	Use Case specific USDLs for TaaS

Figure 1: WP23 Approach and focus of this deliverable

Other inputs to this deliverable can be found in D11.1, as both deliverables are dealing with the notion of modeling artifacts within manufacturing ecosystems. However, there is a strict distinction between the scope of SP1 and SP2; in SP1 focus is put on market-level services, while SP2 builds up the bricks, namely, intangible and tangible assets as a Service on ecosystem level.

The Tangible Asset Ontology depicted in this deliverable is used in T23.3 to virtualize real-world tangible assets as Tangible assets as Services (TaaS) on ecosystem level. Details as well as practical examples on how TAO supports the virtualization process elaborated in D23.1/2. can be found in D23.5/6. In the context of chapter 5, a SotA on semantic tools is outlined, covering requirements about a semantic tool for MSEE that are constantly updated and handed over to SP1 in order to enable SLMToolBox to (partly) cover semantic modeling features (e.g. in a second development iteration in 2013).

[1] Taxonomies are specific types of ontlogies, while ontologies are semantic model that represent a certain domain of knowledge by means of concepts, attributes, relations and instances. Taxonomies use isA-relations between concepts to build up a (strictly hierachical) knowledge tree. In ontologies heterarchical structures are possible and applied in D23.3/.4's tangible asset ontology (TAO).

3. The Open Manufacturing Service Ecosystem (OMSE) framework

Management of tangible assets in an open MSE requests a consistent and comprehensive structure, which can deal flexible and open with always changing situations in Manufacturing Service Ecosystems, from the resource side, as well as from the market side. This implies the importance of a holistic framework for management of tangible assets.

Regarding the resource side, which is based on tangible (and intangible) assets, one potential application idea of the virtualised (and later servitised) assets can be described with the concept of mini-factories operated and managed by mini-enterprises. Mini-factories are small, virtually independent production entities with well-defined interfaces for input and output. Such mini-factories can be formed by a set of combined TaaS and offer the possibility for scaling-up by replication and re-combination of virtualised/servitised assets.

With such a concept e.g. the transformation from mass production to mass customisation can directly be supported. Due to the open and flexible possibility of combination of suitable resources for customised products demanded in a MSE, the concerned capabilities and capacities can be offered as requested. The customer proximity will be increased, also by a more direct involvement in the value creation process, which can be seen in the context of Open Innovation. Further findings will be described in later deliverables, also in those of WP25.

In this deliverable special focus is put on a conceptual-technological perspective in order to allow for effective and efficient management of tangibles in MSEs. From a WP23’s perspective, management of tangible assets in Open Manufacturing Service Ecosystems means to handle, communicate and share, promote, and combine tangible assets in an open and service oriented environment.

As already outlined in D23.1, the overall objective in OMSE is to transform real-world tangible assets of a MSE into TaaS by means of a virtualization method (D23.1/.2). This method needs to be accomplished with adequate categorization structures. As semantic models are prominent examples on how to accomplish holistic structures and facts on certain knowledge domains, this deliverable provides a respective OMSE Ontology to support the management of tangible assets in chapters 4-6.

In context of MSEE, TaaS can be offered online on Ecosystem level in a so called marketplace (see e.g. WP26 and SP3 activities). In this respect business relevant questions arise on three essential levels:

Strategic	• Where to find complementary production facilities? • How to set up logistics? • Which ware house strategy to apply? • Which material/machinery trainings to offer to employers? • What are the assets needed in an MSE? • What assets are missing or insufficient, obsolete or redundant? • Should one make or buy respective assets? • Which enterprises are strategic for my MSE?
Tactical	• Which expert to contact? • Which innovation method to execute? • Which machinery to further develop? • How to fix the machinery park layout? • How to formulate a demand of assets? • How to represent it and how to match it with the offer?
Operational	• Which material to use? • How to substitute a broken machine? • What is the status of production? • How to plan a production sequence? • How to define the shift plan? • How to find quickly a replacement for some shortage of assets in VME (holidays, strikes, failures, delays) by means of similarity?

Figure 2 Need for tangible asset management on operational, tactical, and strategic level

These questions are however beyond the scope of this deliverable and are therefore treated as part of an overall governance process for In- and Tangible assets as a Service in WP25. The governance services provided there shall use the following rules to reason on TaaS stored in the respective repository on Ecosystem level. However, it has to be mentioned, that it's the enterprise's responsibility to define adequate IPR levels, thus stadiums, per virtualized tangible asset.

Strategic	✓ Search (I)/TaaS repository ✓ Analyze which data on tangible assets is used in which order ✓ Optimize TaaS input-output-dependencies in Ecosystem ✓ Identify unsatisfied requests in TaaS repository ✓ Gather TaaS need in specific VME ✓ Reason on TaaS Governance Process ✓ Evaluate TaaS repository status ✓ Look out for similar TaaS in other enterprises, compare offer/requests
Tactical	✓ Search (I)/TaaS repository ✓ Analyze which data on tangible assets is used in which method ✓ Analyze unsatisfied requests in TaaS repository ✓ Optimize machinery input-output-dependencies in Ecosystem ✓ Post a request on the TaaS repository ✓ Semi-automatic matching via Tangible ontology
Operational	✓ Calculate similarity of TaaS, analyze which transformation can use which materials for input ✓ Calculate similar machineries in Ecosystem and request via TaaS ✓ Gather status of TaaS in process for a specific VME ✓ Calculate production plan based on TaaS input-output data ✓ Calculate schedule based on TaaS data on employers ✓ Search TaaS Ecosystem repository

Figure 3: Exemplary rules to be applied in TaaS governance processes in WP25

4. Enabling Management of Tangible Assets in OMSE

While Product or Service Life Cycles (P/SLC) apply a market oriented perspective on value creation from idea to final product/services, there are a number of disciplines that tackle the notion of managing the actual components of product/service – namely resources – in industrial consortia, e. g. Supply Chain Management (SCM), Network Management (NM) as well as Resource Planning and Scheduling (RPS).

SCM focusses on orchestrating networked organizations that are involved in well-coordinated activities targeting on composing respective resources (e. g. material, information, finances) in order to derive dedicated products/services as an output of an overall value-creation process. The common objective to govern all endeavours within an inter-organizational supply chain by building up e. g. virtual enterprises is considered to have a positive influence on increasing competitiveness by means of sharing responsibility, costs and risks (Stadtler 2005). Strategies to improve the performance of SCM are usually aiming at a better integration of affected organizations, enhancing communication and alignment mechanisms, and to streamline value-creation procedures. NM however, is more related to the organizational dimension of SCM, while RPS focusses on the actual orchestration and sequencing of activities as well as resources flows. As a matter of fact, these and other domain specific disciplines contribute dedicated perspective and problem-specific solutions (Lambert and Cooper 2000) rather than providing a holistic thus integrated approach on management of resources in value-creation consortia. To close this gap, the following paragraphs show how Cybernetics, Information Science, and Complexities Studies are contributing to a top-level approach that is driven by System Theory, implies service orientation and finally enables a holistic management of resources – namely tangible assets – in Manufacturing Ecosystems.

4.1. System Theory in Management

System Theory is well known for addressing the concept of management in industry by decomposing an enterprise as well as its Ecosystem into sub-systems that interact with each other as well as the environment (Beer 1962). This is where the theories of control and complexity studies come into play in order to allow systematic management of technical and non-technical sub-systems by means of information-related, financial, organisational, procedural, and technological parameters (Hirsch 2012). In this deliverable, focus is laid on management activities related to organisational and procedural manipulations of tangible assets within (Eco-) Systems. Therefore, the term management is decomposed into sub-activities that are further detailing the concept covered. According to literature, management in industries refers to an iterative and self-referential sequence of planning, execution, and control activities (Fischer 1992). In context of tangible assets this sequence can be further detailed into the following activities: identify, plan, decide, initiate, execute, monitor, assess, check, and update business-related action plans […] (Schubert 2008). Consequently, tangible assets management in MSEE is considered to be about

- identifying,
- handling,
- communicating & sharing, and
- composing

tangible assets.

Furthermore, tangible assets management needs to cover all three decisional levels in MSE, allowing for answering innovation-related questions in industrial consortia (see D11.1):

- Strategic: What are the assets needed in an MSE? What assets are missing or insufficient, obsolete or redundant? Should one make or buy respective assets? Which enterprises are strategic for my MSE?
- Tactical: To support the formation of a new VME from a MSE: How to formulate a demand of assets? How to represent it and how to match it with the offer?
- Operational: How to find quickly a replacement for some shortage of assets in VME (holidays, strikes, failures, delays) by means of similarity.

To conclude: The abovementioned requirements imply that tangible asset management should cover a system theory perspective on management in industries that furthermore features a multi-level access policy in multi-lateral Ecosystem environments and that covers the overall life cycle of tangible assets as well as respective compositions. State of the art concepts that fully cover these requirements derive from service orientation and applied semantics (Hirsch 2012).

4.2. Service-oriented Management of Tangible Assets in Ecosystems

In order to allow businesses to focus on their core competences even in context of globalized industrial Ecosystems, service-orientation plays a major role (Cherbakov et al. 2005). Service-orientation is a term deriving from information science, covering the idea of encapsulating certain functionalities on a specific level of abstraction within dedicated artefacts with well-defined interfaces but hidden internal details. Providing complex functionalities no longer means to build up a complex artefact from scratch but to manipulate and compose already existing – servitized – artefacts according to their input-output-dependencies. The resulting (complex) services are then provided on market level with regards to a service level agreement that treats business-related aspects like accessibility, price, feature descriptions and so on (Erl 2004).

In context of tangible assets management, service-orientation can be applied to transform real-world tangible assets into their virtual representation – namely Tangible Assets as a Service (TaaS) – in order to ease the management of respective assets on enterprise, Ecosystem and Future Internet level (see D23.2 for details). From a system theory perspective, Tangible Assets as a Service 'live' on ecosystem and enterprise level (provider system internally) and not on market level (provider system externally), like (real, business oriented) services. Consequently, Tangible assets as a Service can be used to compose 'real' services on ecosystem level so that 'real' services expose Tangible assets as a Service to the ecosystem's market. The following figure depicts this relation between Tangible Assets as a Service and 'real' services in context of management sub-activities.

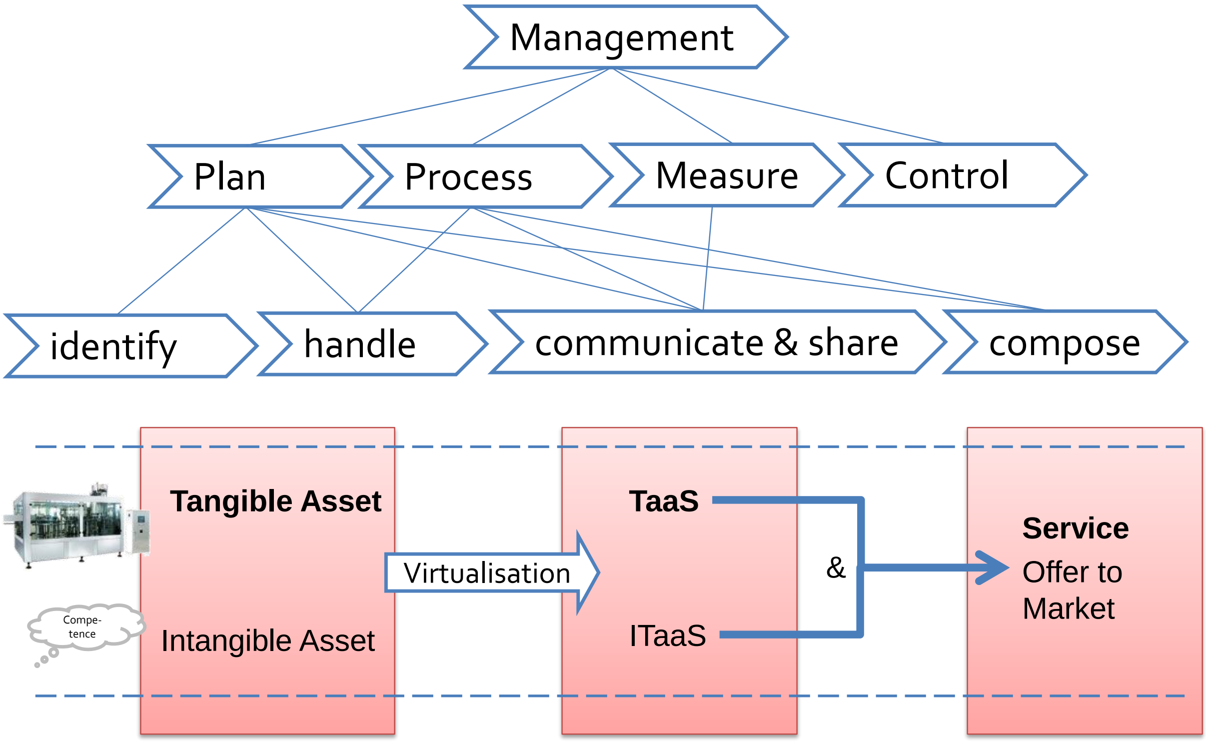

Figure 4: De-composition of the term management in context of a service-oriented approach for (in-) tangible asset management in Ecosystems.

In order to enable tangible assets management, semantic means – namely an ontology – can be applied to support handling, communicating and sharing, promoting, and combining of tangible assets. The herein developed OMSE Framework for management of tangible assets – in particular aiming at the deployment of manufacturing services – will offer generic design structures to collaboratively work on tangible assets within Ecosystems and to allow for integrating customer-specific configuration parameters later on. In addition, the OMSE virtualisation method (resulting from T23.1/.2) will be complemented with semantic features enabling a management of tangible assets, also on Ecosystem and FI level.

5. Conceptual foundation – applied semantics

Formal semantics and semantic models are widely accepted tools in industry and research. There are very different types of semantic representations, starting from a very low complexity and ending up with very strict formal semantics. In MSEE we want to focus on a middle-weight type of semantic model, namely taxonomies. A taxonomy is a hierarchical set of concepts incl. attributes, related by transitive isA- and/or equality-relations. Different (e. g. already existing) taxonomies can be cross-linked by means of e. g. equivalentClass-relations.
The following depiction relates taxonomies to other semantic models like UML models and formal ontologies.

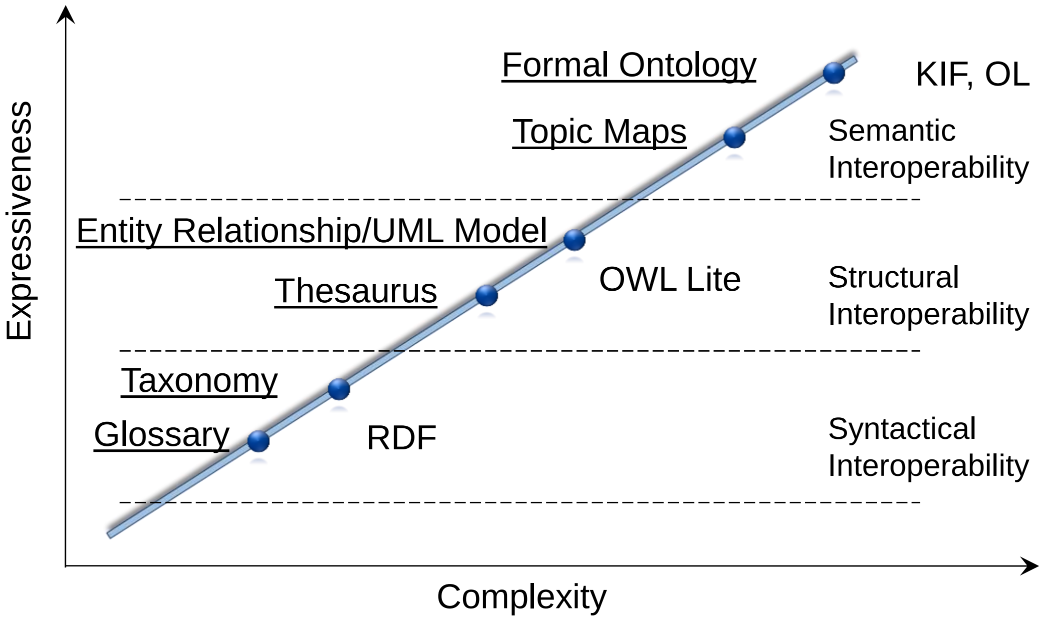

Figure 5: Comparison different types of ontologies

Ontologies can be represented both by textual as well as graphical models. The following figure shows how concepts, sub-concepts, instances as well as attributes and relations between concepts and instances can be modelled graphically.

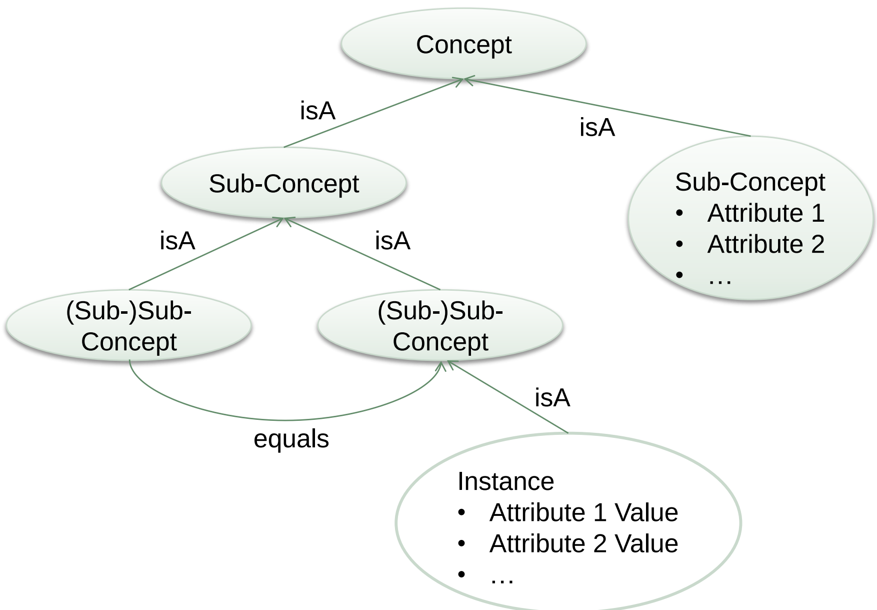

Figure 6: Principle of ontologies

The main reason for applying semantic principles can be found in a huge portfolio of prominent features of applied semantics (based on Hirsch 2012):

Table 1: Features of semantic models (ontologies) supporting the management of formalized tangible assets in ecosystems

Management of tangible assets in terms of…	***Respective features of applied semantics***
Identify	- Ontology Engineering methods guide enterprises as well as ecosystem representatives in identifying key assets to be formalized
Handling	- Gather knowledge on tangible assets - Structuring of information and knowledge on tangible assets - Enable formal description of tangible assets
Communicating and sharing	- Formal semantics are human and machine readable - Standardized languages are available, sharable formats provided - Integration of already existing semantical descriptions of tangible assets
Composing	- Semantic models provide easily manageable knowledge containers - Rule-based evaluation of knowledge bases and reason about implicit knowledge is possible - Easy match and merge of existing semantic descriptions of tangible assets
Distributing	- Ontologies are meant to be published and shared among partners within a certain knowledge domain that can be represented by means of an ecosystem - Ontological models are technologically well equipped to be stored and communicated online by means of web-based ICT tools

5.1. Technical support – management of taxonomies

There are several proprietary and free tools on the market for editing, visualizing, or transforming semantic models graphically or by means of textual manipulations. Due to the requirements of small and medium sized enterprises, in MSEE we try to provide freely available state-of-the-art open source tools. However, in case no adequate open source tool can be found, intermediary proprietary solutions can be applied. The following list of tools has been evaluated against our needs to handle semantic models efficiently and effectively. As a result, no state of the art tool fully reflects our need. Consequently, we are combine existing tools in terms of their features and are further elaborating these tools within MSEE.

Exemplary well-established as well as currently developed Sematic Tools are (according to online studies and on-work experiences):

Tool	***Type***	***Source***
Neologism	Open Source	http://neologism.deri.ie/
OntoStudio	Proprietary	http://www.semafora-systems.com/de/produkte/ontostudio/
Protégé	Open Source	http://protege.stanford.edu/
Web-Protégé	Open Source	http://webprotege-beta.stanford.edu/
SemanticWorks	Proprietary	http://www.altova.com/de/semanticworks.html
SLMToolbox	OpenSource	Applies TAO in order to re-use of virtualized tangible assets (as a service, from the TaaS repository)
USDLEditor	OpenSource	SAP tool to be extended in order to empower industrial partners to virtualize real-world tangible assets by means of a easy to use online tool that features TAO-compatibility

According to D23.1/.2, our aim is to virtualize tangible assets in context of manufacturing ecosystems, to eventually compose complex virtualized tangible assets, and to provide linkedUSDL-like descriptions. A criteria set for semantic editors in MSEE has been deduced from expert interviews within SP2 and SP1 as well as input from D15.2, where – among others – generic IT-service criteria are addressed.

Technical requirements:

- Architecture
    - **Accessibility**
      Depending on the foreseen usage, tools have to be accessibly online or as rich client by users or other IT systems.
    - **Interoperability**
      As it is most likely that a set of tools will be promoted within MSEE, interoperability between these tools has to be guaranteed
- Features
    - **Language**
      The tool should be able to handle OWL and RDF files.
    - **Semantic principles**
      The tool should be able to reflect semantic principles such as namespaces, concepts, attributes, relations, inheritance of features, equivalence, instantiation, reasoning.
- Editing
    - **Building an ontology**
      The tool should allow for graphically editing of strict concept hierarchies (tax-

onomies), where concepts are related by means of an isA-relation. Furthermore Concepts need to be further detailed in terms of Attributes and Relations to other Concepts. The resulting ontology should lead to instances of a specific Concept, of Attributes with specific attribute Values as well as dedicated relations to other instances.

- **Updating the ontology**
  Furthermore the editor needs to be able to re-open existing taxonomies and allow for updating – not just visualizing – it.

- Importing/Merging
  - **Reusing existing external taxonomies**
    In order to be compliant with already existing taxonomies about manufacturing assets in literature and the internet, our tool should be able to import respective sources from a file system and/or URLs.
  - **Mapping**
    In case concepts of two different taxonomies are similar/equivalent, the tool should allow for modeling and formalizing equivalent concepts of different namespaces.
- Exporting
  - **Publishing**
    Semantic models should be published online, e.g. via html-based interfaces and/or rdf/owl-file repositories as well as USDL-like descriptions
  - **Model exchange**
    Models need to be stored in communicable formats to exchange knowledge and collaboratively elaborate the models via RDF/OWL files.
- User Interface
  - **Graphical modelling**
    The characteristic hierarchy of a Taxonomies should be depicted by the tool. Straight forward Concept/Attribute/Relation manipulations should be possibly by means of a graphical interface
  - **Textual editing**
    Advanced features should be provided by means of textual editing, programming, or configuration.

- Transforming
  - **Language transformation**
    The tool should be capable transform OWL, RDF, and other XML-based languages for semantic models from one to the other.
  - **USDL compatibility**
    As the targeted format for representing Tangible assets as a Service in MSEE is USDL, the tool set should be able to process USDL-like formats.

Non-technical Requirements

- Availability and Usability
  - **Costs**
    As mentioned above, we are aiming at providing open source tools within MSEE. However, in order to generate these tools, proprietary tools might be applied first.
  - **Training**s
    Tutorials have to be provided online and in course of hands-on workshops in order to train MSEE partners in adequately using the tools provided.
- Additional material
  - **Online help**
    Additional online knowledge repositories per tool might be provided

- **References and ratings**
  External references and rating of the respective tool will be evaluated in order to make the right choice

The result of our feasibility study is summarized in the following Tool Evaluation Matrix. The colours used in the matrix indicate crucial ratings: Requirements in **bold** are of specific interest in context of building up a top-level ontology on tangible assets in context of a research project (e.g. ability to extend and share the semantic model). Red fields mark very bad performance of the respective tool in terms of a certain requirement; green highlines excellent performance, while yellow marks indicate sufficiency. The classification is based on rating provided in the documentation of each tool, feedback from scientific and/or industrial experts, as well as hints from literature.

Tool / Requirement	Neologism	Onto Studio	Protégé	Web-Protégé	Semantic Works	USDL Editor	SLM-Toolbox
Accessibility	Online	Offline	Offline	Offline	Online	Online	Offline
Interoperability	Strict RDF import/ export	Flexible OWL, RDF Import, Export, e.g. from Protégé	Flexible OWL, RDF Import, Export, but not from Onto Studio	Flexible OWL, RDF Import, Export as XML	Flexible OWL, RDF Import, Export, but not from Onto Studio	Exports xml/rdf to be integrated in other semantic tool	Strict incorporation of pre-defined rdf structures as none-semantic feature
Language	OWL, RDF, not really standardized	OWL, RDF, not really standardized	OWL, RDF, not really standardized	OWL, RDF, not really standardized	OWL, RDF, not really standardized	OWL, RDF, not really standardized	No support of semantic modelling
Semantic principles	Rudimentary, focus on visualisation	Sufficient, but no multi-inheritance of e.g. attributes, relations	Very sufficient, but no real time error check while modelling	Rudimentary and no real time error check while modelling	Rudimentary, focus on visualisation	Rudimentary, focus on visualisation	Rudimentary, focus on re-using already existing semantics
Building a ontology	Rudimentary	Sufficient	Sufficient	Sufficient	Rudimentary	Not possible	Not possible
Updating the ontology	Rudimentary	Sufficient	Sufficient	Sufficient	Rudimentary	Rudimentary	Not possible
Reusing taxonomies	Sufficient	Sufficient	Sufficient	Sufficient	Excellent fit with XSLT-Transformation tools	Sufficient	Sufficient
Mapping	Rudimentary		Sufficient	Sufficient	Rudimentary	No	No

Requirement \ Tool	Neolo-gism	Onto Studio	Protégé	Web-Protégé	Seman-tic Works	USDL Editor	SLM-Toolbox
Publishing	Rudi-mentary	Suffi-cient	Suffi-cient	Rudi-mentary	Suffi-cient	Suffi-cient	Suffi-cient
Mod-el Exchange	OWL, RDF, not really standard-ized	OWL, RDF, not really standard-ized	OWL, RDF, not really standard-ized	OWL, RDF, not really standard-ized	OWL, RDF, not really standard-ized	OWL, RDF, not really standard-ized	Proprie-tary
Graph-ical modelling	No	Yes	Yes	Yes	Partly	No	Yes, nut not se-mantics
Textual editing	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Lan-guage transform ation	No	Yes	Yes	Yes	Partly	Partly	Not yet
USDL compatib ility	No	Yes	Yes	Yes	Partly	Yes, fully covered	Not yet
Costs	Open Source	Proprie-tary	Open Source	Open Source	Proprie-tary	Open Source	Open Source
Trainings	Some are already available	Some are already available	Some are already available	Some are already available	Some are already available	Some are already available	Some are already available
Online help	No	Yes	Yes	Partly	Yes	No	No
Ratings	None	Top, industry	Top, scientific	Top, scientific	Medium, industry	Medium, scientific	On-going evalua-tion
Evaluation	**Good for visuali-sation and ap-plication of exist-ing tax-onomies**	**Excel-lent for editing taxono-mies**	**Excel-lent for editing taxono-mies**	**Backup tool**	**Excel-lent only for data manipu-lation**	**Excel-lent only for data manipu-lation**	**Excel-lent only for data manipu-lation**
Application in MSEE	**Present-ing RDF taxono-mies online and in-stantiate real-world tangible assets**	**Back-stage usage in order to prepare and share the on-tology**	**Main tool in MSEE for edit-ing, im-porting, mapping taxono-mies**	**Not ap-plied in MSEE**	**Back-stage usage in order to trans-form ontology**	**Applied to fill in real-world tangible assets data**	**Applied to re-use already defined semantic struc-tures as well as TaaS**

Consequently, in MSEE we restrict ourselves to apply open source tools Protégé (rich client) as well as USDLEditor to fill in data by the end-users and SLMToolbox to re-use already existing semantics as well as TaaS in MDSEA models (see SP1).

From the above mentioned SotA, requirements about a semantic tool for MSEE were deduced and handed over to SP1 in order to enable SLMToolBox (resulting from SP1) to (partly) cover semantic modeling features (e.g. in a second development iteration in 2013). MSEE Partner Hardis already assesses potential extensions of SLMToolBox.

5.2. Methodological requirements for management of tangibles in OMSE

In addition to the abovementioned technological requirements to the process of ontology development, there are two types of methodological requirements to be fulfilled by the MSEE ontology itself, general ones and domain specific ones.

As a set of general requirements, top-level criteria and requirements for taxonomies are listed here after. According to Dietz (2006) and Gruber (1993), semantic models need to be coherent, appropriate, consistent, precise, generic, and extendable. In context of semantic models, coherent and consistent means that all semantic statement must form a logical theory with no contradictions. In addition, models have to be appropriate for their intended use, covering only problem relevant concepts and attributes. The final model has thus to be precise in a sense that it abandons embellishments. The most crucial requirement is given by demanding a generic model, that builds a good representation of the respective knowledge domain and that can in principle be re-used in other applications within this vey domain.

Domain specific requirements for OMSE Ontology on tangible assets are formulated in terms of Key Questions (KQ) 1-3 to be answered by this ontology. According to Grüninger and Fox, Key Questions are most appropriate guidelines for iterative development of semantic models (like TAO) (M. Grüninger and M. Fox 1995).

Key Questions for TAO are derived by decomposing the core question: “How to manage tangible assets?”. Managing tangible asset means to handle, communicate & share, and combine them. Consequently, Sub-Questions to pose are as follows:

- “How can tangible assets be **handled**,
- **communicated and shared,** and
- **combined** in Manufacturing Service Ecosystems?”

These TAO Sub-Questions (and groups of Suib-Sub-Questions) can be expanded as follows:

- Management of tangible assets
  - **Handling** (SQ1)
    - ***Describing***
      “How can arbitrary tangible assets be adequately categorized, described, and specified by means of types of tangibles, attributes, and feature descriptions?”
    - ***Storing***
      “How can real-world tangible assets be represented and stored virtually by means of a harmonized and homogeneous knowledge base about tangible assets?”
    - ***Substitution***
      “How can damaged, busy, or not available specific tangible assets be substituted by another tangible asset within the Ecosystem?”
  - ***Communicating*** and ***Sharing*** (SQ2)
    “Which details about tangible assets to publish on community and Future Internet level?”
  - ***Combining*** (SQ3)
    “How can multiple tangible assets be composed?”

The abovementioned Key Questions will be used as guidelines in chapter 0 in order to build a domain specific MSEE ontology on management of tangible assets in manufacturing.

5.3. SotA of existing taxonomies for tangible assets

As a starting point for building a domain specific ontology for enabling management of tangible assets in manufacturing ecosystems, the following existing Taxonomies on business goods and factors as well as other resources in industry and research have been analyzed and partly reused later:

Label	**Semantic Model**	**Core Concepts**
PSL	Process Specification Language	Process, object, agent, time
CYC	enCYClopedia	Process, Script, Scene, Role/Participant
eClassOWL	eCL@ss Product Specification	Product
UNSPSC	20800	
eOTD	ECCMA Open Technical Directory	Individual, Organization, Location, Goods, Services, Rules, Regulation
PRONTO	Organisational perspectives, document management	People, Organisation, Location
foaf	Friend of a Friend Ontology	Person
sioc	Semantically interlinked Online Cummunities	UserAccount, Post
MSDL	manufacturing Service Description Language	MetalProduct, Material, Physical Resource, Actor, Service
USDL	Unified Service Description Language	Service, ServiceModel, Resource, Pricing, ServiceLevelAgreement
EID	Electronic Data Interchange	Format
IMKS	Interoperable Manufacturing Knowledge Systems	ManufacturingResource, Manufacturing Method
NACE	Nomenclature statistique des activités économiques dans la Communauté européenne	Product, Service
OWL	Web Ontology Language	Meta-Ontology
EO	Enterprise Ontology	Activity (Event, Capability, Skill, Resource Allocation), Organisation (Person, Machine, Asset, Stakeholder), Strategy (Ojective, Risk), Marketing (Sale Offer, Customer, Sale Price, Market Need), Time (Time Intervall, Time Point)
GR	Good Relations	ProductOrService, Location, Offer, LegalEntity
PTO	Product Type Ontology	Product Sub-Concepts
TRIZ	Method for inventive problem solving	Agent, Activity, Products, Market, Employees, …
DOLCE	Descriptive Ontology for Linguistic and Cognitive Engineering	Physical object, feature, amount of matter, set
CIO	Collaborative Innovation Ontology	Thing, Abstract, Asset, Actor, Activities, Fluents

Concepts in these ontologies – thus namespaces – can be distinguished by the following syntax:

<NAMESPACE>:<Concept>.<attribute>

Single attributes might be referred to as

<NAMESPACE>:<attribute>,

given that each attribute is unique in each namespace. Sub-Concepts – being related by a transitive isA-relation – can be formalized as

<NAMESPACE>:<Concept>{:<Sub-Concept> }^{n}

Instances are described as

<NAMESPACE>:<Concept>::<Instance>>

with attributes and value:

<NAMESPACE>:<Concept>::<Instance>>.<attribute>=<Value>

5.3.1. PSL – Process Specification Language

According to online sources, the Process Specification Language (PSL)[2] is a set of logic terms in first order logics[3] used to describe arbitrary processes. The terms are specified in an ontology that provides a formal description of the components and their relationships that make up a process. The ontology was developed at the National Institute of Standards and Technology (NIST), and has been approved as an international standard in the document ISO 18629. PSL facilitates the representation of manufacturing, engineering and business processes, including production scheduling, process planning, workflow management, business process reengineering, simulation, process realization, process modelling, and project management. In the manufacturing domain, PSL's objective is to serve as a common representation for integrating several process-related applications throughout the manufacturing process life cycle.[4]
Key concepts of PSL are: PSL:Object, PSL:Activity, PSL:ActivityOccurence, PSL:TimePoint (M. Grüninger, Atefi and M. S Fox 2001) that up to now cannot be covered by the TAO:Tangible sub-tree of MSEE ontology:

- PSL:Activity: A type of action, e. g. install-part, which is the class of actions in which parts are installed
- PSL:Activity-occurrence: An event/action that takes place at a specific time, such as a specific instance of install-part occurring at a specific timepoint
- PSL:Timepoint: A point in time, no intervall
- PSL:Object: Anything that is not a timepoint nor an activity

Tangible Assets in MSEE could be subsumed in PSL:Objects, however a dedicated TAO concepts like TAO:TangibleAssets better reflects the crucial importance of tangible assets in manufacturing ecosystems.

[2] http://www.mel.nist.gov/psl/psl-ontology/
[3] PSL uses CLIF: Common Logic Interchange Format
[4] http://en.wikipedia.org/wiki/Process_Specification_Language

5.3.2. CYC Ontology

In a process/planning ontology developed for the ontology Cyc[5], classes and relations above the ground level of PSL allow processes to be described purely at the type-level. The type-levels for the Cyc process ontology above this ground level use the following concepts:[6]

- CYC:Process: formalized as a script
- CYC:AggregateProcess – a process at a level above that of a single episode of a process, to represent the numbers of participants in an action by ranges of integers and qualitative values like few or many
- CYC:Script:a typical pattern of events that can be expected to re-occur a script has subevents, which means that scripts are composite events
- CYC:Scene: A sub-event of a CYC:Script
- CYC:Roles/participants – specifies types of actors and objects that may play in the script or scene
- CYC:Conditions: precondition(s) that must be true for a scene (event) to be executable, and postcondition(s) (effects) that must be true after a scene
- CYC:Repetition: the number of repetitions of a process may be known, or may be unspecified, or may be repeated until a specific condition is true Properties of ordering and constitution of repeated subevents for composite processes:
    - CYC:Begin-Ordered: subevents start at distinct time points that are totally ordered
    - CYC:End-Ordered: subevents end at distinct time points that are totally ordered
    - CYC:EndsBeforeEnd: subevents end before or at the same time as subevent instances which start before them
    - CYC:Sequential: no overlapping subevents
    - CYC:Terminating: there is a subevent after which no other subevents begin, and since all activities have a begin and end point, there is a time point at which the process ends
    - CYC:Uniform: all subevents are of the same event type
- CYC:Identity: The identity of participants in a process, that actor(s) or object(s) playing a role in one scene or repetition are the same as those in another scene or repetition, is represented by constraints on possible participants

Leaving the notion of processes and timepoints to other WPs within MSEE, TAO for tangible assets takes on the core concepts of CYC (CYC:Process as TAO:Activity, CYC:Role/ Participant as TAO:Actor) and adds containers for business-related assets like TAO:Factor::TangibleAsset.

5.3.3. eClassOWL

eCl@ss[7] is an international product classification and description standard for information exchange between customers and their suppliers. eCl@ss is characterised by a 4-level hierarchical classification system, each adding a 2-token prefix to the eCl@ss-code, forming an 8 character numeric code. In addition to the classification, eCl@ss provides for each class in the classification hierarchy a so-called application class, which is characterized by certain defined properties. eCl@ss covers about 25600 concepts! The eCl@ss data model is based on ISO 13584-42. From this model, TAO attributes for e. g. tangible assets as well as products can be derived (Hepp, Leukel and Schmitz 2007). However, a licence has to be purchased to use eCL@ss. Thus it's not fully applicable within MSEE and FI works. Still, essential concepts can be adapted within TAO ontology.

---

5 http://www.opencyc.org/doc
6 http://en.wikipedia.org/wiki/Cyc
7 http://www.eclasscontent.com/index.php?language=en&version=7.1

5.3.4. UNSPSC - United Nations Standard Products and Services Code

The United Nations Standard Products and Services Code (UNSPSC) provides an open, global multi-sector standard for efficient, accurate classification of products and services. Search the code on this website to locate commodity codes that can be used by companies (http://www.unspsc.org/). It's a huge database on classifications, lacking dedicated attribute sets per concept. Thus it might only contribute categorisation means to MSEE TAO ontology (http://www.unspsc.org/search.asp).

However, the numbers of concepts per branch is very different in UNSPSC. Of course, one cannot assume that all branches need the very same amount of entries, but this objection does not justify the order or magnitude found in current PSCS. As a summary, the total number of classes obscure that many of the branches are still very much incomplete, and potential users are advised to check the coverage of entries in their domain prior to adopting a PSCS PRONTO (Hepp, Leukel and Schmitz 2007).

5.3.5. eOTD

"The eOTD (ECCMA Open Technical Dictionary) is ISO 22745 compliant and similar to a normal dictionary with the exception that each concept, term and definition is given a unique public domain identifier by ECCMA (Electronic Commerce Code Management Association). This identifier allows companies to communicate accurately."[8] eOTD consist of about 60000 concepts, most on medical, dental (14000), but does not focus on in-/tangible parts of goods or services at all.

5.3.6. PRONTO - PROTON Ontology

"The PROTON Ontology (PROTo ONtology) is a basic upper-level ontology that contains about 300 classes and 100 properties, providing coverage of the general concepts necessary for a wide range of tasks, including semantic annotation, indexing, and retrieval of documents. Its design principles can be summarized as domain-independence light-weight logical definitions alignment with popular standards."[9] It covers:

- PROTO:People being too specific for our MSEE purpose of representing multiple actor types in manufacturing ecosystems.
- PROTO:Organization being again too specific. This concept has to be subsumed by TAO:Actor
- PROTO:Location is essential thus not relevant as concept. The attribute TAO:hasLocation will cover this issue.
- PROTO:Number
- PROTO:Date
- PROTO:Address will be covered as TAO attribute, TAO:hasAddress

5.3.7. FOAF - Friend of a Friend Ontology

"FOAF (an acronym of Friend of a friend) is a machine-readable ontology describing persons, their activities and their relations to other people and objects. Anyone can use FOAF to describe him or herself. FOAF allows groups of people to describe social networks without the need for a centralised database."[10] FOAF is used in linked USDL specification of SAP to refer to persons in context of service provision.

[8] http://www.eccma.org/whyeotd.php
[9] http://en.wikipedia.org/wiki/PROTON
[10] http://en.wikipedia.org/wiki/FOAF_%28software%29

FOAF (http://xmlns.com/foaf/0.1/) covers:
FOAF:Person and FOAF:Agent with attributes like FOAF:name, FOAF: homepage, FOAF:interest, FOAF:knows that links to other FOAF:Persons, and FOAF:Account

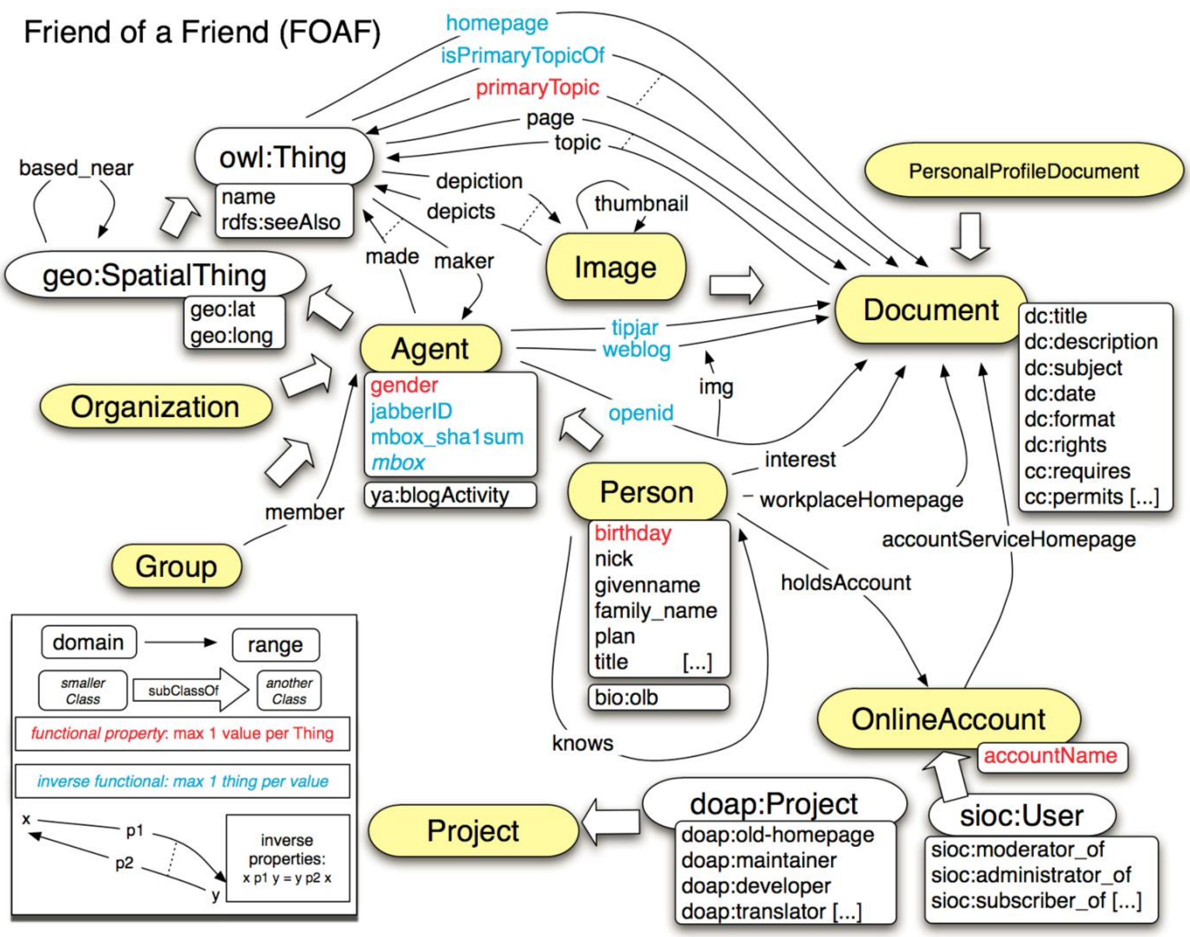

Figure 7: FOAF Specification[11]

5.3.8. SIOC - Semantically-Interlinked Online Communities

Online community sites (weblogs, message boards, wikis, etc.) are a valuable source of information and quite often it is a community site where you will end up when searching for some information. SIOC[12] provides semantic bridges between different web-communities.

The XML Namespace URIs that MUST be used by implementations of this specification are:

- http://rdfs.org/sioc/ns# - SIOC Core Ontology Namespace
- http://rdfs.org/sioc/access# - SIOC Access Ontology Module Namespace
- http://rdfs.org/sioc/types# - SIOC Types Ontology Module Namespace
- http://rdfs.org/sioc/services# - SIOC Services Ontology Module Namespace

SIOC's main concepts are:

- SIOC:Community representing an online community
- SCIOC:Item e.g. a SIOC:Post that comprises arbitrary pieces of information.
- SCIOC: Role and SIOC:UserAccount representing a user of a community, e.g. a real FOAF:Person or a FOAF:Account (see 4.4.7).

[11] http://magnetik.github.com/node-webid-report/img/foaf-spec.jpg
[12] http://rdfs.org/sioc/spec/

5.3.9. MSDL - Manufacturing Service Description Language

“The Manufacturing Service Description Language (MSDL) is a formal ontology for describing manufacturing capabilities at various levels of abstraction including the supplier-level, process-level, and machine-level. The concept and design of MSDL comes from the work of Farhad Ameri of Texas State University.“[13] It covers

- MSDL:Actor
- MSDL:Material like MSDL:Ceramic, MSDL:Composite, strong focus on MSDL:Metal, and MSDL:Polymer, which can be seen as sub-classes of TAO:Material as well.
- MSDL:PhysicalResources that can be linked to TAO:Tool and TAO:Machinery, like e. g. MSDL:CuttingTool and MSDL:DriveSystem
- Named MSDL:Products exposing MSDL:Materials.
- Named MSDL:Services, which is MSDL:enabled by MSDL:MachineTool and/or MSDL:hasMaterial MSDL:Material
- MSDL:SupplierProfil, which is similar to TAO:Actor, FOAF:Person with a specific role. MSDL:SupplierProfil.has:Service

However, no explicit linkage between MSDL:Service and MSDL:Product exists. In addition, no integration of intangible assets can be found in MSDL. Consequently MSDL is strictly focussing on manufacturing of metal substrates, even though it claims to be a generic manufacturing service description language. MSEE will use parts of MSDL and extend it towards a more holistic view on the manufacturing domain.

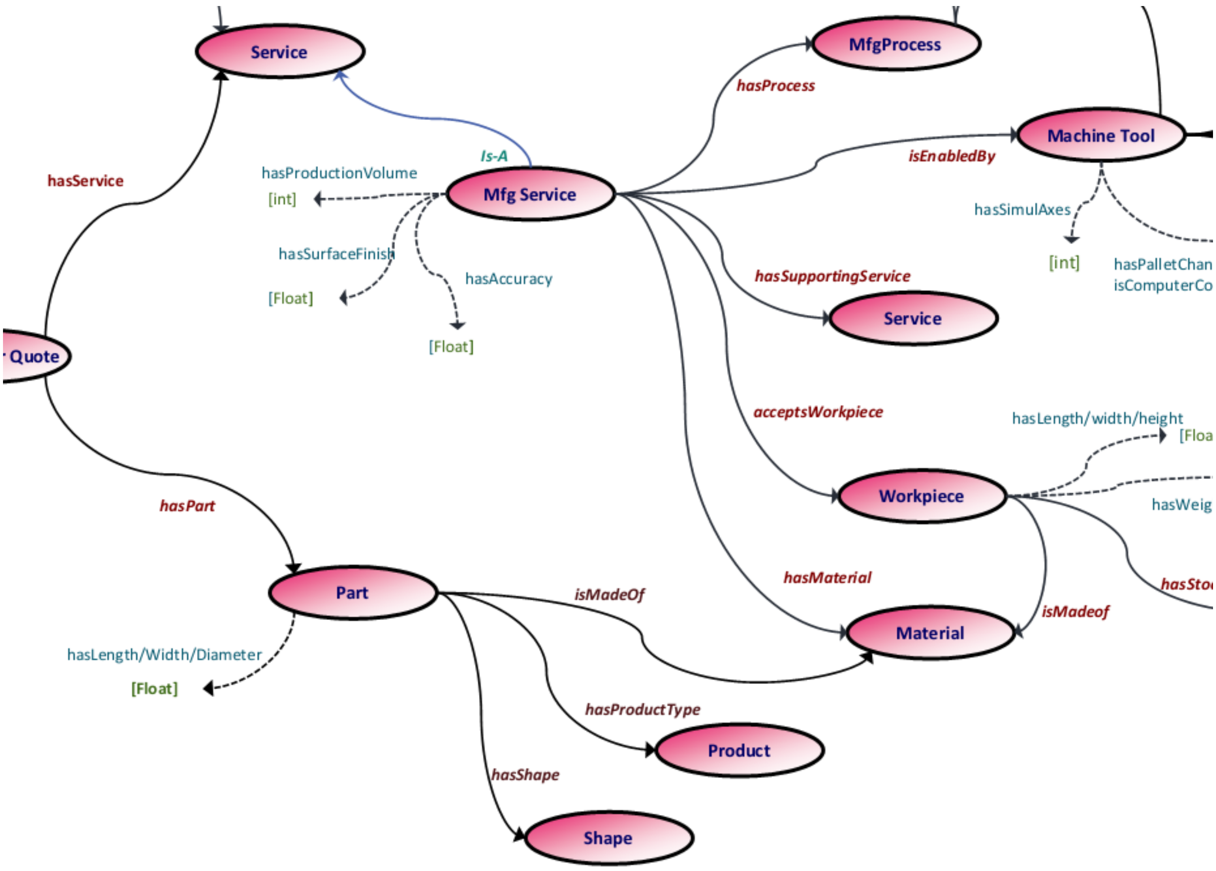

Figure 8: Part of MSDL Ontology, dealing with Services/Products based on tangible assets[14]

13 http://www.kirkman-enterprises.com/MSDL

14 http://www.kirkman-enterprises.com/sites/kirkman-enterprises.com/files/MSDL/Poster-MSDL.pdf

5.3.10. USDL - Unified Service Description Language

USDL is widely used in MSEE. Details on its structure, applications, and features can be found in SP1 Deliverable D11.5. In this document, USDL is seen as future container of formalized tangible assets. Consequently, there is no direct conceptual input from USDL, but a dedicated link to it. USDL can be used to model service offers on market level. Therefore USDL provides concepts for services, service interactions, costs, and exposed resources. USDL covers comprehensive means to detail service offers in terms of arbitrary business aspect. However, USDL does not allow for editing many details on e.g. specific attributes of the exposed resources.

Currently, there are about 10 core concepts covered by linkedUSDL, which is a lightweight online version of USDL. More details on specific aspects can be modeled by means of linked USDL extensions – namely USDL-Pricing-Extension and USDL-SLA-Extension. The USDL-Core ontology covers the concepts, *CompositeService*, *Condition*, *Fault*, *Interaction*, *InteractionProtocol*, *Parameter*, *Resource*, *Service*, *ServiceModel*, and *ServiceOffering*.
This is where TAO comes in. To link details on tangible assets described in TAO, tangible assets have to be conceptually linked to USDL:Resource. This is realized by setting up a equivalentConcept-Relation between USDL:Resource and TAO:Factors:TangibleAssets. The following figure depicts this linkage.

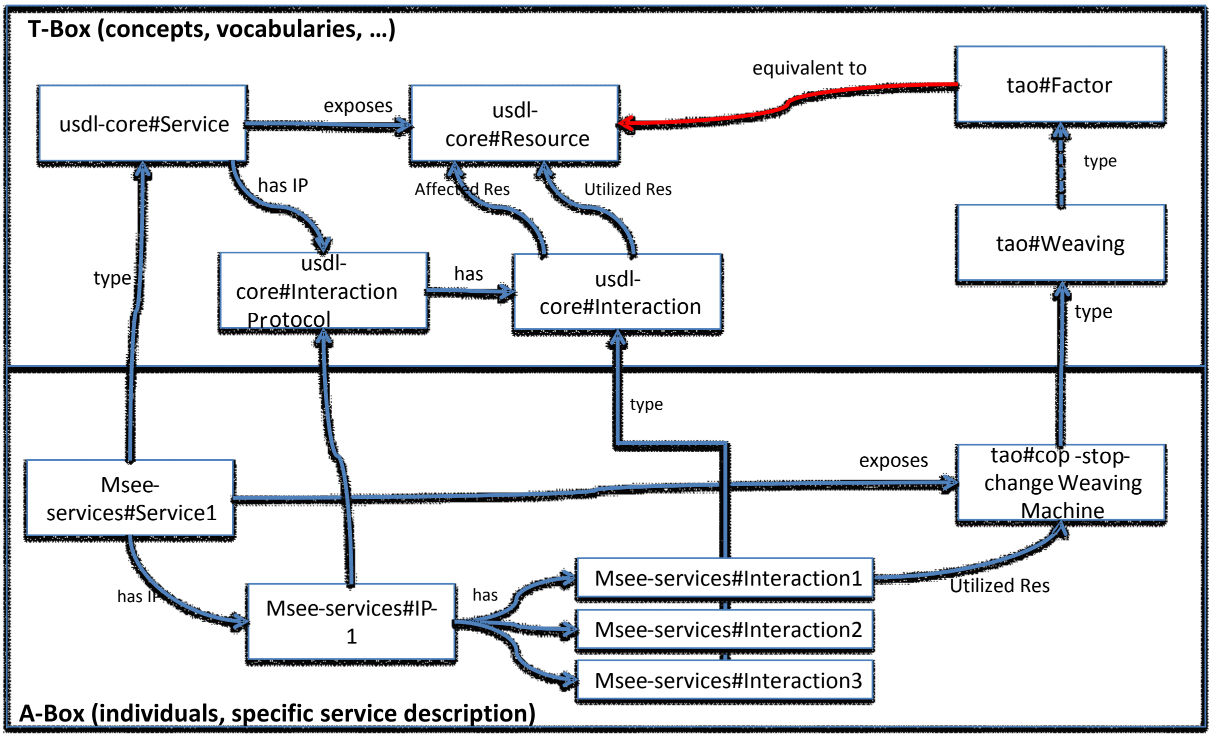

Figure 9: Linkage of USDL to TAO (source: DITF update of Engineering picture).

5.3.11. EDI - Electronic Data Interchange

EDI[15] or X12 provides a very generic schema for representing arbitrary data by means of EDI:DataSegment,, EDI:DataElement, and EDI:Format. It might be used in MSEE to ensure data-level interoperability of multiple online tools, repositories, and information systems.

15 http://www.wsmo.org/TR/d27/v0.1/20050621/

5.3.12. IMKS - Interoperable Manufacturing Knowledge Systems

The scope of IMKS[16] is on products from a design and manufacturing perspective including manufacturability rules and constraints. IMKS:Product features are seen as set up by IMKS:Part using IMKS:ManufacturingTools that might be identified as TAO:Transformations.

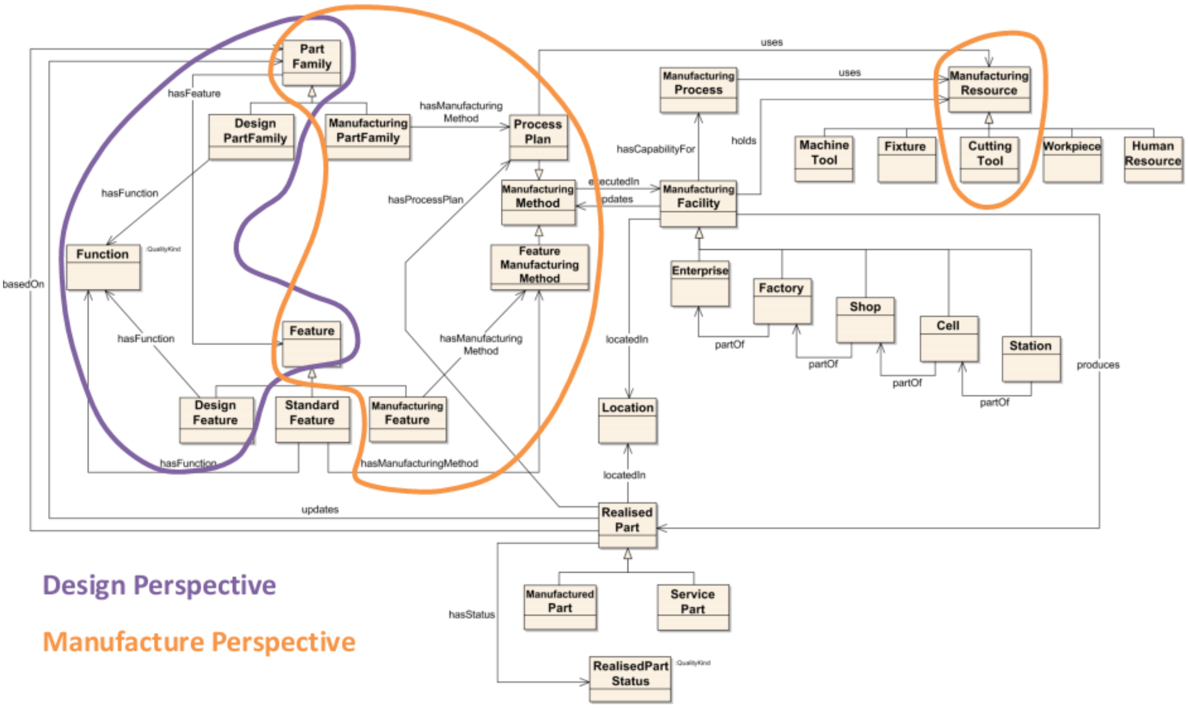

Figure 10: IMKS Ontology on Manufacturing (source see footnote 17)

5.3.13. NACE - Nomenclature statistique des Activités économiques dans la Communauté Européenne

"The Statistical Classification of Economic Activities in the European Community (in French: Nomenclature statistique des activités économiques dans la Communauté européenne), commonly referred to as NACE, is a European industry standard classification system consisting of a 6 digit code."[17] It covers about 996 classes in order to classify products and services traded in the EU (and partly America). Being a market oriented perspective, NACE can hardly be used to categorize production and manufacturing factors like tangible assets. However, it is promoted to SP1 in order to group MSEE services and may be even to verify MSEE containers about organizational, ICT-related, and physical services.

[16] http://www.lboro.ac.uk/departments/mm/research/product-realisation/imks/Results/IMKS%20Ontology%20Development%20and%20Demo%20Concept.pdf

[17] http://ec.europa.eu/competition/mergers/cases/index/nace_all.html

5.3.14. OWL - Web Ontology Language

"The Web Ontology Language (OWL) is a family of knowledge representation languages for authoring ontologies. The languages are characterized by formal semantics and RDF/XML-based serializations for the Semantic Web. OWL is endorsed by the World Wide Web Consortium (W3C) and has attracted academic, medical and commercial interest."[18] Among other features, OWL allows for specifying concepts, respective attributes, and relations between concepts.

Thereby, the predefined relation OWL:equivalentClass[19] is of specific interest to our approach of building up a MSEE ontology iteratively. This very relation can be utilized to refer from newly defined MSEE concepts to already existing, equivalent concepts in other namespaces and taxonomies. As an example, TAO:Actor can be identified as OWL:equivalentClass of FOAF:Agent.
As a first shot, this relation might be crucial to our attempt to carefully extend the existing linked USDL specification towards TAO's view on in-/tangible assets in WP22/23: OWL-like RDF descriptions of linked USDL can be complemented by identifying USDL:Resources as TAO:Factors (incl. in-/tangibles assets concepts as well as respective attributes) and thus link USDL to TAO-ontology.

In its simplest form, an equivalentClass axiom states the equivalence (in terms of their class extension) of two named classes. An example:

```
<owl:Class rdf:about="TAO#Factor">
  <equivalentClass rdf:resource="USDL#Resource "/>
</owl:Class>
```

NOTE: The use of OWL:equivalentClass does not imply *formal* class equality. Class equality means that the classes have the same intentional meaning (denote the same concept). In the example above, the concept of "President of the US" is related to, but not equal to the concept of the principal resident of a certain estate. Real class equality can only be expressed with the OWL:sameAs construct. As this requires treating classes as individuals, class equality can only be expressed in OWL Full.

5.3.15. EO - Enterprise Ontology

The Enterprise Ontology (Uschold et al. 1998) is a collection of terms and definitions relevant to business enterprises, e.g. process related, strategy related, organizational, and marketing related concepts including time. And there is details about the concept EO:Asset, which is an Entity legally owned that has monetary value. Similar to MSEE, EO sees examples like:

- TAO:TangibleAssets: machine, equipment, land, building, material,
- TAO:IntangibleAssets: idea, design, patent, information.

Furthermore, EO distinguishes an entity may be both an asset and a resource but some asset are not resource and some resource are not asset. While EO:Resource is defined as a role of an entity, where a role corresponds to the semantics of an argument in a relation – bringing in the notion of relativity. Consequently, entities can be specified as EO:Resources in order to express that the entity is or can be used or consumed during e.g. an EO:Activity. However, EO:Resources are still EO:Entities. Note: an entity is everything in EO, comparable to the concept TAO:Thing.

[18] http://en.wikipedia.org/wiki/Web_Ontology_Language
[19] http://www.w3.org/TR/owl-ref/

5.3.16. GR – GoodRelations

"The GoodRelations ontology provides a generic yet lightweight vocabulary for describing in a machine-readable way the details of offers made on the Semantic Web. This allows vendors to add a machine-readable definition of their offers so that Semantic Web search engines can find such Web resources more precisely. It empowers them to return exactly matching offers for a given need."[20]

Core concepts of GoodRelations ontology are:

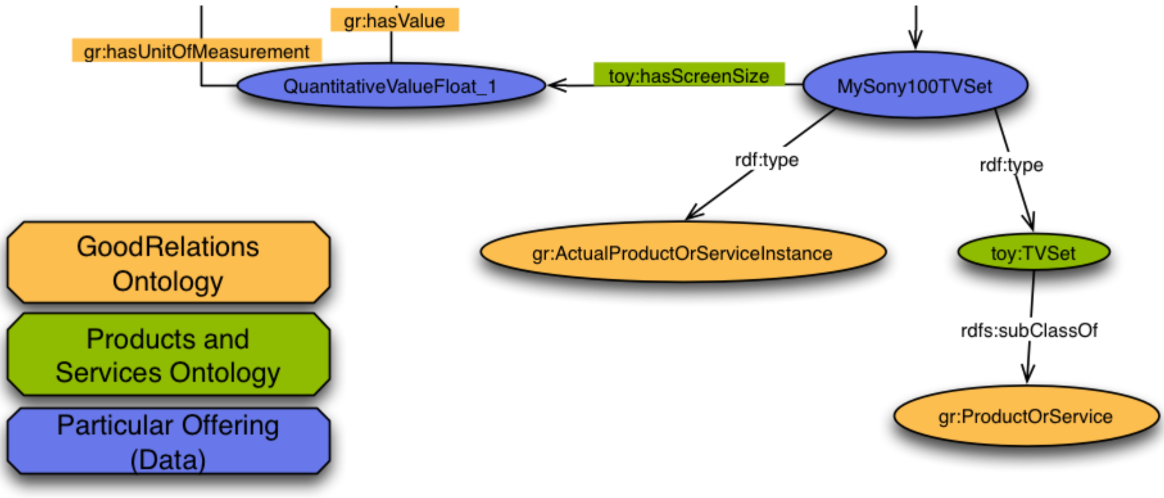

Figure 11: RDF graph of a GoodRelation example[21]

Sharing USDL's mission, but providing a focus on physical goods, the main features of GoodRelations are as follows:

- Support for all common business functions, like buy, sell, lease, dispose, repair, etc.
- Suits both for explicit instances, product models, and anonymous instances
- Supports different prices for different types of customers or quantities
- Supports product bundles in combination with any kinds of units of measurements ("2 kg butter plus 2 cell phones for € 99" would be no problem)
- Supports price specifications both as single values or price ranges
- Supports intervals and units of measurements for product features
- Compatible with eClassOWL and other ontologies
- Supports ISO 4217 currencies
- Supports defining eligible regions
- Supports common delivery and shipping methods
- Supports specifying accepted payment methods
- Offerings can be constrained to certain eligible business entities (e.g. resellers only)
- Supports warranty promises, i.e., the duration and scope
- Supports charges for certain payment or delivery options; the latter also individually per region

[20] http://www.heppnetz.de/projects/goodrelations/primer/
[21] http://www.heppnetz.de/projects/goodrelations/primer/images/fig1.png

Consequently, GoodRelation is not meant for describing Goods, but their offering in context of e-Commerce. GoodRelations is compatible with international standards: UN/CEFACT, eCl@ss, etc. that might be used to specify the actual good. GoodRelations comprises the following core concepts: GR:BusinessEntity (e.g. a company), GR:Offering (e.g. a product or service offered), GR:ProductOrService (as a reference to an already described Service or Product), GR:Location (reflecting the fact that some physical products can be bought only in physical shops and that even some services are provided at specific locations only).

5.3.17. PTO - Product Type Ontology

The Product Type Ontology[22] can be seen as a good complement of the abovementioned Good Relations Ontology. Product Types Ontology steps in where GR leaves off, as the latter's identifiers can't be used to represent e.g. class membership, because (1) it lacks a suitable semantics for being used as classes, and (2) it's not valid OWL DL. Consequently PTO might be utilized to provide a useful RDF representation that describes types of objects. Good Relations properties such as GR:weight and GR:isConsumablefor can be used in conjunction to describe typical characteristics of the object that is indicated to be a machine, or a men's shirt, or whatever. PTO therefore offers high-precision identifiers for product types based on existing and well defined Wikipedia articles.

5.3.18. RDFS schema.org

"The Resource Description Framework (RDF) is a general-purpose language for representing information in the Web. This specification describes how to use RDF to describe RDF vocabularies [and taxonomies]. [RDFS] defines a vocabulary for this purpose and defines other built-in RDF vocabulary initially specified in the RDF Model and Syntax Specification."[23] Therefore, the RDFS namespace provides concepts and attributes to specify named RDF:resources and RDF:classes including descriptive RDF:literals, RDF:datatypes, and RDF:properties. Examples for RDFS properties are: RDFS:subClassOf is used to state that all instances of one class are instances of another. RDFS:sub-PropertyOf is used to state that all resources related by one property are also related by another.
In MSEE RDFS properties are used to build up a ontology of generic classes, namely concepts in the domain of tangible assets in manufacturing.

5.3.19. TRIZ – Inventive Problem Solving

TRIZ is "a problem-solving, analysis and forecasting tool derived from the study of patterns of invention in the global patent literature" (Hua et al. 2006). Following Altshuller's ideas, TRIZ developed on a foundation of extensive research covering hundreds of thousands of patents across many different fields to produce a theory which defines generalizable patterns in the nature of inventive solutions and the characteristics of the problems that these inventions have solved.

There are three primary findings in TRIZ[24]:

1. Problems and solutions are repeated across industries and sciences
2. Patterns of technical evolution are also repeated across industries and sciences
3. Real inventions use scientific effects outside the field in which they were developed.

In the application of TRIZ all these findings are applied to create and to improve products, services, and systems. In context of this very generic approach, functional classifications are applied to characterize technical, tangible, invention-related assets of very different industries and business alike.

[22] http://www.productontology.org/
[23] http://www.w3.org/TR/rdf-schema/
[24] http://en.wikipedia.org/wiki/TRIZ

The resulting TRIZ classification might be a significant input when building the MSEE ontology on tangible assets in manufacturing ecosystems. TRIZ categories are as follows[25]:

- Interaction of systems and elimination of harmful effects
- Evolution of System
  - Changing the state
  - Introducing control mechanisms
  - …
- Transition to/from macro/micro
  - Decompose system
  - Integration of additional components into a single system
- Measurement and Detection
  - Introduction of additives
  - …
- Other
  - Introducing Substances
  - Use products as instruments
  - Disappearance of substance
  - …

5.3.20. DOLCE - Descriptive Ontology for Linguistic and Cognitive Engineering

DOLCE is the first module of the WonderWeb Foundational Ontologies Library (WFOL). It is implemented using first-order logic. The specific assumptions adopted for DOLCE presented in terms of a rich axiomatic characterization, aimed at clarifying our assumptions and illustrate their formal consequences (theorems).[26]

Interesting concepts are: physical object, feature, amount of matter, set in context of other top-level concept like abstract or spatio-temporal particular.

5.3.21. CIO - Collaborative Innovation Ontology

The Collaborative Innovation Ontology (CIO) (Hirsch 2012) has been created in context of the AVALON collaborative innovation initiative funded by the European Commission in FP6. CIO intents to support cross-sectoral knowledge workers in capturing, sharing, discussing, and further elaborating domain knowledge by means of semantic models and ontology-based services, so called Smart Services. As a result, CIO builds up a comprehensive top-level ontology about crucial success factors in innovation-related projects, covering the alignment of core concepts like CIO:Agents, CIO:Activities, and CIO:Knowledge-Objects. CIO tackles the notion of knowledge integration, coordination, and communication in industrial communities and networks.

As a result, CIO represents a specific semantic model covering the domain of “collaborative innovation” (see Figure 12) that can be adapted and extended according to MSEE requirements that have been identified in e. g. WP1.

[25] http://www.triz.co.kr/TRIZ/frame.html
[26] http://www.loa.istc.cnr.it/DOLCE.html

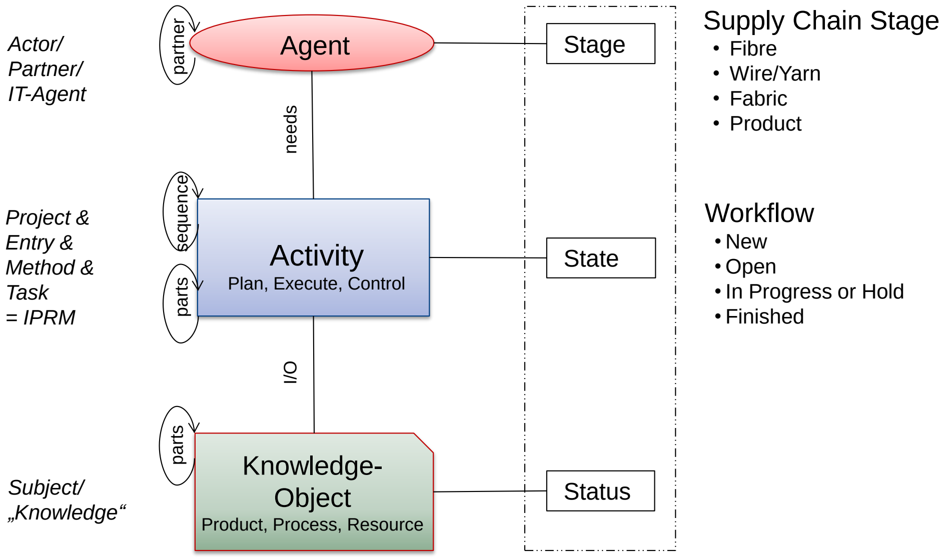

Figure 12: Collaborative Innovation top-level Ontology

As mentioned above, other scientific approaches try to cover similar knowledge domains. In their Open Innovation and Heterogeneity (OHI) theory, Meersman et al. (2010) focusses e. g. on product innovation in context of the open innovation idea and heterogeneity, incorporating OIH:Product, OIH:Component, OHI:PropertyFunction, but neglecting notions of services and service innovation. Bullinger (2008) instead, highlights the importance of the ideation phase in context of innovation, covering the fuzzy front-end idea without providing appropriate linkage to succeeding innovation phases. CIO is different from these top-down approaches at it derives from empirical studies and evolutionary developments of ontology-driven services. However, being an engineering perspective on innovation, CIO lacks the notion of pure business aspects like finances and IT-hardware components, like in (Wojda and Waldner 2000). In context of MSEE these assets cannot be neglected and have to be covered by WP22/23 efforts on in-/tangible assets management.

In its current state, CIO focusses on rule-based cross-links within the knowledge domain of “collaborative innovation” and lacks deep taxonomies covering issues like equality and ambiguity between concepts. This is covered partly by the MSEE BOA ontology – for tangible assets of the manufacturing domain, specified by MSEE use cases. Nevertheless, by comparing CIO with other prominent ontologies, it can be seen as a good starting point for MSEE’s TAO ontology:

- CIO:Activity: Activities in CIO are very similar to EO:Activity of Dietz (2006), but adds the dimension of cross-enterprise collaboration. In addition, PSL:Activity can be seen as an equivalent concept to TAO:Process, as both are top level conetpts that are directly linked to TAO:Actor or PSL:Agent respectively and TAO:Assets or PSL:Object respectively. PSL additionally covers the notion of queued activities and situations, derived from that. TAO tackles the same abstraction level and sees aggregated TAO:Activities again as TAO:Activitiy.
- CIO:Actor: CIO:Actors comprise partners in innovation networks as well as generic agents that perform actions, e. g. IT-Agents. This contrasts EO:Person and other concepts that distinguish between human and e. g. IT agents (Dietz 2006). Most important about CIO:Actor definition is, that it does not map business relations like being a customer or supplier as concepts (like e. g. Customer, Supplier) but keeps the relative notion of context-specific and time-dependent business relations by implementing attributes like CIO:hasCustomer, CIO:hasSupplier instead.

- CIO:KnowledgeObject: Knowledge objects in CIO reflects the idea of not being able to represent real things (e. g. in- and tangible assets) by means of an ontology, but knowledge about those things, which is in any case intangible and/or abstract. CIO:KnowledgeObjects therefore covers descriptions of innovation-related methods and competences (intangible) as well as materials and machinery in networks (tangible). Furthermore, CIO distinguishes between object-like things (Riedl and May 2009) and transformation-like things (Laufs 2008).
- CIO:Fluent: Inspired by PSL:Fluents (M. Grüninger 2003), CIO:Fluents cover the notion of status, states, and stages of CIO:KnowledgeObjects, CIO:Activities, and CIO:Agents. The main characteristic of fluents is that they can only be changed as a result of activities (Mello, Montali and Torroni 2008; M. Grüninger and M. S Fox 1994). In order to reflect the need within MSEE to provide semantic models of in-/tangible assets on different IPR levels, an additional fluent got introduced to manage access rights on enterprise, community/ecosystem, and future internet level (see 6.2.2).

Even though CIO derives from a very specific innovation project, thanks to its proven applicability in context of AVALON it can be considered to be a legitimate model of most relevant business assets (Jarrar and R. Meersman 2010).

The main result of the analysis performed is that there is no sufficient semantic model for managing tangible assets in ecosystems available in literature. Consequently, a dedicated domain specific MSEE/OMSE ontology is needed, integrating already existing ones – e.g. Enterprise Ontology, USDL, and others. This will be performed in the next chapter.

6. Building the OMSE Ontology

The OMSE ontology on tangible assets enables the virtualization of tangible assets as "Tangible assets as a Service" on ecosystem level, to be used to compose service on market level. The ontology helps to classify and to specify tangible assets by means of dedicated attribute sets. These attribute sets can also be used in SP1 models to model tangible assets appropriately.

6.1. Semantic modeling method

There are just a few dedicated development methods for domain ontologies well described in literature (De Nicola 2009; Bullinger 2008; Lenat and Guha 1989). Some of them focus on automatic deduction of semantic models from a given set of real-world instances (Cimiano 2006) other suggest to reuse and merge existing top-level ontologies (Sure and Studer 2002), and other promote a middle-out approach, guiding the development process by means of Key Questions, merge principles, and iterative procedures (M. Grüninger and M. Fox 1995; Uschold and Michael Grüninger 2009). The method applied in MSEE takes on this latter idea.

The so called METHONTOLOGY (Fernandez, Gomez-Perez and Juristo 1997; Lopez et al. 1999; Corcho et al. 2005) approach, suggests to follow dedicated phases in order to develop a comprehensive domain ontology: analyze, specify, merge core concepts of existing ontologies, provision of semantic model, and update. These phases are executed for an arbitrary set of Key Questions, while in each iteration newly developed semantic models are merged with already existing ones. The Key Questions to be answered by TAO ontology are already outlined in chapters 4.1 and 4.3. In the following, each Key Question will be further analyzed and respective knowledge structures to support these questions are provided by means of semantic models.

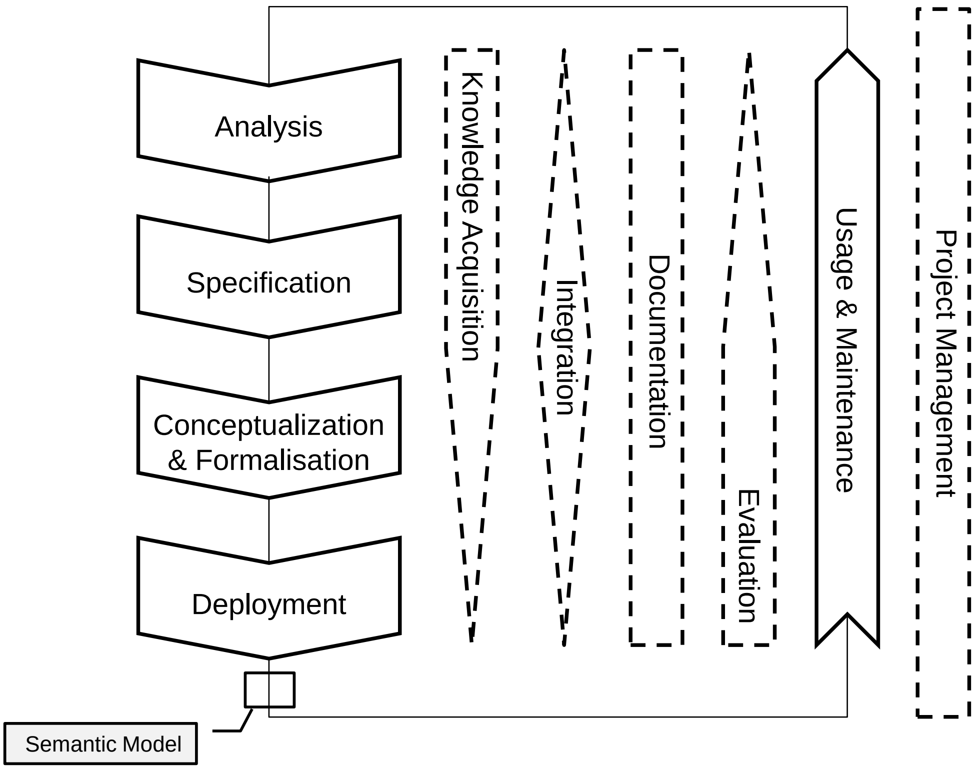

Figure 13: METHONTOLOGY method (source: DITF based on Fernandez 1997)

The method comprises five stages reflecting development stages of semantic models that finally lead to a domain specific ontology (prototype). These stages are supplemented by supporting tasks like knowledge acquisition, model and instances integration, documentation, and service model evaluation. The analysis stage focuses on capturing relevant input from service-oriented business models, service environment requirements as well as usability context information. In the second stage, the respective Key Question that has to be answered as guideline of the conceptualization and formalization activities, which is about coding concepts, relations, and attributes of ontology elements. In the fourth step, a working prototype of the to-be developed ontology is deployed in e.g. ecosystems. Feedback is gathered and thus an on-going update and refinement step follows in phase five of METHONTOLOGY.

METHONTOLOGY refers to an iterative procedure; however, in this deliverable only the outcome of the method, not each detail of the actual execution of this method is outlined. Still, according to Methontology, Performance Questions were deduced, existing ontologies were analysed and partly re-used, TAO was build up evolutionary, feedback from end-users and expert was gathered, and prototypical implementations were evaluated against respective requirements (derived from Performance Questions).

6.2. Semantic model of tangible assets

Here, the core ontology on tangible assets in manufacturing is developed by answering to abovementioned Key Questions. Each sub-section is structured according to respective sub-questions:

- Handling **(SQ1)**,
- communicating & sharing **(SQ2)**, and
- combining **(SQ3)**

tangible assets in manufacturing.

For each development cycle outlined in the following, the aforementioned METHONTOLOGY method has been applied, focusing on the conceptualization and formalization step in order to build up a comprehensive ontology on tangible assets in manufacturing.

6.2.1. Handling of tangible assets (SQ1)

Here, concepts, relations and attributes that are needed in the OMSE ontology to answer SQ1 are gathered and defined.

According to the taxonomies outline in chapter 5.4 on SotA ontologies, concepts that tackle the notion of handling real-world tangible assets virtually by means of formal semantic models are expressed in the following knowledge structures – where each sub-concept represents disjunctive classes, related by isA-relations. This sub-ontology represents the **core concepts** of TAO:

- **Assets** (see 5.4.21 CIO and 5.4.15 Enterprise Ontology)
  - **(Production) Factors** (as subcategory of resources, see 4.4.10 USDL, 4.4.15 EO, 4.4.9 MSDL, in contrast to services/products see 4.4.5 eOTD, 4.4.13 NANCE)
    - **Tangible Assets** (in MSEE we distinguish between in- and tangible assets, see 5.4.9 MSDL, 5.4.20 DOLCE)
      - **Tangible Objects** (General business theory objects are kept separate from transformations, see (Kosiol 1966))
        - **Concrete**
          - **Complex** (Wojda and Waldner 2000)
            - Building
            - Shirt
              - Men's Shirt
            - TV
            - Human
              - Person
            - Plant
          - **Flat**

            - Area Segment
            - Floor
            - Panel
                - TV Panel
            - Textile_Fabric
        - **Concave**
        - **Convex**
        - **Stretched**
        - **Conical**
        - **Discrete**
        - **Liquid**
- **Tangible Transformations** (General business theory objects are kept separate from transformations)
    - **Creation**
    - **Deformation**
        - Cutting
        - Drilling
        - WashingDevice
    - **Density_related**
    - **Displacement**
    - **Elasticity_related**
    - **Electric_Tool**
    - **Friction_related**
    - **GasPowered_Tool**
    - **HandTool**
    - **Heating**
    - **Joining**
        - **Knitting**
        - **Sewing**
        - **Weaving**
        - **Welding**
    - **Magnetic**
    - **MeasuringEquipment**
    - **Optical**
    - **Storage**
    - **Surface_related**
        - **Anti-Fouling**
        - **EasyCleaning**
        - **Embroidery**
        - **Finishing**
        - **Printing**
    - **Transportation_Device**
    - **Volume_related**

The following distinct concepts can be found in TAO. Concepts differ in both, their meaning and in their attribute sets. (Grey rows are not part of the TAO ontology, but parts of potential extensions towards an overall MSEE ontology on Manufacturing Service Ecosystems.)

Table 2: Overview on TAO core concepts

Concept	***Meaning***	***Comment***
TAO:Asset	An TAO:Asset is an economic abstract or concrete object of a certain value. In MSEE we subsume production and manufacturing assets (TAO:Factor) as well as products and services.	Equivalent to PSL:Object; Sub-Concept of TAO:Thing
BAO:Service, see SP1 results	A TAO:Service exposes other services/products and/or factors to the market. Services do have the notion of events, resulting from an interaction between at least two systems, namely the service provider and the service user. Services cannot be owned, bought, or sold but used, licensed, agreed on and so on.	Equivalent to subset of GR:ProductOrService
BAO:Product, see SP1 results	A TAO:Product exposes other products/services and/or factors to the market and can be owned, bought, and/or sold.	Equivalent to subset of GR:ProductOrService
TAO:Factor	A production or manufacturing factor is used on enterprise level to build up products and/or services on ecosystem level. As soon as a company e. g. buys a product of any supplier, this very product becomes a factor within the respective company. The distinction between product/services and factors is due to the fact that the same factor might be used in context of different products and/or services.	Equivalent to **USDL:Resource**, PSL:Object; Sub-Concept of TAO:Asset
TAO:Tangible	Tangible assets comprise any physical object with economic value. TAO:Tangibles can be used to build up services and/or products. Examples for tangible assets are as follows: machinery, tools, and material.	Equivalent to parts of DOLCE:Spatio-temporal physical endurent; Sub-concept of TAO:Factor
TAO:TangibleObject	TAO:Objects are tangible assets that can be used, build up, destroyed and so on – but that do not have input or output relations. That means that TAO:objects are not able to transform or manipulate other tangible or intangible assets.	Sub-concept of TAO:Tangible
TAO:Complex… TAO:Streched	Abstract types of Tangible Objects	
TAO:Tangible Transformation	TAO:Transformations are TAO:Factors that hold input and/or output relations to other tangible or intangible assets. This means, TAO:Transformations are able to transform or manipulate other in-/tangible assets.	Sub-Concept of TAO:Tangible
TAO:Creation … TAO: Voloume_related	Abstract types of Tangible Transformation	
Others	The other sub-sub-concepts within TAO are used to further detail and categorize generic tangibles. However, no domain specific aspects are to be modelled in this part of TAO.	

For example, a real sewing machine in partner Bivolino's ecosystem can be formally described the notion of TAO:Asset:Factor:Transformation:Joining:TextileSewingMachinery.

In this section, essential details on models that allow for effective and efficient handling of tangible assets manufacturing are provided in terms of a holistic sematic model; dealing with both, generic aspects of tangible assets in manufacturing. The following two sub-sections will tackle the notions of sharing, promoting, and composing tangible assets.

6.2.2. Communicating, sharing, and promoting tangible assets (SQ2)

Here, further concepts and especially attributes are elaborated in order to extend the above mentioned semantic model on tangible assets towards features for sharing and promoting assets – namely by introducing means for managing IPR level of tangible assets.

To manage tangible assets on multiple IPR levels, the quality stadium is added to TAO. The concept stadium can be associated with each TAO instance of tangible assets in order to express respective access levels. The stadium concept is just about assigning an IPR flag. This flag has to be evaluated in online repositories for virtualized tangible assets in order to only grant access to eligible groups (e.g. a specific ecosystem or members of a certain organization).

Each instance of TAO that represents a real world tangible asset can be flagged with a specific IPR level/stadium:

- Internal, Organisation
- Community, Ecosystem
- Future Internet level, Public

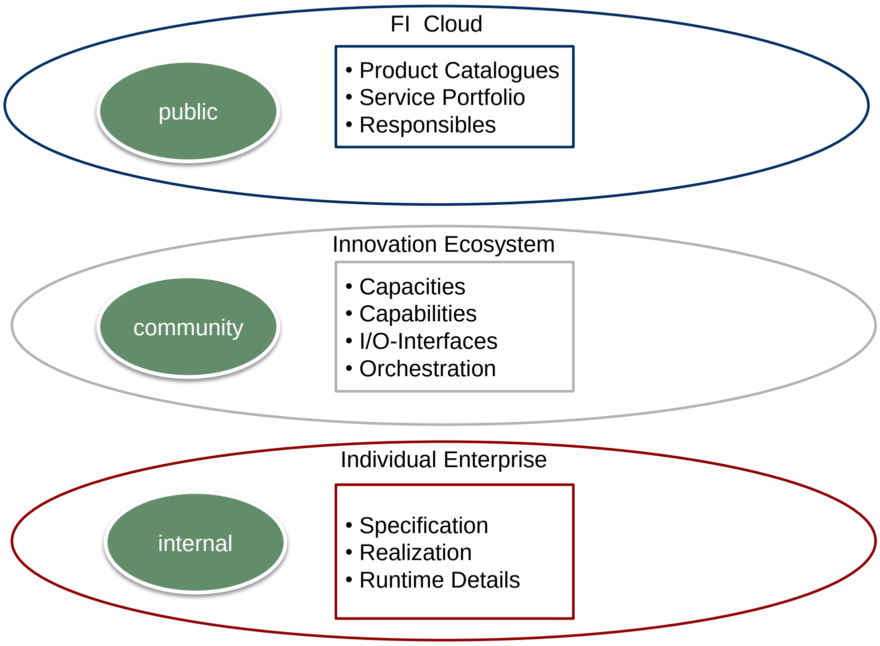

Figure 14: IPR Levels implying different access levels for virtualized tangible assets (TaaS)

Additional Attributes in the OMSE Ontology will be: IPR-Access Level (=Stadium) of all concepts – and maybe even attributes.

As a result, an additional attribute for capturing the IPR stadium of everything within the MSEE ontology can be defined as

TAO:Thing.hasStadium.

The respective part of TAO looks like that:

Thing (inc. *hasStadium* attribute)

- Asset
    - …
- Abstract
    - **…**
    - **Stadium**
        - Intern/Organisation
        - Community/Ecosystem
        - Public/FI
    - …

The Concept TAO:Abstract:Stadium covers three level of IPR: internal, community/ ecosystem, and future internet cloud. The attribute TAO:Asset:hasStadium is inherited to all sub-concepts, namely TAO:Actor, TAO:Activity, and TAO:Asset especially TAO:Factor: TangibleAsset.

Consequently, the top level of TAO Ontology can be extended towards other MSEE concepts (see Figure 15).

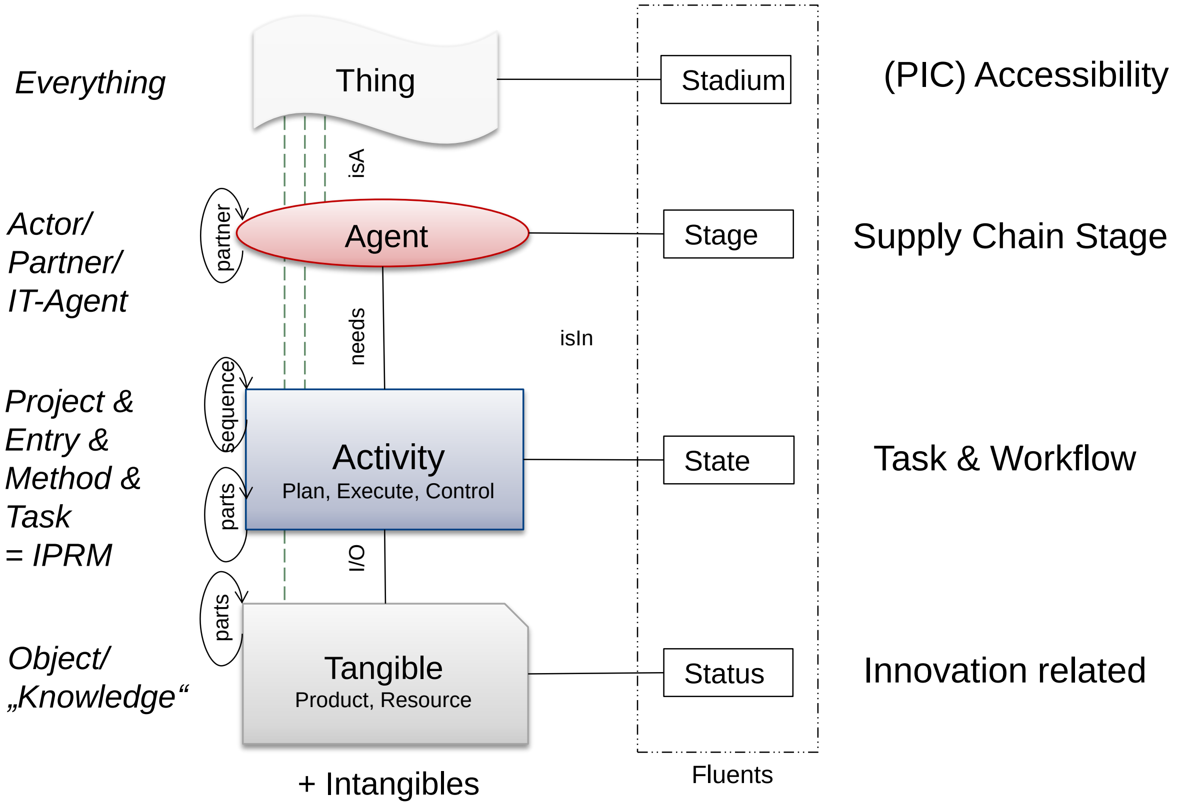

Figure 15: MSEE TAO top-level ontology on business assets with focus on tangible assets.

The details on tangible assets presented above still apply.

Concept	Meaning	Comment
TAO:Thing	Everything in TAO derives from the super class TAO:Thing. In order to assign IPR states to every-thing, the TAO:Thing concepts gets equipped with the attribute TAO:Thing.hasStadium allowing for assign-ing three different TAO:Stadiums, which are internal, community, public.	Equivalent to PSL:Object, ; Sub-Concept of TAO:Thing

6.2.3. Composition of Assets (SQ3)

In this second issue of TAO in D23.6 an extension to support a straight forward composition of tangible assets is provided:

- on Enterprise level (not-yet-virtualized), or
- after virtualization (TaaS)

This extension leads to the incorporation of an additional relation, e.g.:

Thing.comprises

Concept	Meaning	Comment
TAO:Tangible	Adding relation TAO:Tangible.comprises other TAO:Tangible assets	

With respect to also in-tangible assets that are further elaborated in WP22; the following de-piction shows how in-/tangible assets are composed on ecosystem level in order to provide a new product-service bundle on market level.

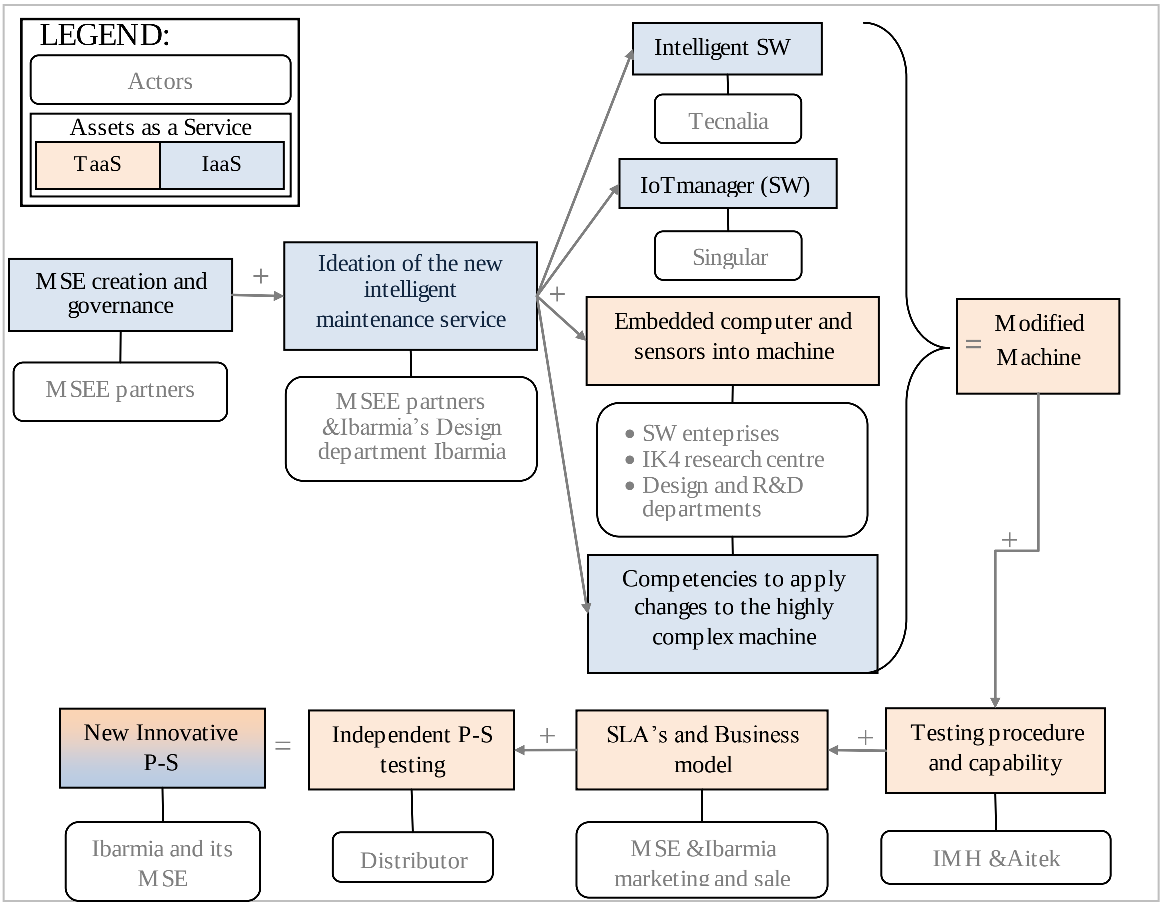

Figure 16: Composition of in-/tangible assets (Source: PoLiMi)

7. The OMSE ontology of tangible assets

7.1. Core TAO

To build up the prototypical Tangible Asset Ontology, the individual models per Key Question mentioned above (chapters 5.2.1-5.2.3) are integrated as follows. It has to be mentioned, that the OMSE ontology can be extended towards intangible assets (see D22.3) and other factors in MSE, e.g. Actors and innovation- and/or manufacturing-related Activities.

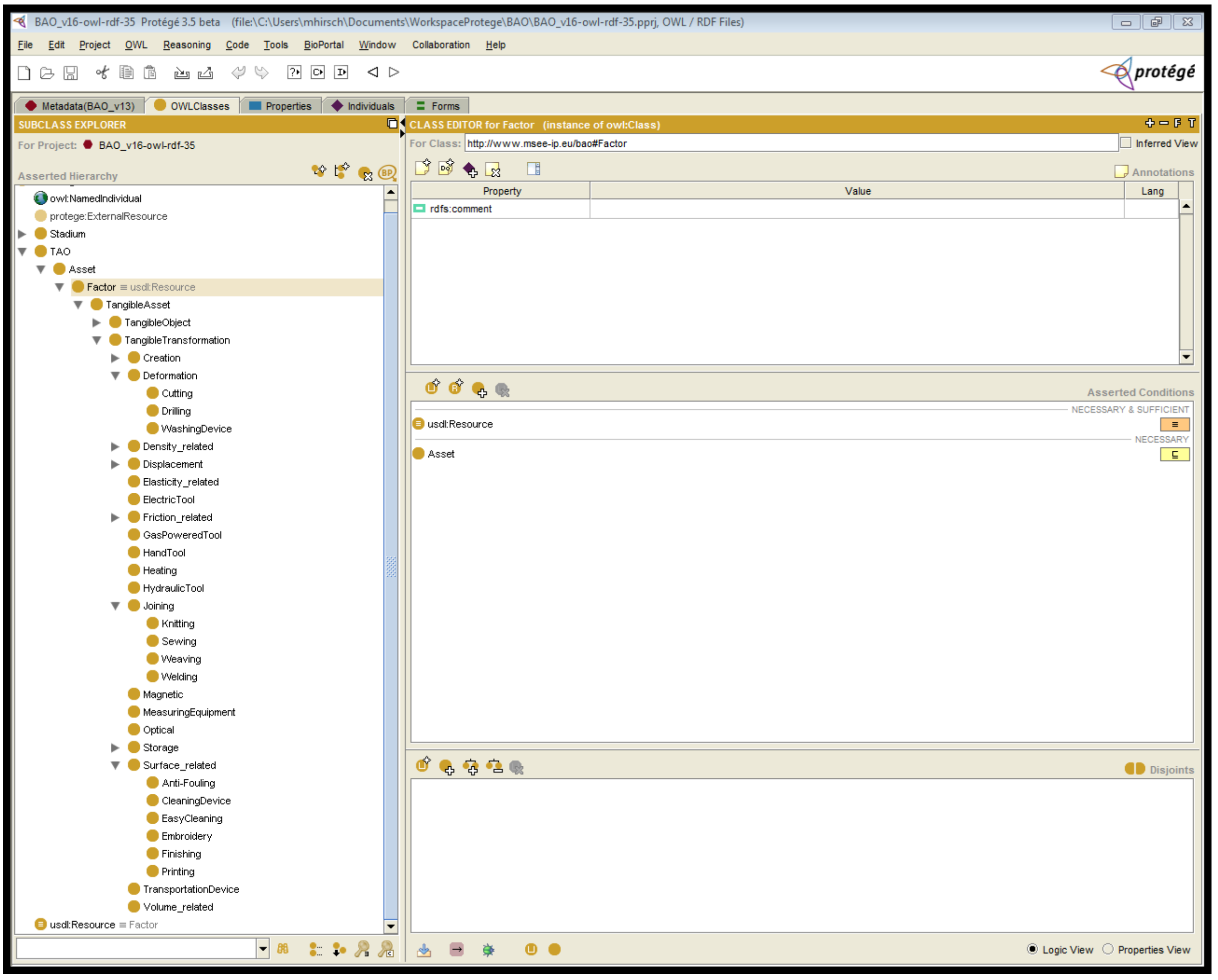

Figure 17: Ontology on assets in MSE – TAO core

Of course, the OMSE ontology on tangible assets is not only about concepts but explicitly about attributes per concepts. This is to ensure, appropriate knowledge structures for arbitrary tangible assets.

7.2. Description of core concepts and exemplary attributes

Table 3: Representative List of concrete attributes per Ontology Concept

Super-Concept	Concept	Description	Additional Attribute(s), important Relations[27]
Thing	Thing	Everything that is modelled in TAO	ID Label Description hasPredecessor hasSuccessor isSubstituteOf
Thing	Asset	In contrast to e.g. actors, activities and may be abstract thinks like qualities and fluents, assets represent business and manufacturing related objects like tangibles, products, methods, plans and so on.	Provider Related_Norm Type Domain isInStadium
Asset	Factor	Production factors are business and manufacturing objects on ecosystem level. They can be used and applied to build up products and/or services for the market.	Drawing Inspection_Intervall Specification Test_Result Volume
Factor	Tangible Asset	Tangible assets are physical objects with business value.	Serial Number Adjustment Environmental_Relevance Limitation Robustness Sourcing belongsToBranch belongsToSector hasComponent hasFunction isComponentOf
Tangible Asset	Tangible Object	Objects are compact tangible assets that can be used, consumed or produced by e.g. transformation processes	hasNature hasShape hasMatterOf-State
Tangible Object	Complex	In contrast to flat, stretched, or simple 3D objects, complex objects represent intermediate products, machine parts, or technical equipment	inBranche partOf applicationArea
Tangible Object	"others"	Descripted en detail in the prototype TAO provided in D23.6	
Tangible Asset	Tangible Transformation	(Physical) Transformations are applied upon input/output objects	hasInput hasOutput Configuration has Agitation

[27] Just additional attributes and/or relations are provided per concept, others are transitivelly inherited top-down from super-concept.

Super-Concept	Concept	Description	Additional Attribute(s), important Relations[27]
Transformation	"sub-concepts"	Sub-concepts as listed above are described by means of the instances they represent (Description attribute) provided in D23.6 as prototypes.	
…	…		…

7.3. Evaluation of TAO against general ontology requirements

Finally, TAO has to be evaluated against the generic criteria for semantic models outlined in 4.3, namely coherence, consistence, precision, usability, and partly even generality. TAO is consistent and coherent in the sense that it can be expected that reasoning upon this ontology results in reproducible and understandable outputs in reasonable time. D23.5/.6 demonstrates how TAO is applied in MSEE use cases. Given that there is positive feedback from the use cases, TAO can be considered to be usable and adequate. As TAO is likely to be applied also in other context within the manufacturing domain, it is seen to be generic in the sense of transferable.

8. Conclusion and Outlook

To sum up, TAO has been designed to meet the requirements of MSEs to *handle*, *share* and *communicate* as well as *combine* tangible assets in ecosystems:

- Therefore, TAO serves as semantic and structural means for capturing real-world tangible assets as virtual representations in order to allow for effective and efficient ICT-driven handling of tangibles.
- Furthermore, TAO-based models of tangible assets can be circulated e.g. by e-mail and online portals, discussed in forums and workshops, and further elaborated collaboratively in manufacturing ecosystems. This aspect addresses the notion of sharing and communicating of information about tangible assets (see also TAO attribute TAO:Stadium, which is designed for IPR management in inter-organizational teams).
- Last but not least, TAO provides means for merging and aligning of semantic models of two or more tangible assets in order to allow for combining respective tangibles virtually as a Service.

TAO is applied in context of T23.3, where dedicated MSEE use cases are instantiated. Therefore, D23.5/.6 shows how real-world tangible assets of Bivolino are virtualized as Tangible assets as a Service (TaaS) by means of a virtualization process. In this virtualization process, TAO serves as reference model for tangible assets in order to provide adequate formal semantics.

The concepts listed in this document might be extended towards a holistic ontological framework for all MSEE in the near future. The resulting ontology will be implemented as semantic reasoning tool in order to support servitization initiatives by means of a knowledge-driven SLM repository. The final SLM Ontology will furthermore cover a dedicated rule-set that captures expert knowledge on how to be successful in servitization and service innovation.

9. References

Beer, Stafford. 1962. *Kybernetik und Management*. S. Fischer.

Bullinger, A. 2008. *Innovation and Ontologies: Structuring the Early Stages of Innovation Management*. Gabler.

Cherbakov, Luba, George Galambos, Ray Harishankar, Shankar Kalyana and Guy Rackham. 2005. Impact of service orientation at the business level. *IBM Systems Journal* 44, Nr. 4: 653–668. (Accessed: 23. March 2013).

Cimiano, P. 2006. *Ontology learning and population from text: Algorithms, evaluation and applications*. Springer.

Corcho, O., M. Fernández-López, A. Gómez-Pérez and A. López-Cima. 2005. Building legal ontologies with METHONTOLOGY and WebODE. In: *Law and the Semantic Web*, 142–157. Berlin, Heidelberg: Springer.

Dietz, J.L.G. 2006. *Enterprise ontology*. Berlin [u.a.]: Springer.

Erl, Thomas. 2004. *Service-oriented architecture*. Prentice Hall. http://www.servicetechbooks.com/ErlFlyer2.pdf (Accessed: 23. March 2013).

Fernandez, M., A. Gomez-Perez and N. Juristo. 1997. Methontology: from ontological art towards ontological engineering. In: *Proceedings of the AAAI97 Spring Symposium Series on Ontological Engineering*, 33–40.

Fischer, Thomas. 1992. *Koordination betriebswirtschaftlicher Regelungsaufgaben im Rahmen eines integrierten Informationssystems der Unternehmung*. Expert.

Gruber, T. R. 1993. Toward Principles for the Design of Ontologies Used for Knowledge Sharing. http://www.ksl.stanford.edu.

Grüninger, M. 2003. A guide to the ontology of the process specification language. *Handbook on on*: 575–592. (Accessed: 14. May 2010).

Grüninger, M., K. Atefi and M. S Fox. 2001. Ontologies to support process integration in enterprise engineering. *Computational & Mathematical Organization Theory* 6, Nr. 4: 381–394.

Grüninger, M. and M. Fox. 1995. Methodology for the design and evaluation of ontologies. In: *IJCAI'95, Workshop on Basic Ontological Issues in Knowledge Sharing*. citeseer.ist.psu.edu/grninger95methodology.html.

Grüninger, M. and M. S Fox. 1994. An activity ontology for enterprise modelling. *Technical Report, Department of Industrial Engineering, University of Toronto*.

Hepp, M., J. Leukel and V. Schmitz. 2007. A quantitative analysis of product categorization standards: content, coverage, and maintenance of eCl@ ss, UNSPSC, eOTD, and the RosettaNet Technical Dictionary. *Knowledge and Information Systems* 13, Nr. 1: 77–114.

Hirsch, Manuel. 2012. *Smart Services for Knowledge Integration - Ontologiebasierte Dienste zur Unterstützung der kollaborativen Wissensarbeit in Innovationsnetzwerken*. Vol. 202. Fortschritt-Berichte VDI 16. Düsseldorf: VDI-Verlag.

Hua, Z., J. Yang, S. Coulibaly and B. Zhang. 2006. Integration TRIZ with problem-solving tools: a literature review from 1995 to 2006. *International Journal of Business Innovation and Research* 1, Nr. 1: 111–128.

Jarrar, M. and R. Meersman. 2010. Formal ontology engineering in the dogma approach. *On the Move to Meaningful Internet Systems 2002: CoopIS, DOA, and ODBASE*: 1238–1254.

Kosiol, E. 1966. *Die Unternehmung als wirtschaftliches Aktionszentrum: Einführung in die Betriebswirtschaftslehre*. Vol. 256. Rowohlt.

Lambert, Douglas M. and Martha C. Cooper. 2000. Issues in supply chain management. *Industrial marketing management* 29, Nr. 1: 65–83. (Accessed: 23. March 2013).

Laufs, Uwe. 2008. Ontologien zur Darstellung von Technologieentwicklungswissen. In: *Fokus Technologie: Chancen erkennen - Leistungen entwickeln*. München: Hanser.

Lenat, Douglas B and R. V Guha. 1989. *Building Large Knowledge-Based Systems; Representation and Inference in the Cyc Project*. Boston, MA, USA: Addison-Wesley Longman Publishing Co., Inc.

Lopez, M. F., A. Gómez-Pérez, J. P. Sierra and A. P. Sierra. 1999. Building a chemical ontology using Methontology and the OntologyDesign Environment. *IEEE Intelligent Systems and their applications* 14, Nr. 1: 37–46.

Meersman, D. and T. Dillon. 2010. The Open Innovation Paradigm and the Semantic Web: An Ontology for Distributed Product Innovation. In: *On the Move to Meaningful Internet Systems: OTM 2010 Workshops*, 49–52.

Mello, F. C.P, M. Montali and P. Torroni. 2008. An Efficient Implementation of Reactive Event Calculus. *Technical Report*.

De Nicola, Antonio. 2009. A software engineering approach to ontology building. *Information Systems* 34, Nr. 2 (1. April): 258–275. (Accessed: 4. June 2010).

Riedl, C. and N. May. 2009. An Idea Ontology for Innovation Management. *Ontology for Innovation Management. International Journal on Semantic Web and Information Systems* 5, Nr. 4: 1–18.

Schubert, P. 2008. Integrationsszenarien für Business Collaboration. *HMD* 45 Jg., Nr. Heft 261: 32–42.

Stadtler, Hartmut. 2005. Supply chain management—an overview. *Supply chain management and advanced planning*: 9–35. (Accessed: 23. March 2013).

Sure, Y. and R. Studer. 2002. On-to Knowledge Methodology: Project Deliverable D18. http://www.aifb.uni-karlsruhe.de/WBS/ysu/publications/ (Accessed: 12. February 2008).

Uschold, M. and Michael Grüninger. 2009. Ontologies: Principles, methods and applications. *The Knowledge Engineering Review* 11, Nr. 02: 93–136.

Uschold, M., M. King, S. Moralee and Y. Zorgios. 1998. The enterprise ontology. *The knowledge engineering review* 13, Nr. 1: 31–89.

Wojda, Franz and Birgit Waldner. 2000. Neue Formen der Arbeit und Arbeitsorganisationen. In: *Innovative Organisationsformen : neue Entwicklungen in der Unternehmensorganisation*, 13–58. Stuttgart: Schäffer-Poeschel.