



WHITE PAPER

Product Service System (PSS) Ontology for Discrete Manufacturing

Specifications

(1st Draft Version)

Introduction

Background: Modern industrial companies aim to extend their products with services as fundamental value-added activities, and reduce the product to be just a part of the offering. One of the key potentials of such services, besides radical improvements in the use of products, is a reduction of environmental footprint of products and services. To support dynamic building and deployment of new services around products, i.e. to build Product Service Systems (PSS), there is a need for strong collaboration among various actors across the value chain. Building services today is connected with adding/upgrading of cyber-physical features, as for example adding sensors and intelligence to the products which can be used for various services. This in turn requires dynamic feedback loops between the design, manufacturing and product-service use. Real time exchange of knowledge between the designers, manufacturers, maintenance experts, as well product-service users is “conditio sine qua non” for the modern PSS design. This includes automatic data gathering and exchange along the value chain (e.g. data on energy consumption for manufacturing of product and/or for its use), but also tacit knowledge from various actors (e.g. experience of the maintenance staff or shop-floor workers on the manufacturability of a part). The ontologies are seen as key tools for effective knowledge sharing in development, deployment and use of PSS in the manufacturing industry.

Objective: The objective of this document is to serve as a basis for the establishment of a standard Product Service System (PSS) ontology in the manufacturing industry. The ontology is a joint approach of the two EU projects, FALCON [9] and DIVERSITY [8, 10], both dealing with PSS in the manufacturing industry.

The two EU research projects investigate methods and tools for PSS development, deployment and use:

- FALCON (Feedback mechanisms Across the Lifecycle for Customer-driven Optimization of iNnovative product-service design) aims to deploy user experiences and data collected via the Internet of Things (IoT) and social media, for the improvement of product-service systems (PSS). Customers play no longer a passive role in the product and service development process, as they express their product and service experiences and opinions through social media. In addition, sensor systems in combination with products incorporated in the IoT, are becoming increasingly common. The potential endless amounts of available information offer a rich ground for value creation in the product-service innovation chain. Accordingly, FALCON develops a Virtual Open Platform to seamlessly connect product-service usage information to design and development processes [9]
- DIVERSITY (Cloud Manufacturing and Social Software Based Context Sensitive Product-Service Engineering Environment for Globally Distributed Enterprise) aims at developing a new cloud-based engineering environment to support modern enterprises in managing their multi-directional exchange of knowledge, and their dynamic and real-time feedback loops, both internally (among product design, service design and manufacturing) and externally (with customers, both business customers and individual customers - consumers, suppliers and other relevant organisations, across the value chain, distributed all over the globe). In this sense, DIVERSITY aims at providing a concurrent collaborative environment for product-service design, supporting companies from the

context-sensitive capturing and searching of knowledge, to the transformation of these data into product-service functionalities. In particular, the project ambition is to support those companies that are changing their business model, by extending their products-offerings with services (PSS - Product Service System) and that are adopting the new mass-customisation paradigm [10]

Both DIVERSITY and FALCON projects deal with the use and sharing of data relevant for the PSS design/development/deployment/use. Therefore, the projects share a common need to establish a PSS ontology for the manufacturing industry. The investigations in both projects have shown that there is no agreed-common ontology for PSS development in manufacturing industry. A PSS ontology has not been yet released beyond research schools [11]. One of the most elaborated solution in PSS ontology is developed by a Cranfield University team [12].

Both FALCON and DIVERSITY projects developed low-level ontologies following the industrial use cases addressed in the projects. The objective of this common PSS ontology is to define the entities and relations which are valid for the use cases in both projects, and which may serve as a mid - level ontology relevant for the PSS development in manufacturing industry.

The document includes the **first draft version of the agreed common PSS ontology**, which is updated based on the feedback from the partners of the two projects, and will be presented as a proposal for a standard PSS ontology.

For the common Product Service System (PSS) Ontology (based on combination and updates of the DIVERSITY and FALCON ontologies) the following two sets of assumptions were agreed.

Main assumptions considered:

- The ontology will focus on Discrete Manufacturing aiming to support the design/development/engineering of PSS, as well as the use of feedback from the PSS-use phase.
- The ontology considers the PSS design/development from the system engineering approach aiming to enhance the work of PSS-systems designers/developers.
- The ontology will be open to extend to other aspects of PSS, such as business aspect, marketing etc.
- The Basic Formal Ontology (BFO) [1] will be used as upper ontology.
- Protégé [15] will be used for the ontology modelling.
- The work is intended to be registered in the Industrial Ontologies Foundry (IOF).

Ontology design principles (from BFO) followed:

- use single nouns (except data) and avoid acronyms (except PSS and KPI)
- ensure univocity of terms and relational expressions
- distinguish the general from particular
- provide all non-root terms with definitions
- use essential features in defining terms and avoid circularity
- start with the most general terms in the domain
- use simpler terms than the term you are defining (to ensure intelligibility)
- do not create terms for universals through logical combination
- structure ontology around *is_a* hierarchy and ensure *is_a* completeness
- single inheritance

Following the BFO as upper ontology, the classes are defined to clearly distinguish between the so-called Continuant and Occurrent (see BFO [1]) entities. For example, the class Service is defined, under Occurrent, as a process which is executed in time (i.e. a specific service with duration), while the class Service Offer under Continuant is used, without focusing on the temporal aspect, to describe the service as a whole, or as a model, which needs to be planned / designed / developed / etc., and might be affected by other entities like the products, actors, etc. The relations between such pairs of Occurrent and Continuant, like for example *Service implements Service Offer*, or *Service is_instance_of/occurrent_part_of Service Offer*, are also defined.

The proposed PSS ontology shares a number of classes with other ontologies relevant for manufacturing, such as Product, Service, Company, Resources, etc. Therefore, the objective was not to further elaborate such generic classes in the manufacturing domain, but to indicate those that of relevance for PSS in the manufacturing industry. These classes serve as ‘interfaces’ to other ontologies and will need to be harmonised with these ontologies under the scope of IOF. Therefore, for the current draft version, such classes, like Product and Product Component, and their relations, are not further elaborated or defined in detail (e.g. for Product Component the Product Component Role is not defined etc.)

PSS Ontology

Entities Description

The hierarchy of the ontology entities in the following table, was made taken into consideration the relation *is_a* (or *is_a_subclass_of*) and in conjunction with the BFO categorisation.

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
Thing						Thing is the most general term to connect the rest entities.	
	Specifically Dependent Continuant					see BFO [1]	
	Business Model					Business Model is a description of a plan and implementation of the plan, aiming the successful operation of a business.	This is an interface class to other ontologies.
	System					System is a regularly interacting or interdependent group of items forming a unified whole [14]. Every system is delineated by its spatial and temporal boundaries, surrounded and influenced by its environment, described by its structure and purpose and expressed in its functioning [13]. In engineering and physics, a physical system is the portion of the universe that is being studied (of which a thermodynamic system is one major example).	This is an interface class to other ontologies.

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						Engineering also has the concept of a system that refers to all of the parts and interactions between parts of a complex project. Systems engineering refers to the branch of engineering that studies how this type of system should be planned, designed, implemented, built, and maintained. System is a set of interacting elements [6] that, as a unity, affects the design/development of solutions. It is considered from the approach of System Engineering.	
		Product Service System (PSS)				Product Service System (PSS) is a System that aims to satisfy a need of the market (e.g. to be sold in order to provide profit and support customers by covering their needs), to be competitive, and jointly fulfil customer's needs [3]. It must include products and services, and may include stakeholders and infrastructure (software or hardware).	Suggested relation: has PSS Role
	Material Entity					see BFO [1]	
	Material Object					Material Object is a group describing manufactured physical/material entities.	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
		Product				Product (for manufacturing industry) is a Material Object, manufactured to satisfy a need of the market [5] (e.g. to be sold in order to provide profit and support customers by covering their needs).	Possible relation: has Product Role It may serve as an interface class for merging with other ontologies
		Product Component				Product Component is a Material Object which is part of the Product. It can be itself a manufactured product, but for the offered product within the scope of PSS, its existence only has a meaning as part of the product.	It may serve as an interface class for merging with other ontologies.
			Firmware			Firmware is a Product Component which is software, i.e. control software of a machine that exists only in combination with specific hardware product.	
			Embedded Data-Source Component			Embedded Data-Source Component is a Product Component that refers to product-embedded information devices / parts (e.g. sensors), which allows for (additional) services to be offered for the product.	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
		Product Integrated Set				Product Integrated Set is a Material Object that consists of a set of products needed to jointly fulfil users' needs.	
	Stakeholder/ Actor					Stakeholder/Actor is an entity that describes the humans (or beings) involved in a PSS (development, deployment, use etc.).	It may serve as an interface class for merging with other ontologies.
		Individual Person				Individual Person is a Stakeholder indicating a separate person who is not legal entity (i.e. not legally considered a corporate group, as for example a company).	
			Individual Customer			Individual Customer is an Individual Person that buys or consumes (consumer) any product/service in the PSS.	
			Employee			Employee is an Individual Person that works in a Company (PSS-related company).	
		Company				Company is a Stakeholder that can be one or more individuals forming a legal entity (corporate body).	
			Business Customer			Business Customer is a Company that buys and uses the products, services or PSS. It is the	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples	
						(group/company) customer of the PSS, using the PSS for their own business.		
			Supplier/ Provider/ Vendor			Supplier/Provider/Vendor is a Company that both produces and sells something (product, service, PSS), or only sells it.	Additional subclasses are possible, e.g. in DIVERSITY material supplier, component supplier etc.	
				Product Provider		Product Provider is a Supplier/provider/vendor that both produces and sells a product, or only sells it.		
				Service Provider		Service Provider is a Supplier/provider/vendor that offers a service.		
				PSS Provider		PSS Provider is a Supplier/Provider/Vendor that offers PSS and owns intellectual property rights (IPR) on PSS offer.		
	Realisable Entity						see BFO [1]	
	Process Definition					Process Definition is a structured set of activities designed to accomplish a specific objective [4]. For example, the Process Definition can be the manufacturing process where the equipment is manufactured, or		

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						<p>the process where the equipment is used, or the development process where products, services or PSS are being developed etc.</p> <p>NOTE: Relation to BFO - Under continuant the process (definition) is being modelled as part of the PSS environment without including the time duration in which this process is valid. The time aspect of the process is included, however, as part of the modelling as occurrent.</p>	
		Service Offer				<p>Service Offer is a Process Definition referring to a set of non-tangible entities (activities, software modules etc.), related to the service part of PSS, which aims to satisfy a need of the market (e.g. to be sold in order to provide profit and support customers by covering their needs).</p>	Possible relation: has Service Role
			Product-Extension Service-Offer			<p>Product-Extension Service-Offer is a Service Offer which adds value to the product.</p>	
		Service-Offer Component				<p>Service-Offer Component is a Process Definition which is part of</p>	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples	
						a Service Offer. It can be itself a service, but for the offered service within the scope of PSS, its existence only has a meaning as part of the PSS service offer.		
		Service Offer Integrated-Set				Service Offer Integrated-Set is a Process Definition that refers to a set of Service Offers, needed to jointly fulfil users' needs.		
		Lifecycle Model				Lifecycle Model is a (set of) Process Definition(s) which includes different activities in the life of PSS, product, service etc. from the idea conceptualisation to its end-of life (beginning-of - life, middle-of-life, end-of-life).	This is an interface class to other ontologies.	
			Product Lifecycle Model			Product Lifecycle Model is a Lifecycle Model that refers to the product within the scope of PSS.		
			Service Lifecycle Model			Service Lifecycle Model is the Lifecycle Model that refers to the Service Offer within the scope of PSS.		
			PSS Lifecycle Model			PSS Lifecycle Model is the Lifecycle Model that refers to the different stages of the life of PSS.		
		Role					see BFO [1]	
			Product Role			Product Role is an optional characteristic of a material object		

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						manufactured to satisfy a need of the market (e.g. to be sold in order to provide profit and support customers by covering their needs).	
			Service Offer Role			Service Offer Role is an optional characteristic of a non-tangible entity that aims to satisfy a need of the market (e.g. to be sold in order to provide profit and support customers by covering their needs).	
			PSS Role			PSS Role is an optional characteristic of a system combining products and services, aiming to satisfy a need of the market (e.g. to be sold in order to provide profit and support customers by covering their needs).	
	Occurrent					see BFO [1]	
		Processual Entity				see BFO [1]	
			Process			see BFO [1]	
				Service		Service is a Process made for, and driven by customers, with economic value, and refers to the Service Offer entity in conjunction with time.	This is an interface class to other ontologies.

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
					Product Extension Service	Product Extension Service is a Service which adds additional value to the product.	
				Service Component		Service Component is a Process, part of a Service, and refers to the Service Offer Component in conjunction with time.	
				Lifecycle		Lifecycle is (a set of) Processes the PSS, a product or a service uses for its activities from the idea conceptualisation to its end-of-life. It refers to the Lifecycle Model entity in conjunction with time.	This is an interface class to other ontologies.
					Product Lifecycle	Product Lifecycle is a Lifecycle that includes only the Product-specific processes, in the scope of PSS. It refers to the Product Lifecycle Model in conjunction with time.	
					Service Lifecycle	Service Lifecycle is a Lifecycle that includes only the service-specific processes, in the scope of PSS. It refers to the Service Lifecycle Model in conjunction with time.	
					PSS Lifecycle	PSS Lifecycle is a Lifecycle that includes the PSS processes from the idea conceptualisation to its	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						end-of-life, referring to the PSS Lifecycle Model in conjunction with time.	
	Generally Dependent Continuant					see BFO [1]	
	Resource					Resource is a mean (source) that can be used for the design, development, offer and delivery of a PSS, from which benefit can be produced [2].	
		PSS Source-Data				PSS Source-Data is a Resource that refers to the digitalised information coming as input from the product or the service, specifically for the scope of PSS.	
			Product Data			Product Data are PSS Source-Data used in the scope of PSS, and refer specifically to the product part of PSS.	
				Embedded Data		Embedded Data are Product Data generated from embedded data-source components (e.g. sensors).	
				Digital Log Data		Digital Log Data are Product Data generated from a software element, part of the product.	
			Service Data			Service Data are PSS Source Data used in the scope of PSS, and are generated specifically in the service part of PSS (e.g. data	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						generated during a call in the service centre).	
		PSS Information				PSS information is a Resource, immaterial, describing aspects affecting PSS, and referring to all the (processed) data that one can acquire knowledge from, or further process.	
			Feature			Feature is PSS Information that describes the characteristics of a product, service, or PSS.	
				Product Feature		Product Feature is a Feature that describes an aspect, or attribute, related to the product within the PSS scope.	
					Product-Type Feature	Product-Type Feature is a Product Feature that refers to characteristics that define the subgroup where a product belongs to.	Product type is sector or company specific. These are features which characterise the specific type (subgroup) of the product.
				Service-Offer Feature		Service-Offer Feature is a Feature that describes an aspect or attribute related to the service within the PSS scope.	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
					Service-Type Feature	Service-Type Feature is a Service Feature that refers to characteristics that define the subgroup where a service belongs to.	Service type is sectorial or company specific
				PSS Feature		PSS Feature is a Feature that describes an aspect or attribute related to the PSS.	
					PSS-Type Feature	PSS-Type Feature is a PSS Feature that refers to characteristics that define the subgroup where a PSS belongs to, and describe the specific focus (orientation or aim) of a PSS, such as to engage the customer with services, or to increase the sales of a product.	Typical examples of PSS with a different type feature are e.g. the product-oriented PSS, the result-oriented PSS and the use-oriented PSS.
			Feedback			Feedback is PSS Information that represents any opinion on PSS, product or service (e.g. comments on social media, opinion expression in online questionnaires, etc.), coming from the Stakeholders (e.g., Business or Individual Customers).	
			Guideline			Guideline is PSS Information referring to a statement describing a course of action	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						aiming to reach a specific goal for the design, development or use of a PSS.	
			Indicator			Indicator is PSS Information used to measure/evaluate any aspect within the scope of PSS, namely a process, a PSS, a product, a service, etc.	
				Key Performance Indicator (KPI)		Key Performance Indicator (KPI) is an Indicator referring to (a set of) measurement(s) that evaluates the performance (or success) of a PSS (concept), and is business relevant.	Various types of KPIs can be defined: manufacturing KPI, environmental KPI etc. This is an interface class to other ontologies.
				Benefit		Benefit is an indicator that depicts a positive value (e.g. financial, satisfaction, assistance, etc.) a stakeholder (e.g. a customer) receives back as a result of the offered PSS.	Examples could be e.g. cost reduction, eco friendliness, performance improvement, risk reduction.
			Requirement			Requirement is PSS Information that depicts the aspects which are necessary for the design, development or offer of PSS.	Requirement can be further extended according to the

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
						Requirement is defined by the Stakeholder.	ISO standard or other System Engineering references. Here it serves as an interface class for merging with other ontologies.
		Infrastructure				Infrastructure is a Resource describing the facilities (physical e.g. buildings or machines, and organisational e.g. computer networks or software applications) used to assist in development and delivering of the PSS.	It may serve as an interface class for merging with other ontologies.
			Hardware Infrastructure			Hardware Infrastructure is an Infrastructure that refers to the physical networks (resources) necessary for the design, development, delivery and operation of the PSS.	
			Software Infrastructure			Software is an infrastructure that refers to the non-material aspects (resources) necessary for the design, development, delivery and operation of the PSS.	
	Independent Continuant					see BFO [1]	
	Immaterial Entity					see BFO [1]	

High-Level Class	1 st -Level Subclass	2 nd -Level Subclass	3 rd -Level Subclass	4 th -Level Subclass	5 th level Subclass	Definition	Comments / Examples
		PSS Condition				PSS Condition is a non-material entity that describes the situation around PSS.	
			PSS-Use Condition			PSS-Use Condition is a PSS Condition which describes the situation under which the PSS is being used (e.g. environment aspects, cultural aspect, geographical location, etc.).	It may serve as an interface class for merging with other ontologies.
			PSS-Development Condition			PSS-Development Condition is a PSS Condition which describes the situation under which the PSS is being developed (e.g. cultural characteristics of the development teams, corporate orientation preferences, etc.)	It may serve as an interface class for merging with other ontologies (e.g. in DIVERSITY to user-centric ontology). [7]
		Spatial Region				see BFO [1]	For the PSS ontology, this is related to both PSS-Use and PSS-Development Condition [7]

Relations *

The following table includes the key relations among the classes which were defined. As indicated above, the hierarchy of the classes was made taken into consideration the relation is_a (or is_a _subclass_of) and in conjunction with the BFO categorisation. Therefore, the relations is_a are not listed in the table.

Domain	Relation	Range	Comments
PSS	<i>belongs_to</i>	PSS Provider	
	<i>is_composed_of</i>	Product	
	<i>is_composed_of</i>	Service Offer	
	<i>has</i>	PPS Role	
	<i>exists_in</i>	PSS Lifecycle	
	<i>implements</i>	Business Model	
	<i>has</i>	PSS Feature	
	<i>has</i>	PSS Lifecycle Model	
	<i>uses</i>	Resource	
Product	<i>is_composed_of</i>	Product Component	
	<i>exists_in</i>	Product Lifecycle	
	<i>has</i>	Product Role	
	<i>has</i>	Product Feature	
	<i>has</i>	Product Lifecycle Model	
Product Component			
Firmware			
Embedded Data-Source Component	<i>generates</i>	Embedded Data	
Product Integrated-Set	<i>is_composed_of</i>	Products	
Stakeholder	<i>defines</i>	Requirements	
	<i>provides</i>	Feedback	
Individual Person	<i>provides</i>	Feedback	
Individual Customer	<i>provides</i>	Feedback	

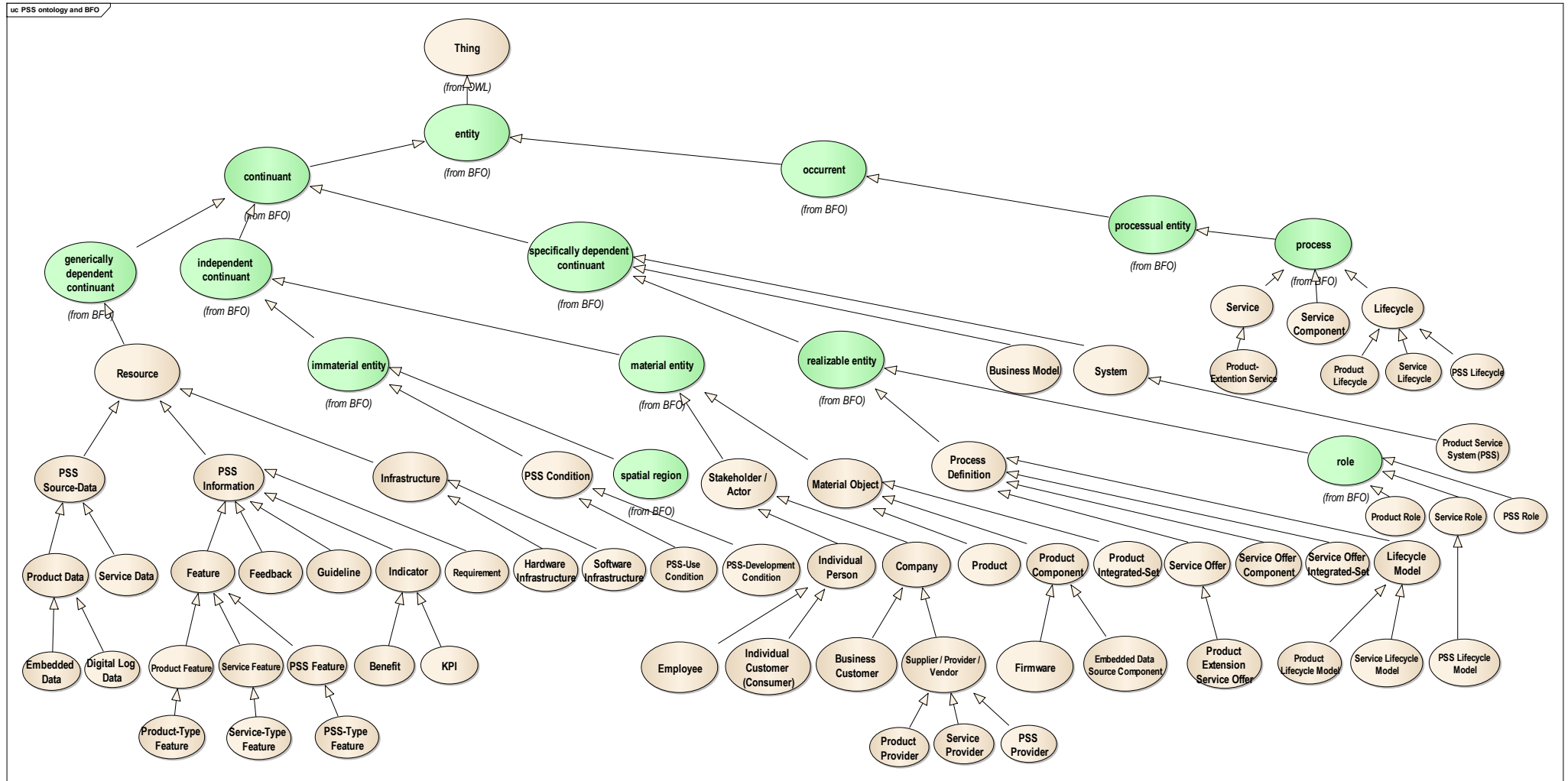
	<i>owns</i>	PSS	
	<i>owns</i>	Product	
	<i>owns</i>	Service Offer	
Employee	<i>uses</i>	Infrastructure	
Company	<i>uses</i>	Feedback	
	<i>uses</i>	Guideline	
	<i>uses</i>	Indicator	
Business Customer	<i>provides</i>	Feedback	
	<i>owns</i>	PSS	
	<i>owns</i>	Product	
	<i>owns</i>	Service Offer	
Supplier/ Provider/ Vendor			
Product Provider	<i>supplies</i>	Product	
	<i>supplies</i>	Product Component	
Service Provider	<i>supplies</i>	Service	
PSS Provider	<i>supplies</i>	PSS	
Service Offer	<i>is_part_of</i>	PSS	
	<i>has</i>	Service-Offer Feature	
	<i>has</i>	Service Lifecycle Model	
Product-Extension Service-Offer	<i>extends</i>	Product	
	<i>uses</i>	Product Data	
Service-Offer Component			
Service Offer Integrated-Set	<i>is_composed_of</i>	Service Offers	
Lifecycle Model			
Product Lifecycle Model			

Service Lifecycle Model			
PSS Lifecycle Model			
Process	<i>implements</i>	Process Definition	
	<i>is_instance_of/occurent_part_of</i>	Process Definition	
Service	<i>is_composed_of</i>	Service Component	
	<i>implements</i>	Service Offer	
	<i>implements</i>	PSS	
	<i>is_instance_of/occurent_part_of</i>	Service Offer	
	<i>is_instance_of/occurent_part_of</i>	PSS	
	<i>uses</i>	Product Data	
	<i>uses</i>	Service Data	
	<i>exists_in</i>	Service Lifecycle Model	
	<i>generates</i>	Service Data	
Service Component	<i>implements</i>	Service Offer Component	
	<i>is_instance_of/occurent_part_of</i>	Service Offer Component	
Lifecycle	<i>implements</i>	Lifecycle Model	
	<i>is_instance_of/occurent_part_of</i>	Lifecycle Model	
PSS Source-Data			
Product Data			
Embedded Data			
Digital Log Data			
Service Data			
PSS Information			

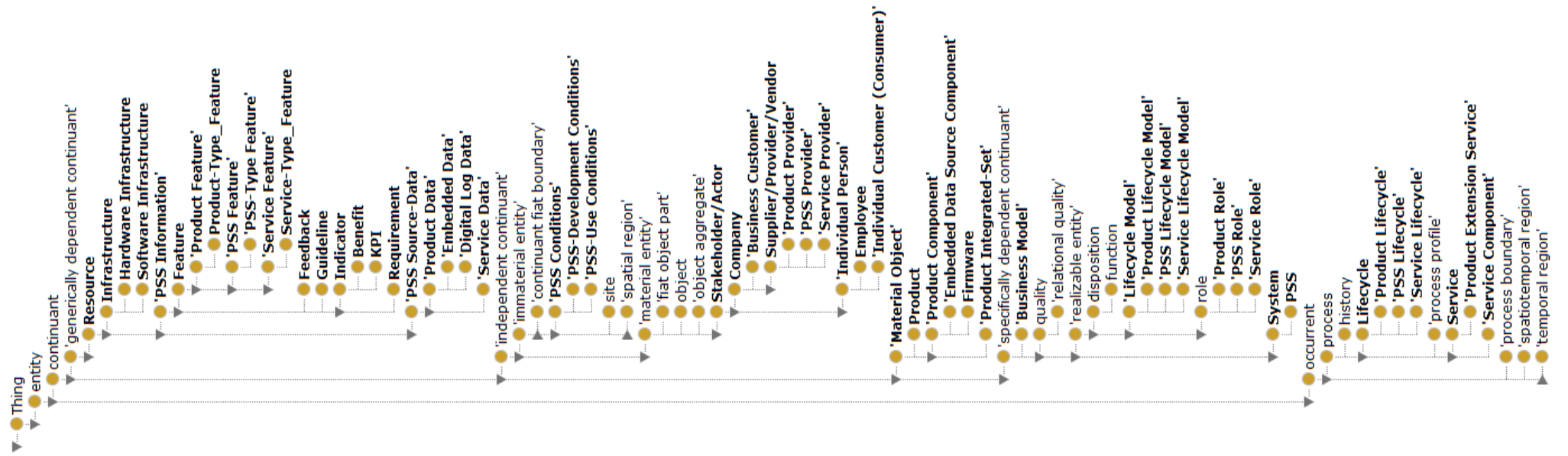
Feature			
Product Feature			
Service Feature			
PSS Feature			
Feedback	<i>refers_to</i>	PSS	
	<i>refers_to</i>	Product	
	<i>refers_to</i>	Service	
Guideline			
Indicator			
Key Performance Indicator (KPI)			
Benefit			
Requirement			
Infrastructure			
PSS Condition	<i>Refers to</i>	PSS	

*the list above constitutes a draft attempt to show dependencies between the ontology entities, therefore, might not be complete, and it is subjected to further improvement

Class Diagram



Tree View *



* created using protégé

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