FLEXINET

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[Initial lightweight ontologies and informal constraint descriptions]

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Executive Summary

This FLEXINET deliverable contains the results of the analysis performed in task T3.1 of each of the 3 industry sector use cases along with the proposed generalisation of these concepts for cross sector applicability. The report has two major elements: (i) the analysis of the key concepts, relations and constraints related to each end user industry sector; and (ii) the evaluation of these end user ontologies in relation to a generalised product-service production reference ontology.

The first major element, covered in sections 4, 5 and 6, provides the high level view of the key concepts and relationships for each end user, modelled using UML class diagrams along with those constraints and rules that have been elicited to date. This provides an initial view that will continue to be developed, as the use cases in WP1 are further developed and as the ontological requirements from WP2 and WP4 become more detailed.

The second major element of the report provides the background to the ontological research of particular relevance to FLEXINET that leads on to the structure the product-service production ontologies that are of fundamental importance to the FLEXINET concept. Within this broad concept the key external factors and risk factors from work package 2 are incorporated as well as those from external ontologies such as those from the MSEE project. Perhaps, most importantly it includes the initial analysis of the end user ontologies in terms of their cross-sector applicability within the context of the product-service production ontology.

This deliverable provides an initial high-level view of the FLEXINET ontologies that are sufficient to start the process of formalisation in task T3.2. This task will not only formalise the existing understanding but will continue to develop and expand that understanding both within the reference ontologies and in the way in which these ontologies can be specialised to suit specific end user requirements.

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1 Scope

This technical report contains the results of the analysis performed in T3.1 of each of the 3 industry sector use cases along with the proposed generalisation of these concepts for cross sector applicability. The report will take the form of a number of UML class models along with a list of informal textual descriptions of the key constraints that need to be considered in the full ontology.

The report also introduces and explains the reference ontology concept being explored in the project and how this is used to support end-user concept generalisation.

2 Introduction

The work reported in this deliverable is based on task T3.1 which has been to identify from the business concepts, constraints and facts detected in the WP1 use cases those that should be included in the ontologies for network configuration support purposes. These have been selected considering the most important interactions existing in global production networks. The resulting business concepts, constraints and facts have been analysed on an industry sector-by-sector basis following our end-user business sectors. The key concepts and their relationships have been modelled using UML class diagrams to provide light-weight ontologies as a basis for initial evaluation and for further development into formal ontologies in task T3.2. The constraints that have been identified are also listed as informal constraint descriptions for further development and formalisation in task T3.2.

The development of the Product-Service Production (PSP) reference ontology concept is described, including the consideration of existing ontologies, as a key contribution to providing a base for general ontology applicability for cross-sector use. In addition, the end-user light-weight ontologies have been analysed to show how they fit against the various levels defined in the developing PSP reference ontology.

It should be noted that this deliverable provides an initial view of the ontology development which will continue to be developed in task T3.2 and will be influenced by the on-going development of use cases in WP1 and by inputs from WP2 and WP4.

3 Objectives

D3.1 has contributed to the two WP3 objectives listed below by documenting the key semantic concepts, their knowledge constraints and their inter-relationships, in the context of globalised production networks. These concepts and relationships have then been modelled as lightweight ontologies using UML and the knowledge constraints are listed as informal constraint descriptions. The formal modelling, in Highfleet's Knowledge Frame Language (KFL), of these concepts, relationships, constraints and facts will take place in task T3.2.

- To interpret each industry use case developed in WP1 to identify and document their key semantic concepts, their knowledge constraints and their inter-relationships in the context of globalised production networks;
- To structure and formally model these concepts, relationships, constraints and related facts to provide an underpinning environment against which specific network configuration designs can be evaluated.

4 Analysis related to food industry

4.1 Scope

4.1.1 Conclusions from Interviews

The purpose of the interviews carried out in WP1 was to develop a basic understanding of the types of concepts involved in the reconfiguration of product-service globalised production networks, the relationships that exist between them and the constraints and rules that must, or may, be considered when reconfiguring a network.

There was also a need to understand the questions that end users would like to be able to answer when considering changes to their production network due to some new product-service change requirement.

With regard to the food industry scenario, the main outputs derived from the interviews are summarised in the following Table 4-1:

Food Industry Scenario Aspects	Food Industry Scenario Answers
Scope of the ontology and FLEXINET services	Made to order customised drinks
Purpose of the ontology w.r.t. FLEXINET services	To understand the constraints of their GPN and enable more agile and informed decisions regarding risks and costs when facing a new product development.
What are the competency questions i.e. what questions do you want the ontology to answer?	In particular, the targeted ontology will help managers throughout the development of a new product, with ongoing advice regarding the customisation process, through the widest possible range of options in terms of product costs, project risks, product configuration and network configuration. In particular: A. What if a customer orders a new customised drink? Which are the outstanding risks and costs of being involved? Should we GO/NO GO? B. What if the manufacturing of the new customised drink is accepted? What are the detailed risks and costs of being involved? What should be the estimated budget and delivery time? C. Once we have the order from the customer, how should we react to new product development problems if/when appear? Which manufacturing process adaptations (product/service/production) should be made? What changes should be made to the budget and delivery time?

Table 4-1: Food industry scenario main outputs

4.1.2 Approach to the food ontology

CustomDrinks bases its business in the 'Made to Order' concept, which can be adapted to the production of all drinks in any format. The Made to Order concept aims to reflect company's service philosophy and its commitment to adapting to customers' needs. In a global world dominated by a tendency towards personalisation that extends to all spheres of life, the need for flexible processes and market adaptation is no longer a plus; instead it has become a competitive requirement. In principle, customers can select any drink from its catalogue (tinto de verano - red wine and soda mix - ecological cider, sangria, a choice of fruit juices, or even create a bespoke drink), adapting to the desired tastes and requirements.

This is also the core business on which FLEXINET will focus:

- On the one hand, the process is initiated when a customer demands a new order for a customised drink. This order can be expressed in terms of the product-service manufacturing capabilities CustomDrinks is able to offer its customers. After having analysed the request, this offer from the customer can be interpreted with regard to 3 main components: (i) the container i.e. the packaging; (ii) the content i.e. the drink; and (iii) the service i.e. the extent of the business service. CustomDrinks offers several service possibilities to its customers, from just packaging an existing drink, to the elaboration of the drink plus the packaging, and even to the delivery at customer's facilities;
- On the other hand, CustomDrinks has its global production network (GPN). In this case, GPN consists of the interconnection of nodes representing players (customer, supplier, manufacturer…), working staff (operator, general manager, marketing responsible, production manager…), production machines (filler, closer, labeller...), IT-systems (ERP, Excel production order...) and so on. In terms of the Mo2Go modelling (From WP1), these nodes correspond to several orders, resources and products, interlinked each other according to a workflow.

According to the results from the interviews, CustomDrinks has three main processes as a basis for its business as set out in Figure 4-1, Figure 4-2 and Figure 4-3:

1. Feasibility study

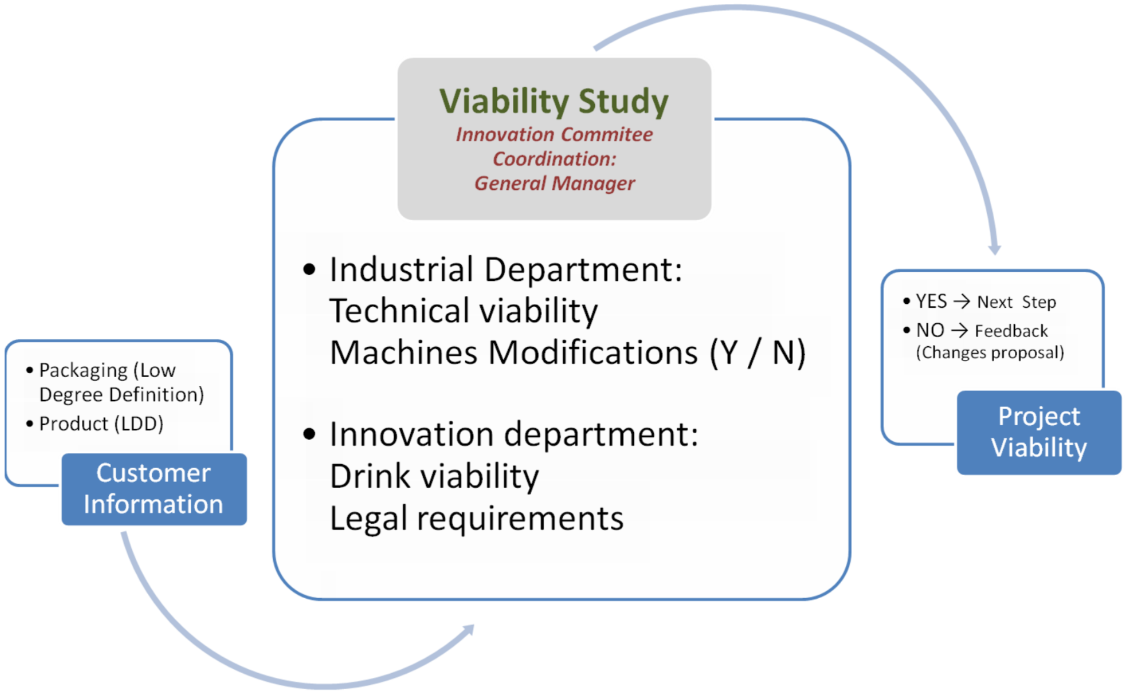

Figure 4-1: Feasibility Study

2. Sales study

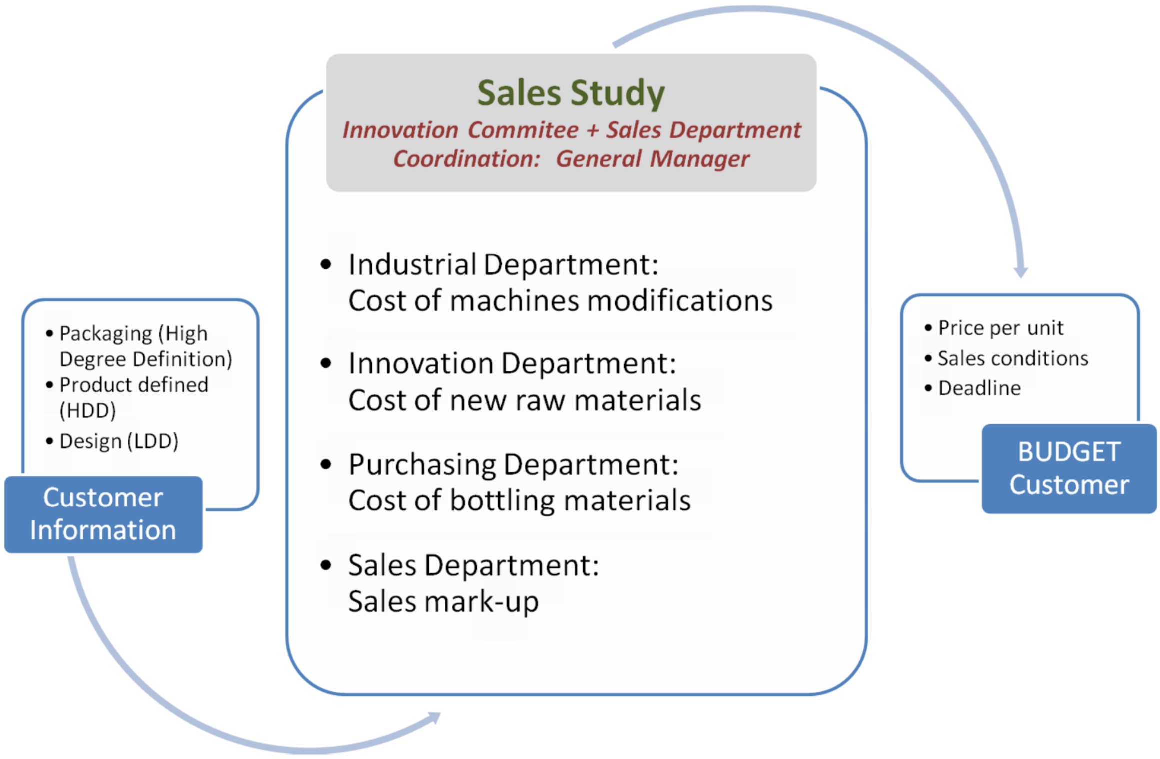

Figure 4-2: Sales Study

3. New project development

Figure 4-3: New project development

To achieve the purpose of the ontology, FLEXINET should be able to provide an understanding of the intrinsic properties of the GPN for the case of CustomDrinks. Each node will represent a set of constraints (Ck, Cl,…Cv), by which the flexibility of the network is affected.

The following picture in Figure 4-4 represents the interpretation of elicited requirements and the approach given to start setting up the ontology:

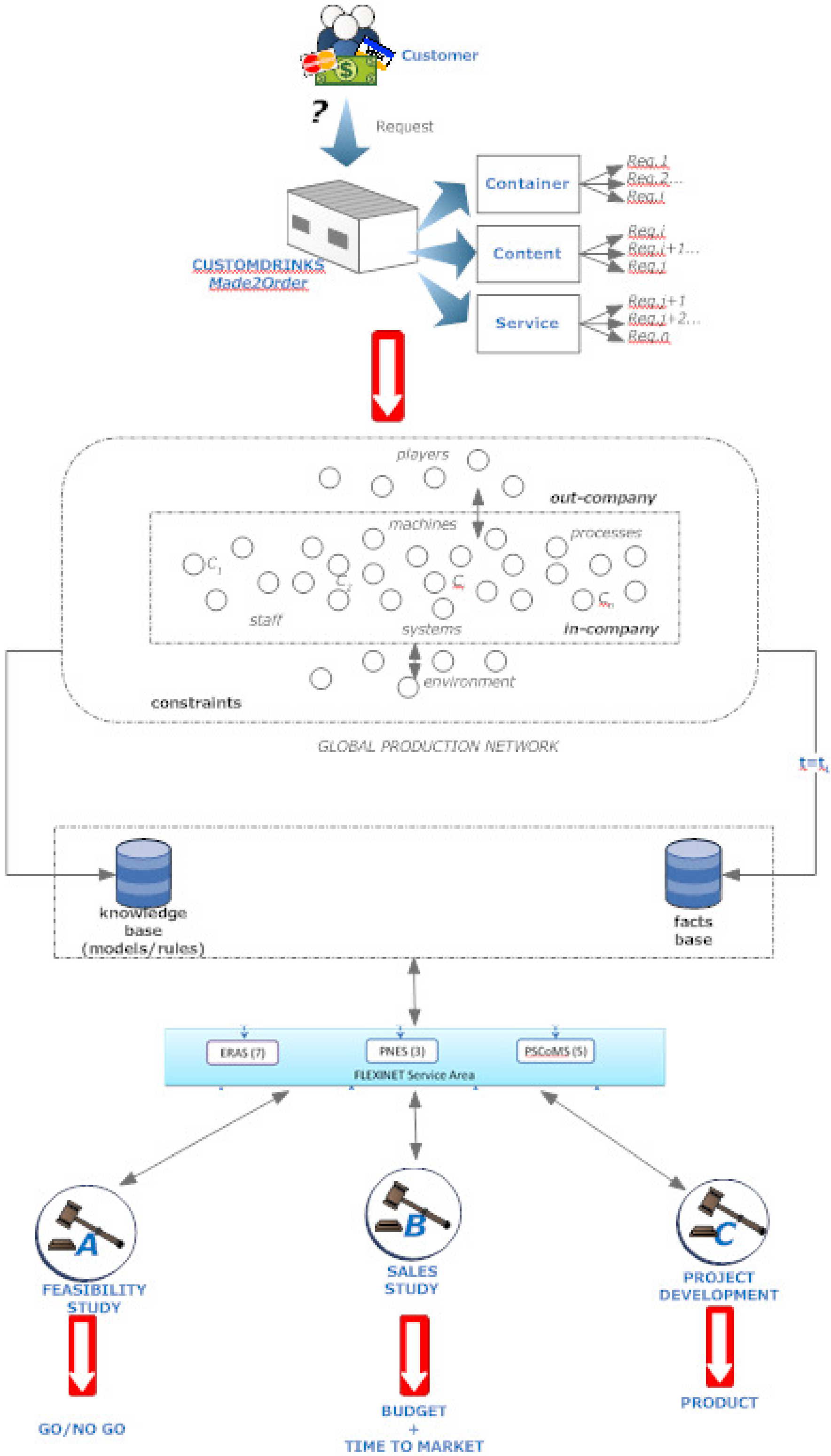

Figure 4-4: Ontology development approach

For each process in CustomDrinks, we have a decisional point A/B/C.

A. is the first decisional point that occurs at the Feasibility Study.
B. is the second decisional point that occurs at the Sales Study.
C. is the third decisional point that occurs at the New Product Development.

The main purpose of the work to be carried out here is to elicit the knowledge behind each decisional point. To that aim we will try to identify the constraints (Ci, Cj,…Cn) that have implications in each decisional point and understand their meaning, their relations and their links to the processes. If we are able to build this understanding we will be able to set up an ontology driven by the product-service-production aspects of CustomDrinks and to be able to answer the targeted competency questions.

4.1.3 Competency questions for the food ontology

Competency Questions about first decisional Point A: 'Feasibility Study':

- What if a customer orders a new customised drink?
- What are the requirements of the client's request in terms of our manufacturing assets: content/container/service?
- Which products are compatible with the request?
- What are the outstanding risks and costs of being involved?
- What are the technical risks involved?
- What are the innovation risks involved?
- What are the production network risks involved?
- What if a new market is addressed for the drink?
- Are there any relevant ingredients to take into consideration?
- Is the client financially reliable?
- Is there any similar past development project?
- Should we GO/NO GO (accept the project)?

Competency Questions about second decisional Point B: 'Sales Study':

- What if the manufacturing of the new customised drink is accepted? What are the detailed risks and costs of being involved?
- What are the raw materials involved?
- Which production machines are involved?
- Which bottling materials are involved?
- What machines spare parts/accessories are needed?
- What are the risks and costs of new production assets if needed? Their availability? The minimum order amount? Specific delivery time?
- Are there any legal requirements to consider?

- Are there any logistic costs to consider?
- Which partners/stakeholders can provide the expected capabilities to develop a specific product?
- Is there any similar past development project?
- What should be the price per unit?
- What should be the estimated budget for the project?
- What should be the time-to-market (available for the client)?

<u>Competency Questions about third decisional Point C: 'New Product Development':</u>

- Does the product fit the expected quality parameters?
- Does the product fit the client acceptance?
- Does the product design fit?
- What logistic aspects must be considered?
- What machine modifications are needed?
- What packaging materials are needed?
- What raw materials are needed?
- What changes over the current formula are needed?
- Which are the restrictions of partners/stakeholders affecting the development of the specific product?
- Is there any similar past development project?
- To what extent is the budget affected?
- To what extent is the time-to-market (to client) affected?

4.2 Initial lightweight ontology

4.2.1 Initial food industry UML model

This subsection contains a graphical representation of the food industry ontology in a lightweight UML model (see Figure 4-5), this takes into consideration all of the business concepts, relations and properties that have been elicited with the help of end users. Business concepts, relations and properties are described in the following subsection.

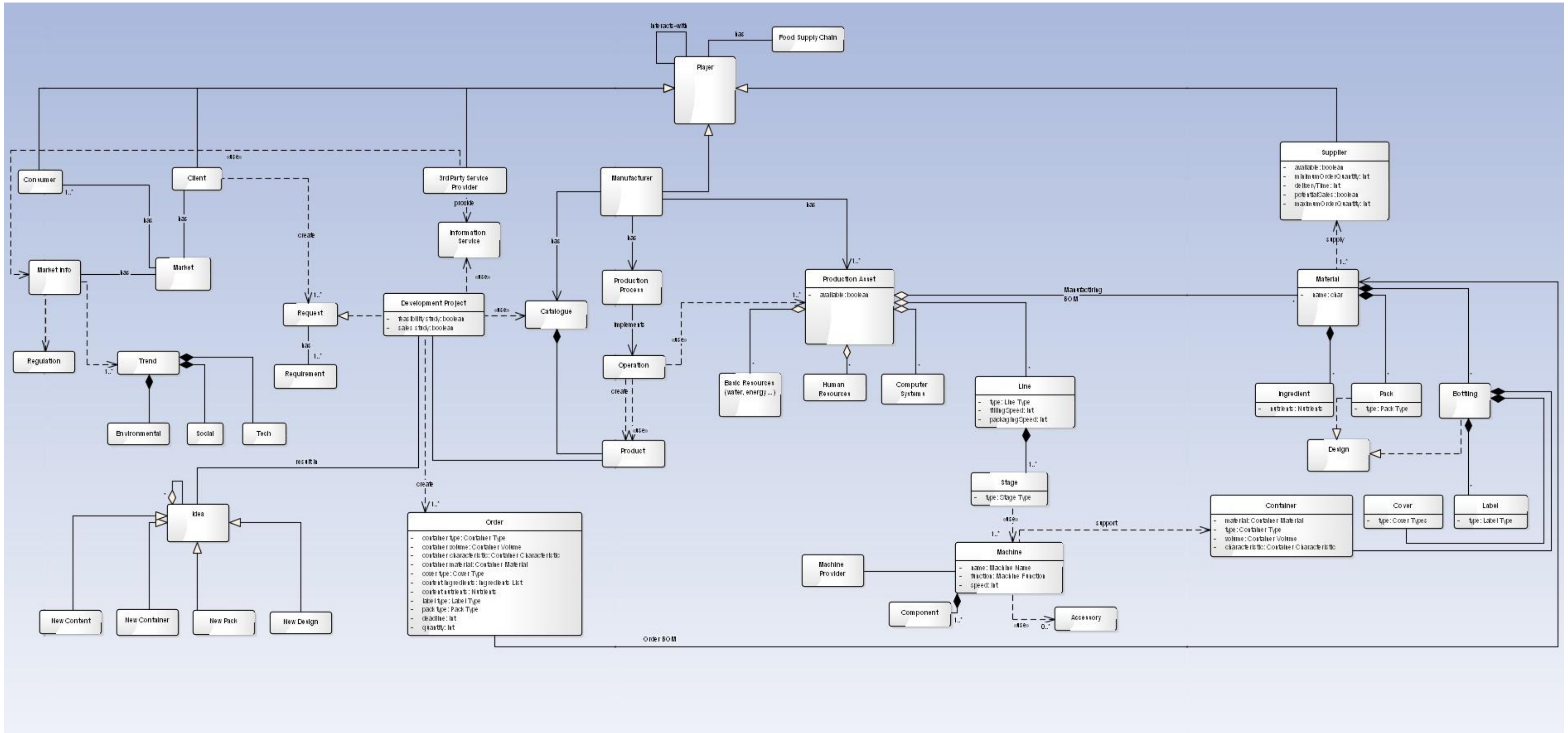

Figure 4-5: Food industry ontology

Error! Reference source not found. compiles the enumerated types developed for the categorisation of attributes in the previous ontology:

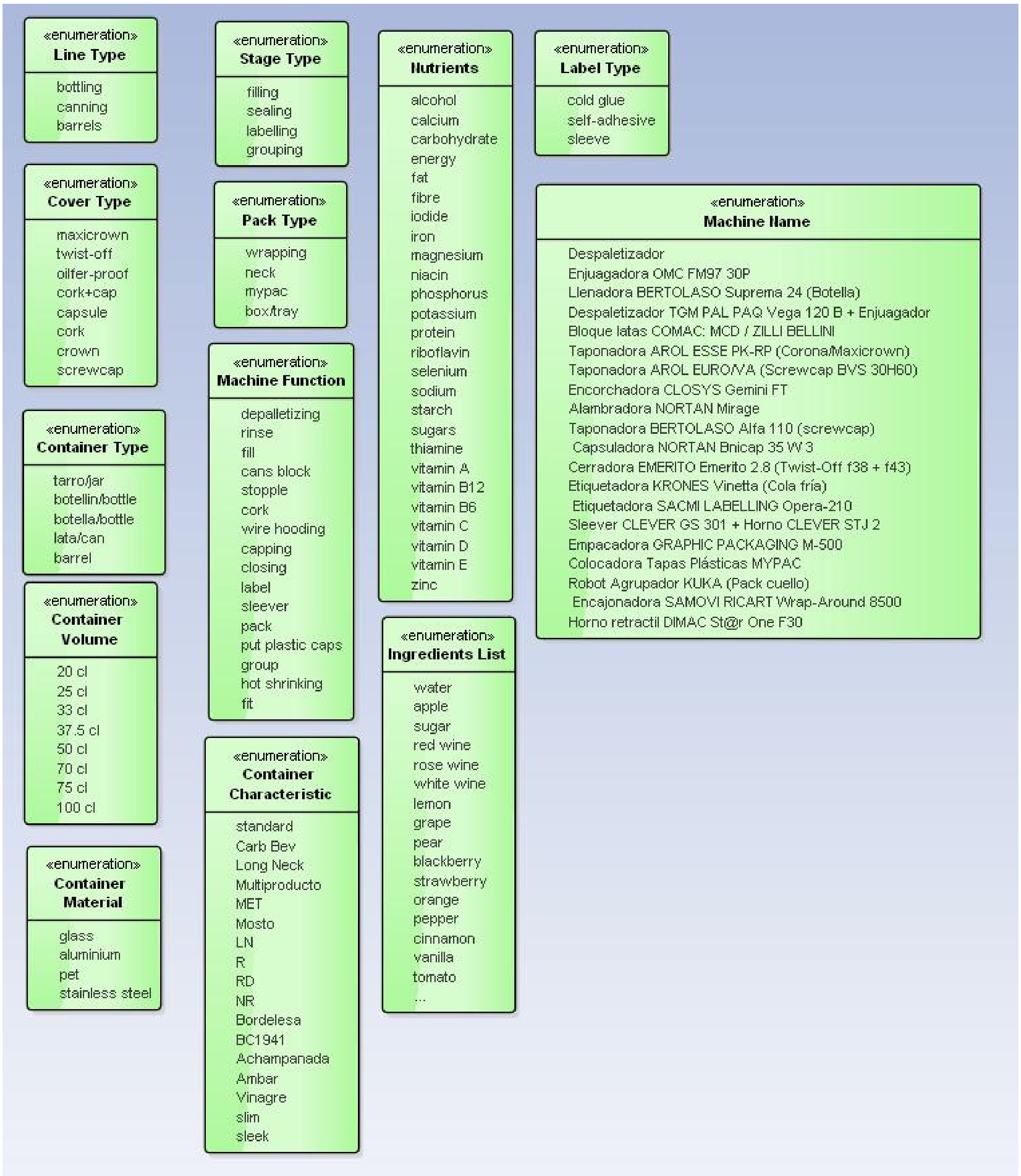

Figure 4-6: Categorisation of ontology attributes

The food supply chain is comprised by a set of players that interact one with another. Manufacturer, Supplier, Client, Customer and 3rdParty service provider are the types of players in this domain, depending on the role they play inside the supply chain. The Manufacturer is responsible for manufacturing the finished products and delivering them to the Client. In this case, the Client is the player who has a business relation with the Manufacturer and asks for customised products (made-to-order drinks). The Client has a Market, corresponding to the area where they sell the product to

Consumers belonging to that Market. The Market has Information about Social, Technological and Environmental trends, as well as Legal regulations. The 3rd Party Service Provider uses Market Information to provide a service (market information) for the Manufacturer. To satisfy the Client the Manufacturer carries out Production processes as a set of Operations that transform the incoming Product to an outgoing product, until the finished product is achieved. Operations make use of Production Assets to achieve the manufactured products. Production Assets are Materials such as Ingredients (raw materials), Bottling Materials and Packing Materials, Human Resources, Basic Resources, Computer Systems and Production Lines. Materials are provided by Suppliers. The relation between Operation and Production Assets gives the assets that were used to manufacture a given product (Manufacturing Bill of Materials). Production Lines are comprised by Stages and contain Machines, which have components and accessories. Machines have compatibility with certain Containers. Bottling Materials are a joint association of Container, Cover and Label. Bottling and Packing Materials can implement Design. The Development Project is initiated when a Request comes from the Client. The Request has a set of Requirements that should be accomplished in the final Product. This process can also start when a new idea is created. The Request uses the Catalogue that is composed of the Products already developed by the company so as to evaluate feasibility. The Catalogue owns the knowledge about product information including necessary production processes and all necessary production assets. The Development Project results in an Order that will initiate the Production Processes in the Manufacturer. The Order predefines the set of Production Assets envisaged to be used in the manufacturing (Ordered Bill of Materials).

4.2.2 Concepts, attributes and relationships

- Food Supply Chain
- Player
- Consumer
- Client
- 3rdParty Service Provider
- Manufacturer
- Supplier

  available : boolean
  minimumOrderQuantity : integer (u)
  deliveryTime : date
  potentialSales : boolean
  maximumOrderQuantity : integer (u)
- Market
- Market Info
- Regulation
- Trend
- Environmental
- Social
- Tech
- Request
- Requirement
- Information Service

- Development Project
  feasibility study : true/false
  sales study : true/false
- Idea
- New Content
- New Container
- New Pack
- New Design
- Catalogue
- Order
  container type : Container Type
  container volume : Container Volume
  container characteristic : Container Characteristic
  container material : Container Material
  cover type : Cover Type
  content ingredients : Ingredients List
  content nutrients : Nutrients
  label type : Label Type
  pack type : Pack Type
  deadline : date
  quantity : integer (u)
- Production Process
- Operation
- Product
- Production Asset
- available : true/false
- Basic Resources (water, energy ...)
- Human Resources
- Computer Systems
- Line
  type : Line Type
  fillingSpeed : integer (l/hours)
  packagingSpeed : integer (u/hours)
- Stage
  type : Stage Type
- Machine
  name : Machine Name
  function : Machine Function
  speed : integer (u/hours)
- Component
- Accessory
- Material
  name : string character
- Ingredient

nutrients : Nutrients

- Pack

  type : Pack Type
- Bottling
- Design
- Container

  material : Container Material

  type : Container Material

  volume : Container Volume

  characteristic : Container Characteristic
- Cover

  type : Cover Type
- Label

  type : Label Type

The following are elicited relationships between CustomDrinks concepts:

- product HAS product type, container, content
- container HAS design, features, container type, components
- design HAS compatibility
- content HAS ingredients, properties
- factory MANUFACTURES product
- factory HAS production network
- factory PROVIDES service
- factory HAS machines, lines
- factory HAS idea
- machine HAS spare parts
- machine HAS restrictions
- factory HAS client
- client ASK request
- client HAS financial situation, reliability
- request HAS requirement
- request RELATES TO product
- factory CARRIES OUT project
- factory BELONGS TO company
- company HAS strategy
- project HAS feasibility
- project HAS risk, cost
- project HAS budget
- project HAS deadline
- project HAS sales study
- project INVOLVES prototype
- prototype RELATES TO product
- product HAS quarantine

- product <u>HAS</u> market
- market <u>HAS</u> legal requirements
- market <u>HAS</u> trends
- raw materials <u>PROVIDED BY</u> supplier
- service <u>PROVIDED BY</u> 3rd party
- product <u>HAS</u> logistic conditions
- packaging materials <u>PROVIDED BY</u> supplier
- spare parts <u>PROVIDED BY</u> machine manufacturer
- product <u>PRODUCED IN</u> factory
- supplier <u>HAS</u> name, country, distance from, supply, price per unit
- supplier <u>HAS</u> maximum range
- supplier <u>HAS</u> maximum delivery time
- transport <u>HAS</u> maximum cost
- supplier <u>HAS</u> minimum order amount
- client <u>HAS</u> acceptance criteria
- ingredient <u>HAS</u> availability

4.2.3 Informal constraint descriptions

1. The order must be validated by one feasibility study and one sales study.
2. The production process operation uses production assets that must be available.
3. The packaging speed will be the minimum speed of machine line.
4. The machine 'Despaletizador' supports any container with glass material. Also supports container of botella/bottle type with aluminium material.
5. The machine 'Enjuagadora OMC FM97 30P' supports any container with glass material. Also supports container of botella/bottle type with aluminium material.
6. The machine 'Llenadora BERTOLASO Suprema 24 (Botella)' supports any container with glass material. Also supports container of botella/bottle type with aluminium material.
7. The machine 'Despaletizador TGM PAL PAQ Vega 120 B + Enjuagador' supports any container with lata/can type.
8. The machine 'Bloque latas COMAC: MCD / ZILLI BELLINI' supports any container with lata/can type.
9. The machine 'Taponadora AROL ESSE PK-RP (Corona/Maxicrown)' supports any container with volume less or equal to 33 cl except container of tarro/jar type or lata/can. Also supports container with BC1941 characteristic.
10. The machine 'Taponadora AROL EURO/VA (Screwcap BVS 30H60)' supports any container with bordelesa characteristic.
11. The machine 'Encorchadora CLOSYS Gemini FT' supports any container with achampanada characteristic or 70 cl glass material.
12. The machine 'Alambradora NORTAN Mirage' supports any container with achampanada characteristic.
13. The machine 'Taponadora BERTOLASO Alfa 110 (screwcap)' supports any container with ambar characteristic or vinagre. Also supports container with 100 cl glass material.

14. The machine 'Capsuladora NORTAN Bnicap 35 W 3' supports any container with achampanada characteristic.
15. The machine 'Cerradora EMERITO Emerito 2.8 (Twist-Off f38 + f43)' supports any container of tarro/jar type.
16. The machine 'Etiquetadora KRONES Vinetta (Cola fría)' supports container of botellin/bottle type with estándar characteristic. Also supports container of botella/bottle type with achampanada characteristic or vinagre. Also supports container with 100 cl glass material.
17. The machine 'Etiquetadora SACMI LABELLING Opera-210' supports any container with glass material.
18. The machine 'Sleever CLEVER GS 301 + Horno CLEVER STJ 2' supports any container with volume less or equal to 33 cl except with MET characteristic. Also supports any container with tarro/jar type or achampanada characteristic.
19. The machine 'Empacadora GRAPHIC PACKAGING M-500' supports container of botellin/bottle type with multiproducto or standard characteristics. Also supports container of lata/can type with sleek or slim characteristics.
20. The machine 'Colocadora Tapas Plásticas MYPAC' supports any container of lata/can type.
21. The machine 'Robot Agrupador KUKA (Pack cuello)' supports container of glass material with less or equal than 33 cl and long neck characteristic or MET or estándar or LN.
22. The machine 'Encajonadora SAMOVI RICART Wrap-Around 8500' supports any container.
23. The machine 'Horno retractil DIMAC St@r One F30' supports any container.
24. The supplier requires a minimumOrderQuantity for serving production assets.
25. The supplier requires a deliveryTime for serving production assets.

5 Analysis related to white good industry (LU)

5.1 Scope

5.1.1 Conclusions from Interviews

The purpose of interviews carried out in WP1 was to develop a basic understanding of the types of concepts involved in the reconfiguration of product-service globalised production networks, the relationships that exist between them and the constraints and rules that must, or may, be considered when reconfiguring the network.

There was also a need to understand the questions that end users would like to be able to answer when considering changes to their production network due to some new product-service change requirement.

With regard to the white goods scenario, the main outputs derived from the interviews are summarised in the following Table 5-1:

White Goods Industry Scenario Aspects	White Goods Industry Scenario Answers
Scope of the ontology and FLEXINET services	Energy saving dryer is the Product-Service to be modelled
Purpose of the ontology w.r.t FLEXINET services	To support the Product-Service co-evolution management (possibly starting from a product to ideate a product/service offer) and the Global Production Network configuration, to support decisions within the 'PSS Ideation' and 'PSS design' processes.
What are the competency questions i.e. what questions do you want the ontology to answer?	**P-S co-evolution:** Understand / Assess how product changes will affect compatibility with related services? Understand / Assess how service changes will affect compatibility with related products? Which services are compatible with a specific product? Which products are compatible with a specific service? **P-S ideation:** Which product-service concepts are related to a given keyword? What are the main product-service concepts that have been tested?

	What are the failure reasons for a concept? What are the main technical solutions needed to enable/realise a specific concept? **GPN:** Identify partners against a set of important factors? Will a specific stakeholder's capabilities fit into our network? What is the GPN network performance for a new/specific stakeholder? Which partners/stakeholders have the level of reliability needed to develop a specific product-service? Which partners/stakeholders have lower costs than the current configuration of partners/stakeholders?

Table 5-1: White goods industry scenario main outputs

5.1.2 Approach to the white goods ontology

According to their product-service development, Indesit currently sells the physical product. Only a few basic services are offered in a traditional way (e.g. warranty, technical support, service call centre, etc.). These Indesit products can be grouped into three different lines: (i) cooling (fridges, freezers, etc.), (ii) washing and drying (washing machines, dishwashing machines, wash and dry machines, dryers, etc.), and (iii) cooking (ovens, hobs, hoods, cookers, etc.). In the FLEXINET project attention has been focused on dryer products. In fact, all Indesit drying appliances ensure optimum performance with minimum expenditure of energy and time, and also offer an impressive array of garment care options, enabling the Company to maintain its outright leadership in the washing sector in Europe. In this context, the product development cycle is strongly centred on physical product and the main business processes are connected to the product stages (i.e. idea generation, feasibility, concept, design, development, testing and delivery). Selling the physical product for Indesit means that the customers usually go to a retailer/distributor to see the product alternatives and choose the best product option according to their needs. Usually the retailer is a big shop specialising in house appliances or domestic items and offer a wide variety of products, from Indesit and from its main competitors. Products are presented in large exhibition spaces and located in different layouts. Then, the household appliance is delivered to the home and installed by a technician. The customer uses the dryer as everybody knows.

Currently Indesit offers only a few supporting services such as warranty contract, 24hours assistance and assistance website. However, they are always sold in addition to the product and they are relatively simple. After purchasing the product, the customer can subscribe to a traditional warranty contract of variable duration according to the customer's choice (1-3 years). It assures:

- Free maintenance;
- Free spare parts;

- Free delivery at the nearest Assistance Centre (when the product cannot be fixed at home);
- Product substitution is it is not reparable;
- On-site intervention of an Indesit technician (only for the first 6 months).

Concerning the service development process, services are actually conceived and designed after the product in a separated way. Usually the product comes first and then the related services are added to the already existing product with minor changes. This implies that services are defined after the product development. As a consequence, services are "added" to an existing product with minor changes (adding a new component, modifying the software control to improve some functions, changing the selling strategy, evolving the user interface, etc.). Services are conceived and designed by the marketing staff they aim to define the "solution" intended as a service, while R&D activities aim to define the "solution" intended as a product.

INDESIT FLEXINET Objectives

With regard to FLEXINET, INDESIT seeks to support the development of a new product-service solution (ENERGY SAVING DRYER) by:

- Flexible configuration of Production Risk and economic management;
- Decision support systems for selecting the best system network;
- Product-service co-evolution management.

The objective is to support the development of a new product-service idea called ENERGY SAVING DRYER, it consists of the development of a new machine (an advanced dryer enhanced by connectivity features) and new services (energy awareness and predictive assistance) to improve the quality and ease of use the product itself. In particular:

- ENERGY AWARENESS SERVICE will offer a set of functionalities to control and optimise the product energy consumption and make the user aware about the energy consumed by each cycle and during the day/week/year;
- PREDICTIVE ASSISTANCE SERVICE is based on the analysis of the current state of the machine, the recognition of dangerous situations able to activate technical assistance actions, the efficient management of the maintenance process also considering the partners involved (user, Indesit Service Dept., external technical partners)

5.1.3 Competency Questions for the white goods ontology

Following the results from the interviews, requirements capture and modelling process, the following are the key FLEXINET Competency Questions from Indesit:

Competency questions related to 'Product-Service Co-Evolution':

- Understand / Assess how product changes will affect compatibility with related services?
- Understand / Assess how service changes will affect compatibility with related products?
- Which services are compatible with a specific product?
- Which products are compatible with a specific service?

Competency questions related to 'Product-Service Ideation':

- Which product-service concepts are related to a given keyword?
- What are the main product-service concepts that have been tested?
- What are the failure reasons for a concept?
- What are the main technical solutions needed to enable/realise a specific concept?

Competency questions related to 'Global Production Networks':

- Identify partners against a set of important factors?
- Will a specific stakeholder's capabilities fit into our network?
- What is the GPN network performance for a new/specific stakeholder?
- Which partners/stakeholders have the level of reliability needed to develop a specific product-service?
- Which partners/stakeholders have lower costs than the current configuration of partners/stakeholders?

5.2 Initial Lightweight ontology

5.2.1 Initial White Goods UML Model

This subsection contains a graphical representation of the white goods ontology in a lightweight UML model (see Figure 5-1), this takes into consideration all of the business concepts, relations and properties that have been elicited with the help of end users. Business concepts, relations and properties are described in the following subsection.

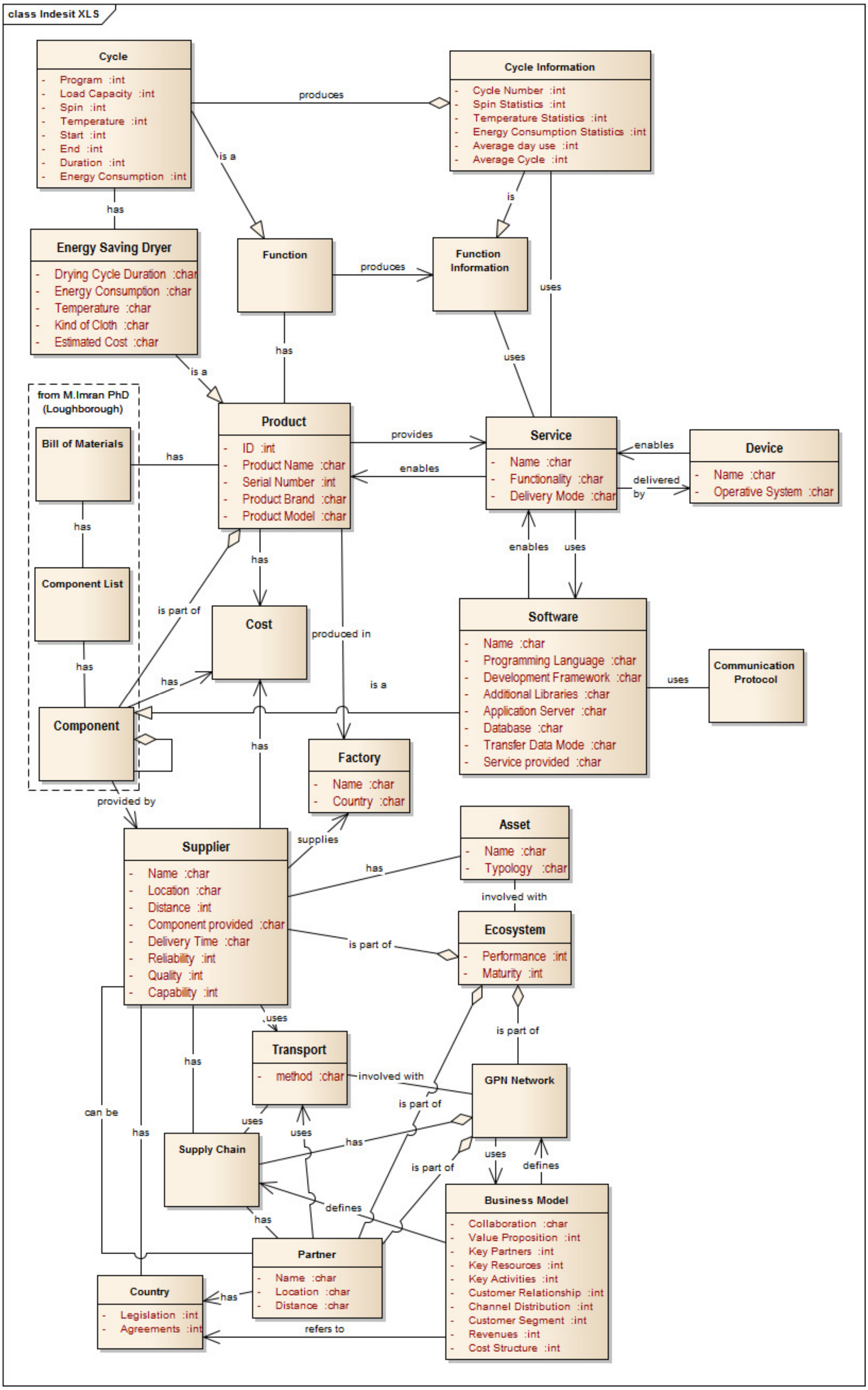

Figure 5-1: Indesit end user UML model

5.2.2 White Goods Concepts and Relationships

Concepts:

- asset, bill of materials, business model, communication protocol, component, component list, cost, country, cycle, cycle information, data type, device, ecosystem, energy saving dryer, factory, function, function information, GPN network, partner, product, service, software infrastructure, supplier, supply chain, transport.

The following are elicited relationships between Indesit concepts:

- asset HAS name, typology
- asset HAS supplier
- asset INVOLVED WITH ecosystem
- bill of materials HAS component list
- bill of materials HAS product
- business model DEFINES supply chain
- business model REFERS TO country
- business model DEFINES GPN network
- business model HAS collaboration, value proposition, key partners, key resources, key activities, customer relationship, channel distribution, customer segment, revenues, cost structure
- component HAS component
- component HAS cost
- component PROVIDED BY supplier
- component IS A PART OF product
- component list HAS component
- component list HAS bill of materials
- communication protocol USES software
- country HAS suppliers
- country HAS legislation, agreements
- cycle HAS energy saving dryer
- cycle PRODUCES cycle information
- cycle IS A function
- cycle HAS program, load capacity, spin, temperature, start, end, duration, energy consumption

- cycle information USES service
- cycle information IS function information
- cycle information HAS cycle number, spin statistics, temperature statistics, energy consumption statistics, average day use, average cycle
- device ENABLES service
- device HAS name, operative system
- ecosystem INVOLVED WITH asset
- ecosystem HAS performance, maturity
- energy saving drying HAS cycle
- energy saving drying IS A product
- energy saving drying cycle HAS drying cycle duration, energy consumption, temperature, kind of cloth, estimated cost
- function PRODUCES function information
- function HAS product
- function information USES service
- GPN network IS PART OF ecosystem
- GPN network USES business model
- GPN network INVOLVED WITH transport
- partner IS PART OF GPN network
- partner IS PART OF ecosystem
- partner HAS country
- partner HAS supply chain
- partner USES transport
- partner HAS name, location, distance
- product HAS bill of materials
- product HAS cost
- product HAS function
- product HAS id, product name, serial number, product brand, product model
- product PRODUCED IN factory
- product PROVIDES service
- service DELIVERED BY device
- service HAS name, functionality, delivery mode
- service USES cycle information

- service USES function information
- service ENABLES a product
- service USES software
- software ENABLES service
- software HAS name, programming language, development framework, additional libraries, application server, database, transfer data mode, service provided
- software IS A component
- software HAS communication protocol
- supplier HAS asset
- supplier HAS cost
- supplier HAS country
- supplier HAS name, location, distance, component provided, delivery time, reliability, quality, capability
- supplier USES transport
- supplier IS PART OF ecosystem
- supplier CAN BE partner
- supply chain HAS supplier
- supply chain USES transport
- supply chain HAS GPN network
- supply chain HAS partner

5.2.3 Informal Constraint Descriptions

- The communication protocol will be a zigbee module.
- The Product-Service will be supported by a tailored Business Model, having like value propositions for the energy saving dryer.
- The New Global Production network will involve the main strategic partners of Indesit, plus others able to develop the Product-Service conceived, according to the Business Model defined and developed.
- The partners in the network will be identified by several factors (e.g. supply quality, cost, reliability, lead time, etc.) that are not standard but directly dependent of the specific supply chain and supplier.
- The partner selection for the network definition must be driven by a specific procedure, able to configure the network.
- The supplier requires a minimum Order Quantity for serving production assets.

- The supplier requires a delivery time for serving production assets.
- The data monitored by the appliance requires to be saved in a tailored database.
- The data monitored and collected in a database must be managed with custom algorithms to give the desired results in terms of energy saving and smart maintenance.
- The appliance must be connected to a network in order to monitor the needed data.
- The Product-Service proposed has several functionalities thanks the installation of specific sensors in the product architecture.

6 Analysis related to pump industry (IPK, ITI)

6.1 Scope

Based on the requirement analyses in the scope of WP1, a basic understanding of the concepts involved in the configuration and reconfiguration of product-service globalised production networks has been outlined along with the relationships that exist between these concepts and a preliminary outline of constraints and rules that must, or may, be considered when reconfiguring the network. In this context, WP1 delivered a set of information based on the definition of the:

- Requirements based on the "real-life" business processes;
- Outline of Use Cases;
- Outline of Competence Questions.

This information delivered an understanding about the questions that end users would like to be able to answer when considering changes to their production network due to some new product-service change requirement. Consequently, the main outputs derived from the interviews are summarised in the following Table 6-1:

6.1.1 Conclusions from Interviews

Pump Industry Scenario Aspects	Pump Industry Scenario Answers
Scope of the ontology and FLEXINET services	The scope of the Pump Industry Ontology includes the knowledge and information needed to evaluate a new business idea against present production activities and the configuration of a global production network.
Purpose of the ontology w.r.t FLEXINET services	The main objective of the pump industry ontology is to provide an informational base for decision support about the feasibility of new product or service considering the interdependencies of the "real-life" concepts and constrains of the production network.
What are the competency questions i.e. what questions do you want the ontology to answer?	During the Interviews we can summarise the following competency questions: What is the distance between the current business and the new business opportunities being measured? How does a new business opportunity fit in the current business types of KSB? Which markets are relevant for the new business idea? Which markets are relevant for the business idea? Are the required experts (internal/external) available in

	the targeted markets? Which new technologies are mandatory for specific markets and are they over-engineered? Computation of technology affinity? How to push the new technology into a market? What is the impact of the new technology? Which existing customer / technology requirements will be solved by new technologies / opportunities / services? How to push the new technology into the market? How to relate with the new technology for FUTURE standards and regulations?

Table 6-1: Pump industry scenario main outputs

6.1.2 Approach to the pump ontology

The complexity and the global dimension of the production and customer network of KSB, implies legal, environmental and policy constraints which need to be considered when specifying and negotiating new business approaches inside the production-service network. Consequently, KSB has a very complex offer and order process, this situation results in currently 6 different business types depending on the product complexity as well as the resulting complexity of the processes. This is especially true for new KSB products with a higher level of complexity, they take a lot of time to implement in KSB's product configuration and production system, which, in turn requires a longer testing phase. At the moment KSB uses a lot of different configuration and production systems and at the same time, performs product development and provides different kinds of services. The pump industry ontology should capture those aspects, their interrelation and provide information to enable the decision in the early design phase. This should also include sustainability aspects e.g. human, ecology and global economics, these are only partly covered in the current assessment of the business scenarios.

Based on the requirement analyses and parallel to the efforts for the definition of the FLEXINET Architecture, the following basic requirements were specified at this stage for further development of the FLEXINET Pump Ontology:

- The feasibility of a new business opportunity in the current business case related to resources (human, competencies, production assets);
- Provision and evaluation of a specific technology and their feasibility for the production of specific pump or service;
- Feasibility of new technologies against new standards and regulations for new markets.

6.1.3 Competency questions for the pump ontology

During the requirement analyses in WP1, the following set of competency questions were defined and further used for initial definition of the ontology for the Pump Industry.

a) What is the distance between the current business and the new business opportunities being measured?
To answer to this competency question there are a number of relevant aspects to take into account, namely:

- Identification of the Data, Facts and Figures that define a business opportunity/model and strategy.
- Identification of the variables that can be analysed, measured, and eventually used for the determination of the distance between two business models.
- Description of the Market share for a certain product or services, geographic location and customer.
- Description of external Suppliers for the specific markets.

b) How does a new business opportunity fit into the current business types of KSB?

To answer to this competency question, the following concepts need to be included:

- Definition and determination of the ideal product mix according to product quantity and price.
- Consideration of environmental aspects and regulations that may affect the new business (either a product or a service) in the particular market it address.
- Description of present and future potential customers.
- Description of present and potential project partners.
- Analysis of current markets depending on customers, competitors and locations.
- Relevance of the Product complexity to the market.
- Expertise needed to develop the new business, according to the staff and their present location.

c) Which markets are relevant for the new business idea?

To answer to this competency question, several considerations need to be taken into account:

- Description of the new markets according to the description of the product and services.
- Definition of the market with concepts relevant to the KSB Products and services.
- Customer information and requirements for the relevant market (plant construction firm, industrial consumer, end customer, official and tenderer).
- Levels of distribution and implementation in the market.

- Connection to main Tender documentation and required information.
- Requirements for the qualification of distribution partners.

d) Are the required experts (internal/external) available in the targeted markets?

To answer to this competency question, the following concepts need to be considered:

- Qualification and profile of the experts and distributers.
- What expertise is needed for the product/service?
- Knowledge about the customers and their technological competences.
- Qualification needs in RTD for complex products and a product as service.

e) What is the impact of the new technology for the specific market? What is the technology affinity between a product and market?

To answer to this competency question, the following questions need to be considered:

- Which new technologies are mandatory for specific markets and are they over-engineered?
- Which existing customer / technology requirements will be solved by new technologies / opportunities / services?
- Which regulation applies for the deployment or adoption of a new technology? Capturing information about the relevant legislation and regulations.
- Capturing of information from interviews with customers and distributors, assembly employees, maintenance and construction firms.
- Capturing of information from presentations of new technologies and feedback.
- Capturing of information from trade fairs in markets.
- Collection of requirements – saved data in PM department (also in Excel chart).
- Application of a check lists.
- Interaction with the market concepts and technological affinity.

6.2 Lightweight ontology

6.2.1 Initial pump industry lightweight ontology

The following Figure 6-1 illustrates the initial formal lightweight UML representation of the pump industry.

One of the primary goals of KSB is to evaluate new Ideas in the early stages of the product development anticipating the functional requirement specification for a product Idea. Having this in mind, Figure 6-1 shows a set of entities grouped as follows:

- The left side of Figure 6-1 represents the main concepts that will lead the definition of the ontology; Business Idea, Business Model and Strategy. These three entities will be defined, analysed and evaluated against the Factors and Indicators specified in the ontology.
- Factors are divided into internal and external factors; the former expresses concepts and relationships that represent the concrete organisation of the End-User. External factors will be external entities that will influence the End-User Business Ideas. They are based on STEEP factors tailored to the End-User needs. They are social, technical, economic, environmental and political factors.
- Internal factors describe internal aspects of the company that may impinge on company decisions. Business Product refers to the Catalogue that End-User offers to Customers, KSB Technology defines technologies that they are currently being used by KSB, Markets, IT Systems, Human Resources, Market, Logistics, etc., they all are relevant entities to the company decision making. The term Location takes an important role in the ontology because of the importance of represent the GPN of the company.
- We start working with the concept "Business Idea". A new Business Idea is usually created based on a current Product, a Service, or it can be created based on a new idea not yet developed in KSB. This Business Idea is extended with a business model. At this stage an evaluation of the business model may be carried out to take a decision. An initial Specification Book for this Business Idea is also created. Business models are defined on the context of the strategies (new or existing) of the company. Strategies will be evaluated or updated based on different types of analysis.
- A Prototype with an operative Functional Specification book is finally developed and analysed against a set of indicators and factors. This will help the End-User to go for an implementation of the product.

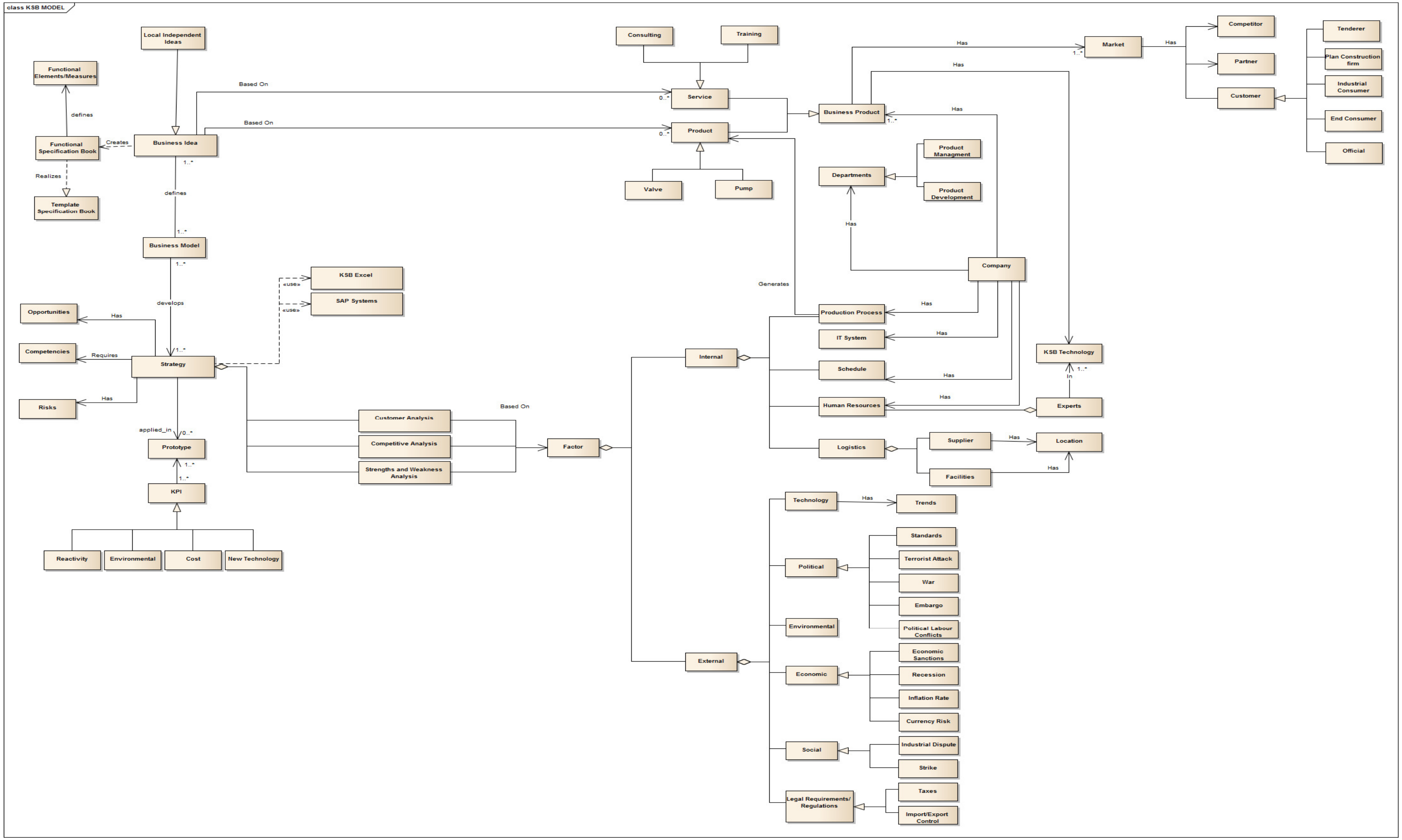

Figure 6-1: UML Light Weight Pump Industry Model

6.2.2 Pump industry Concepts and Relationships

The following is the list of initial concepts that will lead us to a formalisation of the pump industry ontology. We grouped the concepts into three areas:

a) Concepts to indicate entities that will support the process of definition of ideas, business models and strategies. They are:
   - Business Idea, Local Independent Ideas, Business Model, Template Specification Book, Functional Specification book, Functional Elements and Measures.
   - Strategy, Opportunities, Competencies, Risks, Customer Analysis, Competitive Analysis, Strengths and Weakness Analysis, KSB Excel, SAP Systems.
   - New Product, Product Evolution, Prototype, KPI (Reactivity, Environmental, Cost, New Technology).

b) Concepts to indicate internal factors of the End-User.
   - Company, Resources, Human Resources, Manufacturing Resources, Components, Experts, Departments, Product Management, Product, Production Process.
   - Business Product, Product, Pump, Valve, Service, Consulting, Training.
   - KSB Technology, Market, Competitors, Partner, Sustainability, Durability, Customer, Tenderer, Plan Construction Firm, Industrial Consumer, End Consumer official.
   - IT Systems, Schedule, Maximum Delivery Time, Work of Progress, Maximum Production Time, Minimum Production, Daily Production Logistics, Supplier, Facilities, Location.

c) Concepts to indicate external factors of the End-User.
   - Political, Standards, Terrorist Attacks, War, and Political Labour Conflicts.
   - Economic, Economic Sanctions, Recession, Inflation Risks, Currency Risk, Logistics
   - Social, Industrial Dispute, Strike, Labour Conditions, Staff Insurance.
   - Legal Requirements/regulations, Taxis, Import/Export Control.
   - Technology, Trends, Manufacturing Machines and Constraints, IT – System, Hardware.

The following is the initial list of relationships.

- Business Idea <u>CREATES</u> Functional Specification Book
- Local Independent Idea <u>IS</u> Business Idea
- Business Idea <u>BASED ON</u> Service, Product
- Business Idea <u>DEFINES</u> Business Model
- Functional Specification Book <u>REALIZES</u> Template Specification Book
- Functional Specification Book <u>DEFINES</u> Functional Elements/Measures
- Business Model <u>DEVELOPS</u> Strategy
- Strategy <u>USES</u> KSB Excel, SAP Systems
- Strategy <u>HAS</u> Risks, Opportunities
- Strategy <u>REQUIRES</u> Competencies
- Customer Analysis <u>IS PART OF</u> Strategy
- Competitive Analysis <u>IS PART OF</u> Strategy
- Strengths and Weakness Analysis <u>IS PART OF</u> Strategy

- Strategy APPLIED IN Prototype
- Reactivity, Environmental Cost, New Technology IS KPI
- Competitive Analysis, Customer Analysis IS BASED ON Factors
- Strengths and Weakness Analysis IS BASED ON Factors
- Logistics, Human Resources, Schedule, IT-System, Production Process PART OF Internal Factors
- Production Process GENERATES Product
- Company HAS Business Product, Production Process, Departments, Human Resources, IT-Systems, Schedule, Logistics
- Product, Service IS Business Product
- Consulting and Training IS Service
- Valve, Pump IS Product
- Product Management, Product Development IS Departments
- Business Product HAS Market
- Market HAS Competitors, Partner, Customer, Durability, Sustainability
- Tenderer, Plan Construction firm, Industrial Consumer, End Consumer, Official IS Customer
- Business Product HAS Technology
- Experts IN KSB Technology
- Supplier, Facilities PART OF Logistics
- Supplier HAS Location
- Facilities HAS Location
- Technology, Political Environmental, Economic, PART OF External Factors
- Social, Legal Requirements/Regulations PART OF External Factors
- Technology HAS Trends, IT- System, Manufacturing Machines and Constraints, Hardware
- Standards, Terrorist Attack, War, , Political Labour Conflicts IS Political Factor
- Economic Sanctions, Recession, Inflation Rate, Currency Risk, Logistics IS Economic Factor
- Industrial dispute, Strike, Labour Conditions, Staff Insurance IS Social Factor
- Taxes, Import/Export Control IS Legal Requirements/Regulations Factor

6.2.3 Informal Constraint Descriptions

An initial list of informal constraints has been identified. They are listed below:

- Constraints included in the Requirements Specification book.
- Constraints included in the Functional Specification.
- More Specific Constraints:
  - A new business opportunity fits the current business types of KSB if:
    - Has high number of pieces for a cheap price AND/OR
    - Has small number of pieces AND/OR
  - A required expert should be categorised by:
    - Qualification.
    - Multi-level knowledge.
    - Priority for industry.
    - Back office for outside sales person.
    - Qualification in RTD for complex products.

7 Evaluation of generalisations for cross-sector applicability (ITI)

This chapter explains the current state of development of the FLEXINET product-service production reference ontology and the evaluation of our end-user ontologies against it in order to show how these can be generalised for cross-sector applicability. It explains how existing work on ontologies have influenced the development of the FLEXINET product-service production reference ontology and goes on to explain the concept and how it has developed. This included drawing in concepts on risk and external factors fromWP2 as well the analysis of our end user ontologies to assess these for generalisations and cross sector applicability.

7.1 The Use of Existing Ontologies in FLEXINET

This section briefly describes ontologies influencing the development of the FLEXINET reference ontology. The key research projects which impact upon FLEXINET are discussed and standards which influence FLEXINET are described. As FLEXINET considers interoperable networks of production systems, a brief consideration of the main systems modelling approaches is also relevant. A short explanation is provided as to how FLEXINET will utilise the methods described.

To begin the discussion on ontologies influencing FLEXINET, the Interoperable Manufacturing Knowledge Systems (IMKS) project will be considered. IMKS, a UK EPSRC funded project, demonstrated the potential of reference ontologies for interoperable manufacturing knowledge sharing (Young *et al.*, 2007) across a range of company groups operating within and across product life cycle phases. These groups may work across multiple organisations and make use of a variety of software systems. The IMKS project explored the concept of a reference ontology to afford an effective basis for concept specialisation across a range of manufacturing systems within an individual enterprise. The IMKS project developed a set of core concepts to specifically enable the sharing of knowledge across design and production domains. Design and production concepts were specialised from generic foundation ontology concepts in order to provide the required level of interoperability (Usman *et al.*, 2013).

The IMKS project exploited a Common Logic-based ontology language to express the core concepts. In order to avoid subjective interpretation and to model relationships consistently between concepts, the underlying semantics upon which the concepts are based need to be formalised. Chungoora (2012) justified the use of Common Logic to capture manufacturing concepts, discovering that in order to model complex manufacturing domain the capabilities of Common Logic are preferable to the less expressive capability of the Web Ontology Language (OWL). The use of Common Logic also enables the utilisation of the Process Specification Language (PSL) (ISO 18629-1:2004), as PSL is written in the Common Logic Interchange Format (CLIF) (PSL Website, 2014). PSL provides formal process reasoning enabling the capture of generic manufacturing process semantics.

Imran (2013) extended the IMKS concept to consider the use of formal Common Logic-based ontologies to support knowledge sharing within the assembly domain. Imran (2013) proposed a framework of key reference concepts specialised from a generic foundation supporting the creation of interoperable application specific ontologies.

Hastilow (2013) also progressed the work of the IMKS project, also employing a Common Logic-based approach applied to systems interoperability. Hastilow (2013) used a core concept ontology to describe manufacturing systems, extending the ontology coverage across the product lifecycle and considering interoperation between defined systems. Hastilow (2013) developed a Manufacturing Systems ontology applicable to any Manufacturing Systems domain. The combination of these works was fundamental to the development of the FLEXINET approach.

The Manufacturing Service EcoSystem (MSEE, 2014) FP7 project and the POP* methodology created by the Athena FP7 project (Athena, 2006) are European projects with parallels with FLEXINET. The Manufacturing Service EcoSystem (MSEE) FP7 project aims to produce "new Virtual Factory Industrial Models where service orientation and collaborative innovation will support a new renaissance of Europe in the global manufacturing context" (MSEE, 2014). MSEE considers the hierarchical modelling of tangible and intangible manufacturing assets. MSEE utilises formal semantics but is based on OWL Description Logic so, whilst it provides an effective framework from which to draw manufacturing concepts, FLEXINET is able to extend MSEE capabilities through the more expressive manufacturing business modelling provided by Common Logic.

The POP* (Athena, 2006) methodology aimed to develop ways of capturing the design and management issues which occur during enterprise collaboration. The POP* (Process, Organisation, Product and others) language provides a set of concepts to support model exchange between collaborating enterprises. POP* consists of five dimensions: Process, Organisation, Product, Decision and Infrastructure. The POP* objective was to provide a mapping methodology from several enterprise modelling languages to the POP* format. The aim of this was to enable interoperability between collaborating enterprises using different modelling languages. The POP* language utilises the object-role-action paradigm. "According to this approach, there are two basic domains in an enterprise: object domain (both physical and information objects) and action domain (such as activity, process, tasks, operations, etc.). The concept of role enables these two domains to be related. Indeed, various objects play different roles in different actions (for example, objects plays roles as input, output, resource and control in a process)" (Athena, 2006).

FLEXINET will potentially utilise concepts from the following standards: ISO 10303-239:2012 and Core Product Model by NIST (Foufou *et al.*, 2005). For more details of existing standards relevant to FLEXINET see Deliverable D8.4 Standardisation Plan, section 2.5. "ISO 10303-239:2012 (PLCS) specifies the information required to support a product throughout its life" (PLCS.org, 2014) and a structure for information exchange. PLCS supports feedback of information acquired during product usage, including feedback on product usage, support activities and resources used to provide support. PLCS contains an activity model defined in the IDEF0 modelling language (IDEF0, 2014) and an information model written in the Express information modelling language (Object Management Group, 2010). The activity model describes an application in terms of its processes and information flows. The information model has three key concepts (product, activity and resource) each of which may be associated with properties, states or locations. PLCS makes the important distinction between planned products (i.e. those still at the design stage) and realised products (i.e. those in use).

The Core Product Model by NIST (Foufou *et al.*, 2005) captures product model data over the lifecycle of the product. The product is modelled in terms of three concepts: function (what the product is supposed to do), form (in terms of geometry and material) and behaviour (how a form implements its function) and is represented in UML. The Core Product Model defines core manufacturing concepts such as Feature, Form and FormFeature.

As FLEXINET considers production systems, systems modelling approaches are also considered. Well known standardised concept models for systems engineering are the Systems Engineering Conceptual Model, SysML (Object Management Group, 2012) and AP233 Data Exchange Standard for Systems Engineering (ISO 10303-233:2012). An alternative approach is the Object Process Methodology (Reinhartz-Berger *et al.*, 2002).

The Systems Engineering Conceptual Model was developed by members from the International Council on Systems Engineering (INCOSE), the AP233 committee, and SysML development group and represents a consensus on the definition of some of the key system modelling concepts. The Systems Engineering Conceptual Model is expressed as a UML class diagram and captures essential concepts of systems engineering such as System, Requirement, Stakeholder, Behaviour and Environment (Oliver, 2003). The Systems Engineering Conceptual Model was used as input to requirements for SysML. SysML is a general purpose modelling language intended to model systems from a broad range of industrial domains. SysML is graphical language which extends UML and provides a foundation for representing the requirements, behaviour, structure and properties of a system. AP233 is an information exchange model for the exchange of data between Systems Engineering, Systems Architecture Description and related tools. It could be used to exchange information between a SysML and another Systems Engineering application. AP233 is based on the Express modelling language (Object Management Group, 2010) and is a product-centric information model containing concepts of Product, Product Version and Product View Definitions (ISO 10303-233:2012).

The Object Process Methodology (OPM) unifies function, structure and behaviour in a single model. OPM is a graphical representation language which considers the interactions between entities and the processes which act upon them. It can be translated into natural language (OPL, object process language) and RDF (W3C, 2014). OPM is better able to model processes and interaction between systems than SysML.

The reference ontology approach demonstrated by the IMKS project (Chungoora *et al.*, 2012) is utilised by FLEXINET. FLEXINET will make use of concepts derived from the work of Imran (2013) and Hastilow (2013). Understanding gained from the MSEE project (MSEE2014) on the modelling of tangible and intangible production assets and product and service lifecycle relationships will also be utilised within FLEXINET. PSL will be employed for the capture of generic process semantics as appropriate (ISO 18629-1:2004). More details of these approaches are provided in the following subsections. FLEXINET will also consider the applicability of lifecycle concepts from PLCS (ISO 10303-239:2012) and manufacturing concepts from the Core Product Model by NIST (Foufou *et al.*, 2005). Key concepts within the FLEXINET ontology are derived from end user partners as described in section 4, 5 and 6 of this report. The derivation of the FLEXINET concepts related to "Risk" and "External" factors from Work Package 2 is described in section 7.2.3.3.

7.1.1 Interoperable Manufacturing Knowledge Systems (IMKS) project

The IMKS project considered interoperability across the design and manufacture stages of the product lifecycle. The project exploited a core ontology and specialisation mechanisms to address the interoperability requirements between stages within the product lifecycle. Creating specialised concept definitions from a core set of concepts enabled the ontology to be customised to suit the different stages of the product lifecycle without enforcing a single structure. Formalised semantics (based on Common Logic) were used create a common foundation providing a means of mapping and verifying concepts across the design and manufacture perspectives. The use of mappings and knowledge verification interacting with the design and manufacture concepts provides a basis for sharing product lifecycle knowledge. Details of the IMKS approach are shown in Figure 7-1 below.

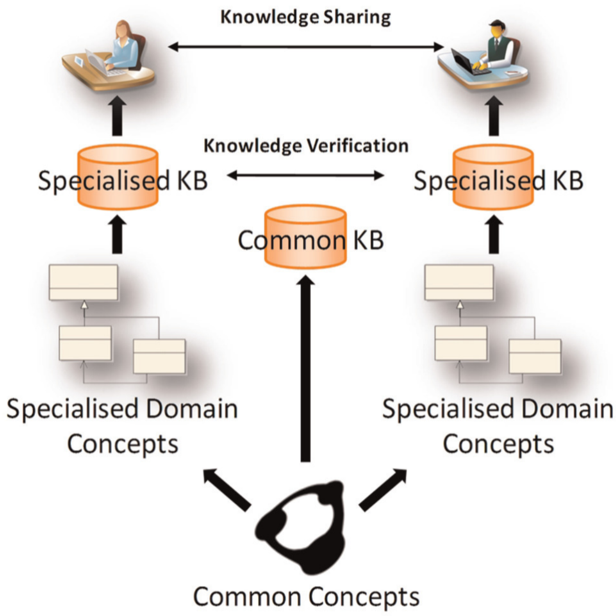

Figure 7-1: The IMKS Approach (Chungoora *et al.*, 2012)

Three levels were identified as necessary to specialise concepts from the foundation to the specific domains, each intermediate level providing an increased degree of specialisation with concepts more closely related to the specific domain. Figure 7-2 demonstrates how core concepts are progressively specialised to support the creation of a knowledge model within the design perspective.

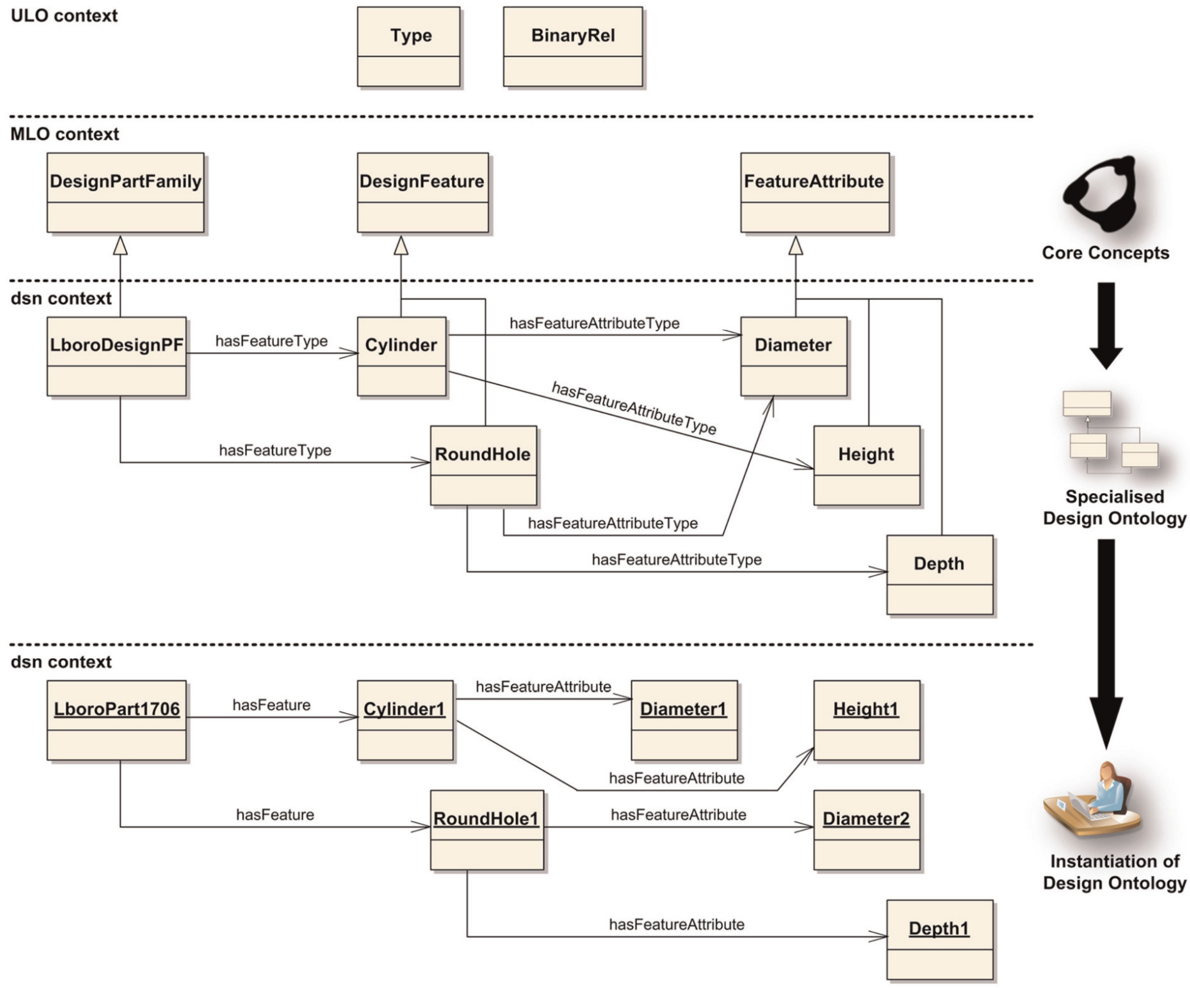

Figure 7-2: Specialising the knowledge model within the design perspective (Chungoora *et al.*, 2012)

7.1.2 Assembly Reference Ontology

Imran (2013) investigated how to support collaboration across the assembly design and assembly process planning domains. An Assembly Reference Ontology was proposed containing five layers of reference concepts commencing with a generic foundation and specialising until the specific concepts layer for the sub-domains of interest was reached. The layers are: generic reference concepts, product lifecycle reference concepts, design and manufacturing reference concepts, assembly domain reference concepts and assembly sub-domains design and planning reference concepts. An example of specialisation is the concept Bill of Materials (BOM) located in the assembly domain layer. A BOM lists the components required to build a product together with information related to the components. BOM is a super-concept of the concepts engineering BOM (EBOM) and manufacturing BOM (MBOM) which represent the assembly design and assembly planning perspectives.

Key reference concepts identified for the assembly domain layer are product, product version, product family, assembly feature, assembly operation, step, assembly resource, manufacturing facility, assembly process, assembly resource feature, BOM, Bill of Process (BOP), Bill of Resource (BOR), shape attribute, spatial location, dimension, tolerance and assembly component. An overview of the assembly reference ontology concepts and their relationships is shown in Figure 7-3.

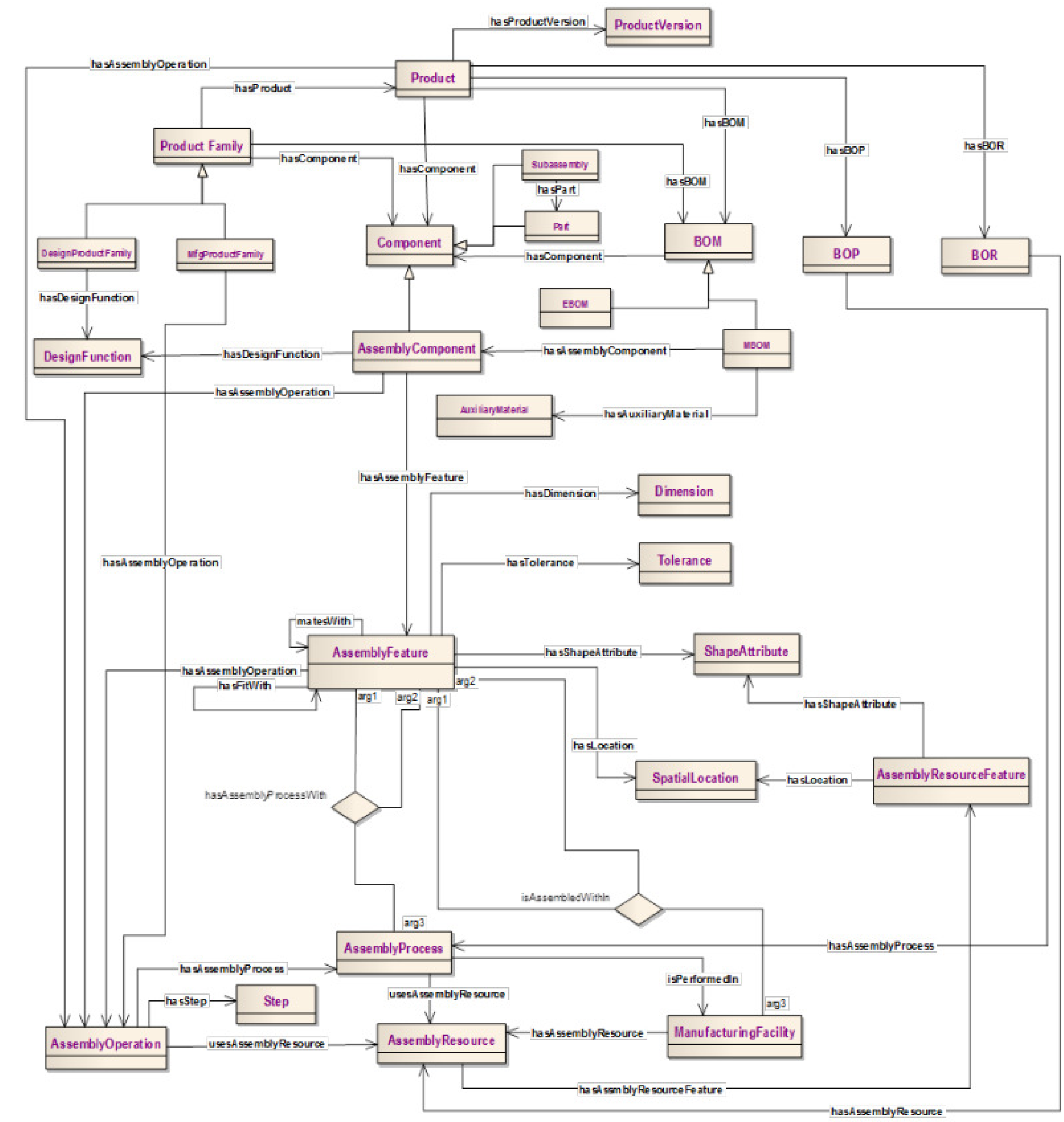

Figure 7-3: Assembly Domain Reference Concepts (Imran, 2013)

7.1.3 Manufacturing Systems Interoperability Ontology

Hastilow (2013) aimed to define a mechanism to evaluate system interoperability requirements and capabilities. The objective was to ensure interoperability for and with future systems by allowing new systems to be developed using new terms, whilst maintaining consistency with legacy terms. The Manufacturing Systems Interoperability Ontology consists of a core ontology containing systems concepts overlaying a more specialised ontology focussing on manufacturing systems. The Systems Core ontology was developed in the context of requirements for system interoperability. Details of the core Systems concepts together with their relationships are illustrated in Figure 7-4.

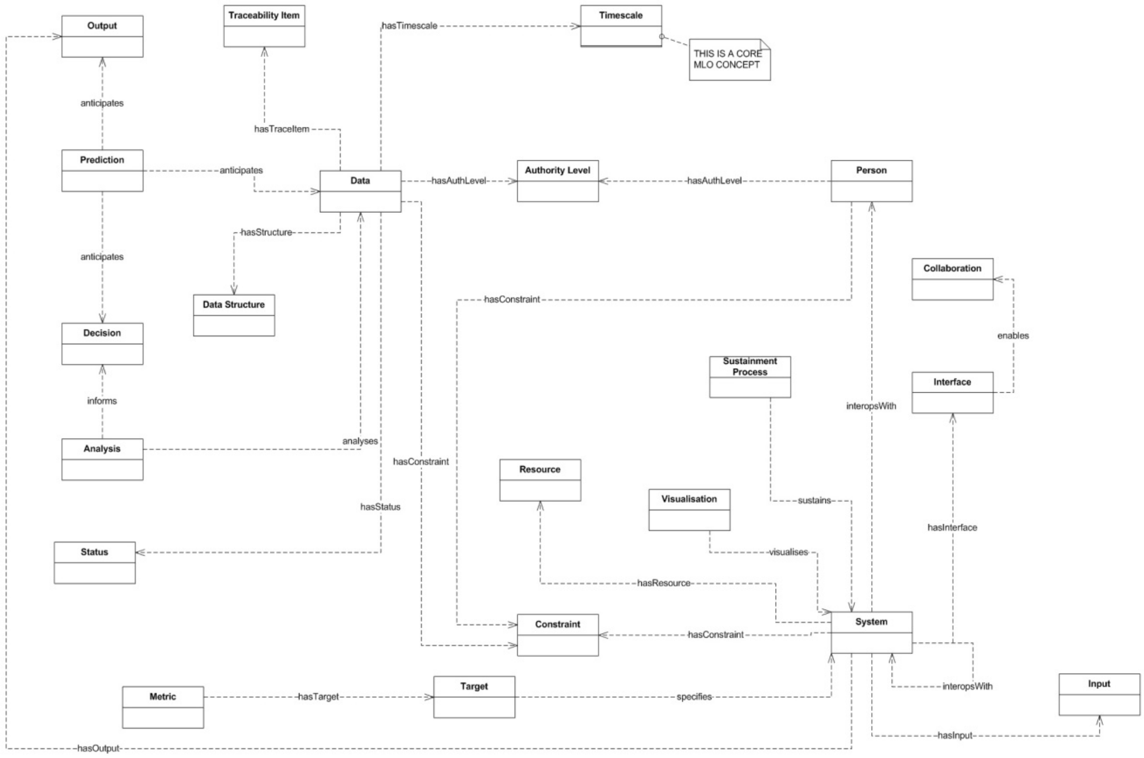

Figure 7-4: System Core Ontology Concepts (Hastilow, 2013)

For a discussion on how concepts from the Manufacturing Systems Interoperability Ontology are applied within FLEXINET see section 7.2.3.2.

7.1.4 Manufacturing Service EcoSystem (MSEE)

The MSEE ontology consists of four main concepts: Technical Intangible Assets, Human Intangible Assets, Organisational Intangible Assets and Relational Intangible Assets. Technical Intangible Assets are organisational assets relating strictly to technical issues such as products design and use; production, modelling and quality processes; research and development; and information systems. Human Intangible Assets capture employee knowledge, skills and experience. Organisational Intangible Assets relate to management issues, e.g. production, logistics, human resources management, marketing and sales, and problem solving and innovation. Relational Intangible Assets consist of the relationships between an organisation and external associated companies such as partnering or distribution arrangements, maintenance and customer supply contracts and people-based customer relationships, advantageous supplier relationships, etc. (MSEE, personal communication). An overview of the MSEE ontology shown in Protégé (Protégé, 2014) is given in Figure 7-5.

Figure 7-5: MSEE Ontology Overview (MSEE project, 2014)

Consideration as to how the MSEE Ontology relates to FLEXINET is given in section 7.2.3.4.

7.1.5 An Integrated Supply Network Ontology (iSNO)

The Integrated Supply Network Ontology (iSNO) is developed to support the visualisation and navigation through multidimensional supply networks initiated during the amerigo project. The objective of amerigo is to develop a platform for gathering and maintaining the information for visualising and analyses of Supply Networks, in a form of a Strategic Supply Network Map. The amerigo Strategic Supply Network Map should answer to the requirements for providing a holistic view of the supply network, distributive modelling and modification, integrating information from different sources, flexibility and scalability. iSNO represent a backbone of the semantic supply network maps, which provides the following:

- a consistent preparation and visualisation of the supplier network with a strategic focus.
- analyses across several levels within the multi-tier supplier network.
- possibility of generating different focus views on the supply network.
- a platform for configuration and modification of the supply network.

The domain of the Supply Network Ontology is described using hierarchically structured classes in several levels. The upper level of the Supply Network Ontology, consist of five classes like Things, Flow, Geo, Time and Unit. The upper classes Things and Flow are strictly specifying concepts of the supply network management domain, while the upper classes Unit, Time and Geo specify more general domains and can interact with already existing ontologies specific for each of the domains.

- The upper class Things includes the necessary concepts to specify the supply networks, as organisations and organisational structure, product and product structure, organisational and product standards as well technologies and core competencies.
- The upper class **Flow** specifies concepts which are dependent on other companies and describe abstract concept of interaction between the members of the supply network, including the subconcepts of Delivery, Market, Capacity, etc. The particularity of the concepts of the above subclasses of the upper class *Flow* is that they are using abstract classes in order to define "higher-arity" relationships.
- The upper class **Geo** specifies the geographical concepts like *continent, country, region, area* and *place*. The resources of this class refer to the geographic locations of organisation and market places of the companies' members of the supply network. Apart from the taxonomic relations which specify that the sub-classes *country, region, area* and *place* are a kind of *Geo_Location*, they are also interconnected to specify that a *continent contains countries*, *countries belong to a an area, countries have places, countries have regions* and *regions have places.*
- The upper class **Unit** specifies the measurement unit, mainly used to annotate the capacities and the transport limitation of a delivery. It is expected, that the concepts of Time and Unit will be specified as a standardised ontology domains in the near future and therewith should be replaced with the standardised ontologies
- The upper class **Time** specifies time measurement units corresponding to the scope of the strategic supply network management like year and quarter of a year. This concept is used for reference to the production capacity of the member company.

The above mentioned upper classes Things, Geo, Flow, Unit and Time and their subclasses specifies the domain of the Supply Network Ontology using in total 160 classes structured on several levels and more than 120 object and data properties. FLEXINET already has its own upper class ontology, based on Highfleet's Upper Level Ontology. However, the more detailed supply network concepts will be exploited where they are consistent with the product-service production reference ontology concept and can benefit the project.

7.1.6 Process Specification Language

Process Specification Language (ISO 18629-1:2004) provides intuitions for reasoning about various forms of processes and thus forms an effective foundation for capturing process-related meaning (Young *et al.*, 2007). The intent of PSL Core is to provide a set of intuitive primitives adequate for describing the fundamentals of manufacturing processes, defined as formal axioms. PSL Core comprises four main concepts, namely "Object", "Activity", "Activity_Occurrence" and "Timepoint". Activities have a multiplicity of zero to many. Timepoints are linearly ordered forwards into the future, and backwards into the past. Activity occurrences and objects are associated with unique Timepoints that mark the beginning and ending of the occurrence or object. The PSL concepts are formally expressed in CLIF (PSL website, 2014).

PSL Outer-Core consists of a number of theories that together bring greater strength to PSL, in terms of logical expressiveness. PSL Outer-Core involves: (1) the theory of Subactivities, (2) the theory of Occurrence Trees, (3) the theory of Discrete States, (4) the theory of Atomic Activities, (5) the theory of Complex Activities and (6) the theory of Activity Occurrences (Chungoora, 2010). While a significant number of these concepts are beyond the requirements of the PSP ontology there are a number of core concepts and relations which are helpful.

7.2 The FLEXINET reference ontology: concept and levels

7.2.1 The FLEXINET reference ontology concept

A simple statement may describe the basis of generalisation in terms on FLEXINET: "A design of an ontology representing the core elements of a particular enterprise, will end up with a good number of **elements** that are not exclusive to this particular enterprise, but common to some other enterprises that operate in the same sector". For the sake of clarification, we use the word "element" to include "concepts", "relations" and "attributes" relating to an ontology.

Following this reasoning, we infer that a subset of the elements that are common to a particular sector might be applicable or extrapolated to different sectors. In other words, some of the elements that are applicable to the **Pumps Industry** sector might be also applicable to the **White Goods** sector. Both sectors are part of the manufacturing industry, so we state that the concepts that are widely applicable to different sectors belong to the broader area of **Manufacturing Industry**, and not to a particular sector. In this area reside the elements that are specific to the manufacturing industry and you won't find in other types of industries like Finance, Assurance, Construction, Mining, Agriculture, etc.

However, even some of the elements identified for the manufacturing industry might be applicable to other different man-made systems. In this case, they belong to the even broader area of **Designed Systems**. A limited set of elements that conform a base knowledge shared among different systems that are under human influence or subject to human decision-making, whether dedicated to manufacturing or not. A limited set of general concepts and relations that are universally accepted and understood across industries and sectors.

The FLEXINET premise is that for ease of construction, effective interoperability and flexible re-use enterprise ontologies must be built from a common base that utilises a common reference ontology wherever possible. To enable the management of complexity within the ontology and to facilitate re-use across domains the FLEXINET reference ontology is organised into five levels, as illustrated in Figure 7-6.

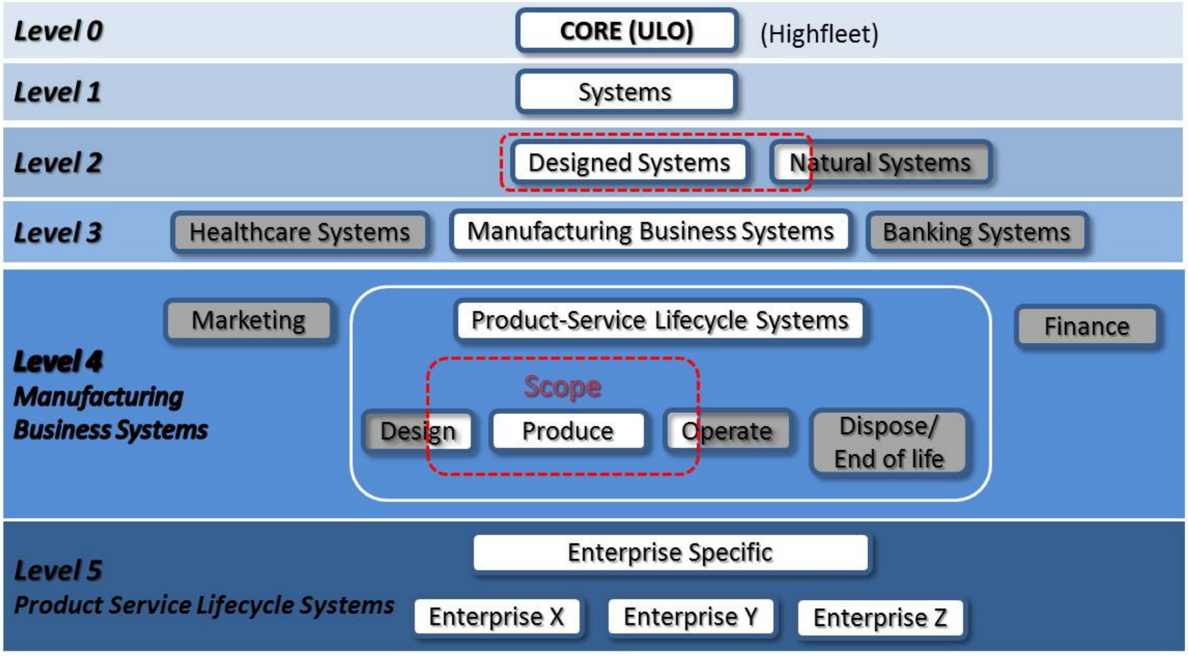

Figure 7-6: The FLEXINET reference ontology levels

In addition there is a fully generically applicable level 0, which is based on the Upper Level Ontology provided by Highfleet's Common Logic based system. Each level inherits concepts from and provides additional concepts to the level above, the ontology becoming more domain specific with each level. Five levels are needed to specialise the concepts from the foundation to the enterprise specific product-service production domain.

The Level 0 Core consists of foundation concepts applicable to all domains, having nothing to do directly with Product-Service Lifecycle Systems. The foundation concepts include time, events, aggregation and lists and are derived from the Highfleet Upper Level Ontology (ULO) (Highfleet, 2014). Level 1 contains the few key concepts necessary to model any system. A system transforms inputs into outputs and is defined as "a combination of interacting elements organised to achieve one or more stated purposes" (Athena, 2006). Level 2 uses Banathy's classification (1992) to specialise systems into "Natural Systems" and "Designed Systems". Natural systems are living systems of all kinds, including the solar system and the Universe as examples. Designed systems, within which FLEXINET sits, are man-made creations, including fabricated physical systems, conceptual knowledge and purposeful creations. As FLEXINET provides decision support that requires human input (i.e. input from a living system), the scope of FLEXINET also overlaps to a limited extent into natural systems.

Level 3 further differentiates designed systems into applicable areas. Example areas are shown in Figure 7-6. The natural systems area could also be differentiated at level 3 but this is not shown as it is outside the scope of FLEXINET. FLEXINET is concerned with the area of Manufacturing Business Systems which provides services to define, design and analyse the Manufacturing Business domain. Manufacturing Business Systems is then further specialised within Level 4 (see Figure 7-6 for example areas). Level 3 areas such as Healthcare Systems and Banking Systems would also possess areas providing relevant specialisations at Level 4 and some of these areas might be similar to those within the Manufacturing Business Systems domain (e.g. finance would also apply to Healthcare Systems) however the concepts contained would be specialised to the parent area (i.e. the Healthcare Systems

Finance area would contain concepts related to healthcare). FLEXINET level 4 contains concepts specifically relating to the Manufacturing Business Systems domain.

The area FLEXINET considers at level 4 is Product-Service Lifecycle Systems, implemented as Global Production Networks. The lifecycle phases are denoted as design, produce, operate and end of life (including disposal, recycling and remanufacturing). The focus of FLEXINET is how to design a GPN to produce and operate a product-service. The main area FLEXINET considers within the Product-Service Lifecycle is therefore "Produce" (producing the product-service) but the scope also overlaps into "Design" (of the network) and "Operate" as the operation of the product and the service needs to be considered in design.

One of the objectives of FLEXINET is to provide formal reference ontologies for product-service lifecycle systems and to evaluate this through three industrial case studies. Each case study considers a different type of GPN implementation. FLEXINET levels, 0-4, provide the reference ontologies which are then specialised at Level 5 to suit specific business requirements for the case studies within the domain of Product-Service Lifecycle Systems. Level 5 provides separate domain areas for the enterprise specific requirements of each case study (see Figure 7-6).

Five levels were found to be necessary to specialise FLEXINET concepts. Level 5 provides enterprise specific concepts for the product-service production domain for each of the three enterprises; above this level 4 provides concepts which would apply to any enterprise in the Product-Service Lifecycle Systems domain. The area generalising Product-Service Lifecycle Systems, covering more areas within an enterprise or network, was considered to be Manufacturing Business Systems (level 3). The super domain for level 3, encompassing all engineering and enterprise systems, was rationalised as Designed Systems. The domain above Designed Systems (at level 2) is clearly Systems. Level 0 was required to capture core foundation ontological concepts. The FLEXINET project is limited to three case studies each within a different business domain. For a more complete ontology, more case studies would be needed to derive concepts from businesses within similar areas. This would enable an extra level providing sector specific concepts to be created which would be located between levels 4 and 5.

7.2.2 Level 1

Figure 7-7 sets out the level 1 ontology detailing the concepts and relations necessary to specify a system. This ontology level utilises the concept TimeSpan (inherited from Level 0) and contains two parent concepts: Basic and Role. A TimeSpan includes the first and last instants of a date and all the instances in between (ISO 10303-233:2012). A Basic concept (ISO/IEC/IEEE 29148:2011) is independent of the system or context, its definition does not depend on another concept and an instance of a Basic always retains its identity as such. Basics occurring at level 1 can be classified as System, Information, Material or Energy. It is anticipated there will be other categories, a potential one being Feature. The ontology will be extended to include these further categories when necessary.

A Basic can be comprised of Basics, e.g. "bottled water" is comprised of the materials "bottle", "cap" and "mineral water". A System is a subtype of Basic and provides a context for the Roles it contains (shown via the "depends on" relation and the composition filled diamond in the figure). The definition of a Role depends on a context and an instance of a Role cannot exist without a context, for example a person Joe has a Role as a lecturer (context "university"); "bottled water" has a role as a product (context "beverage company"). It can be seen that (for example) a lecturer Role cannot exist without the university context. If the university closes the lecturer role ceases to exist whereas the person Joe (an instance of a Basic) will still be present.

Roles may be comprised of Roles (e.g. a lecturer Role may be comprised of administration, teaching and staff Roles).

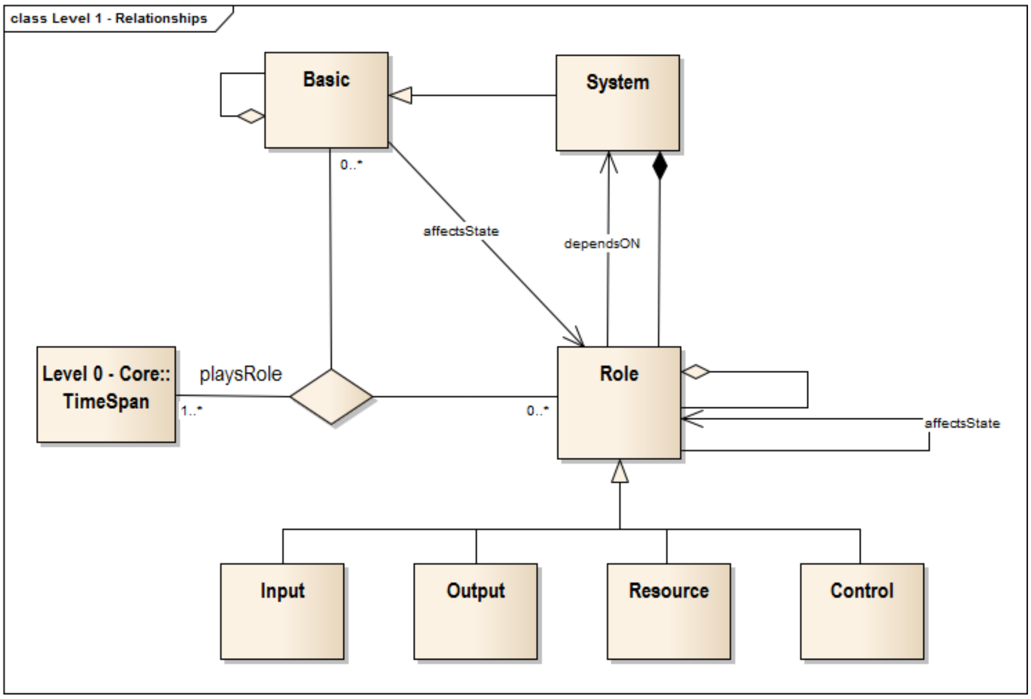

Figure 7-7: FLEXINET Level 1 Systems Ontology

The "playsRole" relation is transient, i.e. it exists for a certain time. A Basic plays a Role for certain TimeSpans, modelled in the ternary relation "playsRole". For example in the context of a manufacturing organisation system, the Basic "bottled water" can play the Role of a Product during the TimeSpan of the system. Within a University a person could, for example, play the Role of a lecturer for a TimeSpan of five years, become unemployed and then play the Role of a lecturer again for a further TimeSpan. Within the widely known ontology analysis methodology OntoClean Roles are modelled as concepts which are not essential to their instances (anti-rigid), a typical example provided being a student (Guarino, 1998) (This vision of Roles is implemented within the Highfleet development environment as the metaproperty "MaterialRole"). However, this research takes the view that many Roles are essential to the System that incorporates them, for example it would be difficult for a university to exist without students. In addition, to model the concept of an empty role (i.e. a vacant or required role) it is essential that a Role concept cannot cease to be (is rigid). This research captures the changeability of Roles through the playsRole relations which explicitly models the times in which individuals participate in a Role.

The modelling of Role as a specific concept is necessary to be able evaluate whether a system is capable of meeting specified requirements. The division of Basic and Role concepts enables the number of Role instances counted to differ from the number of Basic instances playing the Roles (see the Wieringa *et al.* (1995) counting problem). For example, one person (instance of a Basic) can play two lecturer roles, the first time from June 1997 - July 2002 and the second time from May 2005 to the present date. A Basic can play more than one Role at the same time (e.g. a person could be a lecturer (context "university") and a parent (context "family"). A Role can be played by more than one Basic, e.g. the role of a laundry would require a washer and a drier. There is no requirement for a Basic to play a Role (shown by the 0..* multiplicity next to the Role concept in the figure). Role and Basic concepts exist separately and have separate identities. There is also no requirement for a Role to be played by a Basic, enabling empty Roles to be modelled (e.g. if a person Joe left his Role as a lecturer the Role would still exist as a lecturer vacancy; also the equipment features required to fulfil the Role of a cutting resource within a manufacturing cell would be present even though no equipment was available to cut).

In the literature there is discussion of the idea "Roles can play roles" (Steimann, 2000; Loebe, 2005; West, 2008). The rationale behind this premise is the need to capture conditions such as only an employee can play the Role of a manager. However, an "employee" cannot be a "manager" - it is the person (a Basic) who plays the Role of the employee who also plays the Role of the manager. A "RolePlaysRole" relation would imply that all employees would play the Role of a manager, which is unlikely to be the case. In FLEXINET "Role can play roles" conditions will be modelled through the use of constraint axioms. The use of constraints will also enable the following to be modelled: negative conditions such as "Roles cannot play Roles" (e.g. a person playing the role of an evaluator cannot also play the role of a manager at the same time) and cardinality conditions (e.g. only one person can play the Role of U.K. Prime Minister at a time).

The ideas on Roles proposed in FLEXINET share views with those of Kozaki *et al.* (2006), Kozaki *et al.* (2008) and Mizoguchi *et al.* (2012). In common with those views, the concepts of Basic, Role and Role aggregation are captured. However in FLEXINET Time and Role context are explicitly modelled. Time is not considered by Mizoguchi *et al.* (2012); Roles are recognised as being context-dependent but the context is not specified being left to the choice of the modeller, whereas in FLEXINET the context is defined as the System.

A Basic may affect the state of a role, e.g. the size of a Basic "bottled water" playing the Role of a product could influence the dimensions required for a packing resource Role. Additionally a Role may affect the state of a Role, e.g. within the lecturer Role more duties allotted to the administration Role would cause duties to be removed from the teaching Role).

The four key Roles that describe a system are input, output, resource and control. An input represents what is brought into and is transformed or consumed by the system to produce outputs. An output represents what is brought out from or is produced by the system. A resource is used by or supports the execution of the system. A control is a condition required to produce the correct system output (PUBs, 1993; Athena, 2006).

A simple example of the key Roles applied to a Designed system is an IT System in which input Roles are played by the Basics information (for example in the form of keyboard signals and numbers), output Roles are played by information (e.g. in the form of monitor signals and numbers), the resource Role is played by a basic "person" (a Natural System) who acts as the operator and control Roles are played by the material "control unit" and the information "analysis algorithm".

A Natural Systems example is a tree. Input Roles are played by the Basics materials "carbon dioxide" and "water" and energy (solar) which also play Resource Roles for this system. Output Roles are played by the materials "glucose", "oxygen" (both produced by photosynthesis) and "water" (produced by transpiration). Control roles are played by the information "concentration of carbon dioxide", "light intensity" , "temperature" (controlling photosynthesis), "humidity" and "wind strength" (controlling transpiration).

7.2.3 Levels 2-4

The general concepts with levels 2-4 are shown in Figure 7-8, Figure 7-9 and Figure 7-10. The concepts from level 2 onwards are categorised into Basics and Roles and will be subject to update and refinement throughout the project. The majority of Basic concepts will inherit from one of the level 1 Basic concepts: System, Information and Material. To facilitate the construction of the ontology and to aid concept identification within the ontology Roles are categorised. System requirements are categorised as functional and non-functional: a functional requirement "specifies a function that a system or system component must be able to perform" (ISO/IEC/IEEE 24765:2010); a non-functional requirement places a constraint on how the system will operate (ISO/IEC/IEEE 24765:2010; ISO/IEC/IEEE 29148:2011). To aid the evaluation of potential system designs against specific requirements, it makes sense to have Roles being similarly categorised. Participators are Roles capable of fulfilling functional requirements. Participators are processes that perform functions and are played by Basics which are subtypes of System. Qualifiers are Roles which are able to fulfil non-functional requirements. Qualifiers define how a system will operate by controlling the system processes and are played by Basics which are subtypes of Information. The Participator and Qualifier concepts are placed with the Designed Systems area, as insufficient knowledge is available as to whether these concepts also apply to Natural systems and Natural systems are not the focus of FLEXINET.

Within the ontology levels, Level 2 contains the greatest number of concepts as it is most generally applicable and for ease of comprehension the Level 2 Basic concepts are further divided into External Factors. External factors are issues which impact upon a Designed System but are external to it. These are of particular importance to the global context of production network configuration.

7.2.3.1 The development of the reference ontology levels 2-4

The reference ontology starts from the basic understanding developed in the IMKS project but extends and revises this in relation to the reference ontology levels and system level ontology defined above. Related existing ontologies are then analysed against the reference ontology concept in order to populated and develop the levels of the ontology. This starts with Hastilow's (2013) manufacturing systems interoperability ontology but then includes the consideration of WP2 risk and external factors, and finally the MSEE tangible and intangible assets ontology.

The ontology will continue to be developed as new understanding arises from WP2 and WP4 as well as from other ontologies. Most importantly the levels in the ontology will be developed and extended as our understanding of generic concepts of relevance to our end users become apparent.

7.2.3.2 Analysis of Manufacturing Systems Interoperability Ontology

FLEXINET utilises the concepts defined by Hastilow (2013) but reappraises the concepts in the context of the reference ontology levels (see section 7.2.1) and also against existing end user concepts. The Level 2-4 diagrams (see Figures 7-8 to 7-14), identify in green those concepts which Hastilow (2013) identified as significant in addition to those already identified by the end user partners. As both Hastilow (2013) and FLEXINET consider interoperable manufacturing systems it is unsurprising that there is an overlap in the concepts identified. Five of Hastilow's (2013) core level concepts have been placed at FLEXINET Systems Level 0 (System, Input, Output, Resource and Constraint (renamed Control in FLEXINET to avoid confusion with Highfleet terminology)). The remainder of Hastilow's core concepts are located at FLEXINET level 2 Designed Systems as Hastilow's (2013) core ontology is more specialised than the FLEXINET Systems view, focusing on top level concepts relating to manufacturing systems. The concepts from Hastilow's (2013) more specialised ontology level are located at Levels 2, 3 and 4 of the FLEXINET reference ontology. Concepts identified by Hastilow (2013) are located at level 4 Product Service Life Cycle Systems as Hastilow (2013) considered issues relating to manufacturing operation.

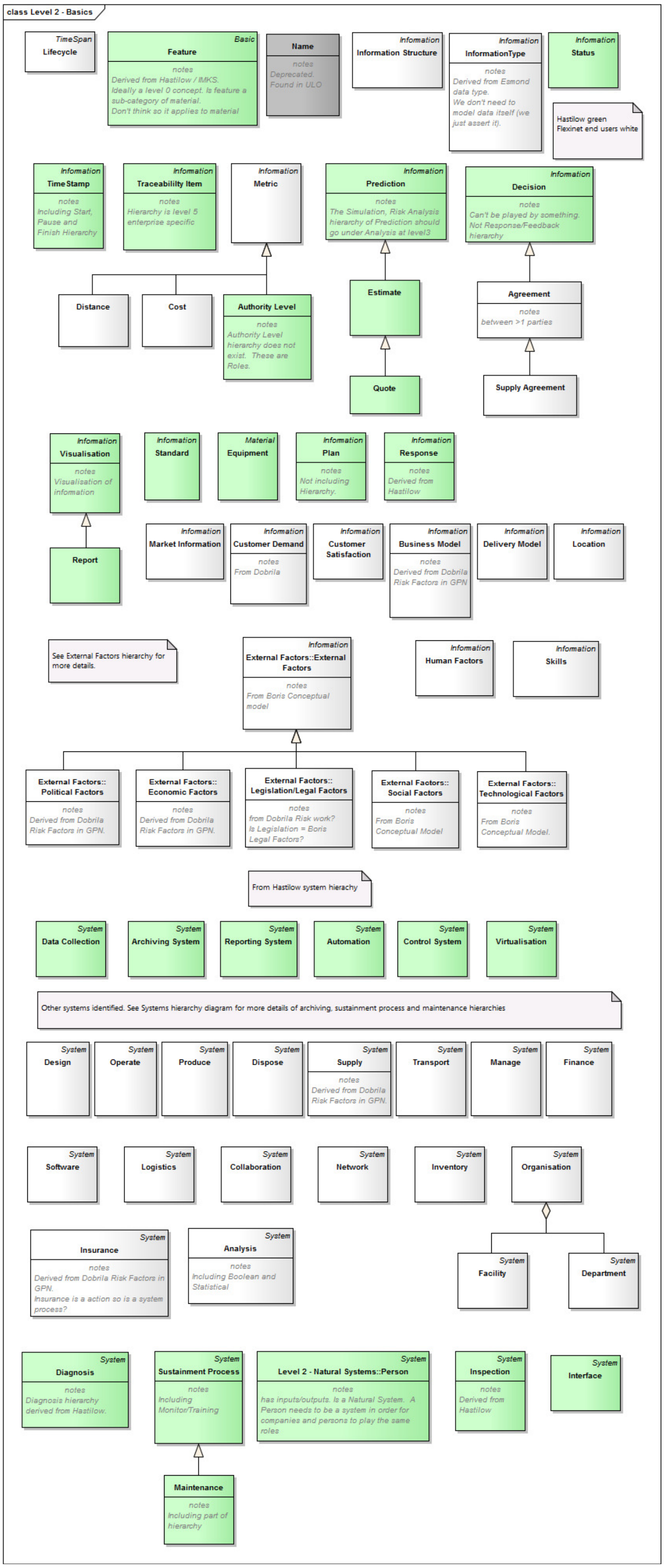

Figure 7-8: Level 2 'Basic' concepts from Hastilow (2013) and end users

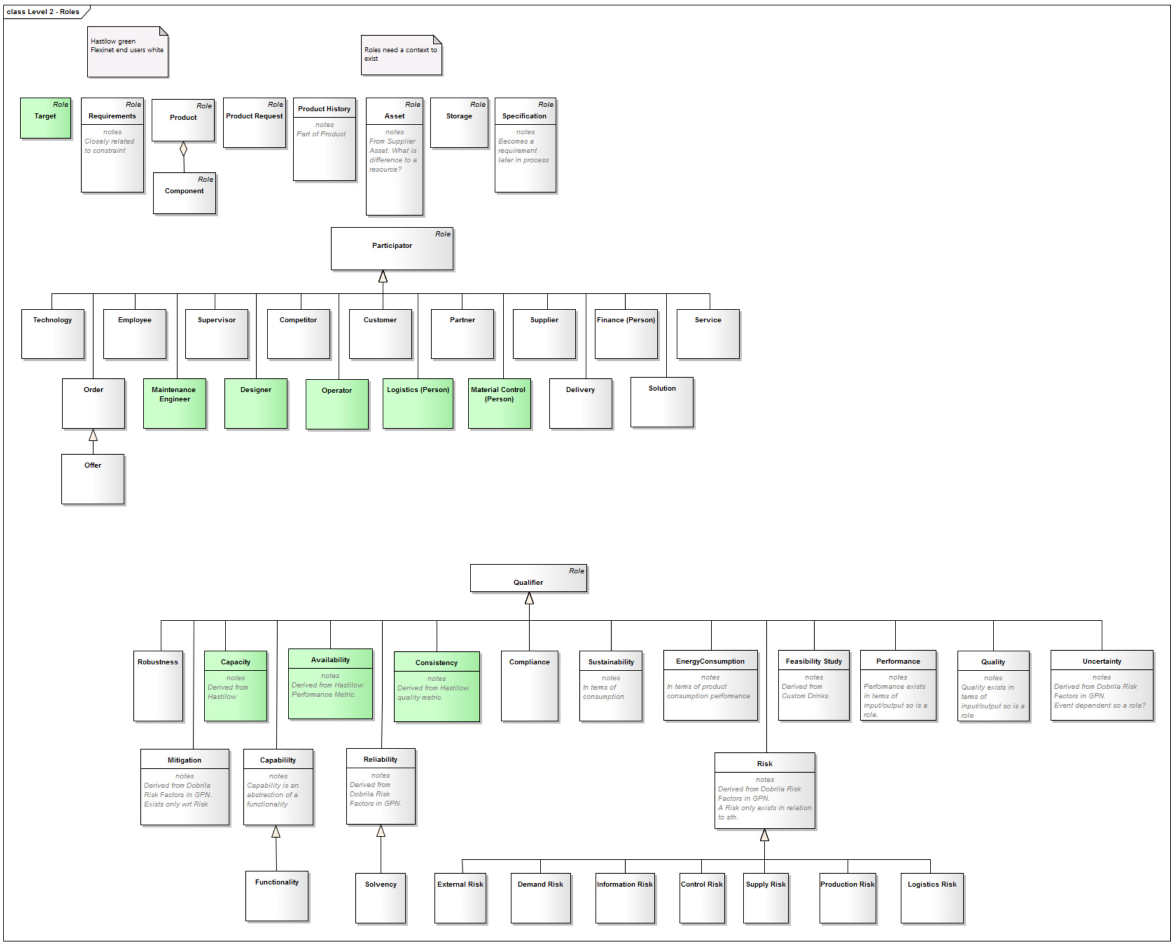

Figure 7-9: Level 2 'role' concepts from Hastilow (2013) and end users

Level 2 System Hierarchy

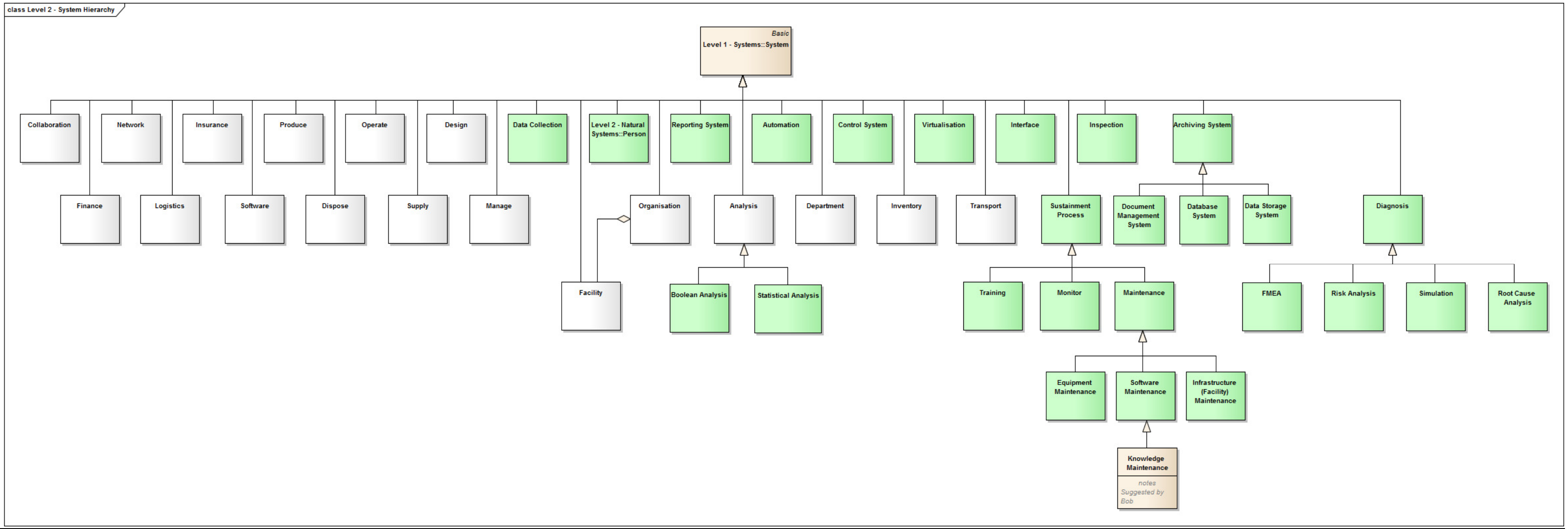

Figure 7-10: Level 2 "system" concepts hierarchy from Hastilow (2013) and end users

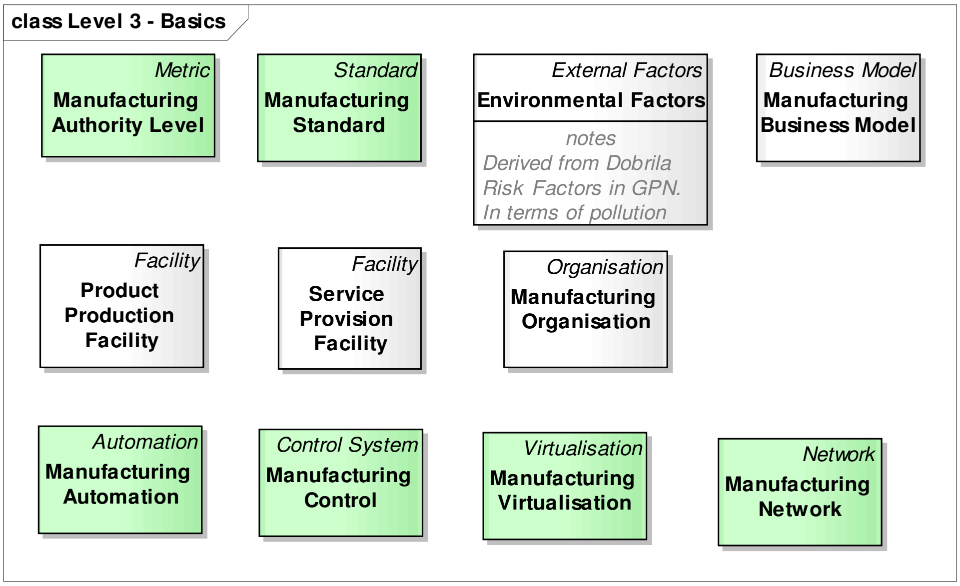

Figure 7-11: Level 3 'Basic' concepts from Hastilow (2013) and end users

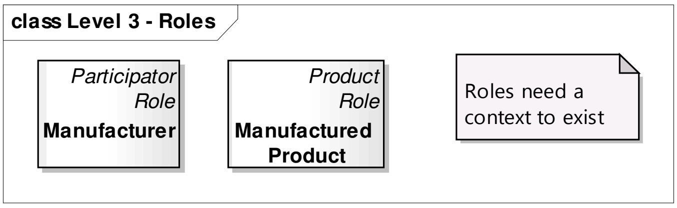

Figure 7-12: Level 3 'role' concepts from Hastilow (2013) and end users

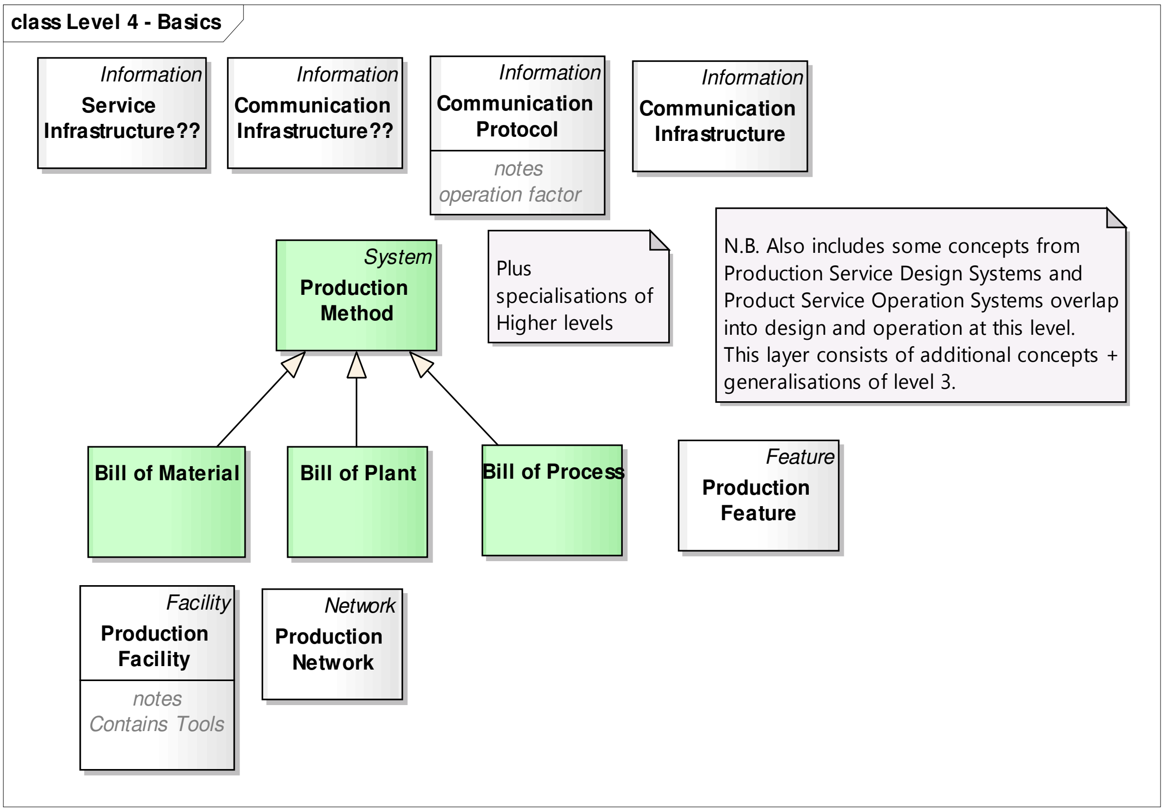

Figure 7-13: Level 4 Basic concepts from Hastilow (2013) and end users

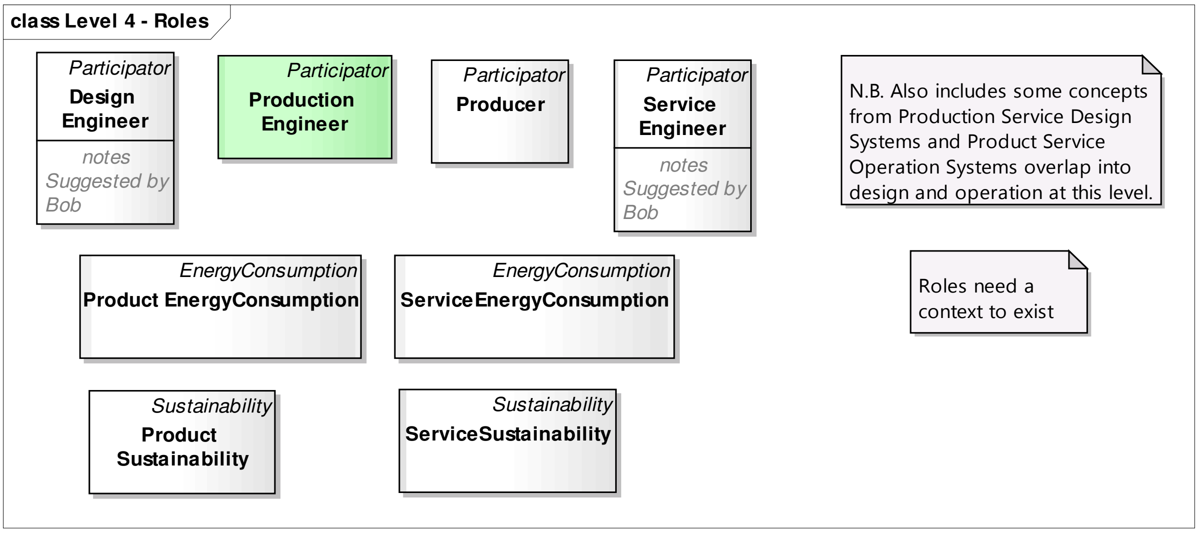

Figure 7-14: Level 4 role concepts from Hastilow (2013) and end users

7.2.3.3 Analysis of External Factors and Risk Factors

This section considers where External and Risk Factors from WP2 are positioned with the within the FLEXINET ontology levels. External factors are issues taking the form of information located outside the global production network that influence the business model, such as regulations or other compliance aspects. External factors modelled within FLEXINET are located at level 2 of the reference ontology (Designed Systems, see section 7.2.3) as they are applicable to a wide range of systems and are placed in a separate package for clarity. FLEXINET External Factors are shown in the Figure 7-15 below. The top level factors (Economic, Technological, Political, Legislation/Legal Factors and Social) are derived from the document "Conceptual model for business model innovation" (Schlosser and Otto) whilst the other factors originate from "List of Risk Factors in Global Production Networks" (Niknejad and Petrovic). Risk Factors which Niknejad and Petrovic identified as external have been classified within the categories found by Schlosser and Otto. An additional External Factor "Environmental Factors" (identified by Niknejad and Petrovic) is not shown within the diagram as it is located at level 3 of the reference ontology. This is because it relates to pollution so was deemed to be more specialised to the area of manufacturing. The overlap of concepts between the "External Factors" and "Risk" areas within FLEXINET demonstrates the need for a reference ontology to avoid duplication and maintain consistency across sub-domains. The occurrence of a concept within more than one area also indicates the importance of the concept to the ontology.

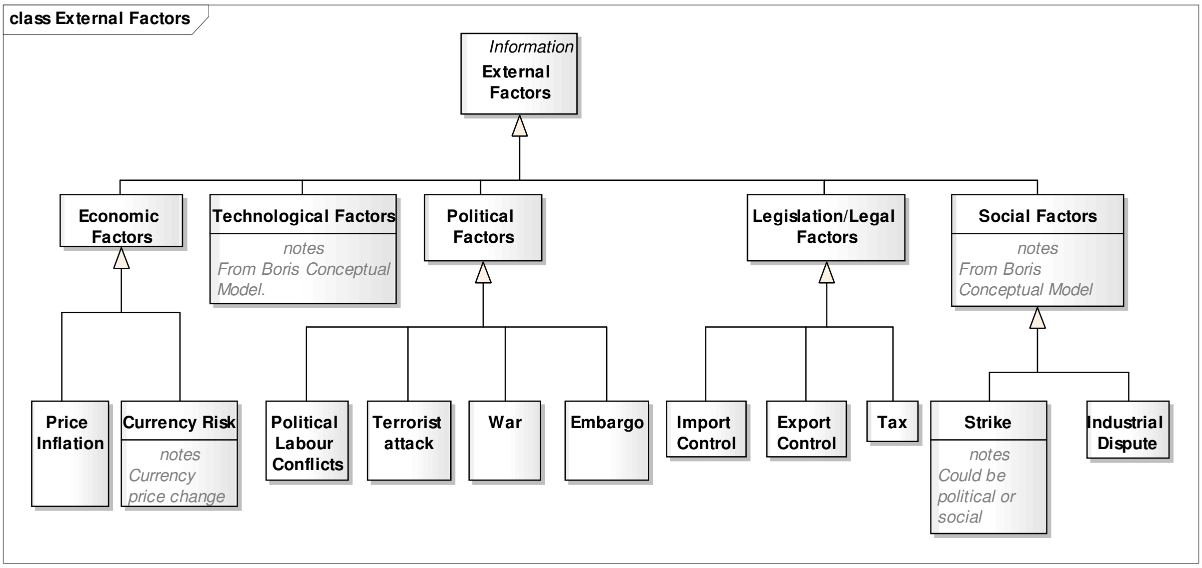

Figure 7-15: FLEXINET External Factor Hierarchy at level 2

Risk Factors are located with FLEXINET at level 2 because all man-made systems contain risks. As risk only exists in relation to something else, risk is classified as a role. The risks shown in the Figure 7-16 below are the top level classes identified by Niknejad and Petrovic in the document "List of Risk Factors in Global Production Networks" based on zone of influence within the GPN.

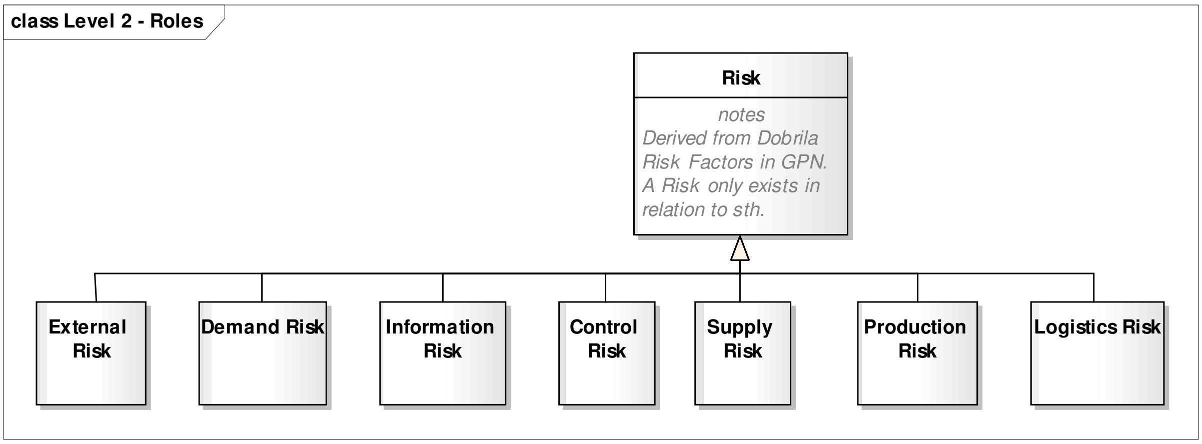

Figure 7-16: FLEXINET Risk Factors at level 2

These concepts will be updated as new concepts become available from work package WP2 and deliverable D2.1

7.2.3.4 Analysis of MSEE Assets Ontology

This section considers how the concepts of the MSEE ontology are related to the FLEXINET ontology. MSEE considers the hierarchical modelling of manufacturing assets, defining four parent Intangible Asset classes: Technical, Human, Organisational and Relational. The assumption is made that MSEE considers Intangible Assets to be types of Information. However the majority of these concepts are actually types of systems as shown in the following diagrams. The top level MSEE classes are shown within the diagrams in order to demonstrate the relations between FLEXINET and MSEE but will not be implemented within FLEXINET. Figure 7-17 presents an overview of the relationship between FLEXINET and MSEE. The diagrams within this section will adopt a convention of showing MSEE concepts in yellow and FLEXINET concepts in white and the assumption will be made that a diagram refers to level 2 of the FLEXINET reference ontology unless indicated otherwise. For details of the concepts referred to within the FLEXINET reference ontology see section 7.2.1.

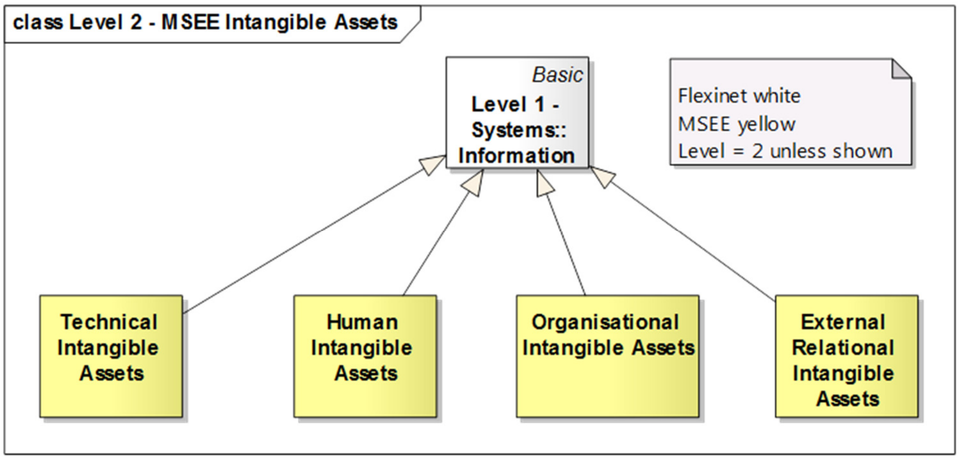

Figure 7-17: Relationship of MSEE Intangible Assets to FLEXINET

Correlations between MSEE concepts and FLEXINET concepts will be defined within the context of the four MSEE top level classes, with a subsection devoted to each class hierarchy. The subsections describe how MSEE concepts relate to FLEXINET concepts and where the MSEE concepts are located within the levels of the FLEXINET reference ontology. Concepts where no direct mapping of MSEE to FLEXINET is possible are noted and overlapping concepts whereby MSEE and FLEXINET refer to the same concepts are also noted. The majority of MSEE concepts were discovered to be located within level 2 of the FLEXINET reference ontology as they are widely applicable to Designed Systems.

7.2.3.4.1 Technical Intangible Assets

MSEE Technical Intangible Assets relate to an organisation's technical issues and are subclassed into Product Design, Products Use, Production Processes, Website Functionalities, Research and Development, Information Systems and Software, Quality Processes and Modeling Processes. These classes contain sub-classes as noted in Figure 7-18, Figure 7-19, Figure 7-20 and Figure 7-21 below. Due to space considerations four diagrams are used to depict MSEE Technical Intangible Assets. MSEE class Products Design forms a sub-class of FLEXINET Design (Basic level 2) and is positioned within the reference ontology at level 3 as it refers to the design of physical products. The sub-classes of MSEE Products Design (Drawings, Tests, Lessons Learned, Trademarks and Specifications) don't necessarily relate solely to the product, or the product design, hence are located at FLEXINET level 2 forming a potential conflict in mappings between MSEE and FLEXINET (the MSEE sub-classes being located at a more general level within FLEXINET than the parent class). MSEE classes Drawings and Trademarks are sub-classes of FLEXINET Visualisation. MSEE Tests forms a sub-class of FLEXINET Diagnosis. MSEE class Specifications is a FLEXINET Role (named Specification).

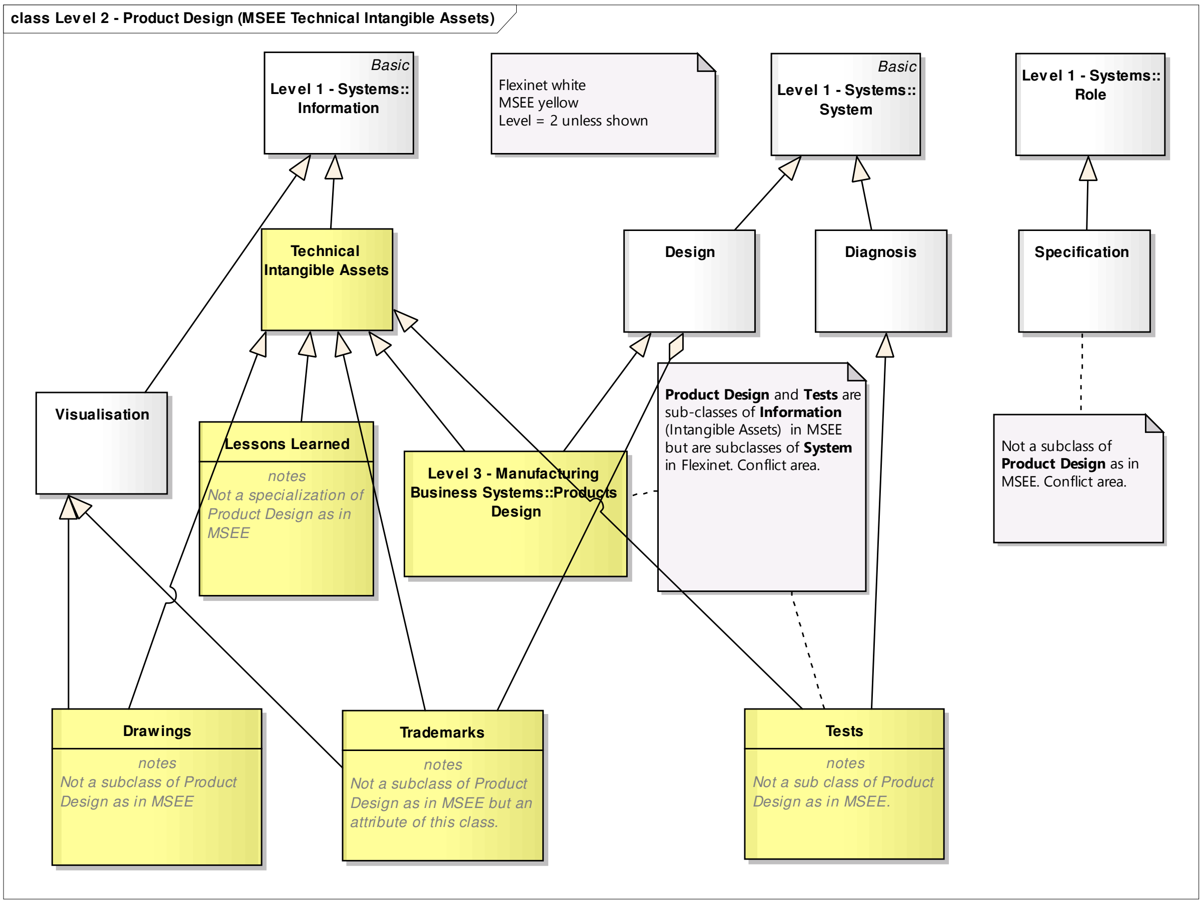

Figure 7-18: Relating the MSEE Product Design Hierarchy to FLEXINET

FLEXINET already contains the MSEE Products Use sub-classes Maintenance and Disposal (Dispose in FLEXINET). MSEE class Production Processes and its sub classes form a sub-class hierarchy inheriting from the FLEXINET class Produce located level 2 as Produce would also apply to a service and are therefore located at FLEXINET level 4 in Product-service life cycle systems.

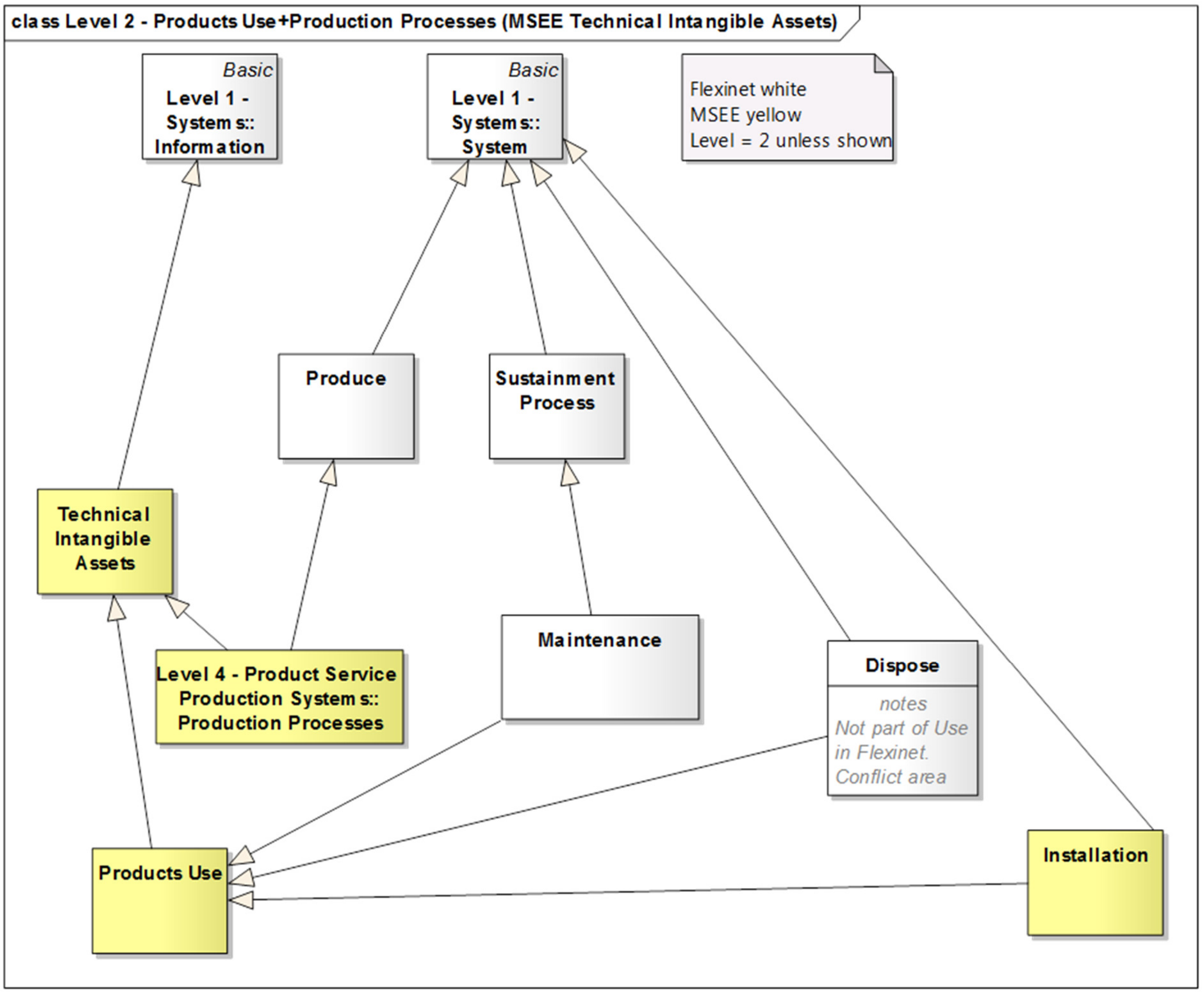

Figure 7-19: Relating MSEE Products Use hierarchy and Production Process to FLEXINET

MSEE class Website Functionalities is part of a separate domain. To model it requires a new domain “IT Systems” to be created at FLEXINET level 3 and a new sub-domain “Website Systems” to be added at level 4 to contain the Website Functionalities class.

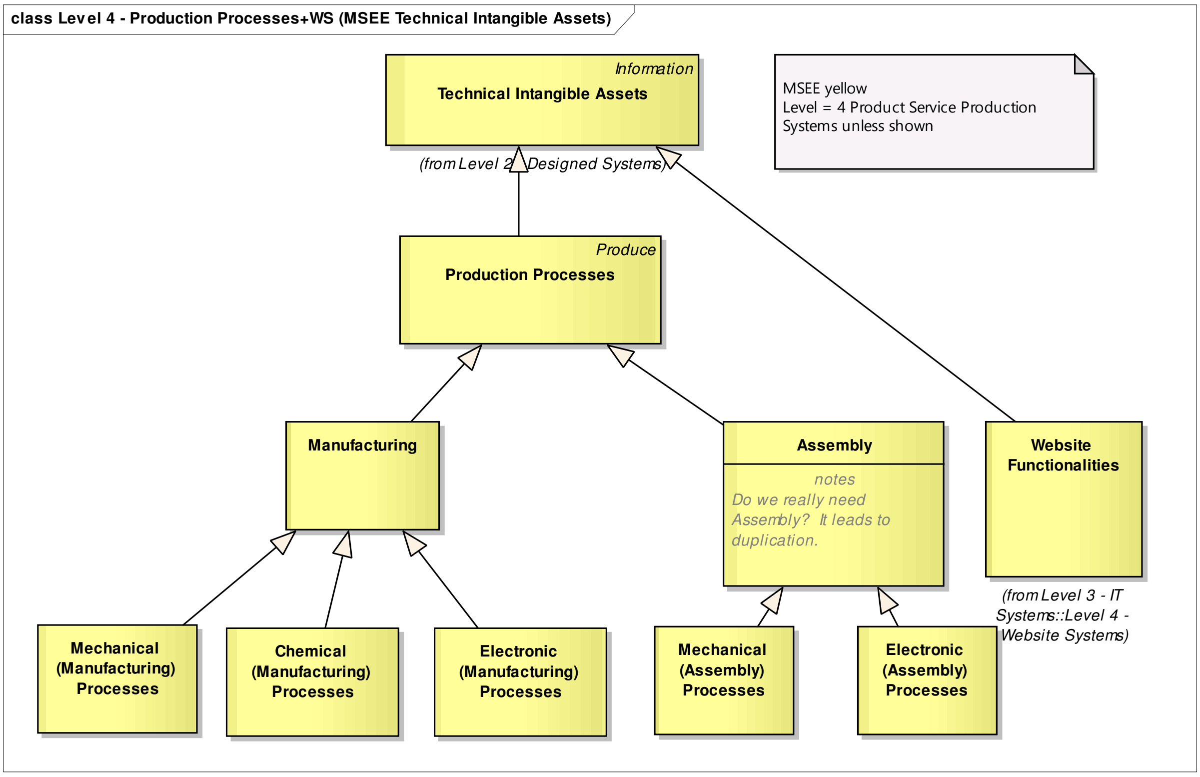

Figure 7-20: Relating the MSEE Production Processes Hierarchy and Website Functionalities to FLEXINET

MSEE class Research and Development inherits from FLEXINET class System. MSEE class Information Systems and SW equate to FLEXINET Software class level 2 Basics. MSEE class Modelling Processes is equivalent to the FLEXINET Analysis class (level 2 Basics). MSEE class Quality Processes forms a subclass of the FLEXINET class System. This class should not be confused with the FLEXINET level 2 Role class Quality which considers metrics not processes. Quality Processes has two sub-classes: Statistical Methods and Procedures. Statistical methods cover a similar but more specialised area than the FLEXINET Level 2 System class "Statistical Analysis" which inherits from the class Analysis in FLEXINET. A sub-class could be added to the ontology should a more specialised form of analysis relating solely to quality be required.

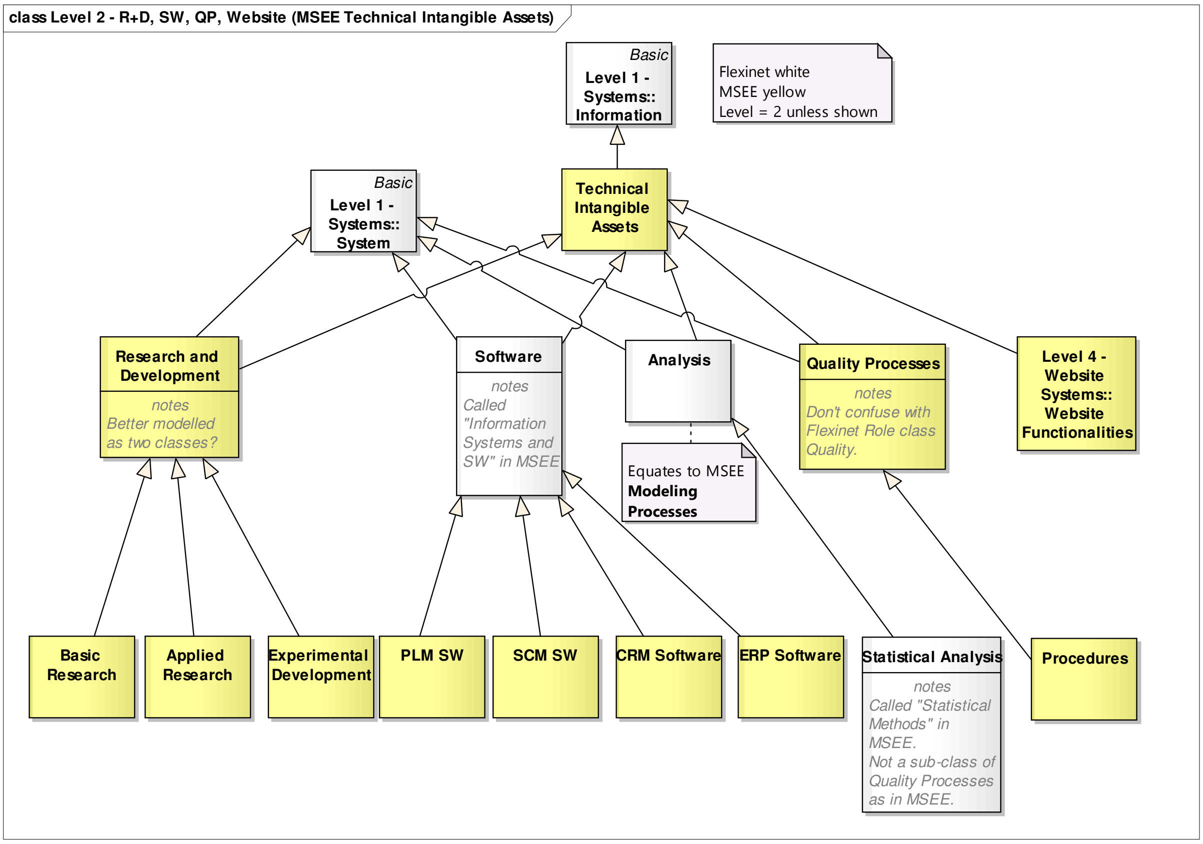

Figure 7-21: Relating the MSEE Research and Development hierarchy, Information Systems and Software hierarchy, Quality Processes hierarchy and Modelling Processes to FLEXINET

7.2.3.4.2 Human Intangible Assets

MSEE Human Intangible Assets are defined as the sum of employees' knowledge, skills and experience. The assets are classified as Employee, Top Manager and Line Manager Intangible Assets each of which contains the following sub-classes: Education, Creativity, Attitude, Job expertise, Problem Solving Capabilities and Training. MSEE Human Intangible Assets are located within the FLEXINET external Person Domain (see Figure 7-22). Employee, Top Manager and Line Manager form FLEXINET Roles (Participator Roles), located at level 2 of the reference ontology. MSEE sub-classes Education, Job expertise and Training are Basics within FLEXINET while Creativity, Attitude and Problem Solving Capabilities form FLEXINET Roles (Qualifiers). All these sub-classes will be located at FLEXINET level 3 as they relate more specifically to Manufacturing Systems.

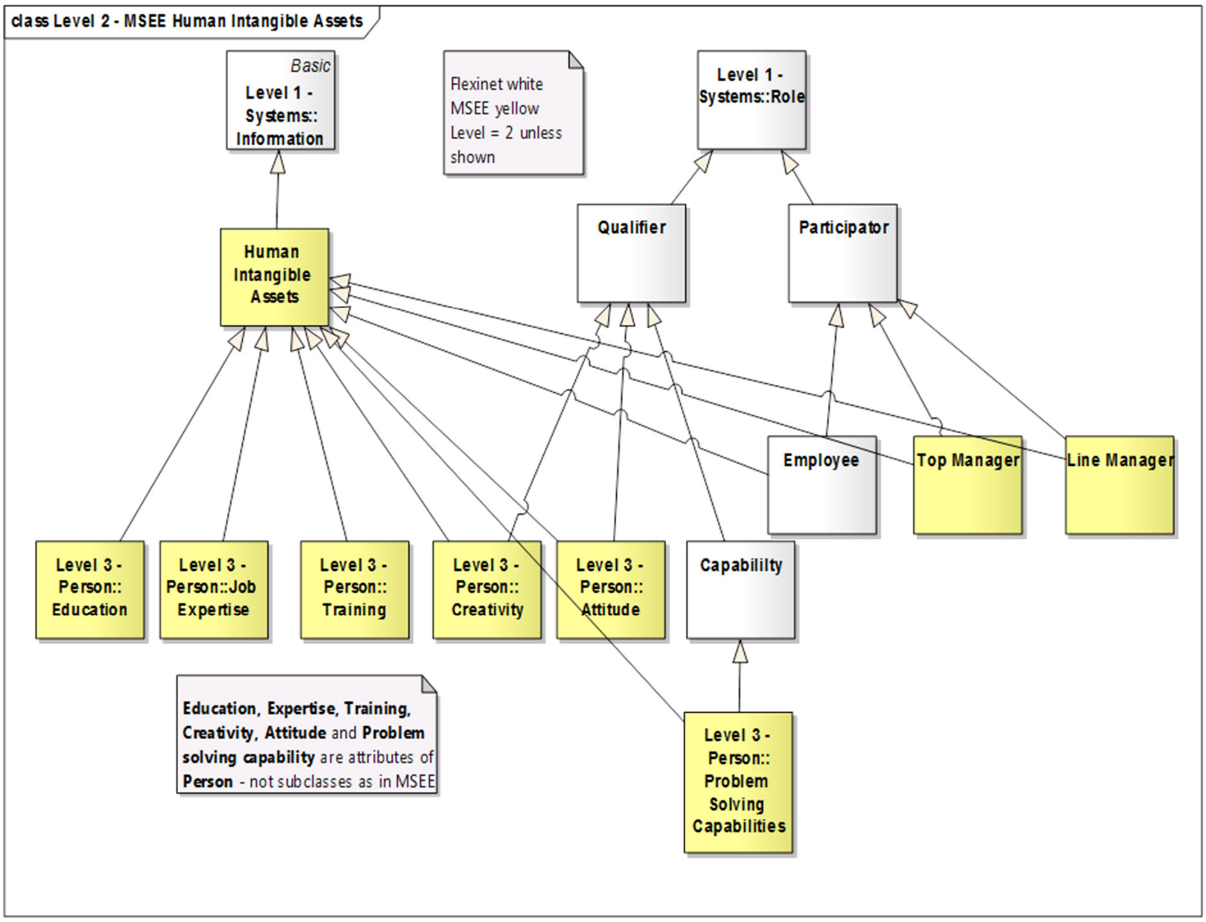

Figure 7-22: Relating MSEE Human Intangible Assets to FLEXINET

7.2.3.4.3 Organisational Intangible Assets

MSEE Organisational Intangible Assets relate to the management issues within an organisation. Organisational Intangible Assets are classified within six top level classes: Production, Logistics, HR Management, Problem Solving and Innovation, Marketing and Sales and Government. Four diagrams are used to relate the concepts to the FLEXINET reference ontology. MSEE class Production is located at FLEXINET level 4. Of the MSEE Production sub-classes Production Schedule and Operative Scheduling are also located at level 4 but Demand Forecasting is located at level 2 and Stock Management is located at level 3 suggesting a possible modelling problem as a class is unable to inherit from a more specialised level of the ontology. Potential methods of solving this conflict are noted in the Figure 7-23.

Logistics is present at FLEXINET level 2 as a Basic (subtype System). The MSEE sub-classes Inbound Logistics and Outbound Logistics would be captured within FLEXINET by the Logistics class playing FLEXINET Input and Output Roles.

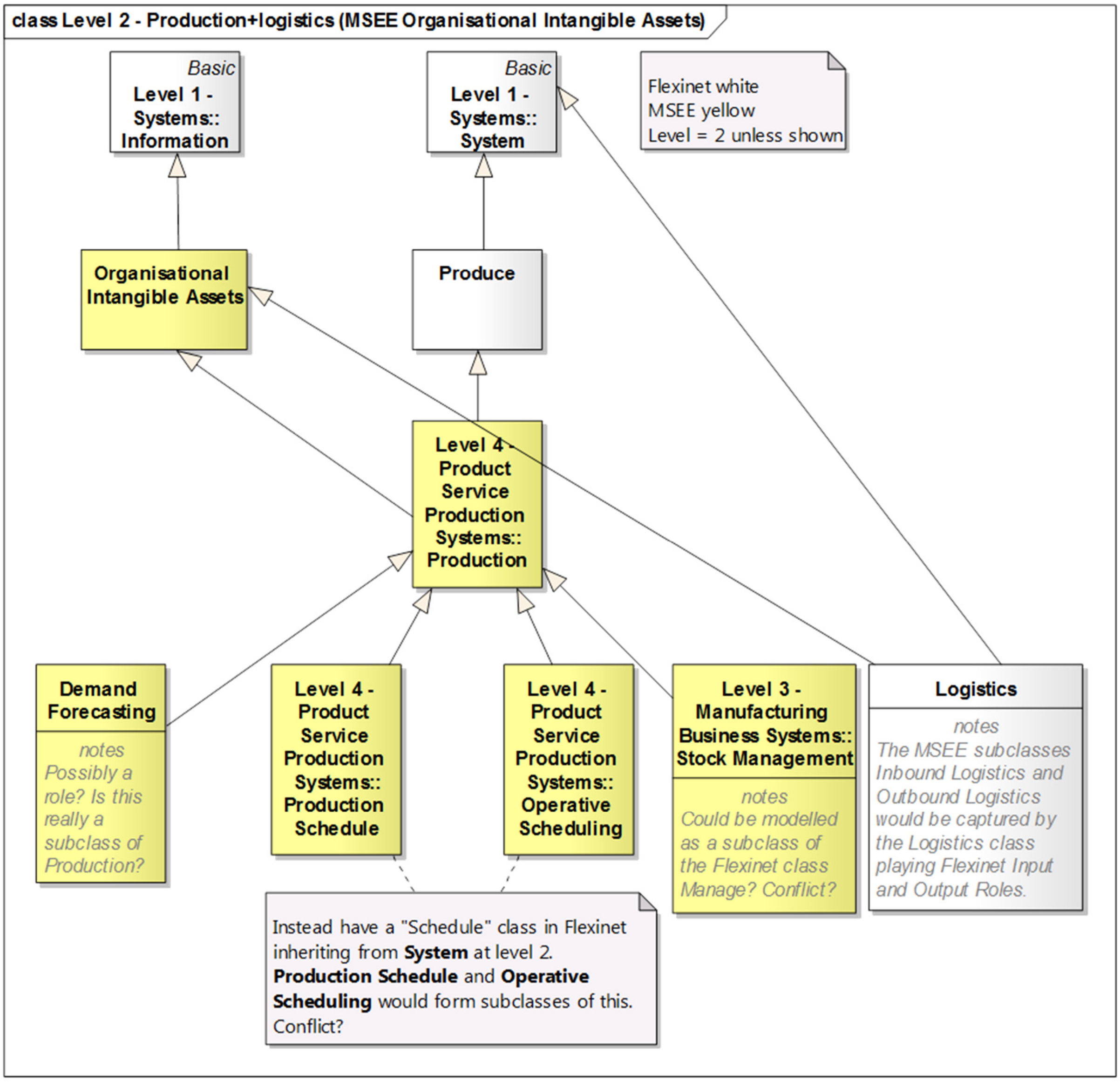

Figure 7-23: Relating MSEE Production hierarchy and Logistics to FLEXINET

MSEE class HR Management consists of two sub-class hierarchies: Individual Management and Collective Management. The sub-classes of Individual Management are: Training and Development; Rewards Management; Evaluation and Performance Management; and Acquisition. The Collective Management sub-classes are Wage; and Safety and Health. HR Management is a sub-domain of FLEXINET Manufacturing Business Systems and to capture its concepts would require a new sub-domain to be added at level 4 of the reference ontology. HR Management is outside the scope of FLEXINET.

The sub-classes of the HR Management hierarchy are located at FLEXINET level 2 as they are generally applicable to Designed systems. FLEXINET already contains a Basic class Training at level 2 which is equivalent to the MSEE class Training and development. MSEE classes Individual Management, Rewards Management, Collective Management, Wage and Safety and Health are subclasses of the FLEXINET level 2 Basic class Manage. MSEE class Evaluation and Performance Management is a sub-class of FLEXINET level 2 Basic Analysis. As Analysis is a sub-class of Technical Intangible Assets (see Figure 7-24) Relating the MSEE Research and Development hierarchy, Information Systems and Software hierarchy, Quality Processes hierarchy and Modelling Processes to FLEXINET) this suggests a variance between the MSEE and FLEXINET viewpoints. MSEE class Acquisition is positioned at FLEXINET level 2 as this is a broad concept and could equally relate to the acquisition of raw materials and equipment as well as worker acquisition. Within an HR management sub-domain more specialised concepts could inherit from the level 2 concepts described here. For example, a level 4 HR Management concept "Worker Acquisition" could inherit from the level 2 Designed Systems concept "Acquisition" and a level 4 HR Management concept "Personnel Evaluation and Performance Measurement" could inherit from the level 2 concept "Evaluation and Performance Measurement".

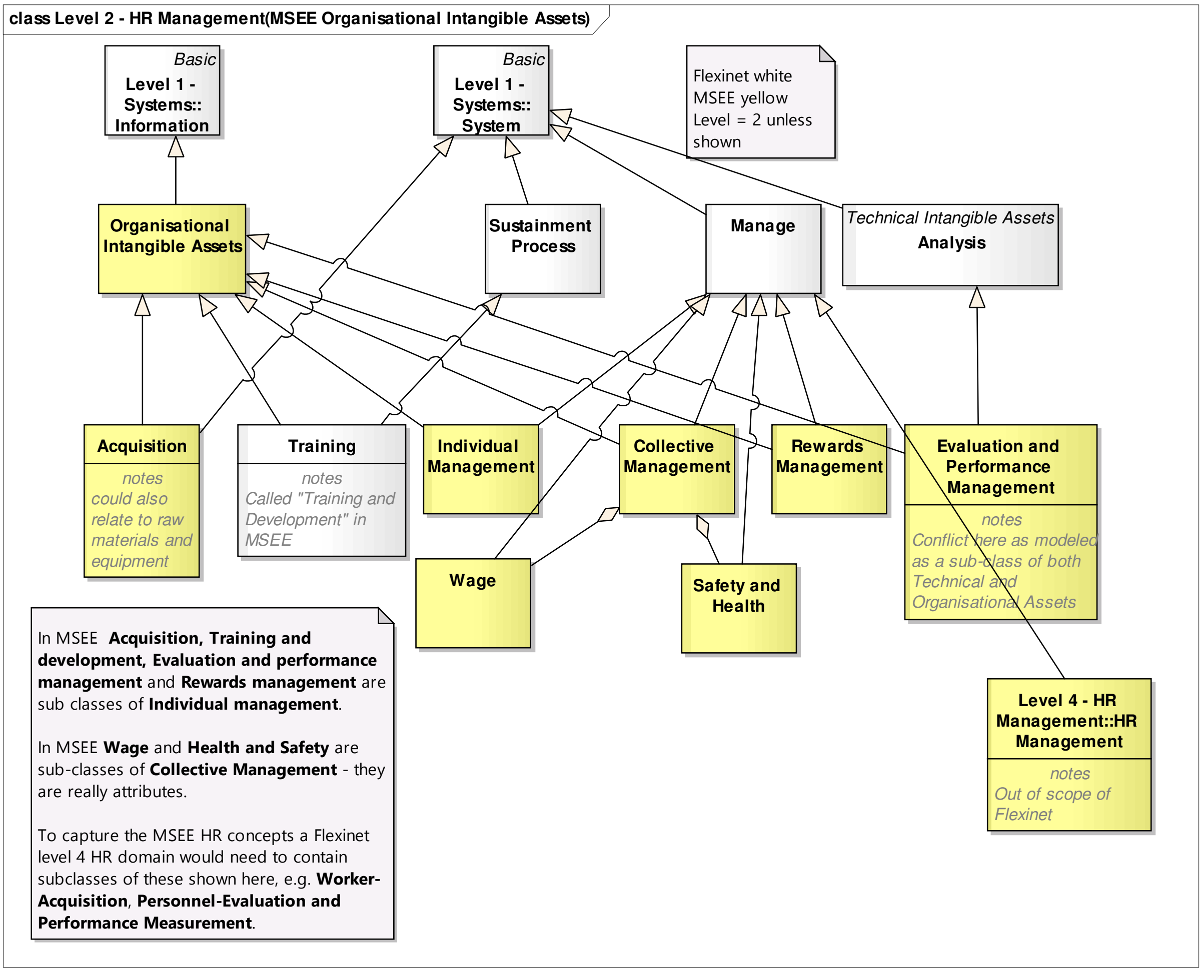

Figure 7-24: Relating MSEE HR Management Hierarchy to FLEXINET

The MSEE class Marketing and Sales equates to FLEXINET Level 2 Basic Market Information. In the MSEE ontology Marketing and Sales generalises the classes Product, Price, Place and Promotion. Product is similar to the FLEXINET level 2 Role Product (see Figure 7-25). However the FLEXINET class covers a broader range than marketing issues and would also contain attributes relating to the product components, description, function, operation etc. The Marketing and Sales sub-class Price equates to the FLEXINET level 2 Basic Cost. Possibly another class Discount, inheriting from the FLEXINET level 2 class Metric, could be added to level 2 of the reference ontology to cover the full extent of this MSEE concept. The Marketing and Sales sub-class Place corresponds to FLEXINET level 2 Basic class Location. The MSEE Marketing and Sales class hierarchy does not map readily to FLEXINET.

The MSEE class Problem solving and Innovation contains two sub-classes: Problem Solving and Innovation which form sub-classes of Capability, a FLEXINET level 2 Role.

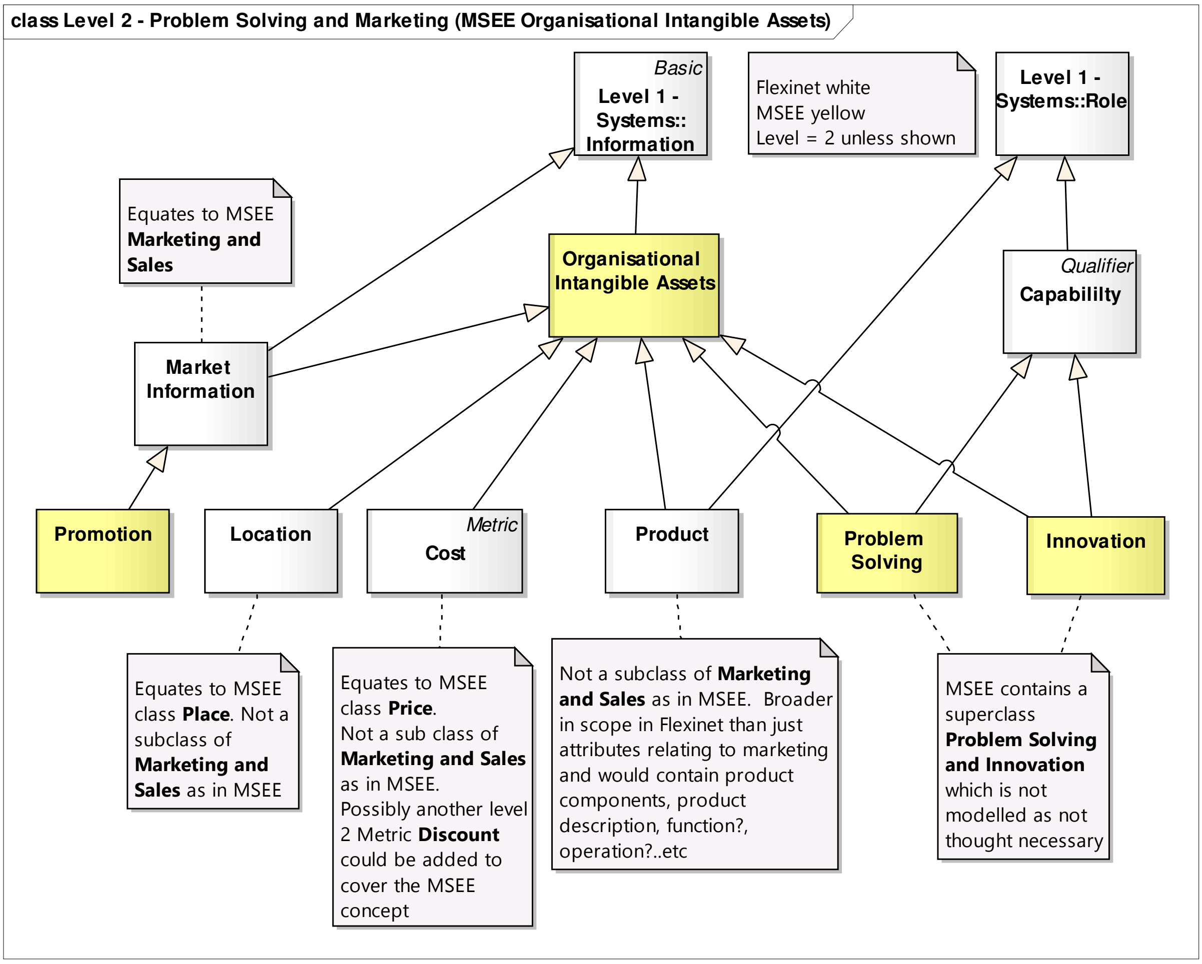

Figure 7-25: Relating MSEE Problem Solving and Innovation classes and Marketing and Sales Hierarchy to FLEXINET

The MSEE class Government is divided into four sub-classes: Finance, Control, Administration and Legal Affairs. Government appears to be very close in conception to the FLEXINET level 2 class Manage. FLEXINET has a Level 2 System class Finance which looks similar to the MSEE Government subclass Finance, however it is unclear whether these two classes equate – possibly the MSEE ontology is referring to financial information rather than processes. The MSEE Government subclass Control is a subclass of FLEXINET level 2 Analysis and is equivalent to the class Evaluation and Performance Management added to FLEXINET level 2 (see Figure 7-26) relating MSEE HR Management Hierarchy to FLEXINET. A specialist sub-class considering organisational performance could be added to this level for refinement if necessary, for example to consider KPIs.

The MSEE Government sub-class Administration includes documents management which is an existing FLEXINET Level 2 Basic subclass. The sub-class Legal Affairs is similar to the FLEXINET level 2 class Legislation/Legal Factors but is broader in scope as it includes insurance policies and legal arguments. It should be noted FLEXINET contains a level 2 System class Insurance, but this does not correspond the MSEE vision which refers to a type of information. To capture the intention of MSEE a new class Insurance policy is required which would inherit from the level 2 FLEXINET class External

Factors. As shown in the diagram below the MSEE Government hierarchy does not align directly with FLEXINET.

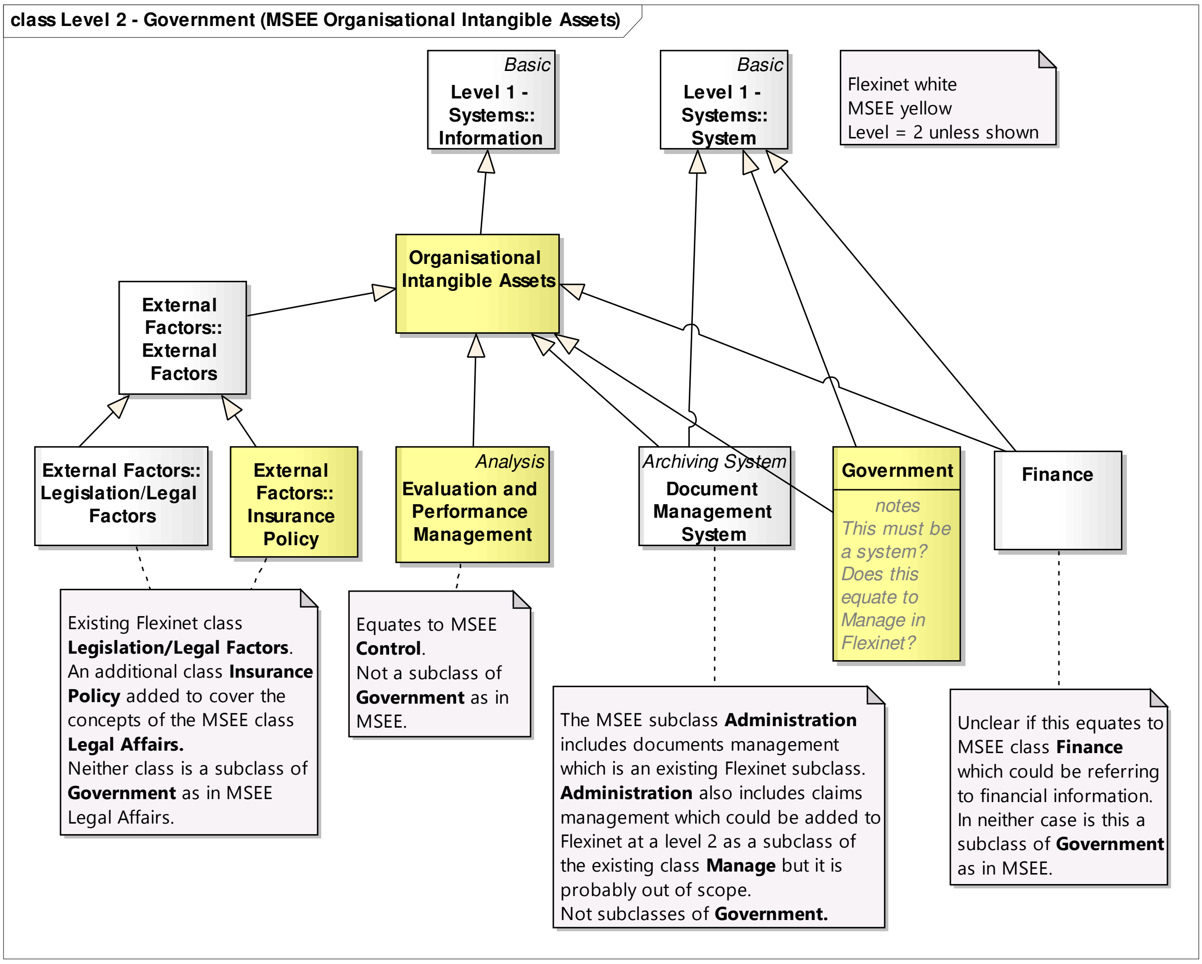

Figure 7-26: Relating MSEE Government Hierarchy to FLEXINET

7.2.3.4.4 Relational Intangible Assets

MSEE defines Relational Intangible Assets as the relationships between an organisation and its external stakeholders and presumably internal stakeholders although this is not specified. MSEE Relational Intangible Assets are divided into two main classes: External and Internal. External Relational Intangible Assets contain the classes With Customers, With Suppliers, With Financial Authorities, With Financial Investors and With Trade Associations. The With Customers and With Suppliers classes are sub-classed into R&D Relational Intangible Assets, Maintenance Relational Intangible Assets and Supply Relational Intangible Assets. The Internal Relational Intangible Assets are classified into With Trade Unions, With Top Managers and With Owners.

A new class is needed within FLEXINET to encompass the length, strategic importance, type and reliability of inter and intra network connections. A possible name for this new class would be "Interaction". The concepts of With Customers and With Supplier could be captured within FLEXINET by a ternary relation hasInteractionWith (arguments: System, Interaction, and System). An example of the MSEE With Supplier concept as modelled within FLEXINET would be:

- Cider_Plant hasInteractionsWith InteractionID_CP1, Browns_Bottling_Plant Browns_Bottling_Plant playsRole Bottle_Supplier

Where Cider_Plant and Browns_Bottling_Plant are instances of System, InteractionID_CP1 is an instance of an Interaction class and Browns_Bottling_Plant is playing the role of a supplier.

Concepts already exist within FLEXINET capable of modelling issues related to R&D, Maintenance and Supply Relational Intangible Assets. R&D Relational Intangible Assets corresponds to the class Research and Development added to FLEXINET level 2 (see Figure 7-27), relating the MSEE Research and Development hierarchy, Information Systems and Software hierarchy, Quality Processes hierarchy and Modeling Processes to FLEXINET. Maintenance and Supply are Basics existing at level 2 of the FLEXINET reference ontology (see section 7.2.3.4.1).

MSEE classes With Financial Investors and With Owners could be added as FLEXINET level 2 Participator Roles if needed. Concepts such as With Authorities, With Trade Associations and With Trade Unions could be added to FLEXINET level 2 as sub-classes of Organisation. The concept Top Manager placed in FLEXINET level 2 (see Figure 7-27) relating MSEE Human Intangible Assets to FLEXINET can be used to model the With Top Manager Relational Intangible Assets.

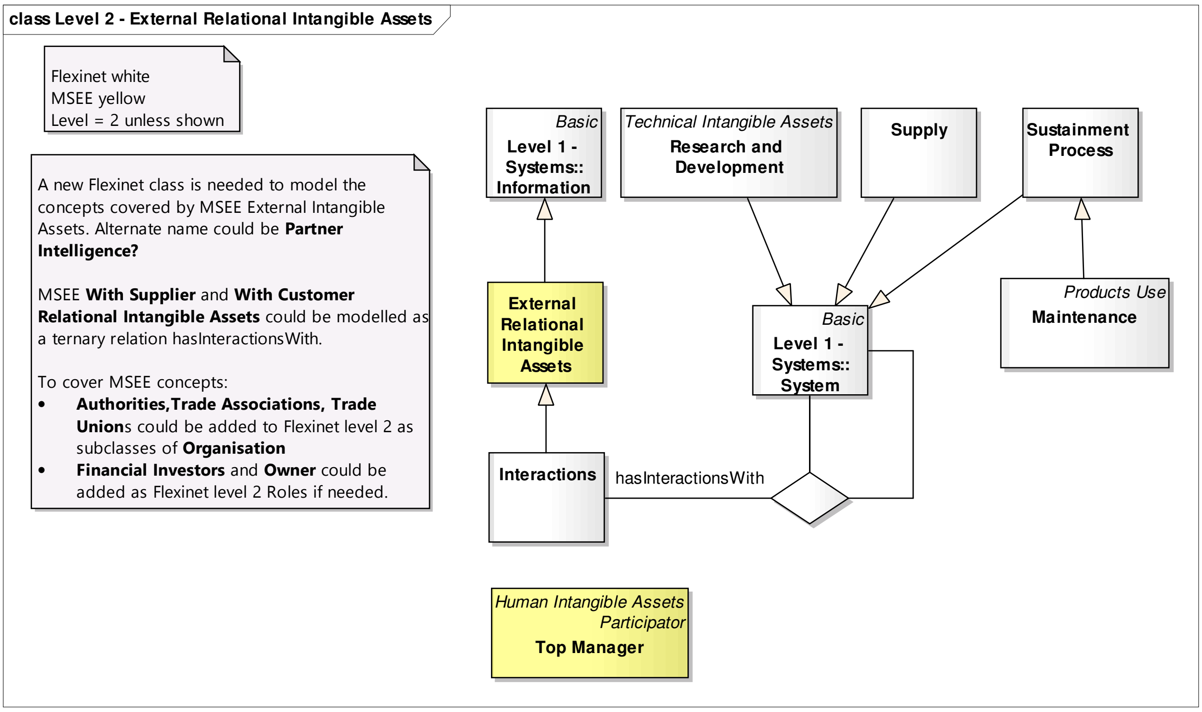

Figure 7-27: Relating MSEE External Relational Intangible Assets to FLEXINET

7.3 Exploitation of reference ontologies

7.3.1 Consistency of reference ontologies

All the identified elements, conveniently analysed, described, and catalogued, define the Reference Ontologies, crowned with the **System Foundation Ontology** as the top-level ontology, defined as such in terms of its wide range of applicability and its generalisation.

Figure 7-28 represents a simplification of the reference ontologies in order to better highlight its generalisation purposes. For instance, **Standard** concept in terms of "Designed Systems" is defined at Level 2 as a specialisation of **Basic** concept, defined at Level 1 in terms of "Systems". On the other hand, a **Production Standard** is a Level 4 specialisation of **Standard** concept from Level 2. Also **Manufacturing Standard** (a concept defined at Level 3) is a specialisation of **Standard**, from Level 2. These are just a few examples that illustrate the connection between the different reference levels and how the consistency among the different levels is promoted.

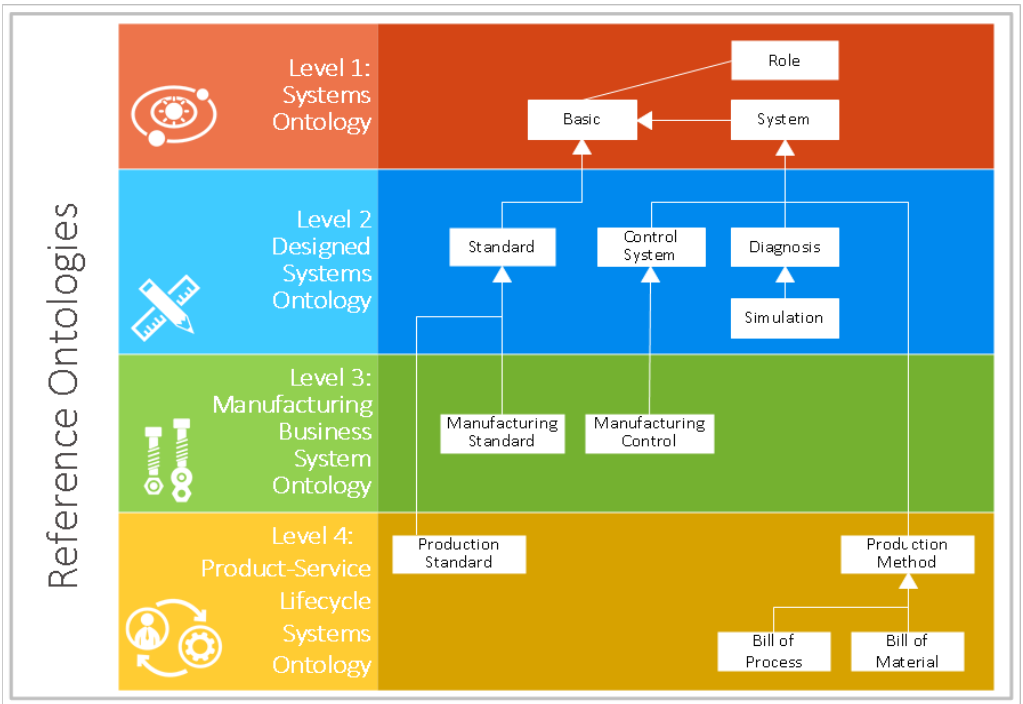

Figure 7-28: Inheritance in reference ontologies

7.3.2 Enterprise specific ontology

The reference ontologies will serve as a solid foundation for end users interested in creating their own ontology for their manufacturing enterprise. Extensive experience and knowledge has been combined to represent the levels of Systems, Designed Systems, Manufacturing Business Systems and Product-Service Lifecycle Systems for Manufacturing Industry within the reference ontology. The main concepts will exist, ready to be used as needed, within the reference ontology. The application and reuse of stable concepts that are repeated once and again in many different manufacturing scenarios, will assure a high level of interoperability and standardisation. If fact, having a reference ontology fulfils at least three objectives:

- The structure provided by the ontology aids the user in recognising concepts.
- Help the user to find the right concepts and relations, based on the extensive experience behind the definition of the ontology. This will help, for instance, to avoid duplicating concepts when creating new terms that refers to the same thing and have the same meaning.
- Help the user to validate their own ontology against concepts that are stable and commonly acknowledged. This will help, for instance, to detect irregularities or unusual relations among concepts.

Figure 7-29 represents the four levels that conforms the reference ontologies (Level 0 representing the core is omitted for simplification purposes) along with an Enterprise Specific Ontology that makes use of them.

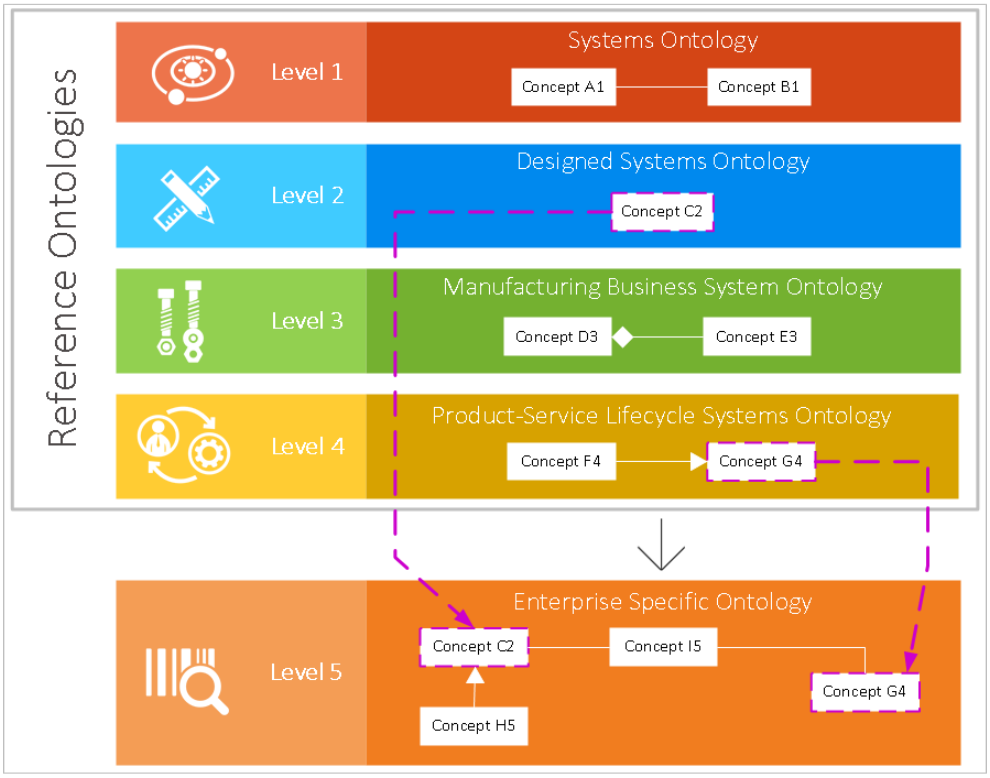

Figure 7-29: Creating an Enterprise Specific Ontology

In the scenario presented in Figure 7-29, the Enterprise Specific Ontology introduces two new concepts (Concept H5 and Concept I5), and reuses two other concepts, both coming from the reference ontologies. Concept C2 comes from the Designed Systems Ontology. This means that the user, when creating the ontology that represents their company, decided that Concept C2 perfectly suited the concept that they use in their particular enterprise, and then reused it. The same applies to Concept G4. The user works for a Product-Service sector company, and they found that Concept G4 (coming from Level 4) perfectly suited the concept they had in mind for this particular company.

In summary, the Enterprise Specific Ontology is the one that represents the concepts and rules driving the Global Production Network of a particular company or business. While most of the main concepts in this ontology should derive from those already included in the reference ontologies, there might be a number of truly specific concepts that are particular to a specific enterprise. Both of them, along with their relations, will form the Enterprise Specific Ontology.

Considering two similar enterprises, working for the same sector, we may think that the resulting Enterprise Specific Ontologies will be similar for them both. That is, they will share a good number of concepts and will have a handful of relations in common. The differentiation will reside in:

- Particular concepts that are specific to each company and do not appear in the other.
- Relations (and cardinality) connecting concepts.
- The rules that drive the decision making process.

In particular, the key difference among companies will reside in the set of rules that enables its business to function.

7.3.3 Applicability of reference ontologies

The reference ontologies are meant to be publicly available, open to debate and discussion, as part of its maturing process. Thus, the reference ontologies are a living entity, in constant –although limited, process of refining and evolution. A few new concepts may be added in time as a result of the feedback from the community, the same way that new relations may arise or disappear over time. Eventually, all of them will be part of a common reference for all users designing ontologies in this area of knowledge.

In conclusion, the generalisation approach, slicing the knowledge into several layers of applicability, assures:

- The reutilisation of concepts and relations: different industries can take advantage of the very same "System Foundation Ontology", the same way that manufacturers coming from different sectors can take advantage of the very same "Manufacturing Systems Ontology".
  The scope of each of the ontologies is restricted: it is not the target to create one single and –most probably, overloaded ontology. On the contrary, the foundational concepts are meant for the System Foundation Ontology, while more specific concepts are meant for the Manufacturing Systems Ontology. Again, new layers can be added below, addressing more specific scenarios, resulting in more specific concepts and relations only applicable in the particular scenario they address.

7.3.4 Cross-Sector Analysis of Enterprise Specific Ontologies

FLEXINET Reference ontologies are intended to be used by end-users as a basis for creating and developing their specific enterprise ontologies. At this stage, the Enterprise Specific Ontologies described in previous sections reflect the needs and requirements of the end-users at a lightweight level, and they represent the applicability of the reference ontologies to specific sectors in the context of the end-users. They belong to Level 5 of the FLEXINET ontologies. What is presented next is an analysis of the end user lightweight ontologies against the FLEXINET Reference Ontologies.

The first step has been to identify the terms that are derived from upper levels. Figure 7-31, Figure 7-32 and Figure 7-33 illustrate the results of this analysis. Concepts are grouped by the levels to which they are related. Legends used for this analysis are shown in Figure 7-30. All levels are presented by rectangles but Level 5 terms are grouped by a rounded rectangle.

Since FLEXINET reference models are still under development and some terms may be reconsidered in their placement. In addition some concepts may, based on their significance, be placed at different levels. A brief description of the analysis performed is described below.

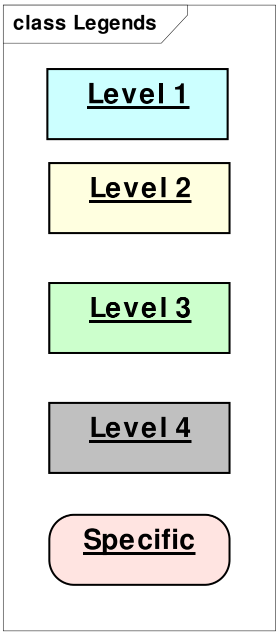

Figure 7-30: Legend for FLEXINET Reference Ontologies Levels

7.3.4.1 CustomDrinks Cross-Sector Analysis

Customs Drinks ontology derives most of their concepts from Level 2 (Figure 7-31). This is a common characteristic to the three End-User ontologies. We should highlight the level 1 term included in the ontology: Material. More specific materials should be defined at lower levels. Customs Drinks Ontology also offers a big range of concepts of Level 4 related to the Product-Service Lifecycle belonging to the food sector. Resulting diagram can be shown in Figure 7-31.

In summary, we identify the following list of concepts grouped by Levels:

<u>Level 1:</u>

- Material.

<u>Level 2:</u>

- Supplier, Design, Machine, Component, Accessory, Player, Operation, Product, Basic Resources, Human Resources, Computer Systems.
- Consumer, Client, Market Info, Market, Regulation, Trend, Environmental, Social, Tech, Requirement, Request, Development Project, Information Service, Order, Idea, New Design.

<u>Level 3:</u>

- Line, Stage, Production Asset, Manufacturer, Production Process.

<u>Level 4:</u>

- Food Supply Chain, Catalogue, 3rd Party Service Provider.

Level 5:

- Pack, Bottling, Cover, Label, Ingredient, Container, New Content, New Container, New Pack.

7.3.4.2 INDESIT Cross-Sector Analysis

In the case of the INDESIT Ontology (Figure 7-32) the terms that have been mostly identified are Level 2 terms. Terms such as Cycle, Cycle Information, Function and Function Information are terms specialised at level 5. We could consider these terms upper level terms (level 2) but they are specific terms relating to the product Energy Saving Dryer so they remain at Level 5.

We present the list of concepts of Indesit Ontology sorted by levels:

<u>Level 2</u>

- Product, Service, Device, Cost, Factory, Software Infrastructure, Software System, Asset, Data Type, logistics.
- Supplier, Component, Component List.
- Country, Business Model, Partners, Transport, Supply Chain.

<u>Level 4</u>

- GPN Network, Bill of Materials.

<u>Level 5:</u>

- Energy Saving Dryer, Cycle, Cycle Information, Function, Function Information.
- Ecosystem.

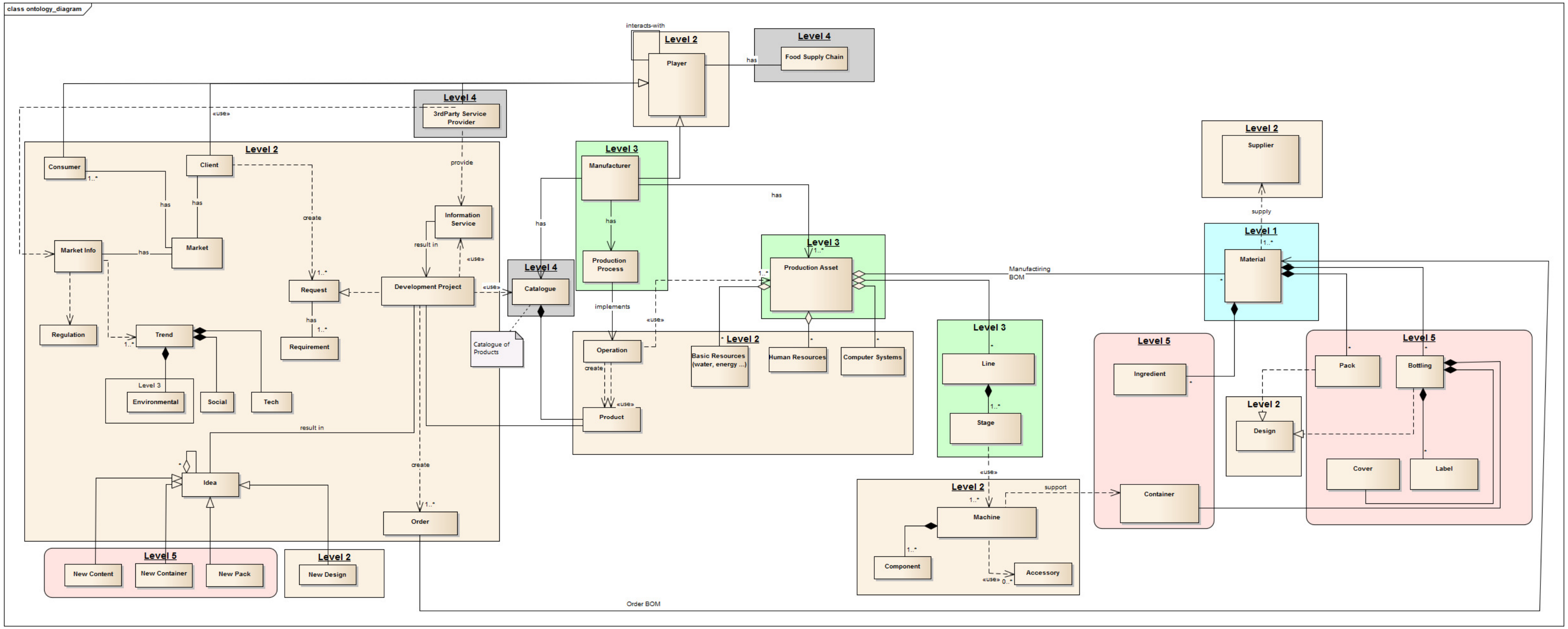

Figure 7-31: Cross-Sector Analysis of CD Specific Enterprise Ontology

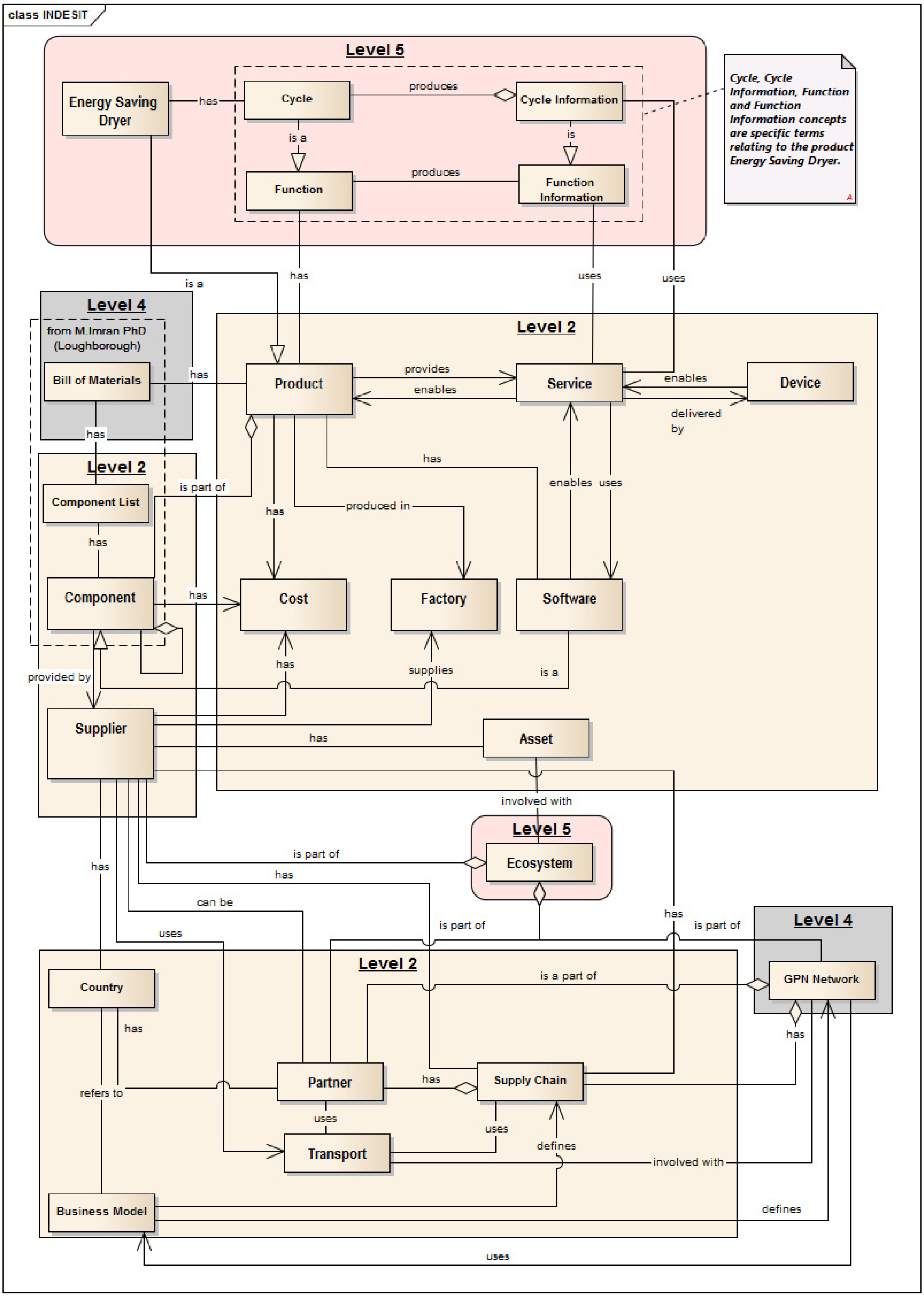

Figure 7-32: Cross-Sector Analysis of Indesit Specific Enterprise Ontology

7.3.4.3 KSB Cross-Sector Analysis

The cross-sector analysis of the KSB ontology follows the pattern found in the previous two ontology analyses, i.e., level 2 terms make up most of the main concepts of the ontology. Figure 7-33 illustrates in a graphical manner how level 2 terms form the basis of the ontology. Furthermore, the KSB ontology provides a wide range of concepts at level 5; for example, KSB considers five "Images" of Customers such as Tenderer, Official, End Consumer, Plan Construction firm and Industrial Consumer. KSB technology or KSB tools for internal use are also important terms that fall into the level 5 of the FLEXINET Reference Ontology. Additionally to the other ontologies, a list of terms related to KPI (Key Performance Indicators) has been incorporated to the ontology. These terms are placed at level 2. Some other relevant concepts such as Valve and Pump are specific sector and they are placed at level 4 along Product Management and Product Development.

Next, the terms are listed by levels:

Level 2:

- Local Independent Ideas, Business Ideas, Business Model, Strategy, Opportunities, Competencies, Risks.
- Prototype, KPI, Reactivity, Environmental, Cost, New Technology.
- Company, Customer Analysis, Competitive Analysis, Strengths and Weakness Analysis.
- Consulting, Training, Service, Product, Business Product, Market, Competitor, Partner, Customer.
- IT Systems, Schedule, Human Resources, Logistics, Supplier, Facilities, Location.
- Technology, Trends, Political, Standards, Terrorist Attack, War, Embargo, Political Labour Conflicts, Economic, Economic Sanctions, Recession, Inflation Rate, Currency Risk, Social, Industrial Dispute, Strike, Legal Requirements/regulations, Taxes, Import/Export Control.

Level 3:

- Production Process, Environmental.

Level 4

- Valve, Pump.
- Product Management, Product Development.

Specific Concepts Level 5:

- KSB Excel, SAP systems, KSB Technology.
- Experts.
- Tenderer, Plan Construction firm, Industrial Consumer, End Consumer, Official.

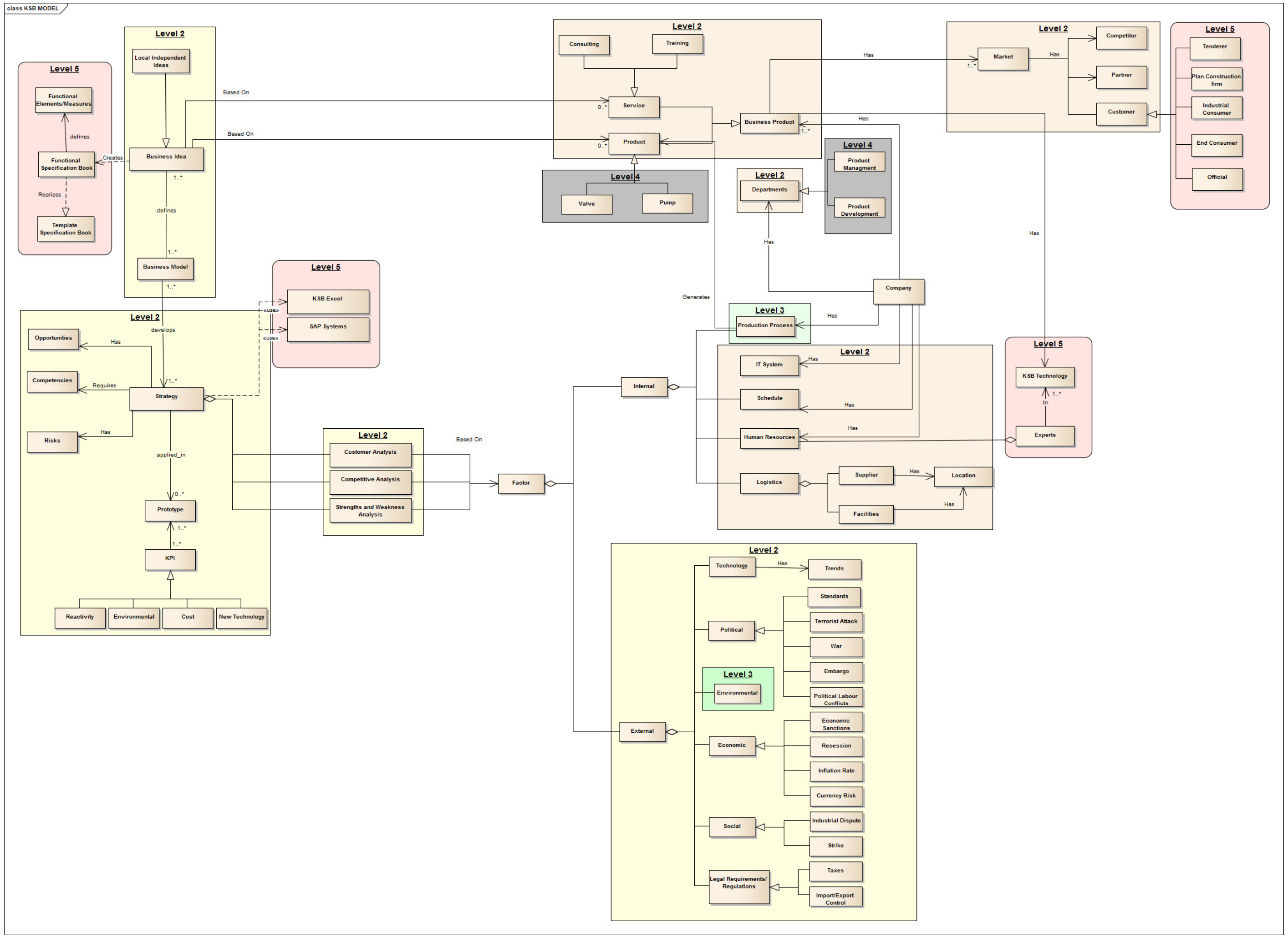

Figure 7-33: Cross-Sector Analysis of KSB Specific Enterprise Ontology

We can conclude that most of the terms defined in the Enterprise Specific Ontologies are derived from Level 2. Design Systems in level 2, as FLEXINET defines, refer to fabricated physical systems, conceptual knowledge and purposeful creations. Therefore, the fact that this definition encompasses a broad list of concepts is aligned to the high number of terms defined in the ontology. Levels 3 and 4 are conceived as support levels within specialised areas.

Finally, Level 5 terms give ontologies end-user customisations. In the process of formalisation of the lightweight ontologies more terms at Level 5 are expected to be raised.

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