London Underground is one of the most extensive and complex underground metro systems in the world, and it is the oldest, with the first line having been opened in 1863.

Three million journeys are made each day over 408km of track serving 275 stations.

Obviously, a great deal of effort goes into making The Tube both safe and efficient for the public to use.

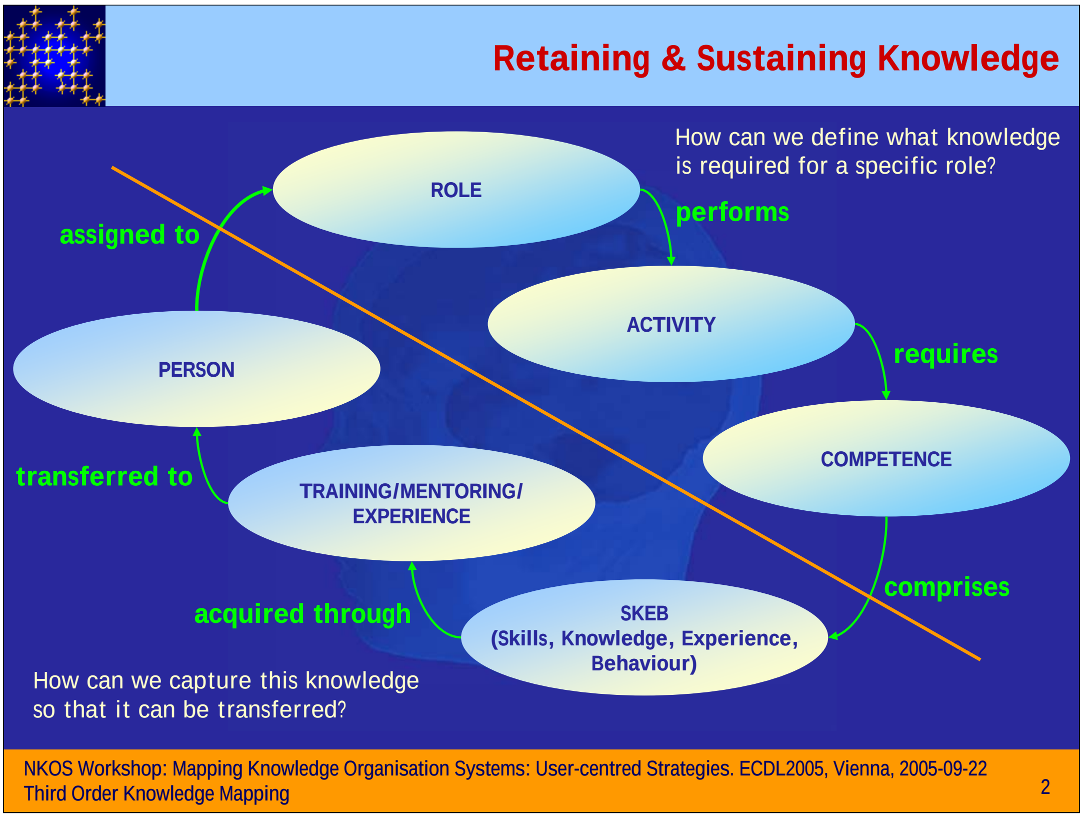
That requires a lot of specialist knowledge, mainly - though not exclusively - in the realm of Engineering.

Much of this knowledge is documented as engineering procedures and standards, but a great deal of key knowledge exists only in the heads of the engineers.

In 2002, London Underground invited us to undertake a knowledge management development project to explore methods for mapping this specialist knowledge.

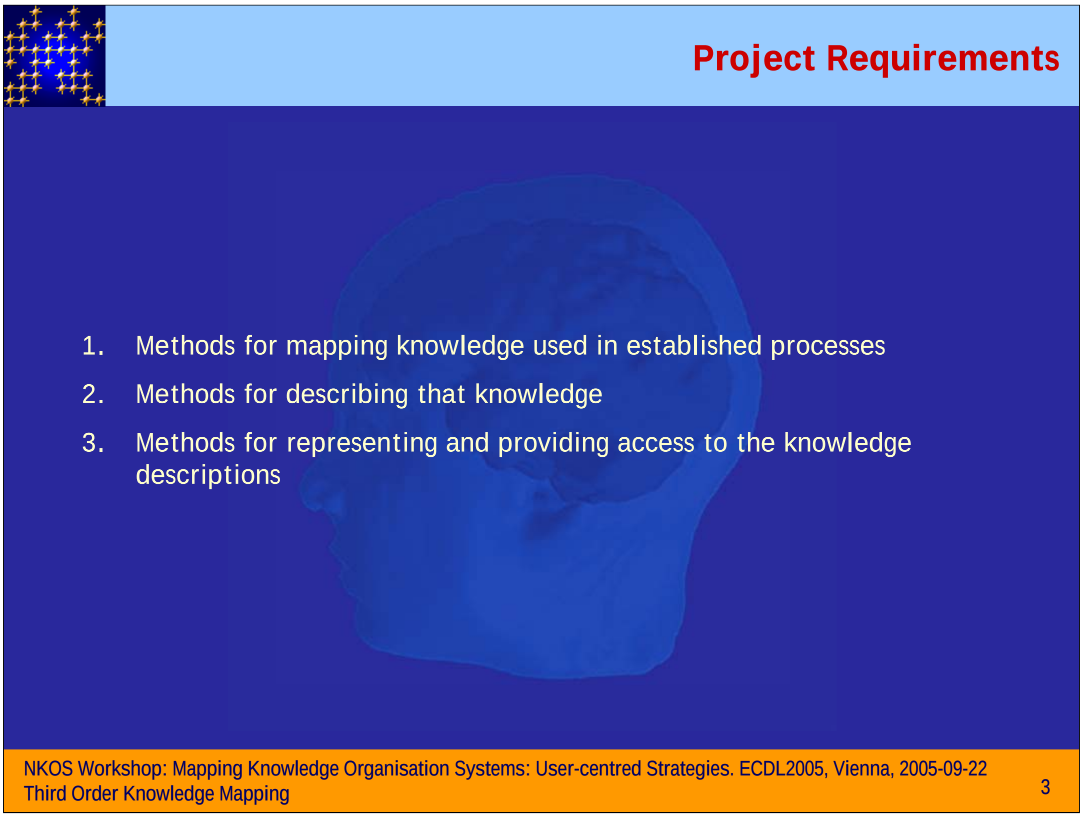
The Client wanted two questions answered:

- - How can we define what knowledge is required for a specific role?
- - How can we capture this knowledge so that it can be transferred?



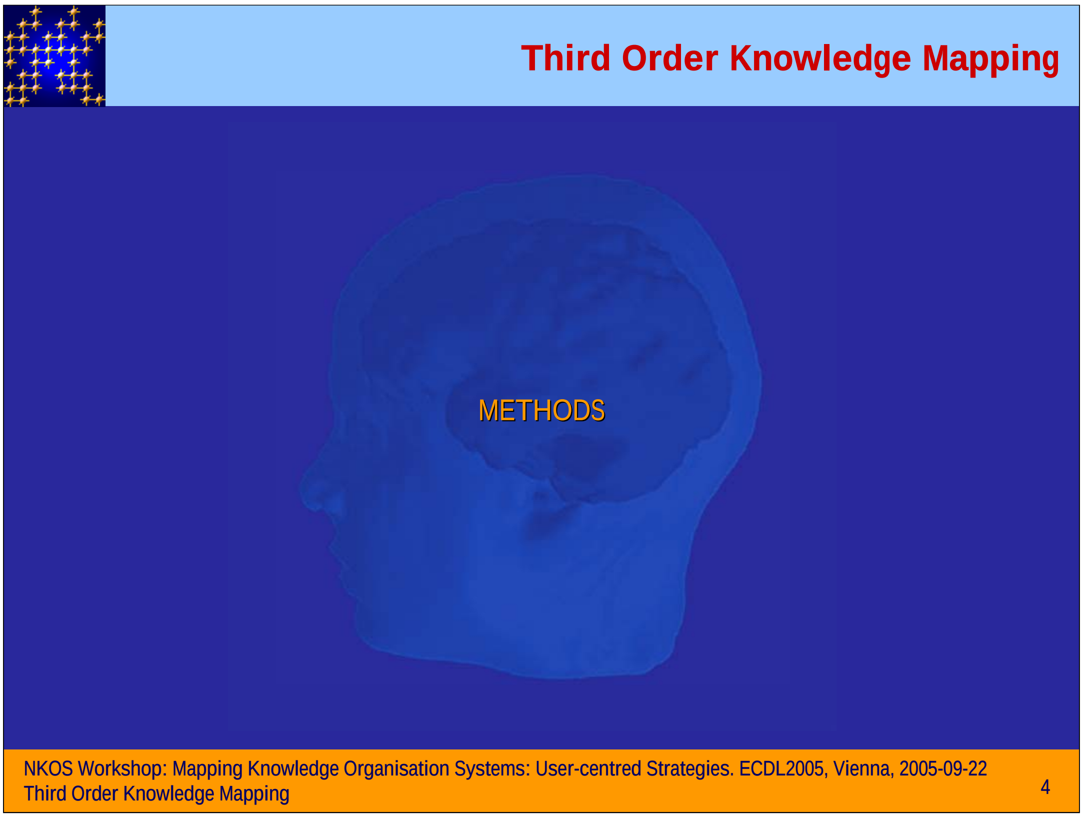
We modelled the first question like this: a ROLE *performs* an ACTIVITY, which *requires* COMPETENCE.

We modelled the second question as: COMPETENCE *comprises* a mixture of SKILLS, KNOWLEDGE, EXPERIENCE and BEHAVIOURS, which are *acquired through* TRAINING AND MENTORING AND EXPERIENCE and thereby *transferred to* a PERSON who is *assigned to* the ROLE.

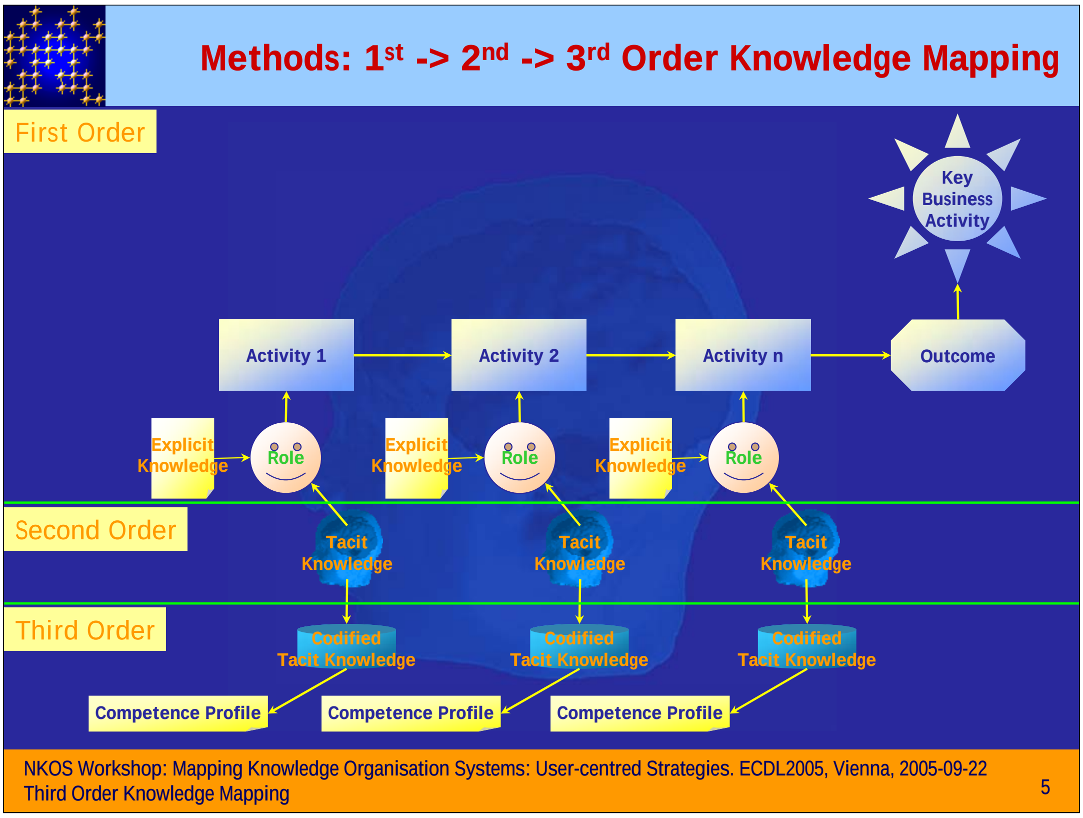


The deliverables for the Client were...

We selected a specific domain for investigation - Track Engineering – and focused on the knowledge required to operate a specific set of processes in that domain: those concerned with enabling London Underground to assure the regulating authorities that the Track was being maintained in a safe condition.



Although we had developed a set of techniques in the 1990s for mapping Knowledge, Information and Skill onto business processes, we knew that this project demanded a greater level of detail.

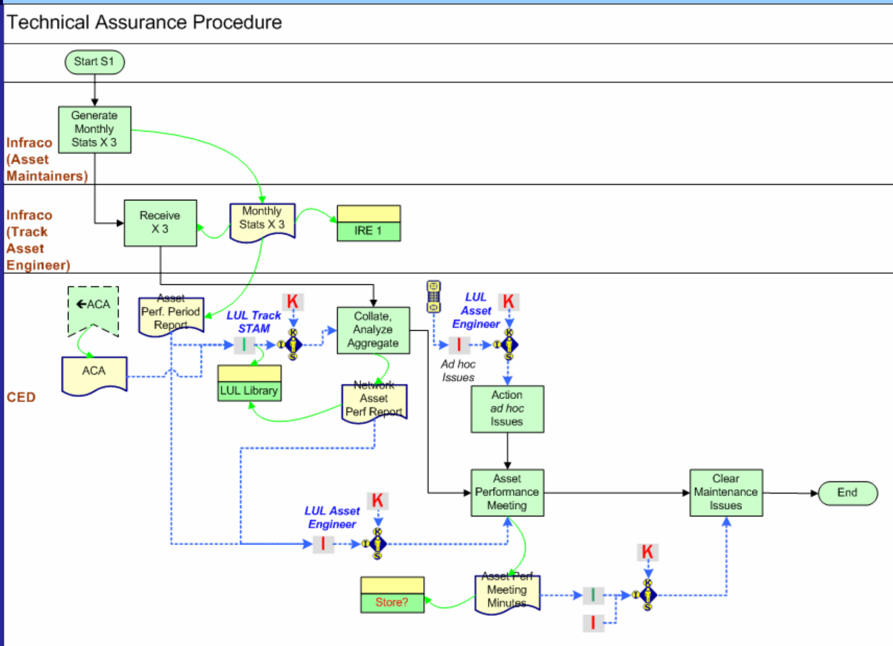


Our FIRST ORDER Knowledge Mapping first modelled a business process, then defined the ROLES performing each ACTIVITY, and finally defined the EXPLICIT KNOWLEDGE – information – required as an input to each ACTIVITY.

Our SECOND ORDER Knowledge Mapping then added to the map, high-level indicators of the TACIT KNOWLEDGE required by each ROLE.

Our first task therefore was to extend our Knowledge Mapping techniques to a Third Order to codify that TACIT KNOWLEDGE in more detail and to aggregate it into COMPETENCE PROFILES for each ACTIVITY.

Methods: First Order Knowledge Map



NKOS Workshop: Mapping Knowledge Organisation Systems: User-centred Strategies. ECDL2005, Vienna, 2005-09-22
Third Order Knowledge Mapping 6

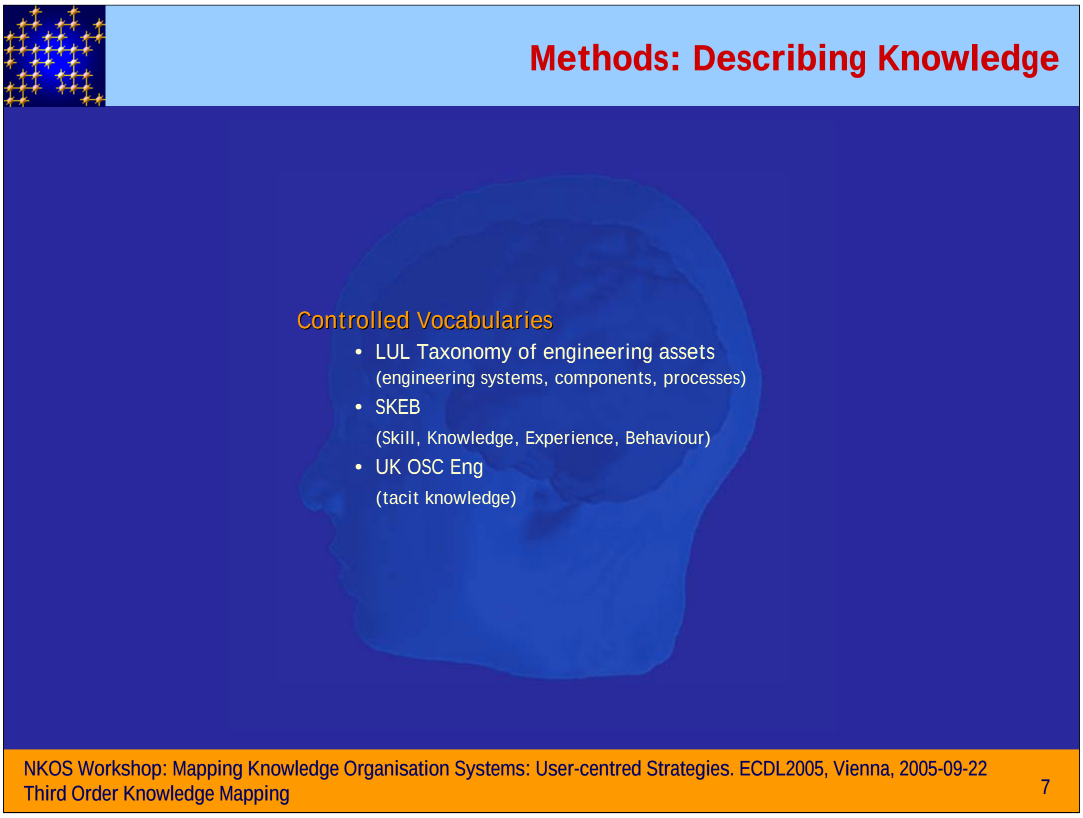
This is an example of what our FIRST ORDER Knowledge Maps looked like, showing the explicit knowledge flows and ROLES involved in each activity of a process.

SECOND ORDER maps were then developed to include a high-level synoptic characterization of the TACIT KNOWLEDGE required by each ROLE.

In order to provide the greater level of detail required, we adopted a number of formal Knowledge Elicitation techniques used in Knowledge Engineering, such as Card Sorting, The Repertory Grid and Laddering.

These gave us enough detail to be able to generate THIRD ORDER knowledge maps showing the competence profiles required by each role.

This then led us to start thinking about the vocabularies we were going to use to DESCRIBE the COMPETENCE PROFILES.



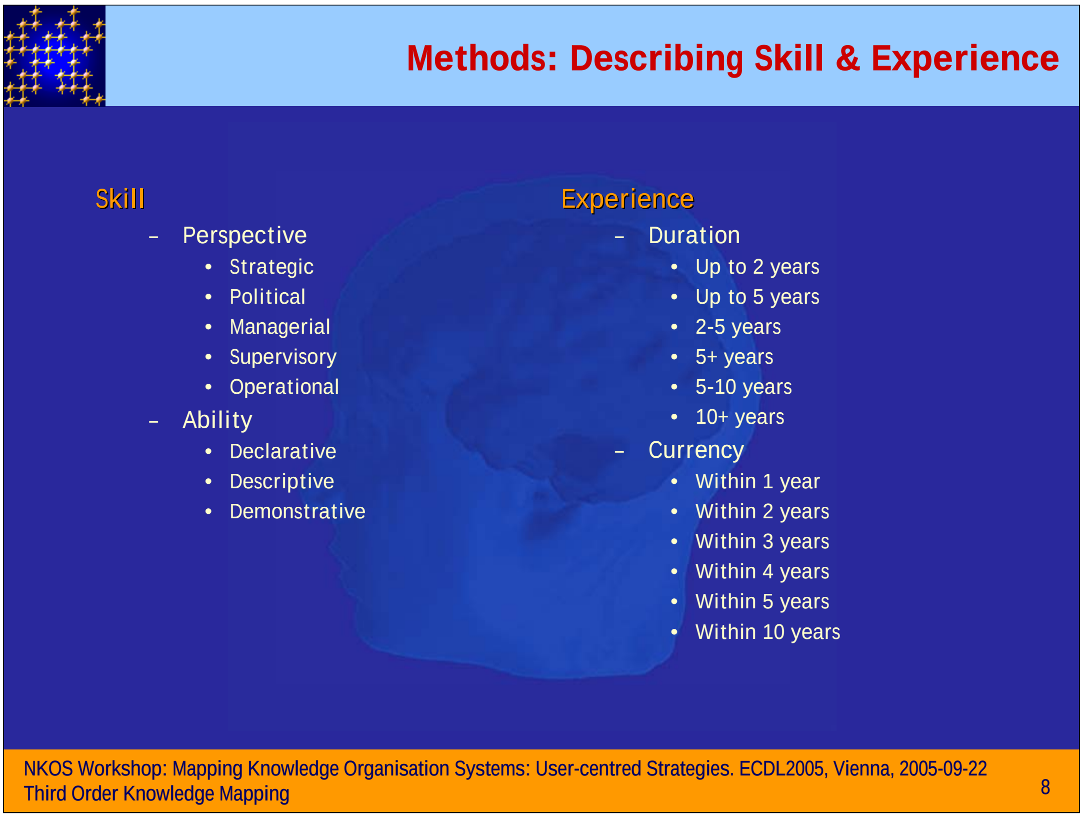
London Underground already had a taxonomy of its engineering assets, so we adopted that for describing engineering systems, components and processes.

For defining competence, we adopted the framework already in use in the company – Skills, Knowledge, Experience, Behaviour (SKEB).

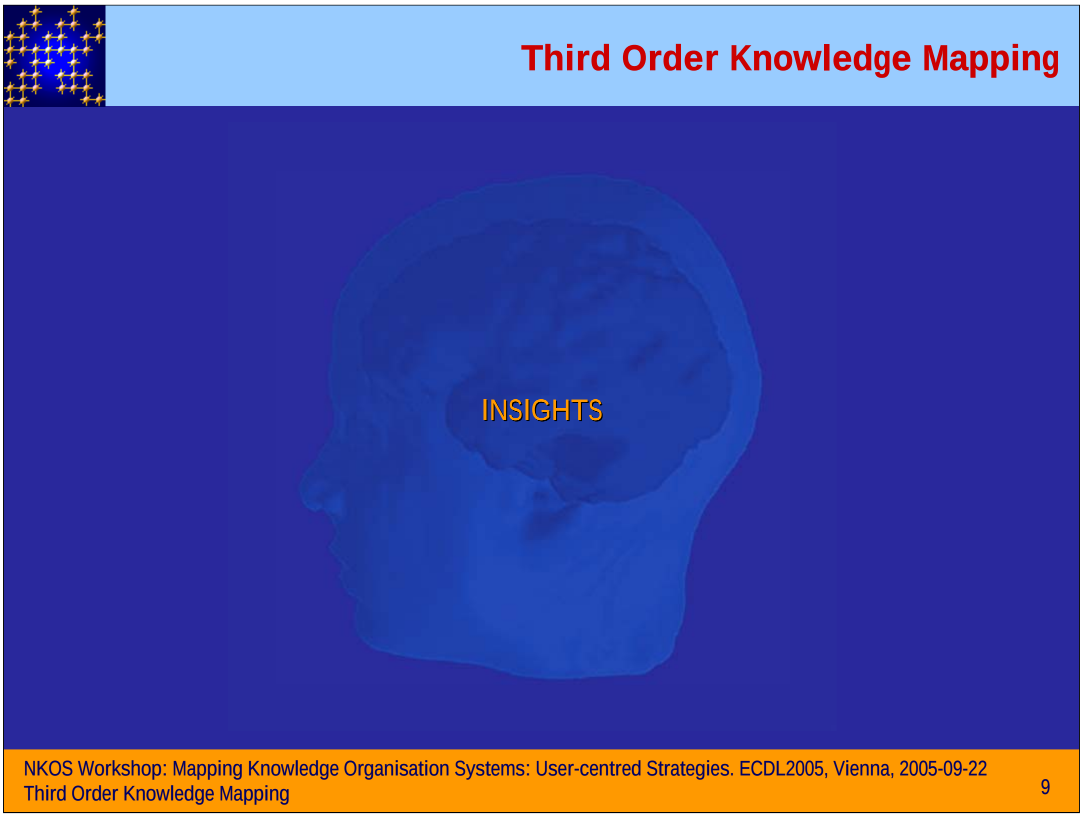
For describing TACIT KNOWLEDGE, we chose the UK Occupational Standards Council's Higher Level Standards for Engineering (*OSC Eng*), which were also already in use in London Underground.

However, the *Knowledge* specified in the OSC Engineering standards is not the same as *competence* in applying that Knowledge.

We recognized that competence depends upon a number of other factors, like SKILL and EXPERIENCE.

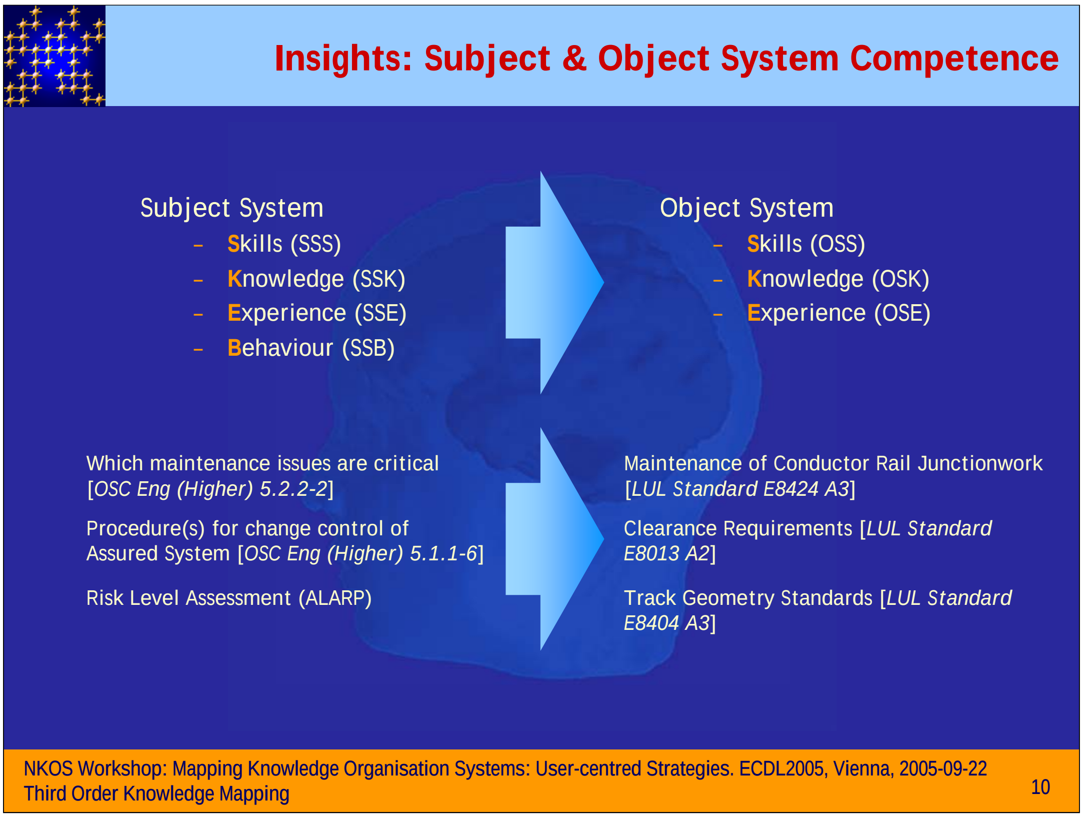


We therefore found it necessary to extend the codification of elements of Knowledge by defining extensive and intensive dimensions for SKILL – Perspective and Ability – and for EXPERIENCE – Duration and Currency - and providing each facet with a finite range of values.



The project produced a number of interesting insights.

For instance, analysis of the OSC Eng standards shows that they comprise a mix of competences from two distinct domains, management and engineering, where the first acts upon the second.



We decided to call these ‘Subject System Knowledge (SSK)’ and ‘Object System Knowledge (OSK)’ respectively, with equivalent terminology for Skill and Experience.

So, in performing an ACTIVITY for assuring the technical condition of Track, the ROLE needs to have certain COMPETENCE in the SUBJECT SYSTEM, which he/she can then apply to their competence in the OBJECT SYSTEM.

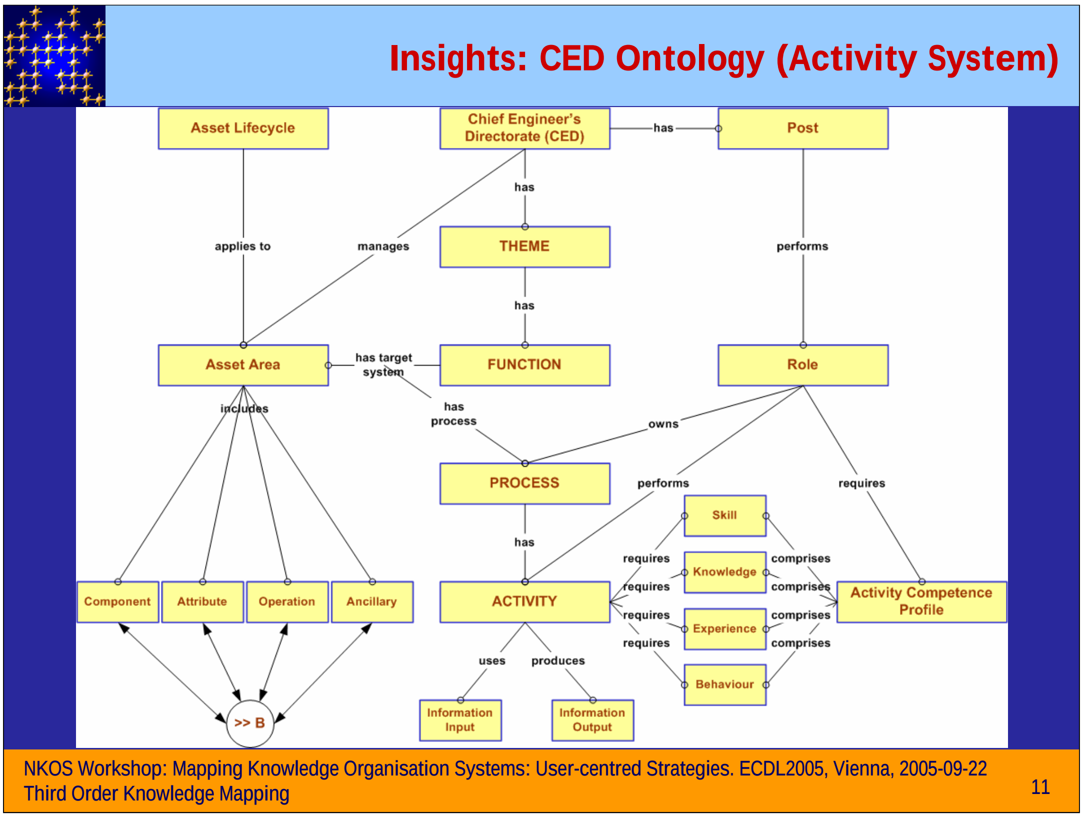
For example, the Assurance Engineer needs to know *Which maintenance issues are critical* – SSK – before she/he can assess whether *Conductor Rail Junctionwork* is being maintained in accordance with the London Underground standard - OSK.

At this point, we realized that we needed an enterprise ontology to represent the increasingly complex relationships we were uncovering.

We prepared this in two parts.

The first part represented the ACTIVITY SYSTEM and showed how any one ACTIVITY required a certain COMPETENCE PROFILE to perform it.

The second part represented the COMPETENCE PROFILE itself and showed the relationships among the SUBJECT and OBJECT SYSTEM competence elements and how they acted upon the engineering systems.



The purpose of the Chief Engineer's Directorate is to *manage* an engineering ASSET AREA – such as Track – to maintain it in acceptable condition throughout its ASSET LIFECYCLE.

Engineering ASSET AREAS of course, are compound entities, comprising assemblies, components and sub-components.

Each of these exhibits certain ATTRIBUTES…

…each has certain OPERATIONS performed upon them to maintain their condition…

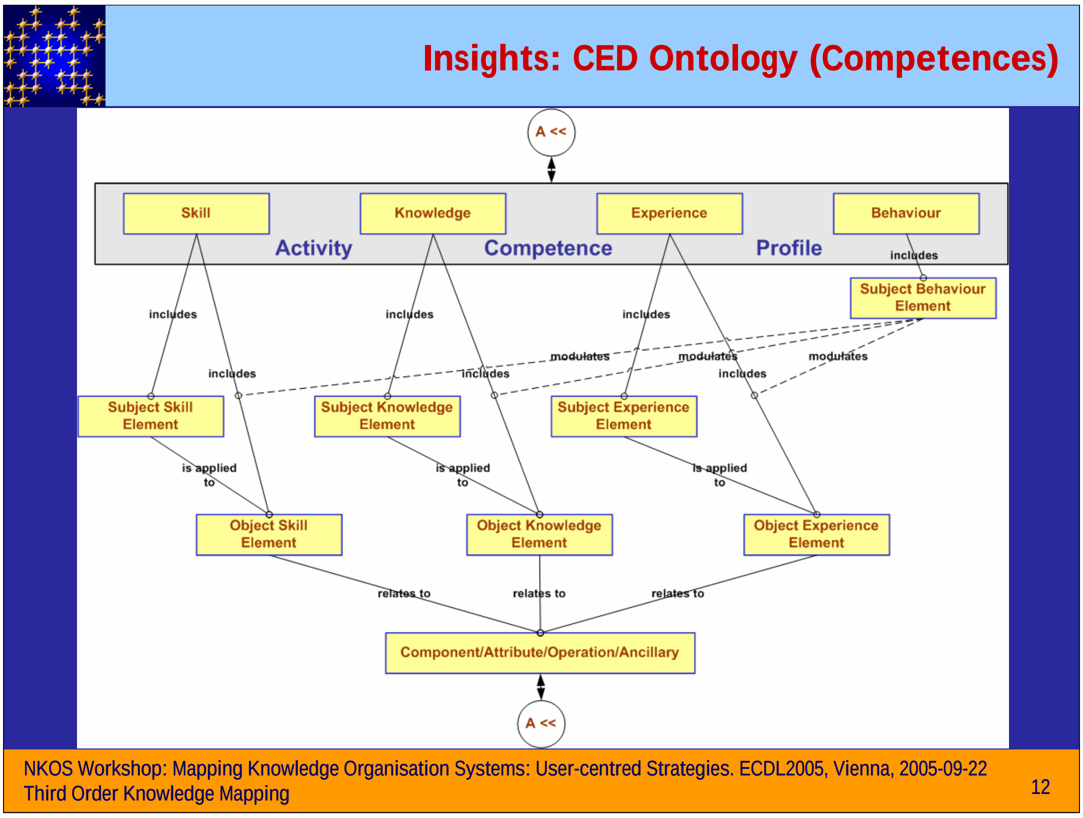
…and each can involve other entities – ANCILLARIES – associated with either the COMPONENT, the OPERATION or both.

The ACTIVITY SYSTEM itself which the Chief Engineer's Directorate uses to *manage* its engineering ASSET AREAS, was codified into a four-level hierarchy:

THEME > PROCESS > FUNCTION > ACTIVITY

ACTIVITIES *use* INFORMATION INPUTS, may *produce* INFORMATION OUTPUTS, and of course *require* SKILL, KNOWLEDGE, EXPERIENCE and BEHAVIOUR, which aggregate into a COMPETENCE PROFILE for that ACTIVITY.

Finally of course, ACTIVITIES don't perform themselves; they are *performed* by a ROLE, assigned to a person occupying a specific POST in the Directorate and who needs to have the *required* ACTIVITY COMPETENCE PROFILE.



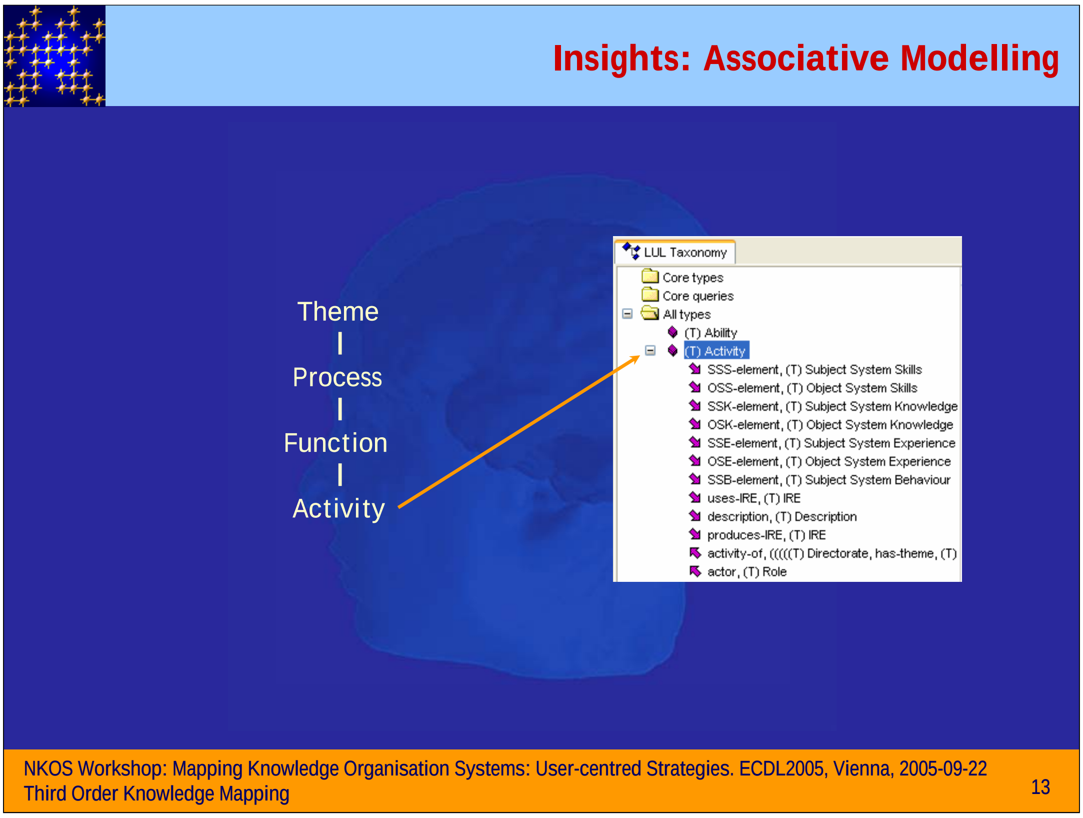
The COMPETENCES ontology shows how SKILL, KNOWLEDGE, EXPERIENCE and BEHAVIOUR each include SUBJECT and OBJECT elements.

We decided that the SUBJECT elements act *through* the OBJECT elements.

However, we suspect that in practice, that is not entirely correct and that the real picture is more complex.

Once we had completed the enterprise ontology, we realized that our conventional visual approach to Knowledge Mapping was inadequate for modelling these complex inter-relationships.

We therefore switched to using an associative database application called ‘Sentences’ to model the knowledge structure.

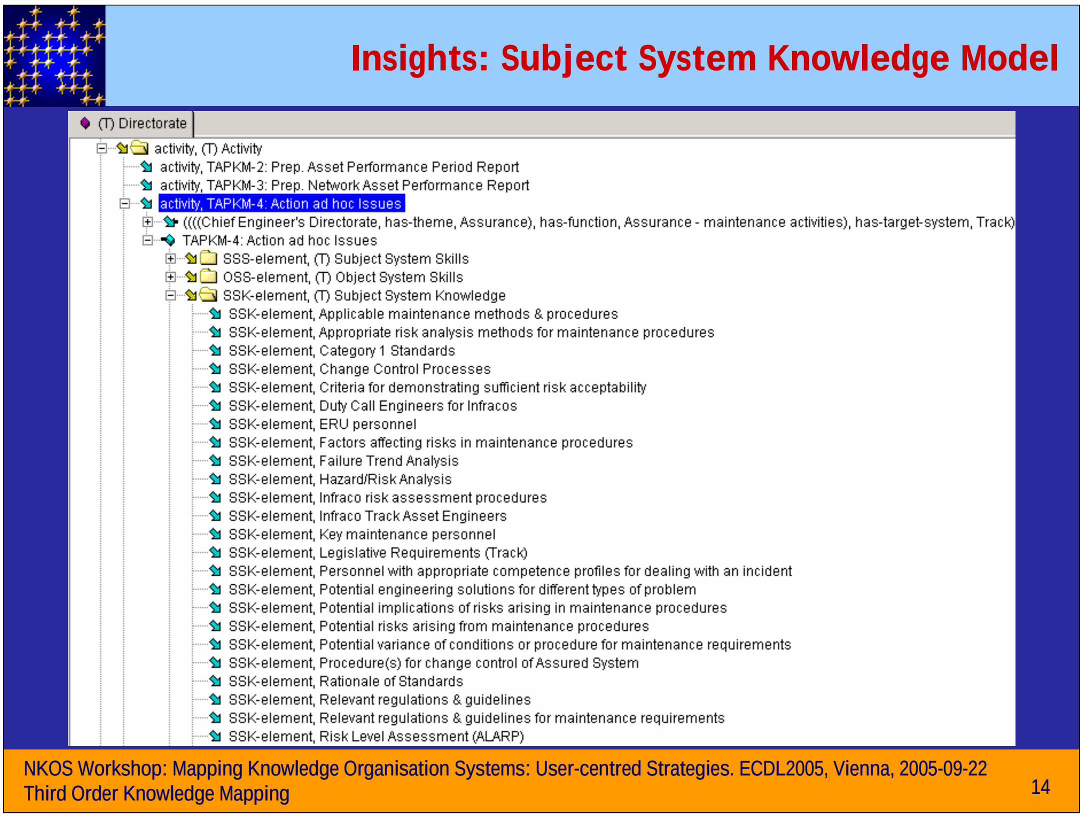


Sentences allows you to specify TYPES and SUPERTYPES of ENTITIES and the ASSOCIATIONS among those ENTITIES.

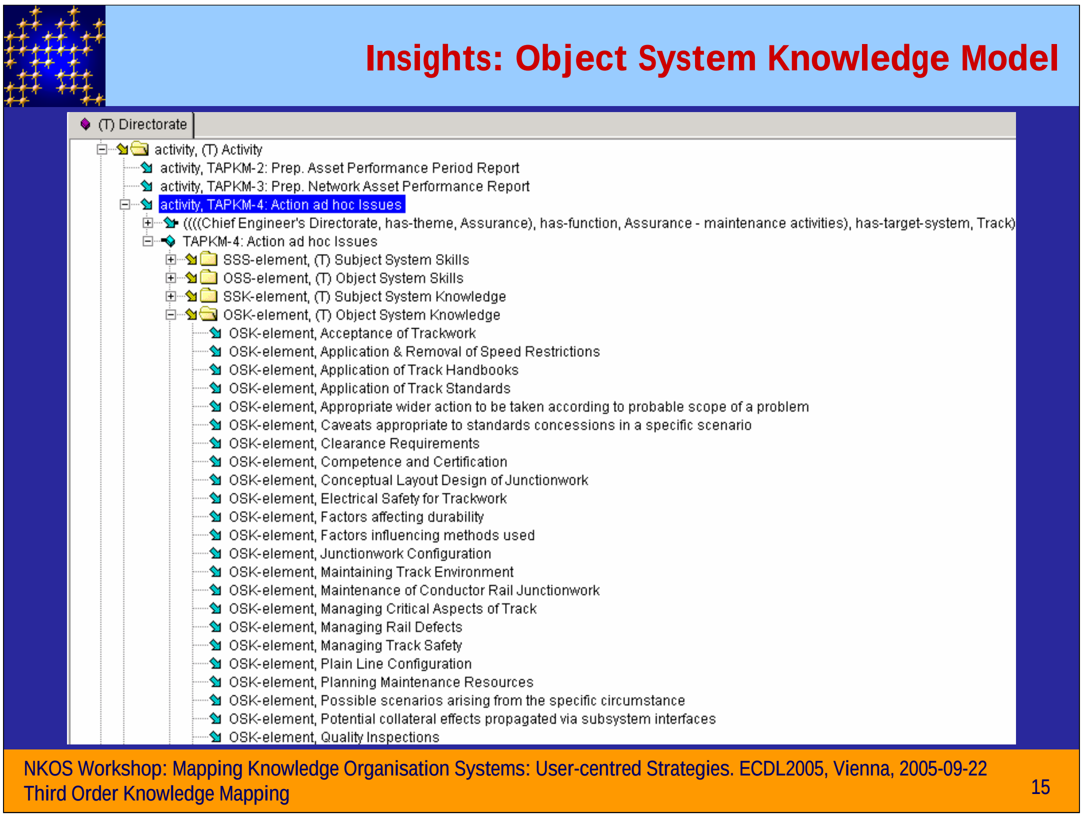
Unlike a relational database, ASSOCIATIONS are named and may be organized also in TYPES and SUPERTYPES.

Using our THEME > PROCESS > FUNCTION > ACTIVITY framework, we constructed a schema which allowed us to map onto each ACTIVITY, the SUBJECT and OBJECT competence elements, any INFORMATION INPUTS and OUTPUTS (IREs – Information Resource Entities), the Actor of the ACTIVITY - a ROLE - and a Description.

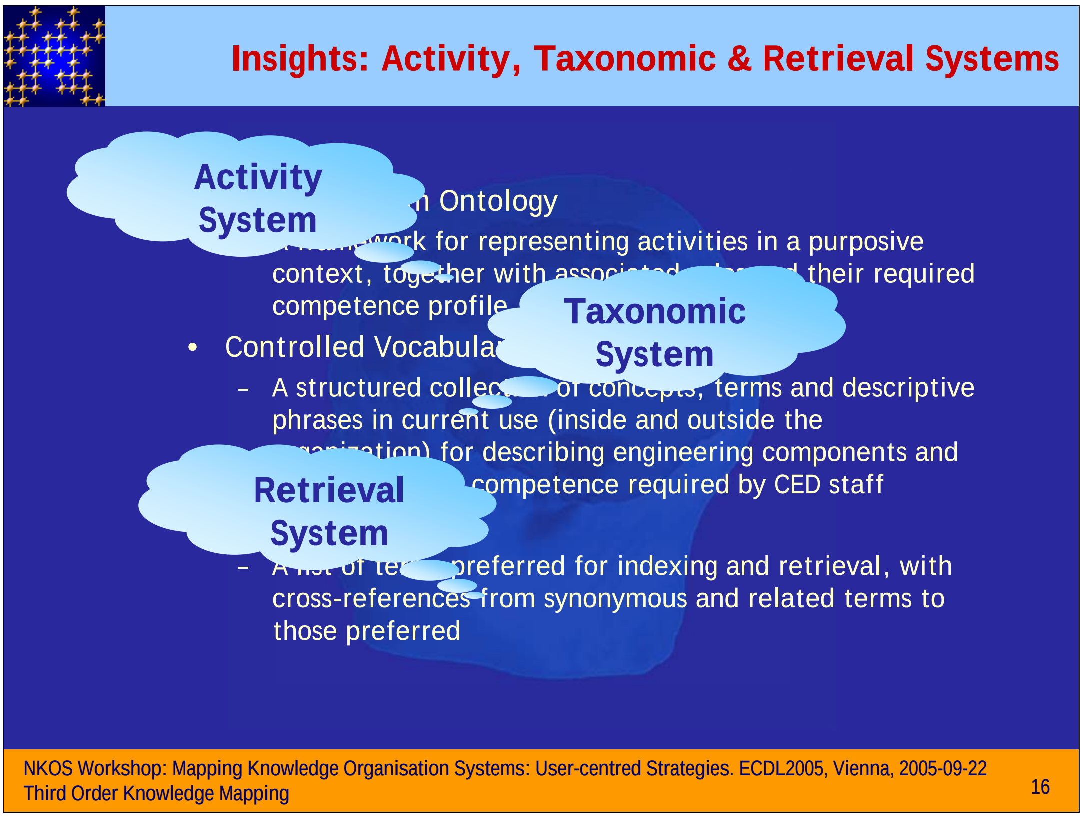
For example, for the ACTIVITY *Action ad hoc Issues*, the SUBJECT SYSTEM KNOWLEDGE elements looked like this:



And for the same ACTIVITY, the OBJECT SYSTEM KNOWLEDGE looked like this:



From the knowledge structure in Sentences, we were able to see that our final knowledge representation system would need to comprise three inter-connected systems.



Firstly, the ACTIVITY SYSTEM ONTOLOGY – THEME > PROCESS > FUNCTION > ACTIVITY – placed in a purposive context – ASSURANCE of proper maintenance – together with a representation of the associated ROLE and its required COMPETENCE PROFILE;

Secondly, a set of CONTROLLED VOCABULARIES comprising the terms and concepts currently in use for describing both engineering components and the COMPETENCE required by engineering staff;

And thirdly, a conventional Thesaurus to assist retrieval of information from the final knowledge representation system.

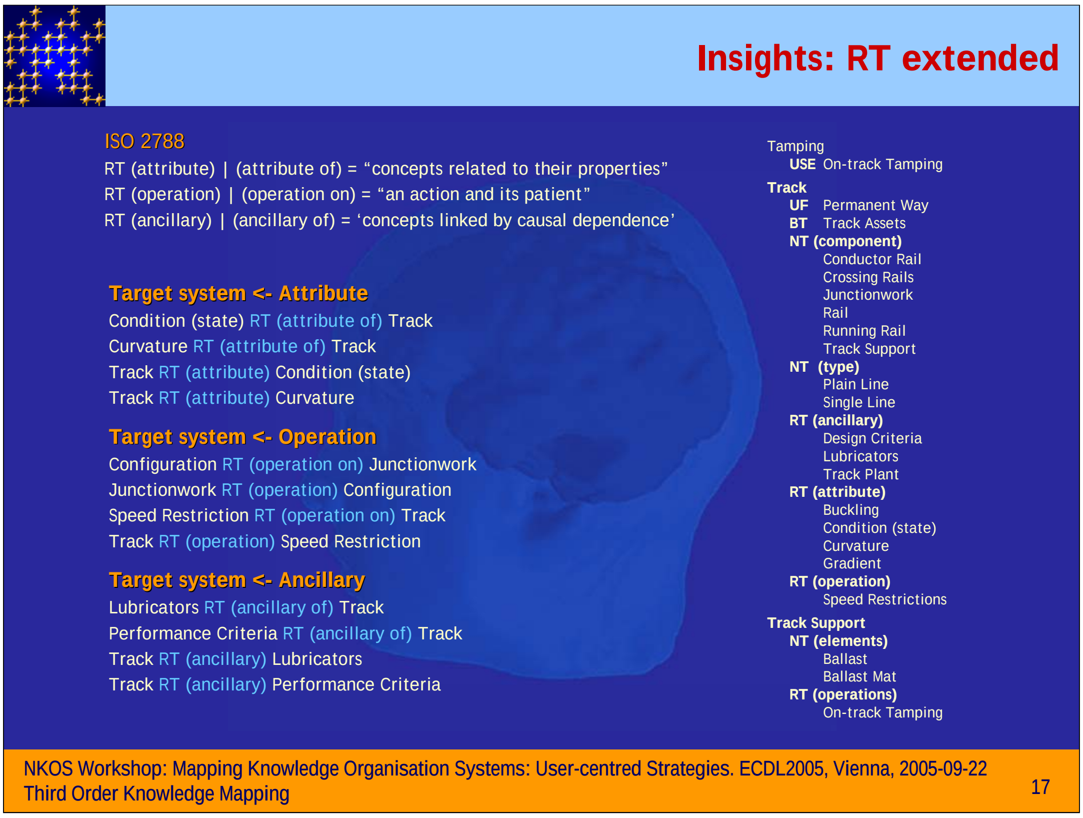
For convenience, we called these the ACTIVITY SYSTEM, the TAXONOMIC SYSTEM and the RETRIEVAL SYSTEM respectively.

In fact, the Thesaurus turned out to be not quite so conventional.

Because Sentences allowed us to *type* ASSOCIATIONS, we were able to extend the conventional uniform Related Term – RT – term relationship to provide richer semantics.

Doug Tudhope has done some work on this, and I must acknowledge that his paper in JoDI Volume 1 Issue 8 provided our inspiration.

Doug's paper notes that the ISO standard for Monolingual Thesauri – ISO 2788 – identifies scope for the extension of the RT relationship in a number of ways.



In our context, we needed to express three types of Related Term…

…RT (attribute) - the ISO standard’s “concepts related to their properties”…

…RT (operation) –“an action and its patient”

…RT (ancillary) – “concepts linked by causal dependence”

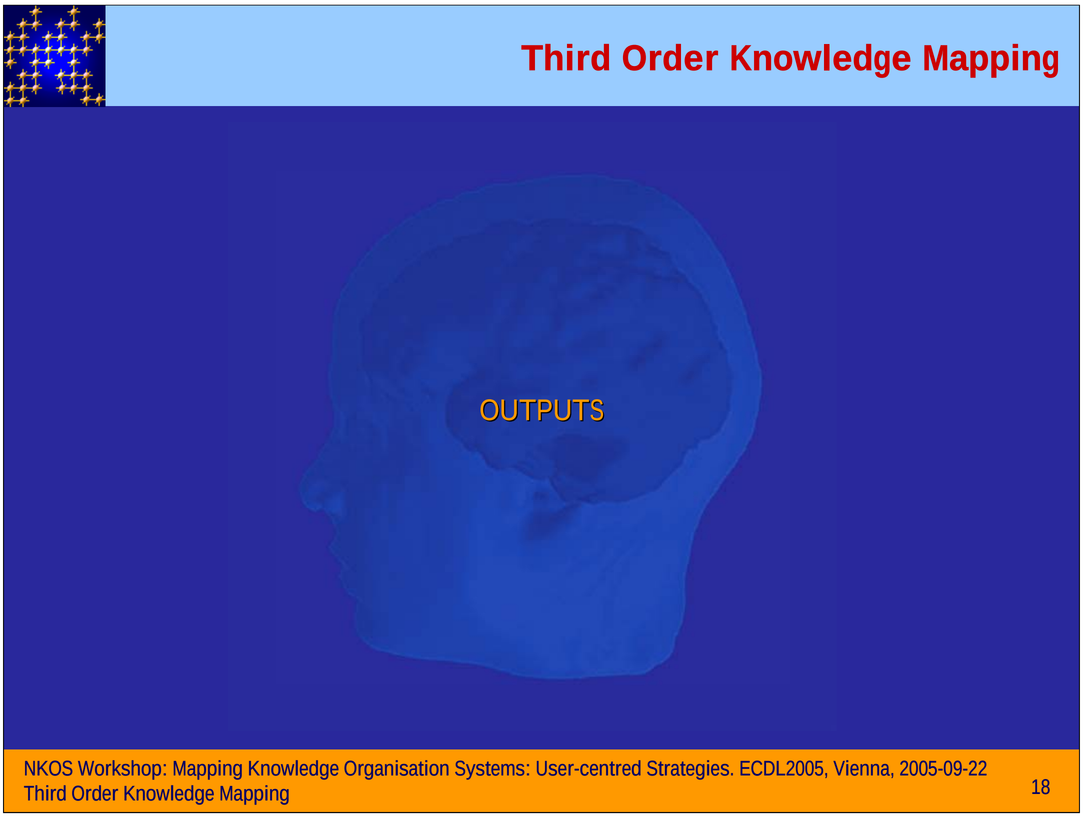
Here are some examples:

The ATTRIBUTE relationship…

The OPERATION relationship…

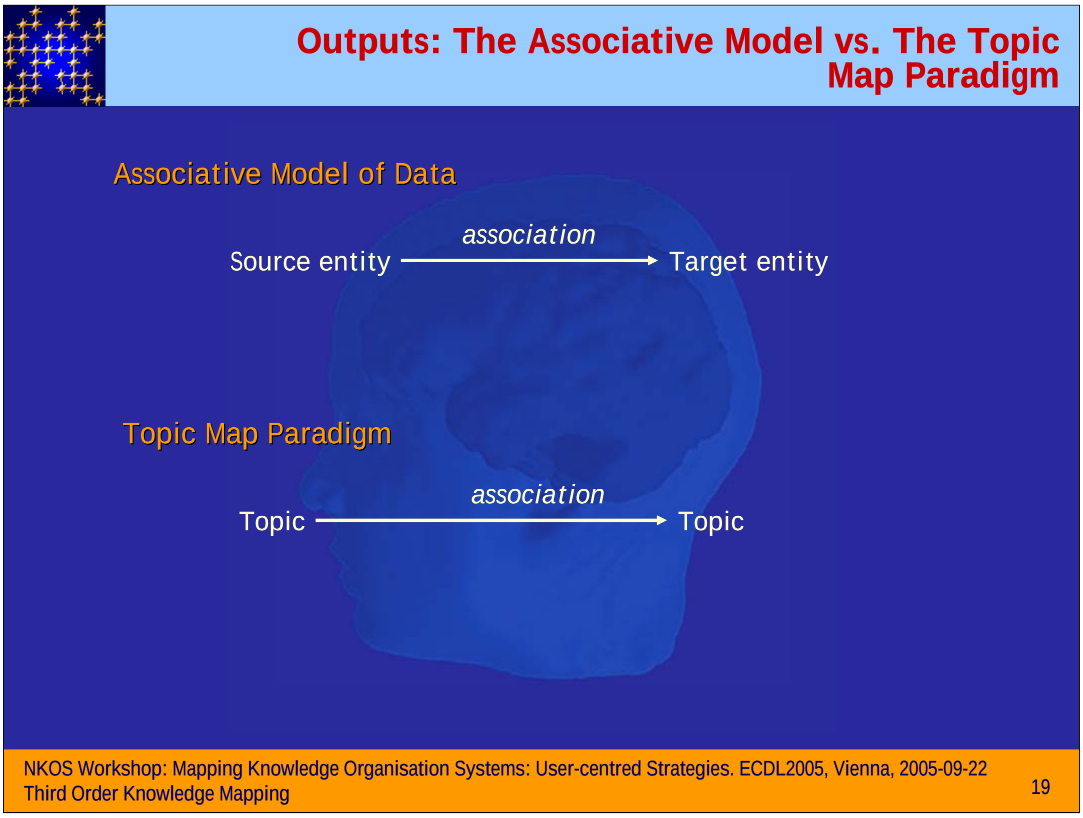
The ANCILLARY relationship…

We therefore envisaged that the eventual Thesaurus would look something like this:



Our final task was to represent this complex knowledge structure so that users could explore its complexities and gain a better understanding of the bigger picture.

We had captured this knowledge structure in a Sentences database, and in fact, it was Sentences which suggested the solution.



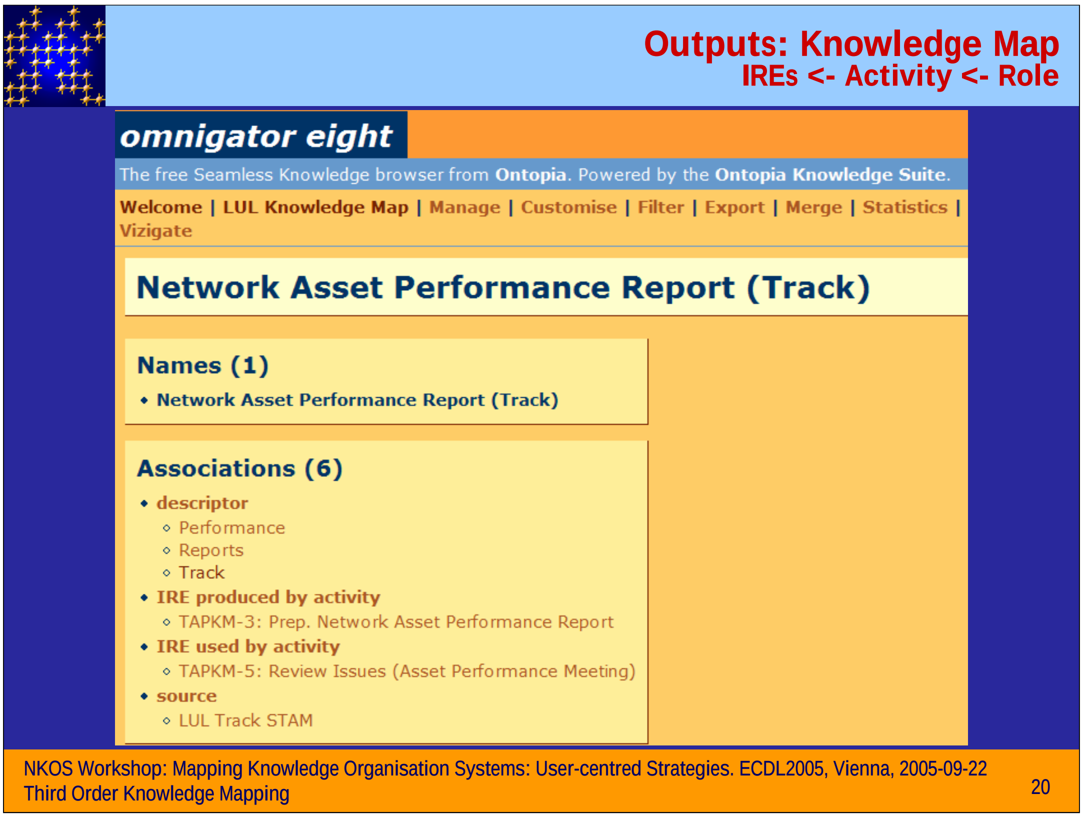
The Associative Model of Data as used in Sentences is virtually identical to the basic paradigm of XTM Topic Maps, as defined in ISO 13250, second edition, 2001.

It seemed logical therefore to use Topic Maps as the means of representing our knowledge structure.

However, at the time, there was no easy-to-use visual Topic Map editor available, so we had to resort to largely manual methods.

We built two Topic Maps: a Knowledge Map representing the Activity System; and a demonstration Thesaurus.

We used Ontopia's Omnigator to present the resulting Topic Maps.

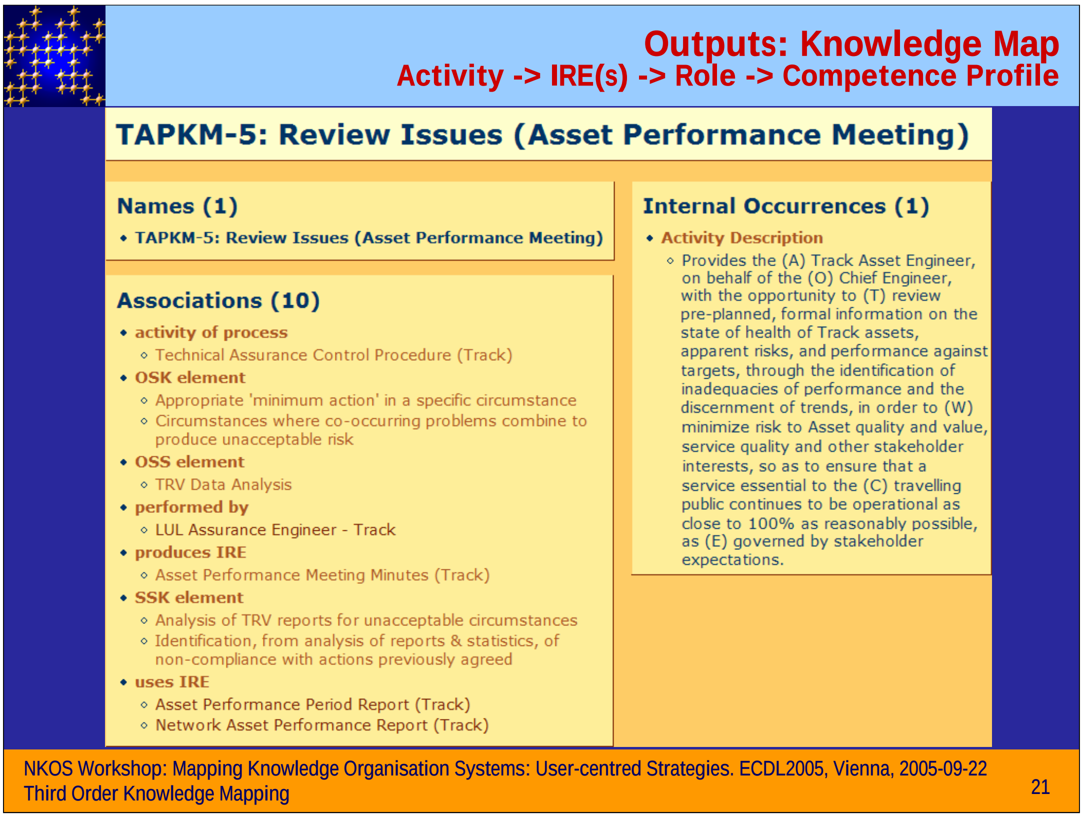


In this screen shot, you can see that we have entered the structure via an information resource entity – the *Network Asset Performance Report (Track)*.

There are six ASSOCIATIONS displayed, which include:

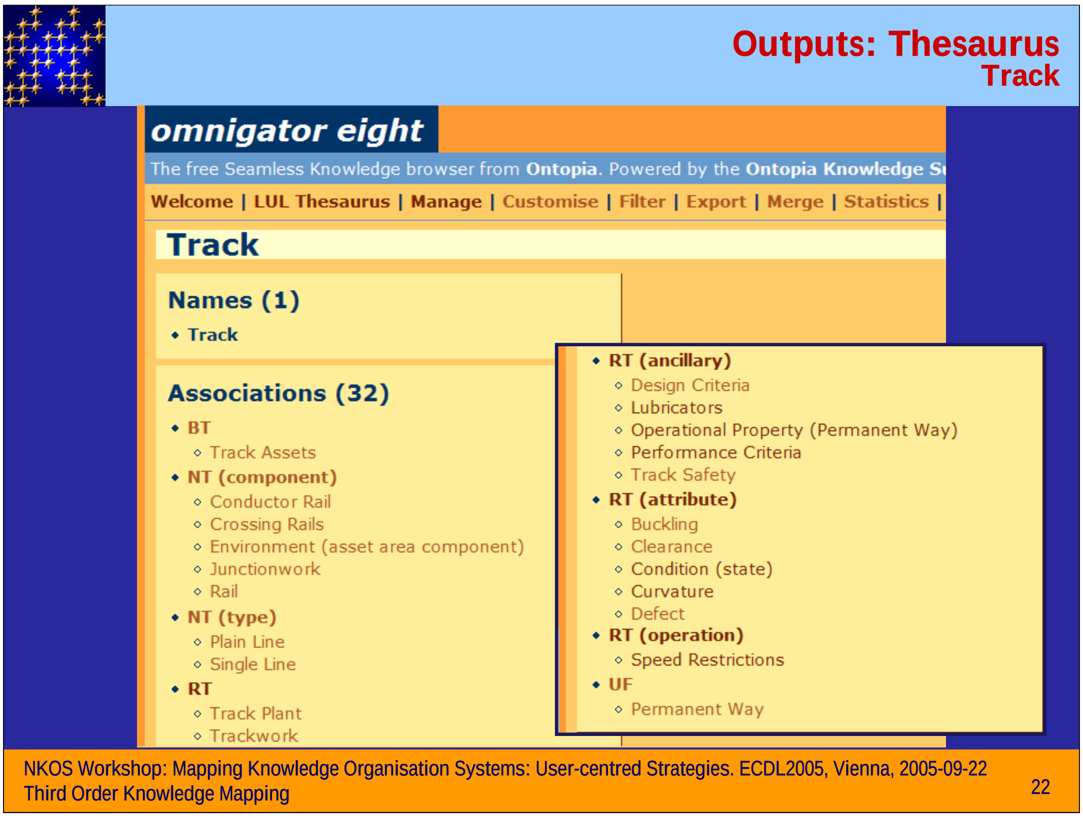
- - Subject DESCRIPTORS
- - the ACTIVITY producing the information resource entity
- - the ACTIVITY using the information resource entity
- - and the source, i.e. the ROLE, which produced it.

Alternatively, we could enter the structure via the ACTIVITY *Review Issues (Asset Performance Meeting)*, as in this screen shot.

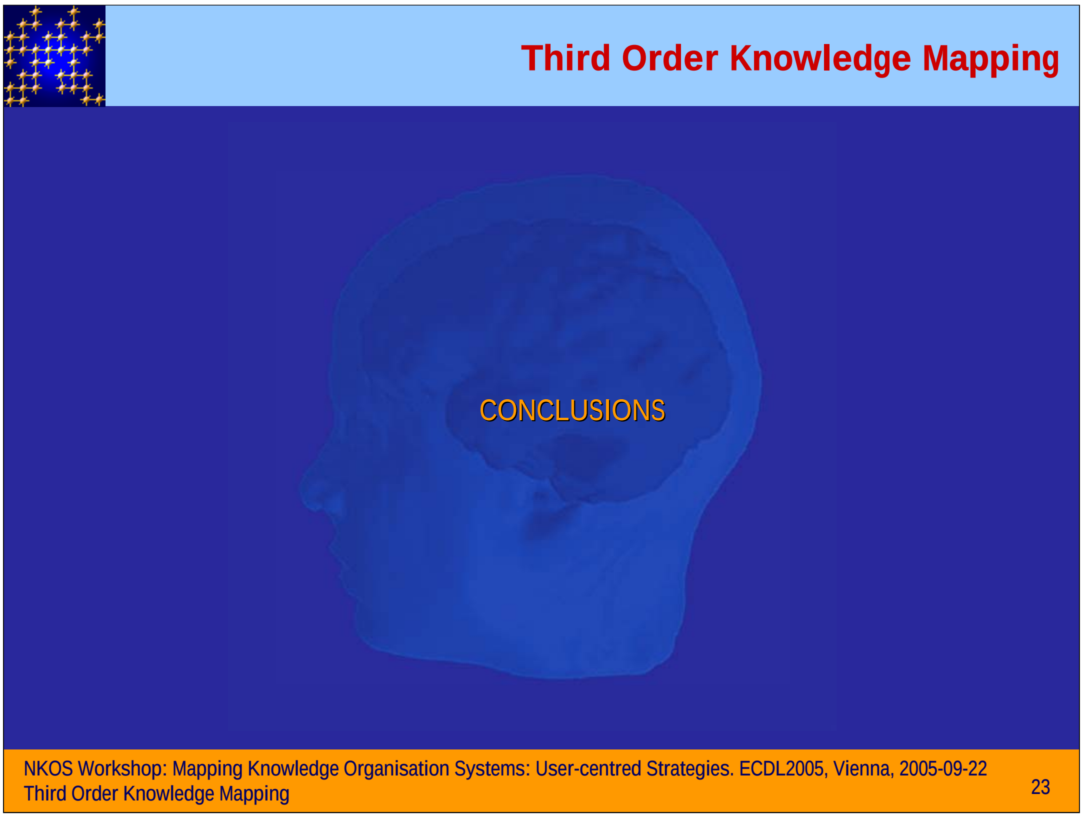


This shows 10 ASSOCIATIONS, including:

- the PROCESS of which the ACTIVITY is a part
- OBJECT SYSTEM KNOWLEDGE – OSK – and OBJECT SYSTEM SKILLS – OSS
- The ROLE performing the ACTIVITY
- the IREs produced and used
- and two elements of SUBJECT SYSTEM KNOWLEDGE



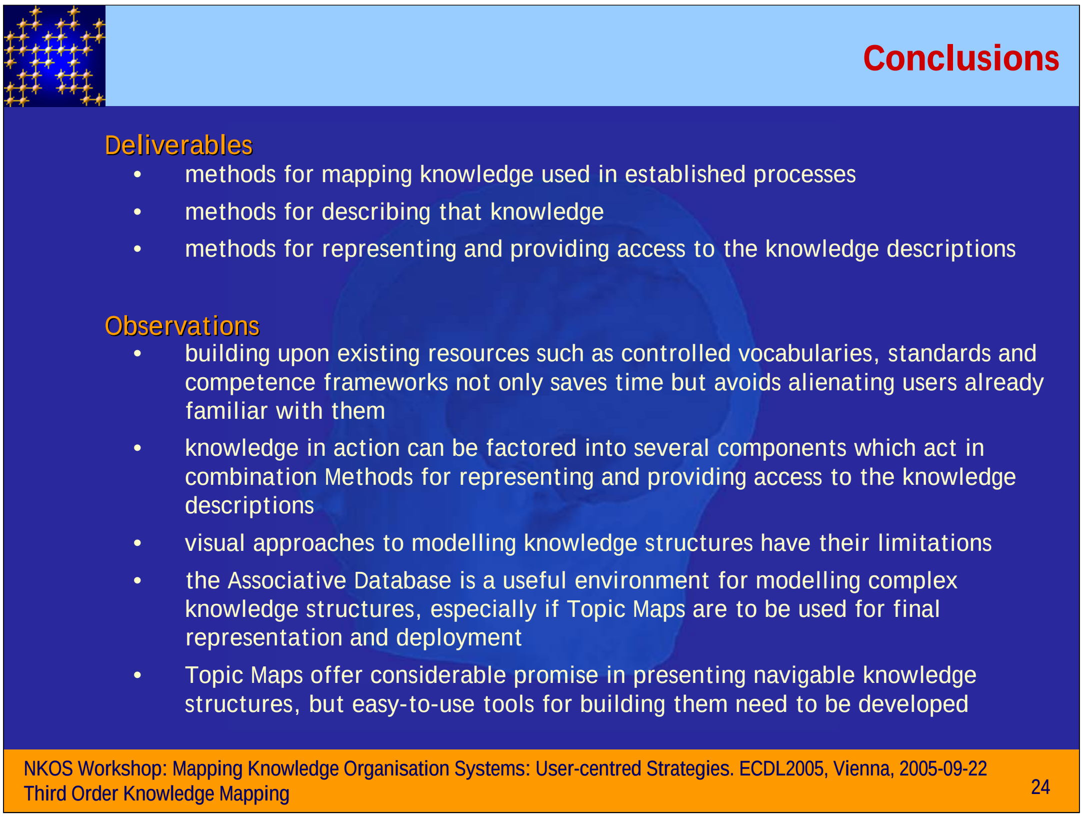
This is a screen shot of the second Topic Map – the Thesaurus - where you can see examples of the extensions we made to the RT ASSOCIATION: ANCILLARY, ATTRIBUTE and OPERATION.



We demonstrated these Topic Maps to the client and they were well-received.

We recommended they undertake a further short project to install the Topic Maps on their Intranet and to cross-link the Thesaurus to the Knowledge Map.

I regret to say that this was never done.



Nevertheless, we consider that we provided the three main deliverables for the project: proving methods for mapping, describing and representing knowledge in engineering management processes.

In addition, we made a number of useful observations:

- building upon existing resources such as controlled vocabularies, standards and competence frameworks not only saves time but avoids alienating users already familiar with them

- knowledge in action can be factored into several components which act in combination

- visual approaches to modelling knowledge structures have their limitations

- the Associative Database is a useful environment for modelling complex knowledge structures, especially if Topic Maps are to be used for final representation and deployment

- Topic Maps offer considerable promise in presenting navigable knowledge structures, but easy-to-use tools for building them need to be developed

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