Capability Modelling and Knowledge Management

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Abstract

Organisations are realising how important it is to "know who knows what" and be able to make maximum use of the knowledge. The field of knowledge management is concerned with this issue. AIAI has been involved in the area of knowledge management for some time. AIAI has also been working on ontologies and – in particular – capability ontologies in the context of workflow systems, and is now applying knowledge management techniques to make additional use of the capability ontologies in knowledge management. A software system for supporting capability management, based on a capability ontology and other, well defined specifications, can help an organisation to align the skills of current and future employees with the strategic business objectives.

1 Problem Description

In this section we outline the problem area, describing why knowledge management and in particular capability management systems are required.
Organisations are realising how important it is to "know who knows what" and be able to make maximum use of the knowledge. All too often one part of an organisation repeats work – and even mistakes – of another part, simply because they don't know who to turn to for advice. And all too often project teams are put together in an *ad hoc* fashion rather than selecting project team members effectively and efficiently based on the most suitable skills to match the project requirements. Knowledge management is concerned with this "knowing who knows what" issue. A precise definition of knowledge management is "the identification and analysis of available and required knowledge assets and knowledge asset related processes, and the subsequent planning and control of actions to develop both the assets and the processes so as to fulfil organisational objectives." [1]. This definition of knowledge management implies that it is necessary for organisations to:

- be able to identify and represent their knowledge assets;
- share and re-use these knowledge assets for differing reasons and by different users; this implies making the knowledge available where it is needed within the organisation;
- create a culture that encourages knowledge sharing and re-use.

In this paper, we focus on knowledge management through the explicit modelling and management of capabilities. Capability management is the practice of understanding the capabilities an organisation requires to fulfil its business objectives. It is concerned with identifying what skills individuals within the organisation have, and being able to compare the required expertise versus the available expertise to enable any skill gaps within the organisation to be closed. It is the alignment of current and future employees' expertise with the strategic business objectives. Organisations need staff who possess very specific skills, whether these are technical, operational or management. As the organisation develops to meet future strategic needs, these skills need to be kept track of and potential gaps identified. Specifically, organisations need to to be able to:

1. appreciate the key skills of individuals needed for its existing and future business,
2. explicitly recognise the promising skills of individuals that could be utilised for existing and future business,
3. recognise the skills that are important for survival of the business in the short and long term
4. identify individuals who have specific skills, and
5. allocate staff with appropriate skills to projects efficiently and effectively.

AIAI has been working on ontologies and – in particular – capability ontologies in the context of workflow systems [2]. The two related projects are Enterprise [3,4,5] and TBPM [6]. We are now

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applying knowledge engineering techniques to make additional use of the capability ontologies in knowledge management. In the following, we describe a capability management system which aims to address these five business needs with the help of such explicit capability modelling. The system has been implemented as a proof of concept demonstrator for a specific company which had recognised a business requirement for capability management. The is a large organisation that provides complex technical systems that include hardware and software components. However, the five business needs above are experienced by many organisations in industry, commerce, and government, especially by those who depend critically on the quality of the knowledge which those organisations apply to their key business processes. This is particularly true for organisations whose knowledge is distributed between different departments or different sites but must be amalgamated to cover business needs. For example, in industry, the supply chain depends on knowledge of diverse areas including raw materials, planning, manufacturing and distribution. Likewise, government services depend on knowledge of diverse areas including education, planning, roads and transport, social services, etc.

2 Application Description

This section discusses the requirements that the above problem results in and gives an outline of a capability management system that covers these requirements. In order to describe a capability management system, we restrict the capabilities to those of humans (also referred to as "skills"), ignoring for the moment the capabilities that software agents may have. This restriction is not a severe limitation because most of the issues and solutions discussed for skill management can be transferred to capability management in general which also covers the capabilities of software agents.

A capability management system should provide strategic and tactical decision-support and planning facilities to address the five business requirements identified in section 1. At the strategic level, the system should support the identification of skill gaps within the organisation. The system should analyse the current set of skills available and determine where skills are missing or at risk, where skills are under-utilised, and where there are opportunities for skills development. At the tactical level, the system should address matching skills to projects. Given the skill requirements of a project the system should identify the people who are best suited to work on the project either because they have skills required or they are well suited to obtain such skills. In summary, a capability management system has the potential to deliver the following benefits:

- **Skill gap analysis**, identifying skills missing or skills at risk, i.e. identifying the difference between the company skills requirement and existing staff skills and identifying key skills likely to be lost (e.g. retirement of experts);
- **Project team building analysis**: identifying staff who can cover the requirements of a project or identifying suitable staff for skill development;
- **Recruitment planning**: identifying the type of staff the organisation needs to recruit.
- **Training analysis:** identifying suitable skills for people to develop and identifying suitable projects to use for training people "on the job".

Such a system also has the potential benefit to retain key staff. Typically such people want to work in a company where project teams are chosen through objective skills analysis and because more personalised training can be provided which is well aligned with the company strategy.

Past experience shows that any established mechanisms for recording skills need to be acceptable to staff. If possible, they should be freely accessible to all staff and be relatively easily interrogated and updated by the managers that need the information. An open policy toward the information needs to be adopted. This does not necessarily mean that everyone should view each others skills and levels of attainment, but rather that staff should be able to enter their own skills information and freely view their own profiles. Accuracy of information given by staff can be achieved via peer pressure (for information visible to other staff) or via comments from managers.

Appropriate managers should have access to these decision support facilities so that they can see their skill-based risks and can plan to develop skills where they are most needed. This will allow objective planning of training budgets.

Risks in developing a capability management system arise if the system is used in ways that are different from the stated objectives. For example, the system should not be treated as a replacement for the formal appraisal process. It would be difficult to get staff to register accurately their skills and levels of attainment if they believed that this information would be used in promotion and salary decisions. Other problems arise through the availability of information about staff. For example, staff may be "poached" by other sections of the organisation or even external to the company. Staff may also be tempted to adjust their skill specifications to ensure they are chosen for a particular project or to ensure that they can avoid working with other individuals they do not like. Finally, there are legal issues concerned with personal data and the data protection act needs to be taken into consideration.

Finally, a capability management system is likely to be used in conjunction with other software systems, such as databases of staff details and qualifications. The capability management system should not unnecessarily duplicate such information, but should instead be integrated with the relevant existing systems to make use of the information they hold.

3 Models Required for a Capability Management System

In order to meet the above requirements of a capability management system, the following need to be characterised to a suitable level of detail:

- the existing skills of staff;
- the skills staff would like to utilise more (or perhaps less) within the organisation, i.e. the aspirations of staff;
- skills external to the organisation that it takes advantage of;
- the skills needed by projects - this can help to staff projects, but also point towards relevant skills;
- the key skills needed by the organisation - it is important to determine the set of skills required by the company to perform well within its business.

It is important that the specification of existing and required capabilities are independent of each other because it is impossible to predict the exact environment in which capabilities will come into play. When specifying capability requirements we should avoid referring directly to individuals who hold capabilities because at the actual time when these capabilities are required, the individual may not be available or a more suitable individual may have joined the organisation. Similarly, when people specify their own capabilities they should not be restricted to those capabilities that are currently required by the organisation because those may change in future; part of capability management is to identify opportunities for future developments. In order to be able to make use of such independent specifications, it is important that the specifications can be linked at a later stage. For this it is important to have an ontology of capabilities, which is a common set of well-defined terms, that is used for the specifications. Knowledge-based matching techniques can then take advantage of the knowledge contained within the capabilities ontology to determine whether and how closely independently specified capabilities match.

A capability ontology and capability models for a capability management system can be based on more general capability ontologies and capability models like the ones that were developed for adaptive workflow and other agent-based systems [6,7,8]. These are described in the next sub-section. Note that they were developed not just to cover human skills but also the capabilities of software agents. Further sub-sections below describe the extensions that are required to capture the characteristics of capabilities needed for skill management support, and additional models (and ontologies) required to capture characteristics about people, projects, and the organisation itself. These additional models currently only cover human skills, but they should be easy to extend to other capabilities.
In summary, the basic concepts relevant are:

- **capabilities** (or skills) which can be held or required
- **people** who can hold skills
- **projects** which require skills
- (the) **organisation** which has skill requirements through its business and holds skills through its staff.

3.1 Capabilities

Hierarchical representations of capabilities are useful because they take into account the natural and intuitive tendency for specifying capabilities at different levels of detail. Terms that appear lower in the hierarchy are more specific than terms higher up. However, the systematic specification of capabilities in a hierarchical way soon comes up against a problem of scale. Most capabilities can be classified into several higher-level ones and hierarchies become unwieldy very quickly. Analysing the characteristics of capability specifications it becomes apparent that many capability specifications can be split into two parts: the capability to do something and the things to which it can be done. For example, the capability expression “design software systems” can be split into “design” (the capability itself), and “software systems” (the area in which the “design” capability is applied). This strategy results in a representation of two hierarchies (a hierarchy of basic capabilities and an application area hierarchy) which are combined into capability specification expressions. An example of such an expression is Design(Software Systems).

The hierarchy of application areas is a large but straightforward hierarchy of “Entities”. Each area in the hierarchy has a name and a definition which ensures that the term is used consistently. Figure 1 shows an example of a high-level application area hierarchy.

- Entity
  - Project
  - Person
  - Document
    - Guide
    - Procedure
    - Standard
    - Documentation
    - Publication
  - Physical Device
  - Abstract Device
    - Software System
    - Operating System
  - Language
    - Computer Language
    - Natural Language
  - Physical Substance
  - Physical Property

Figure 1: High-level Hierarchy of Application Areas

Figure 2 shows details of the higher levels of a generally useful capabilities hierarchy. This hierarchy also references (in parentheses) application areas, expected to be found in an application area hierarchy, specifying in which area a capability can be applied. If no application area is given for a capability it can be applied in the same area as its parent capability (e.g. Testing takes its area Device from Analysis).

- Technical Capability (Entity)
  - Analysis (Device)
    - Requirements Analysis
    - Hazard Analysis
    - Quality Analysis
    - Testability Analysis
    - Testing
    - Review
    - Assessment
  - Modelling
  - Engineering
    - Design
    - Integration
    - Maintenance
    - Use
  - IT-Capability
    - Database Capability (Data)
      - Storage
        - Structured Storage
          - Hierarchical Storage
          - Relational Storage
        - Unstructured Storage
      - Retrieval
      - Search
    - Calculation
    - Simulation
  - Cognitive Capability
    - Understanding
    - Reasoning
    - Creativity
    - Knowledge
  - Authoring (Document)
  - Management (Device)
  - Development (Device)
- Physical Capability (Entity)
  - Manual Capability
    - Repair
    - Removal
    - Fitting
    - Connecting
    - Replacement
  - Sensory Capability
- Project Capability (Project)
  - Management
    - Planning
    - Organising
    - Controlling
  - Communication (Entity)
    - Request
    - Respond
    - Inform
  - Co-operation (Entity)
- Business Capability (Entity)
  - Marketing
    - Customer Liaison
  - Commercial
    - Contracts
    - Bidding
    - Commissioning
    - Procurement
  - Personnel
  - Financial

Figure 2: High-level Hierarchy of Capabilities

This capabilities hierarchy represents a capabilities ontology, i.e. an agreed set of well-defined terms relating to capabilities. There are four main types of capabilities: technical, physical, project, and business capabilities. Technical capabilities relate to specific engineering and IS techniques, methods, tools and platforms. Project and business capabilities relate to the ability to mange teams and projects and to provide business services. Technical and physical capabilities tend to be demonstrable whereas project and business capabilities are more subjective and less easy to confidently quantify competence. Capabilities may be very general, for example Design Devices, or very specific, for example Repair a specific device. The trade-off is greater decision making detail at the cost of a larger, harder to maintain capabilities register. The system needs to define capabilities at the level needed to provide the organisation with strategic and tactical decision-support facilities.

3.2 Extensions for Skills

There are several extensions to the basic capability models described above. These relate to the context in which the capability models are used, i.e. capability management. The extensions can be split into general extensions to capability specifications, extensions for specifying skills held, and extensions for specifying skill requirements.

3.2.1 General Extensions

There is additional information that should be specified for basic capabilities: application area restrictions and specificity. The application area restriction is a list of areas from the application area hierarchy which specifies to which areas the capability can be applied. For example, the capability "author" can be applied only in the "Document" area; it does not make sense to apply it, for example, to projects. The specificity states whether the capability general (e.g. project management) or specific (knowledge about a specific piece of machinery);

When capabilities are used in relation with people, projects or an organisation, further general extensions to the capability models are needed, most importantly the sub-set of application areas that the skill can be applied to in general. For the specification of skills held this states where the person can apply the skill, for skill requirements this states where a suitable person has to be able to apply the skill. Further extensions include the level of attainment that the person has achieved (or is required to have achieved) for the skill, the person's (held or required) experience in using the skill, and any relevant formal qualifications for the skill.

3.2.2 External Skills

There may be skills that an organisation decides not to cover with their existing staff. For such skills external sources are used, usually by contracting out work. Such skills should be taken into account when the organisation's skill gaps and other strategies related to skills are considered. These external skills are not linked to individual people. At best they are linked to external companies which are used to provide the skills (via sub-contracts or similar).

3.2.3 Extensions for Skills Held

Specifications of skills held are given by people when they state what skills they have and for external skills. Skills held by the organisation itself would not be specified explicitly, but rather inferred by collecting all skills held by its staff and all external skills specified. When specifying skills held, the extended capability specifications above are used with some additions. These are a rating of the person's interest in using a skill (e.g. experts may indicate that they are tired of using a specialist skill; a person may specifying the desire for career development into a new area) and a list of past or current projects on which the person has applied the skill.

The skills held within the organisation either internally by its staff or in the form of external skills available comprise the organisation's "skill base".

3.2.4 Extensions for Skill Requirements

Skill requirements can be specified for individual projects or for the overall organisation. Such skills required should be covered by available skills held by people or by external skills. When specifying skill requirements, the extended capability specifications above are used with some additions. These include the number of people required who have the skill with the given level of attainment and experience, an indication of whether this is a key skill or not, and possibly the task for which the skill is required.

3.2.5 Roles

It should be possible to specify roles which stand for combinations of skills that must be held by one person in order to fulfil requirements. Such roles would be specified using a name and a set of skills to be held by one person. Each of these skills refers to a skill requirement specification of a project or the company as described above

For specifying skills held, roles can provide a short-hand for specifying combinations of skills, but this would only add convenience. A person's skill specifications should be sufficient to determine which roles can be filled by them. However, for the specification of skill requirements roles are an important way of indicating which capabilities are required to be held by the same person. For example, a project with particular technical difficulties may require the project manager to have technical skills as well as management skills. Role requirements are specified in the same way as capability requirements, adding number, task and importance to the specification above.

3.3 Other Models

3.3.1 People

In addition to the skills they hold, there is other relevant information about the people themselves. This includes the person's name and an identifier, like a personnel number, which can be used to uniquely identify a person, and perhaps for linking to information in other systems, like a personnel database. Other useful information may include the person's position in the organisation, contact information, and current and future commitments. These last two items are likely to be held in an existing database. Such external databases could be queried separately to ascertain the relevant information or, in the future, the capability management system could be linked to them.

3.3.2 Projects

There is general information about projects that is relevant for skill management, including its name, status (in progress, not started, etc.), its importance and relevance to the company. The importance may be useful in determining strategies and priorities of project staffing, the relevance may be useful to infer a company's past and future skill demand, ranking skill requirements of projects by how relevant the projects are to the company.

3.3.3 Organisation

With respect to skill management, useful information about the organisation itself includes an indication of the amount of use a skill has had on past projects and is likely to have on future projects. There may be other useful information, like the organisational structure, but these issues are outside the scope of this paper.

4 Details of a Capability Management System

The capability management system should provide operational support at the project level and planning information at the strategic level by addressing the issues identified above as requirements: skill gap analysis, project team building analysis, recruitment planning, and training analysis. In order to address these issues it is necessary to:

1. Specify
    - ontologies (hierarchies of terms for basic skills and application areas)
    - skill base (people's skills in-house, external skills)
    - skill requirements for projects and the organisation in general.
2. Determine
    - skill gap - check whether all required skills are covered
        - for projects (identify skills that cannot be covered)
        - for the organisation (identify skills that are not covered or that are at risk)
    - people who are in a position to develop their skills for the benefit of the organisation
    - projects that could be used for skill development
    - profiles of people who should be recruited by the organisation
3. Match staff to projects

- identify people suitable for the project requirements (people who hold the required skills or are suitable to train)
- select project team from identified people.

Some details of how these can be supported are discussed below.

Matching skills against each other is important for all three areas, but particularly for the second and third. Matching two skills, there is generally one required skill (target) and one held skill (being checked). Target skills can be skills specified as requirements for projects or the organisation in general; held skills can be specified as skills of existing staff or as external skills. The held skill matches the target skill if it covers its basic capability, application areas and has the required level of competence, experience, etc. Using the ontology hierarchies, a higher-level term is taken to cover all its lower-level specifications. For example, a person with the capability "Communication (Entity)" is suitable to cover the requirement "Inform (Standard)".

4.1 Specify

Support that can be provided for users to enter the information required by the system ranges from simple input support to the use of templates for skill specifications and the overlap between person, project and company skill specifications.

4.1.1 Ontologies

Ontologies are maintained by an ontology manager who needs modelling expertise and a good understanding of the organisation's current skills ontologies. The ontology manager's task is to ensure that the ontologies cover the specifications that need to be made, i.e. that they include the terms that the users of the system need to specify skills. They also need to ensure that the ontologies remain coherent and well-defined and that backward compatibility with previous versions is considered. Finally, the ontology manager must ensure that all users of the system share a common understanding of what the terms provided mean.

The basic support required for ontology specifications is a hierarchical editor which allows the ontology manager to add terms at the proper level in the existing hierarchy, specifying multiple parents where necessary, and to add a definition to the term which specifies how it is to be used. For specifying the basic skill ontology, it must also be possible to specify the application areas that each skill can be applied to. A simple editor for basic skills is shown in Figure 3.

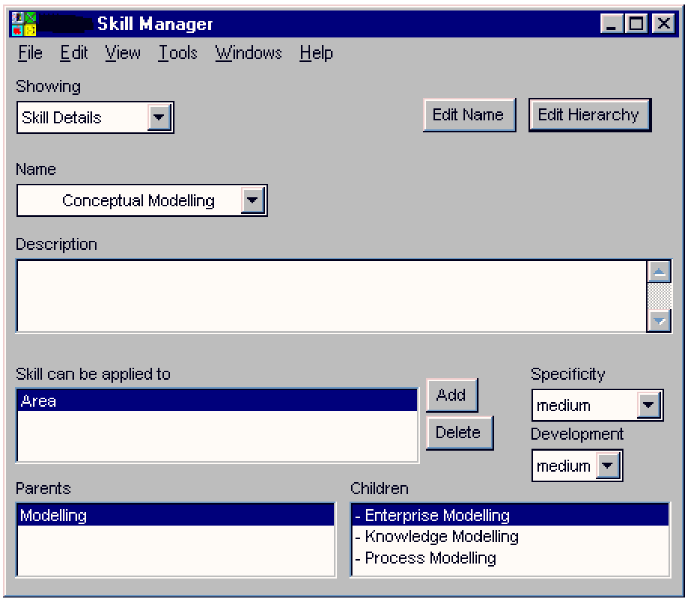

Figure 3: Simple editor for basic skills

Further support for the ontology manager can be provided by collecting requests for ontology alterations from the users of the system which can then be integrated into the existing ontology.

4.1.2 Person Profile

For a capability management system to be accepted, it must be easy for a person to specify and update their own skills in a way that makes it possible to use them for the analyses outlined above. The following support can be provided for a person specifying their own skills:

- The skills ontology together with its application areas provide good support for ensuring that specifications given by the person about their skills can be related to specifications of skill requirements.
- The hierarchical nature of the ontologies allows users to specify their skills at a level of detail that is most suitable to their skill profile - specifying a skill at a high level of abstraction is a short-hand for specifying all the more detailed skills below the high-level one.
- It may be possible to pre-specify common roles so that they can be referred to by name rather than having to specify skill combinations from scratch.
- It may be possible to provide templates as a starting point. Such templates could relate to roles, typical types of employees, or similar.

Figure 4 shows a simple editor for specifying person profiles.

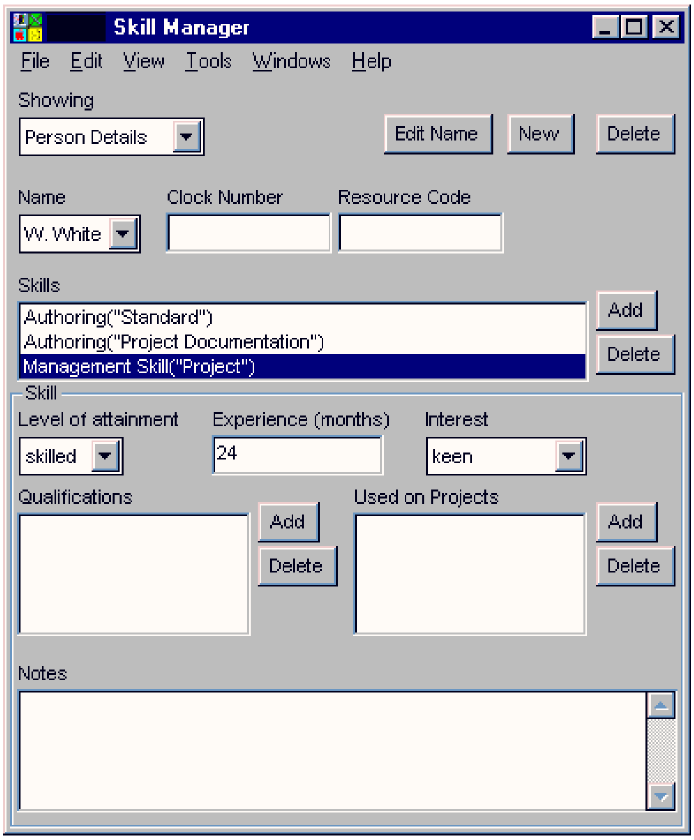

Figure 4: Simple editor for person profiles

4.1.3 Project Profile

Project details should be specified by a project-level manager, possibly with the help of managers of relevant technical areas. All of the support suitable for person profiles is directly suitable for supporting the specification of project profiles. In addition, the following support can be provided:

- There may be typical types of projects which can be described and provided as project templates. These can be used as starting points for project profiles.
- It may be useful to let users copy other projects to use as a starting point.
- In many cases the person specifying project requirements will have a suitable individual in mind. While we do not want to allow individuals to be linked directly (see model section above), we should take advantage of this by allowing requirements to be specified by referring to specific people. For example, specifying project requirements a short-hand

would be to say “we need somebody like Bob”. The system can then offer Bob’s set of skills to let the user identify which of the skills are relevant to specify the relevant skill requirements. Staffing the project the system would then find Bob (because he matches the specifications) but it may also find other people who share Bob’s relevant skills.

4.1.4 *Company Profile*

Company details should be specified by a strategy-level manager. As for project profiles the ontology related support for person profiles is directly relevant here. In addition, some of the support related to the skill requirements of the project profile applies here (support through roles and referring to people). Further support can be provided:

- Information about projects can be used as a starting point for company requirements. Details about the project such as its status (past, current, future) and its relevance should be taken into account as well as its skill requirements and their relative importance.
- It may be possible to use templates and specifications of typical or common roles and projects to inform the specification of the company profile.

4.2 Determine

Given the relevant information through specifications, the system can help to determine skill gaps and how to deal with them.

4.2.1 *Skill Gap*

For skill requirements of specific projects and the overall organisation there are different scenarios in which a required skill is not covered:

- the skill is not available at all
- the skill is not available in enough numbers (very similar to the previous reason)
- the skill is not available to a suitable level of attainment or experience
- the skill cannot be applied to the right application area
- the skill is available but there is no interest in applying it (skill holder wants to avoid using the skill).

Having identified a skill gap, a natural next step is to try and close it. This can be done by identifying skill development opportunities, by recruiting new staff or by relying more heavily on skills external to the company.

4.2.2 *People for skills development*

People should be identified who can be trained for a required skill in order to close a skill gap that has been recognised. A person is suitable for skill development if:

- the person has relevant existing skills, where relevant skills are ones that are
    - close in the hierarchy of skills
    - before the skill in a progression relationship, e.g. implementation is suitable for progression to system design
- the person has expressed interest in the skill
- the person has the required skill but not a sufficiently high level of attainment
- the person has the required skill but in a different application area
- the person has most other skills for a specified role.

4.2.3 *Projects for skills development*

Having identified training requirements for an individual person or for the company as a whole, it is feasible to identify projects that can be used to support the training requirements. For example, the individual to be trained can be assigned to a project that requires the skill even though the individual does not have the skill to a sufficient level of attainment, thus using the project for on-the-job training. Whether or not a project is suitable for this depends on the following:

- how well does the skill the project requires match the skill to be developed (basic skill and application area)? The closer the match the better the project;

- how big is the gap between the level of attainment (or experience) required by the project compared to that of the person to be trained? Ideally the required one should not be much higher than the available one;
- who else is working on the project?
- Ideally there is another person with a sufficient level of attainment for the relevant skill working on the same project so that the trainee can watch this skilled person or get feed-back from them;
- There should not be too many other trainees on one project;
- how important is the project? Projects of critical importance should probably not be used for training.

4.2.4 Recruitment profiles

Through the system it should be possible to list the skills that are required by the company but are missing or at risk. Such a list can be used to guide the company's recruitment efforts.

4.3 Match staff to projects

There are two stages to matching staff to projects: identifying potential project team members (identify options for staffing the project) and actually selecting a project team.

4.3.1 Identify people for projects

For a given set of project skill requirements people can be identified who hold the required skills or are suitable to train. The first step is to identify all people who have relevant skills and to identify the skill gap. The second step is to identify people who are suitable to train in order to close the skill gap. This process generates three lists, any of which may be empty:

1. a list of people who have relevant skills and are thus suitable for working on the project
2. a list of people who can be trained to cover those required skills that are not covered by the people in the first list
3. a list of skills required that cannot be covered by the people in the first list, and for which no suitable people can be found for training.

4.3.2 Select project team

It is difficult to envisage how fully automated selection of a project team can effectively support the staffing of projects. Even if all relevant criteria could be used by the system, which is doubtful, the number of possible permutations would make it difficult for the user to understand what the system does and which option should be chosen. However, working in an interactive way a capability management system is well placed to assist a project-level manager in selecting a project team. The support outlined for identifying people for projects is, of course, the first stage. In addition, the following support can be provided:

- the people identified as suitable can be listed for selection by the user. Once a user has selected one or more people for the project team, the system can help to identify the people who can cover skills that are not covered by that initial team;
- the user can rule out people from the project team (e.g. because they are known to be unavailable); the system would identify suitable people (including training) without considering the people that were ruled out;
- the people identified as suitable can be ranked according to different criteria, e.g.
    - how closely they match the requirements
    - how well they complement the team
    - how difficult it is to assign them to projects (demand on experts, etc.)

What kinds of visualisations and mechanisms are required for supporting the precise selection of project teams depends, for example, on how many alternative project teams there tend to be, how often the company's training needs are taken into account, how critical people's availability is, etc.

5 System Development

AIAI has implemented a prototype of a capability management system that covers most of the requirements and support outlined in this paper (details below). The system is implemented in CLIPS and runs on a PC under Windows 95.

There are two main areas of development: the specification of ontologies and other models (providing relevant information) and the implementation of support for capability management activities. The system contains some specifications which represent a simplified set of information about skills, people, projects, and the organisation. The system currently covers the following support for the activities discussed above:

1. Specify: there are editors for entering specifications for all concepts except roles and external skills.
2. Determine
    - skill gap: a version of this has been implemented for the simplified set of information on projects and the company the system currently knows about;
    - people for skill development: a version of this has been implemented for the simplified data;
    - projects for skill development: this has not been implemented; further understanding of how projects and training are managed is required
    - recruitment profiles: nothing specific has been implemented for this; further understanding is required.
3. Matching Staff to Projects:
    - identify people suitable for the project requirements (inc. training): a version of this has been implemented using the simplified data
    - select project team: this has not been implemented; further understanding of how project teams are selected within the organisation is required.

The main areas of future work are to

- add to the system to include all functionality presented in this paper;
- improve the system's user interfaces, particularly for activities 2 and 3 above;
- take the system into the real world to determine
    - how people cope with the system's requirements for specifications
    - how the system scales up (how does it behave with significant numbers of staff with many capabilities etc.)
    - what issues arise in the area of maintaining the ontologies.

However, even with the limited system that has been implemented so far, the company for which the system was developed are already recognising potential benefits that such a system can bring.

6 Conclusions

Ontologies of capabilities and their application areas provide a sound basis for specifications required for effective capability management. The ontologies can be used to support the specification of required information, ensuring the consistency between independently specified pieces of information, so that these can be related and linked to each other during the analysis and decision making phases of capability management. The greatest benefit of these techniques is likely to be in the form of a decision support tool for human users, rather than a stand-alone tool that tries to perform capability management on its own. Such a decision support system for capability management can provide a valuable contribution to the overall knowledge management of an organisation.

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References

[1] Macintosh A, Filby I and Tate A. Knowledge Asset Road Maps. In: Proceedings of the Second International Conference on Practical Aspects of Knowledge Management (PAKM98). Basel, Switzerland, 1998.

[2] Alonso G, Agrawal D, El Abbadi A, and Mohan C. Functionality and Limitations of Current Workflow Management Systems. *IEEE-Expert*, 1997.

[3] Stader J. Results of the Enterprise Project. In: Proceedings of the 16th Int. Conference of the British Computer Society Specialist Group on Expert Systems, Cambridge, UK, 1996.

[4] Stader J. An Intelligent System For Bid Management. The International Journal of Project and Business Risk Management, Vol 1, Part 3, pp 299 - 314, 1997.

[5] Uschold M et al. "The Enterprise Ontology". The Knowledge Engineering Review, Vol. 13, Uschold M and Tate A (eds.), 1998.

[6] Jarvis P, Stader J, Macintosh A, Moore J, and Chung P. What Right Do You Have to Do That? In: ICEIS - 1st International Conference on Enterprise Information Systems*;* Portugal, 1999.

[7] Wickler G, and Tate A. Capability Representations for Brokering: A Survey. Submitted to Knowledge Engineering Review, November 1999.

[8] Gil Y. http://coabs.globalinfotek.com/coabs_public/project_overview_pages/usc_isi_03.html. Work on the Phosphorus project, concerned with capability matching for agent-based systems.