Design and Prototyping of Knowledge Management Software for Aerospace Manufacturing

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ABSTRACT: At the University of the West of England we are involved in a project with Rolls-Royce Aero-Engines. This is the Design Analysis Tool for Unit-cost Modelling (DATUM) project. The aim of this project is to produce a knowledge based system which is capable of costing an aircraft engine and its' sub-components, and generating a process plan for the manufacture of the engine. From this we hope to learn how to develop a generic knowledge-based system that could be used for the manufacture of any product. We also hope to learn about the best methods for using software to share knowledge within and between organisations. We are researching how to structure this knowledge in such a way as to make it easy to retrieve both by humans and automated software. We are also examining how to visualise the results output from the software in a way which carries the meaning to the user. Our preferred method of delivery for this project is the use of open-standard Web technologies such as XML (eXtensible Markup Language). This will be used to provide a high level view of information held in distributed data sources.

Keywords – Parametric Costing, Generative Costing, Decision Support, Knowledge Management, XML

1 INTRODUCTION

1.1 *Aims*

At the University of the West of England we are working on managing knowledge within engineering organisations with the aim of using this knowledge to reduce the costs of manufacture of products. In many engineering organisations employees and departments create spreadsheet models of manufacturing information. Because this information is not held in a central repository, it is not shared and is easily lost when those employees responsible for its' upkeep leave. So it is important to create a knowledge base that can be maintained and updated easily, and is managed effectively. A knowledge-based system is the information source for our decision support systems. We are working on constructing the knowledge-based system, based on an Ontology of engineering terms. Ontologies are explained later and in (Denny, 2002). At present there is a conflict between the needs of employees to create decision support systems for analysis of effectiveness in fast changing economic conditions, and those of the IT managers who need to provide a stable centralised system. A centralised knowledge base, which links to decision support software that employees distributed around an organisation can use, solves both problems.

The intention of the Design Analysis Tool for Unit-cost Modelling (DATUM) project is to make it possible for Rolls-Royce employees, and employees of Rolls-Royce suppliers to view a knowledge representation of an engine, and of the engine components. Menus of engine components, materials, manufacturing processes etc will be created automatically from a central database(s). For each engine component a model is to be created which will give the cost of that component and may give other information such as materials, and process plan. The visualisation is via a web interface.

This should make it possible for designers to see the effect of their design changes on manufacture, and for the whole specification, design, manufacture, maintenance cycle to be managed more efficiently.

The software consists of modules that are directly related to items in a separate data source. It is important to separate the data from the software, so that this data can be easily used by any other software, which exists now, or will exist in the future. This architecture also ensures that if the data changes the models will update automatically, and models can be added just by adding to the database. For simple parametric models this works well with no requirements for software apart from browser languages. If this same methodology is to be used for more complex models a server program will be required.

Instead of relying heavily on artificial intelligence techniques such as rule-based reasoning, our intention is to use standard software, and construct the system rigorously for ease of maintenance and update. We believe software can be made to act intelligently by the use of a large number of simple modules co-operating together, each being responsible for their own data and calculations.

The aim of this project is therefore to provide network software that gives users easy access to engineering information. This can relieve bottlenecks in the flow of knowledge between individuals.

1.2 *Past Research*

We have undertaken work relating to aerospace manufacturing for Airbus, and Rolls-Royce. The University of the West of England Implied Cost Evaluation System (ICES) group have produced manufacturing decision support systems. The aims of the ICES team were outlined in (Scanlan et al. 2000). A prototype expert system shell (Marsh et al. 2000) has been created. This system (COINER) has much of the functionality required of a knowledge-based system, but is usable on a single PC only. (Bru et al. 2002) have worked on visualisation of cost information. (Hale et al. 2002) have undertaken research in evaluating Web technologies for providing a knowledge-based decision support system.

1.3 *Current Research*

It is proposed that we expand the aims of the research, which created the COINER system. This together with the visualisation research will be the basis for the Web based system currently under construction. We are looking for ways of representing the information in an open standard data source such as XML (eXtensible Mark-Up Language), and processing this information to provide a Generative Costing system. We define Generative Costing as costing based on the automated generation of a process plan.

2 BACKGROUND

The aim of the DATUM project is to provide software to allow a user to obtain the cost of a component or assembly of components at any stage in the design. As the design progresses towards production, more will be known about the product, and eventually it will be possible to create a process plan for its' manufacture. In the early stages of design it will only be possible to use parametric equations to estimate the cost. These models are based on past data and involve the use of data mining software. In the later stage of design much more is known about the final form the product will take and we can create software for this which creates a process plan and a more accurate cost. We call this Generative costing. This corresponds to the bottom two layers in the diagram below. The lowest layer involves detailed simulation of the manufacturing process flow, while the second lowest layer can be used when the detail of the process is not yet clear. So as we have more detail the software needs to intelligently use more generative costing techniques and less parametric in order to produce higher accuracy. Figure 1 shows this.

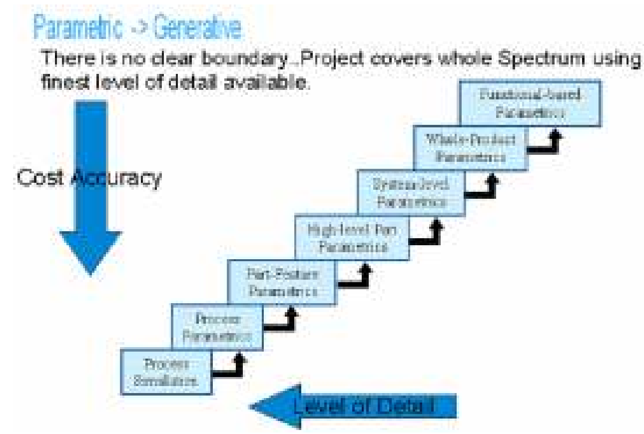

Figure 1. Parametric to Generative Costing

An example of the interface for parametric cost estimation via the Web is shown in Figure 2.

Figure 2. Parametric Cost Estimation Software

Examples of parametric cost estimation software can be found at

Engine example
http://www.cems.uwe.ac.uk/~cbru/pce.htm?id=engine

Bolt example
http://www.cems.uwe.ac.uk/~cbru/pce.htm?id=bolt

In order to create a software costing system that can judge what information to use at the current design stage it is essential that the information is well structured. A comprehensive library of information is required in order to allow us to create rules and algorithms for accessing the information required in order to create the cost estimate. Because of this problem, and the need to easily share information over a range of computers and users we have examined the creation and use of ontologies.

2.1 *Ontologies*

An Ontology is a classification structure. The basis for this is a Taxonomy, which can be a single tree for a convenient way to represent information, or part of a much more comprehensive 'thesaurus' which describes and agrees the meaning of things. This 'thesaurus' structure is the Ontology and may contain one or more taxonomies.

Engineers may have different names for the same thing, e.g. wing skin stiffeners may be referred to as stringers, but rib stiffeners are never called stringers. There is a relationship of stringer to stiffener, which needs to be defined, and this definition depends on the context. An engineering classification scheme or Ontology is necessary in order to make communication between engineers precise. Such an Ontology can also be used to help non-engineers to understand the terminology.

These complex relationships between words make the construction of the Ontology more involved than for that of a taxonomy such as a Product Data Structure. Instead of designing the structure as an information source for a software system to operate for a specific purpose(s), it becomes necessary to identify relationships between items that hold true in the long term. These relationships must be true for a variety of applications. The relationships may be many and varied, and each term must be linked with many other terms that have a similar meaning.

The Ontology can also enable communication between the computer systems, users, and administrators. Ontology development tools allow the ontology administrator(s) and representatives of the users to meet discuss and develop the ontology together, using a visual interface. (Hunter, 2002) explains how taxonomies can be the basis of the definitions for the Ontology, and that commercial software is becoming available. Rolls-Royce are using Protégé from Stanford University (Stanford, 2003) to create an ontology for parametric modelling of engine cost. This can be the basis for a more detailed Ontology to be used for generative modelling as well.

The use of Ontologies is being driven by e-commerce and e-procurement where trading is online (ebXML, 2002) such as Exostar. Exostar is the e-commerce system formed in March 2000 by BAE SYSTEMS, Boeing, Lockheed Martin and Raytheon. Rolls-Royce joined in June 2001. This system now links over 20,000 second and third tier suppliers. (Exostar, 2003).

For our ontology the underlying data will employ an object oriented database to hold libraries of objects. This will offer the ability to integrate with other web-based services such as Exostar, which offers the potential to access relevant supply-chain costing data. We will also attempt to make it possible for our ontology to integrate with product and process ontologies being developed as part of STEP (Standard for the Exchange of Product Model Data) and PSL (Process Specification Language) projects.

2.2 *Knowledge-based systems in Practice*

In order to construct a knowledge-based system, it is necessary to investigate ways to structure the information in a coherent, manageable, and computer independent way. Any system created without this in mind may have temporary success but is doomed to failure in the longer run. This failure is likely because the keeping of information in proprietary formats and within particular computer systems fragments the access of users in such a way that the majority does not have access. The lack of accessibility to the information causes attitudes ranging from indifference to outright opposition to the introduction of such a system over a whole organisation.

This leaves protagonists of such a system wondering how it can fail to take off, when it seemed to them to be useful. The result is to scale back aims, and provide the system for only a particular group or type of user. This is counter to the requirements for a knowledge-based system as it merely helps these users perform a limited variety of organisational functions. Knowledge based systems need to allow a variety of people in different disciplines to share knowledge across functional, departmental, and disciplinary boundaries. The Web makes it easier for users to share information, once the information is on the organisation's Intranet, everyone can access it unless it is deliberately restricted. This access is necessary before even considering the further problem that certain knowledge should be shared with others outside the organisation such as suppliers, and customers.

The varied user base of knowledge systems results in a further problem, which is that of fragmentation of the language itself. As the users are in different trades and professions they will not necessarily understand the same words, or assign to them the same meaning. The use of separate software systems in different departments has made this problem worse as the terminology used in software will tend to become part of the business language for that group of users. Again this makes it necessary to structure the information in a knowledge-based system carefully.

(Sutton, 2001) illustrates how codifying knowledge into a knowledge-based system for decision support is likely to be very difficult. Most people 'just do' a task and therefore never write down instructions for others. This highlights the difficulty of getting information into a knowledge base when it may be either only in individuals' minds, or completely unstructured.

3 RESEARCH APPROACH

3.1 *Knowledge Representation*

Relationships between terms such as kind-of, and part-of become more important than the term itself, as the relationship defines the meaning of the term by relating it to the other terms. The resultant structure can be shown as tree diagrams and those involved can meet in order to amend the structure and agree the most suitable names for items. The SPEDE (Structured Elicitation and Demonstration Environment) project involves Rolls-Royce, Rover/BMW, University of Nottingham and Parametric Technology Corp, and KTI. SPEDE investigates ways of representing products and business for further analysis and simulation.

The aim of the research is to find ways of representing the information in the Ontology in an open, well-structured and accessible format. This must allow for this information to be easily interpreted by users, and processed by computers in order to generate cost and process planning information for a given component. We have made use of web standards to represent and display the information in a web browser.

3.1.1 *The Semantic Web*

The research is not just into representing engineering knowledge on the web. It is also a small part of a much wider world wide effort to make the web into a repository of knowledge, which can be catalogued and searched intelligently. This search task could then be undertaken by humans, or by software agents.

(Berners-Lee, 2002) has envisaged the Semantic Web as a sort of global database with the information held in a structured form where content is separated from markup. To achieve this the structure is created using XML Meta-data tags, and a stylesheet contains separate tags for formatting. This is why in our project we use XML Meta-data tags for organising content and the semantics (meaning) of that content, and separate stylesheets for formatting the information.

3.1.2 *Knowledge Representation Languages*

3.1.2.1 XML (Extensible Markup Language)

The basis for much of this work is XML (eXtensible Mark-Up Language). The Web Based Cost Estimation Software in Figure 2 above uses XML as its' information source. We are creating an Ontology for engine manufacture using relational database tables and software to translate and structure these into XML or RDF (described below). (Huang et al. 2001) examines the issues that are important in developing Web applications for product design and manufacture.

The reason for using this language is that it provides a structured way to represent information that is independent of the way this information is displayed. It is also open standard not proprietary. This is why XML is increasingly being used for communication of data between computer systems, this is the basis for Web Services (W3C, 2002). W3C (World Wide Web Consortium) 'develops interoperable technologies (specifications, guidelines, software, and tools'. Web Services are a means of allowing application to application communication, and acceptance of XML as a W3C standard helps to ensure that many applications are enabled to communicate using XML. The Process Specification Language (PSL) uses RDF (Resource Description Framework) to add a layer of engineering semantics to the XML for communication between process modelling tools, and for use in defining ontologies (PSL, 2000). Figure 3 shows a section from an example PSL process sequence rendered using an XSL (eXtensible Stylesheet Language) stylesheet.

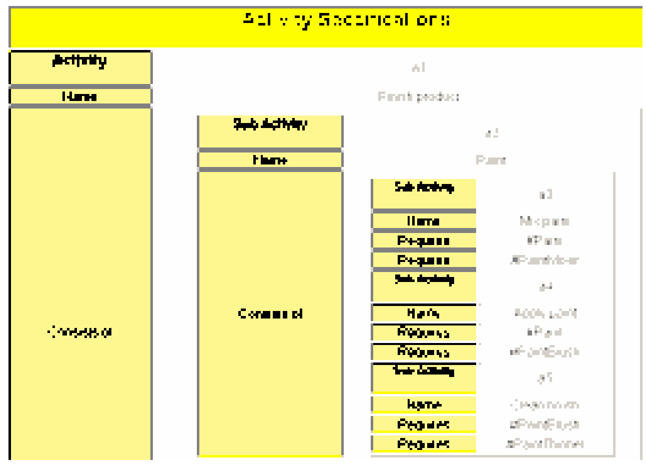

Figure 3. Section from PSL Process Taxonomy and sequence rendered with stylesheet

These semantics languages can be part of a larger effort to provide a Data Grid of information and applications, which can be requested as required (Walker, 2003).

So we have looked for examples of XML being used to solve problems of manufacturing process information representation. XML can be used as a way to manage workflow within and between organizations (Ferreira & Ferreira, 2001). XML provides the basis for creation of taxonomies and Ontologies (Bryan, 2002).

We have also investigated varieties of XML that allow for additional semantics such as standardised representation of inheritance relationships, attributes and sequences or lists of items. RDF and DAML/OIL (DARPA Agent Markup Language/ Ontology Inference Layer) are represented using XML and allow for this additional layer of semantics (Harmelen & Horrocks, 2002). These syntaxes allow us to explicitly represent relationships such as class/subclass, attributes, and sequences. We have used these information representation languages to represent Product Data Structures and Process, Materials and Tooling libraries. An example of a Process Sequence represented in RDF and displayed using a stylesheet is shown in figure 4.

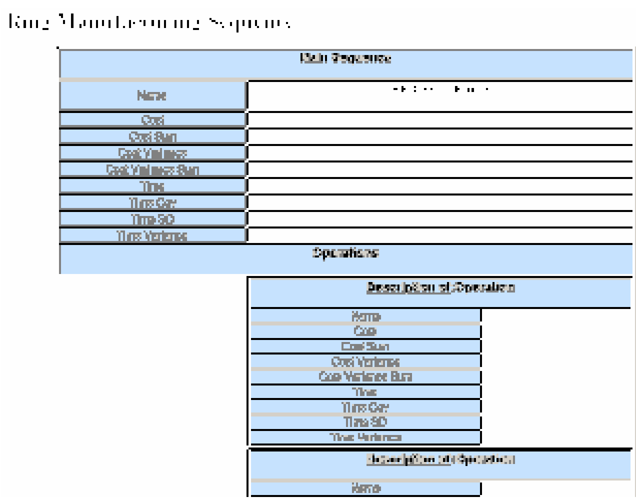

Figure 4. Representation of Engine Ring Manufacturing Sequence

(Ribiere & Charlton, 2002) have evaluated languages, tools, and techniques for creating ontologies.

3.1.2.2 SVG (Scalable Vector Graphics)

We have written software in order to perform queries and calculations on the information, and display it in ways that should enhance the users understanding of the results. The emerging standard of SVG (Scalable Vector Graphics) assists in this. SVG is a specific variety of XML for representing diagrams and allows us to display a graph, or an engineering component and let its' size and shape be altered according to the values in its' information source. This makes it ideal for visualising knowledge. XML information can be automatically translated into SVG format for display using stylesheets. SVG's future, and tools for SVG development are outlined in (Quint, 2002).

3.2 *Knowledge Visualisation*

The importance of visualising the output from queries and calculations in such a way as to convey the meaning of the results cannot be overestimated. In the Implied Cost Evaluation System (ICES) project results were displayed in a sequence diagram. Cost was represented by the size of a node in the sequence. Uncertainty was represented by variations in the shape from square to indicate low uncertainty, through to a circle meaning high uncertainty. Figure 5 shows the output from the cost map software.

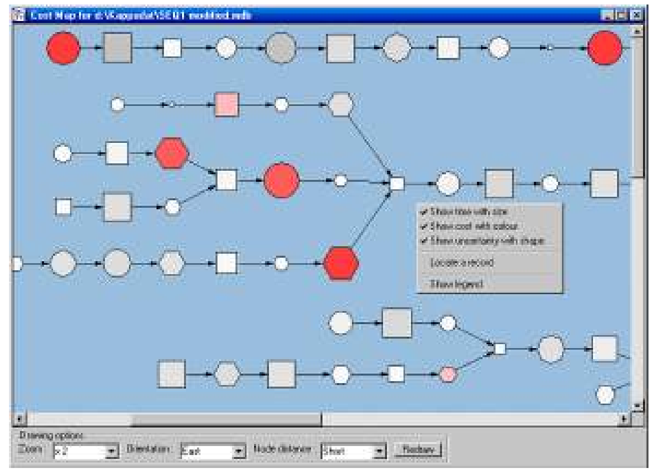

Figure 5. Cost Map from ICES system

Our intention is to reproduce this kind of functionality in our Web system. We are experimenting with SVG as it is a W3C recommendation and is also an XML syntax.

Figure 6. shows an example wing spar, as the user changes the values on the left, the diagram changes shape, and the result values such as volume change accordingly.

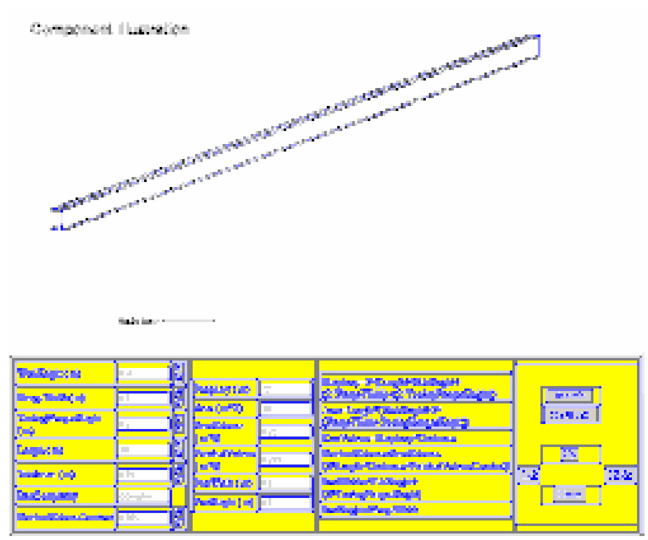

Figure 6. SVG Interactive Spar Diagram

XML can be used both to represent information and to display the information, the example below outputs an XML structure in a menu. This can be created either by writing an XML file directly using a text editor, or by creating or re-using relational database tables and using Active Server Pages (ASP) or Java Server Pages (JSP) code to output the XML. The XML is rendered into html for display using a stylesheet by (De Andreis, 2001). Figure 7 shows this.

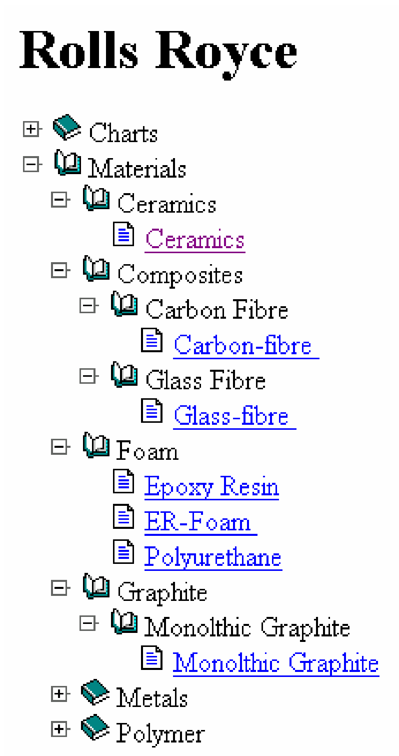

Figure 7. Hierarchical Menu

We use software which allows information to be extracted from a database or XML and displayed in a spreadsheet on the web (Softartisans, 2003). This is useful because many engineers are already used to spreadsheets, and costing models are often prototyped using spreadsheets.

3.3 *Simulation*

Although the use of process models can allow accurate manufacturing times to be generated this does not allow accurate charging rates to be established. DATUM will take into account the need for dynamic models of factories, cells and processes. We intend to develop simulation software, which could verify the process plan. This will alter these details to reflect resource and time constraints.

The development of visual user interfaces and pictorial metaphors are useful for representing a static snapshot at a particular time, usually the end of production. This technique can be used more dynamically in simulations. Simulations represent the real world problem and provide constant feedback to the user. Pictorial metaphors are static, while a person's mental model is made up of mental images connected together by a set of actions. People remember by running a mental model like a simulation. So a dynamic simulation is more memorable and conveys more information than a static picture. In order to be useful for our project simulation software must be able to take inputs from and provide outputs to our other applications.

(Kuljis) gives a summary of the aims of the AARIA project for manufacturing simulation over the Internet. Kuljis argues the need for web-based simulations to be focussed on solving real-world problems in order to be successful. (Miller et al. 2001) also explains the technology behind web-based simulations, and argues the need for demonstration of web-based simulations for major projects. (Chen, 2001) has shown how web-based simulation models can be developed and configured.

DATUM will make use of both discrete-event and sample-based models to analyse dynamic and stochastic cost elements. A framework for a library of processes, cells and virtual factories will be generated within the DATUM project. Product data, sequences and timings will be exchanged with the virtual factories to yield realistic activity based costs.

A significant problem that is not addressed by current costing tools concerns the dynamics of the underlying cost calculation. Essentially current costing tools attempt to predict the resources consumed in designing, producing and operating a product. However they almost always use a static model with simple overhead accounting rates. It is well known, however, that this produces a highly distorted view of actual costs (Sherrard, 1997). A more reliable and accurate cost can be achieved by using differential charging rates based on the principles of Activity Based Costing (ABC) which gives a more authentic analysis of the actual resources consumed in producing a product.

4 FINDINGS

We have found UML (Unified Modeling Language) to be a useful way of agreeing definitions using a pictorial representation, which can then be translated to RDF. (Kogut et al. 2002, Baclawski et al. 2001) explain how UML can be used as a tool to produce Ontologies. It is however necessary to take into account the current nature of information representation within organisations. We realise that we will never be starting with a clean slate, this means it is necessary to use the Ontology as a repository that not only stores information, but also gathers it from various computer systems such as databases and spreadsheets. There is a conflict between the aim to develop an ideal representation of knowledge using an ontology editor, and the practical need to edit the data in the database or application it is currently held. Therefore we have created software to take information from data sources and output it the ontology.

This means it is necessary to provide a software link between these sources of information, and the Ontology. The Ontology is therefore a centralised repository of information within a distributed system. (McGuinness, 2002) provide useful guides on how ontologies can assist in linking distributed data. This use of the Web as a link to a multitude of applications and data sources is termed the Active Web and is described in (Morris et al. 2001).

4.1 *Software Architecture*

Figure 8 shows the architecture of the DATUM system.

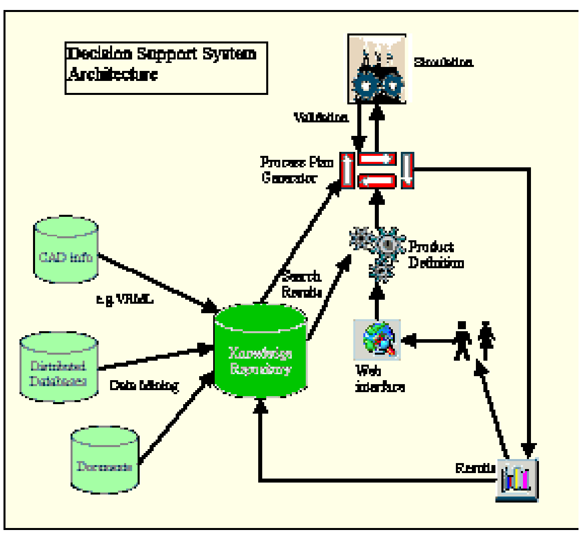

Figure 8. Software architecture for DATUM system

Although much of the software required has been prototyped, it has not yet been fully assembled into such an architecture. This will involve adaptation and integration of components. XML plays an important role in both the Web Services sense of being a communicating language for different systems, and also in the Semantic Web sense of providing an ontology definition language. The Knowledge repository would contain XML data obtained from other applications and from user forms. An extra layer of semantics would be created above the XML syntax layer using RDF and/or DAML/OIL.

We need to investigate further techniques for visualising the information for a wide range of users, and in complex ways. While SVG could prove useful, as an open standard for this, we are still evaluating tools and techniques for production and display of the SVG. Further investigation is also needed into web simulation, both to verify a process plan and to provide results to the users in the most informative way.

5 CONCLUSION

This work has been an essential first step in evaluating and prototyping a knowledge based system. The knowledge we have gained will allow us to create such a system for Parametric and Generative cost estimation, and decision support. However the quantity of information needed for this system imposes extra requirements for automated software links to other systems, and a user interface which allows easy navigation, viewing and editing of information. The difficulty here will be in reading information from these other systems and codifying it into a sensible structure for the Ontology. This means it is essential that we use open data standards. This also implies the need for a semi-automated rule based codifying tool. This could assist administrative users in taking information from various sources and linking it to the Ontology.

The requirement for our system to be relatively easy to maintain and update, and to reach as large a number of users as possible implies the need for use of Intranet technology, and a web based front end. At present it is more important that we have a wide user base then that the software provides an in depth analysis and simulation of the process plan. But this depth is envisaged for the longer term.

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