The Optichem-Infonet DSS

The design and implementation of a DSS prototype to apply chemical knowledge in the paper industry

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The case discussed in this paper is based on the Optichem Infonet Decision Support System, an idea and initiative of Big River Innovation (Doetinchem, The Netherlands).

The report is based on the mater thesis "Integrating separate knowledge domains with a Decision Support System: Applying chemical knowledge in the paper industry" by Kristian Peters

Investing in the future by working together for a sustainable and competitive region

Executive summary

Although chemicals are used widely in the Dutch paper industry, handling chemicals is not a standard component of education programmes, or internal training programmes of future and current individuals that perform tasks relating to paper production. This concerns not only individuals that operate paper machines, actually producing paper, but also employees from transport organisations, cleaning agencies, installation builders, etcetera.

In order to overcome problems relating to the lack of chemical knowledge in the paper industry, the use of decision support systems (DSS) is studied: the Optichem-Infonet DSS. A decision support system intends to provide decision support to a user regarding a specific knowledge domain.

This report describes the design and implementation of a DSS prototype for the safety assessment task within the cleaning and unloading tasks that different organizations perform at a paper mill. Special attention has been paid to the encoding of the knowledge into the decision support system. It needs to be transformed into a shape that is understood by intended users and it should be dynamically generated based on different task and environmental characteristics at the various paper mill locations. The prototype has been evaluated in a controlled setting, and was perceived as highly usable by practitioners.

1 Introduction

In the course of time, the usage of chemicals in the paper industry has increased dramatically, in quantity as well as in variety. Paper mills have enlarged their paper assortment to survive in a competitive market by using extra chemical substances in the paper making process. In addition, the variety of chemical substances from chemical suppliers has increased too, at which new chemical substances replaced old or environmentally unfriendly substances. The Dutch paper industry produced 2,6 million tons of paper in 2009[1]. The costs of applying chemical are estimated on 100 million Euros (Faber and Peters, 2006; Faber et al., 2006)

The traditional production process of paper has turned into a more complex process because of the increasing use of chemicals. More knowledge about chemicals and its implications for the paper making process is required to run operations in an effective, safe and sustainable manner. However, the chemical knowledge level of staff working at the paper mills has not grown proportionally to the increase of the usage of chemicals. The causes of this stagnancy (see figure 1) are insufficient training, reorganizations, at which chemical experts are lost, task enlargements, at which low educated employees become responsible for knowledge-intensive chemical tasks, and absent knowledge management (i.e., employees are not sharing, coding and storing chemical knowledge and experiences throughout the paper industry). Field research showed that there is a significant lack of chemical knowledge in the paper industry, especially at the operational levels. The consequences of the lack of knowledge are numerous and affect the whole industry: production errors, waste of chemical substances, environmental pollution and accidents.

[1] Source: “Jaarstatistieken 2009” http://www.vnp-online.nl/ (accessed Dec 2010)

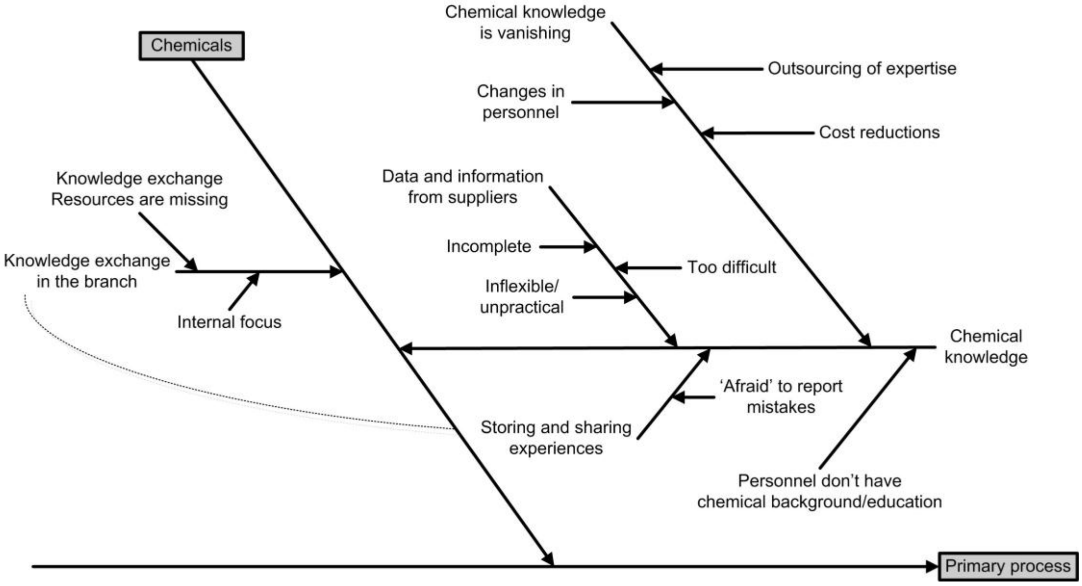

Figure 1 - Ishikawa cause-and-effect diagram of the chemical related problems with rehard to chemicals in the Dutch paper industry

The Optichem foundation, established by Dutch companies active in the paper industry, aimed to tackle these problems. Among them are several paper mills, two suppliers of chemicals, a machine-builder, a cleaner, a transporter of chemicals, a project company and the University of Groningen.

The chemical knowledge domain is complex. Therefore, an obvious way to deal with the problems is to train the employees concerning chemicals and their dangers. However, this is a time consuming and expensive solution. Moreover, the effect of such training is difficult to measure. Another solution is to apply expertise from outside the firm. This solution is expensive as well, and in most of the cases, the expertise will not fit the specific context of the company.

In addition, workers need to have up to date information about the conditions at the paper mills (chemicals, materials, machine settings, temperature, etc.) in order to carry out their tasks in a safe and efficient manner. Because certain workers, like cleaners and transporters work at multiple paper mills a web-based decision support system that can run on a handheld computer or on a mobile Smartphone seems most fruitful.

Therefore, the foundation's objective is to support workers in the paper industry in different ways concerning the transfer of chemical knowledge by using ICT solutions. ICT solutions should bridge the knowledge gap between the knowledge domain of certain task performers and the knowledge domain of chemicals, and to assure timely and context-specific information about the work environment. The network of new ICT solutions was called the "Optichem-Infonet". Via the Optichem-Infonet, users should be able to attend to discussion boards, access knowledge repositories, contact experts and use decision support system modules. These decision support system modules can be seen as specialized decision support systems with each a different set of tasks to support (operational tasks, financial tasks, safety tasks, etc.). The system should eventually be accessible from multiple locations, for instance from the truck of a chemical supplier, outside the mill at a discharging facility or on top of a paper machine during cleaning activities.

This study investigates the design and implementation of a prototype for a specific decision support system for the cleaning and unloading tasks at paper mills (see figure 2).

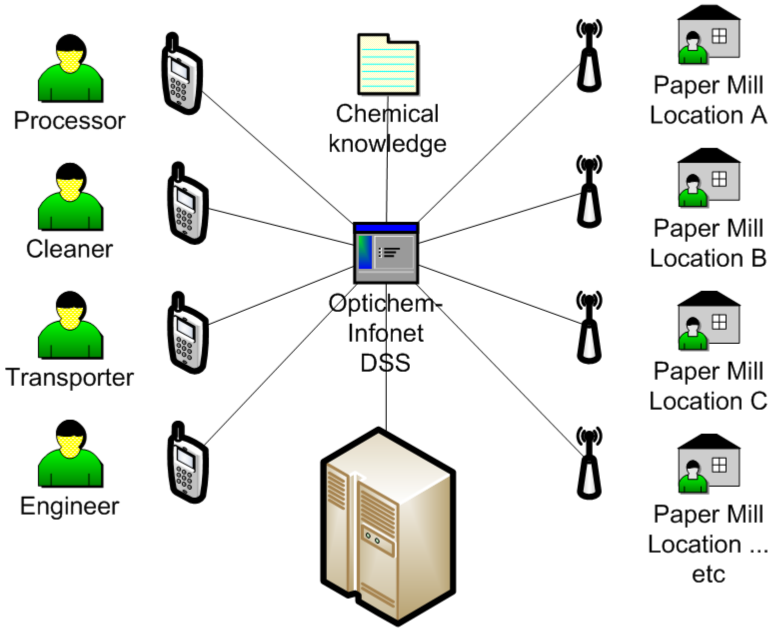

Figure 2 - The Optichem Infonet DSS prototype concept

2 Problem statement

Main problem:

What decision support system design supports task performers in the paper industry regarding chemical knowledge?

Research questions:

Analysis phases
a. What are the properties and steps of the cleaning and unloading tasks?
b. What are the requirements for a system that supports workers in the safety assessment?

Design and implementation phases
a. How can chemical knowledge be implemented in a decision support system?
b. What software architecture and computational mechanisms are required?

3 Analysis

The goal of the decision support system is to improve the personal safety of employees executing tasks in paper production, by reducing the knowledge gap between the expert chemical domain and the application of this knowledge in other knowledge domains that are used in their tasks. The safety assessment sub-task of many tasks in the paper industry has been identified as the most suitable task for support by a decision support system prototype. Furthermore, we concentrate on the cleaning and unloading tasks in which the safety assessment task is a sub task.

3.1 The cleaning and unloading tasks

I can distinguish two parties that are involved in the cleaning task. The primary party consists of the team of cleaners and their project manager. The cleaners execute the cleaning tasks; the project manager is responsible for the preparation and overall quality of the cleaning task. The secondary party consists of the production manager of the paper mill, who is responsible for the machines and its environment.

The project manager starts a cleaning task with a project preparation (see figure 3). He visits the factory site and investigates the task environment together with the local production manager. During this phase, issues associated with chemicals and safety are discussed and documented. After the preparation phase, the actual cleaning task starts with a work and safety briefing of the cleaning team by the project manager. Standard procedures (work instructions) and the documented project preparation are combined here. When the cleaning team has been informed about the task at hand, the project manager secures the targeted machine and its environment, and the cleaning team installs the needed detergents, tools and equipment. Before the cleaning team starts cleaning, a last authorization call from the production manager is needed. Depending on the situation, the cleaning task is performed mechanically or chemically. Inspection takes place during the actual cleaning of the machine and after the cleaning job. After all equipment has been put away safely, responsibility regarding the machine is reassigned to the production manager.

The unloading task refers to the unloading of a truck by its driver into some storage facility (see figure 4). With respect to the unloading task, again I can distinguish two parties. The primary party consists of the truck drivers and the secondary party is the responsible expedition employee of a paper mill. The truck driver is responsible for the transport of the chemical load and his truck. Concerning the chemical substances he is carrying, his responsibility ends at the coupling point. Then, responsibility is transferred to the employee of the paper mill.

After the truck driver receives local safety instruction, he has to find the corresponding site manager, who guides him regarding the delivery of the chemicals. Additionally, he has to find the proper location for delivery. There are usually multiple delivery locations at the site of a paper mill. When the truck driver is at the right location, he receives local work instructions and checks whether the capacity of the storage tank corresponds with the truckload. When the storage tank capacity is insufficient, no delivery takes place. After the capacity check, the truck is coupled to the proper coupling point, and the unloading of chemicals starts. When the tank truck is empty, the truck decouples from the coupling point and both driver and local personnel clean the delivery site with water. The last action is weighing the truck, to check whether the right amount of chemicals has been delivered.

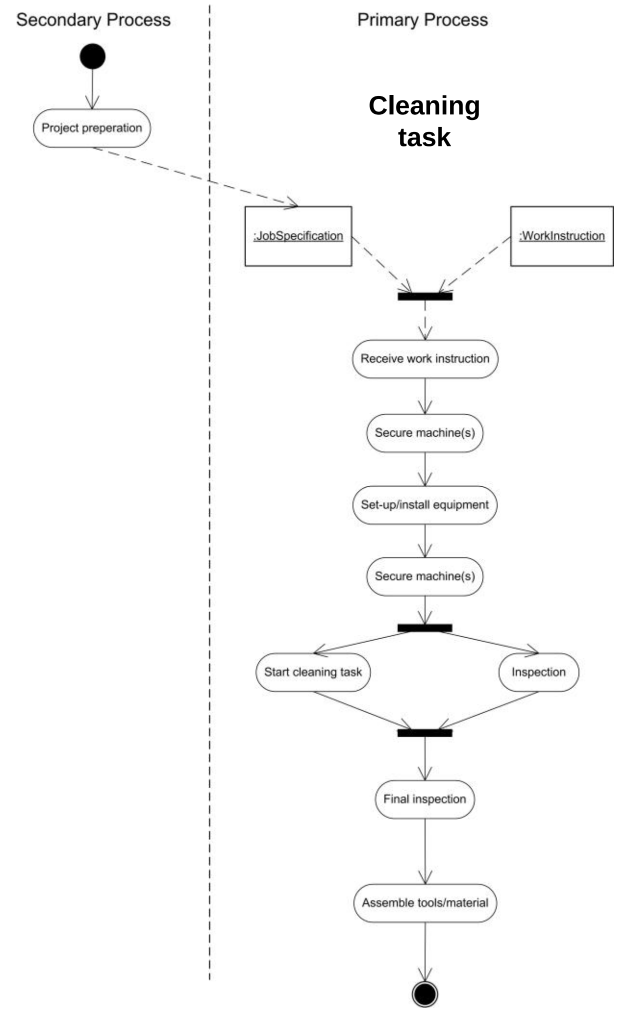

Figure 3 – Cleaning task flow model

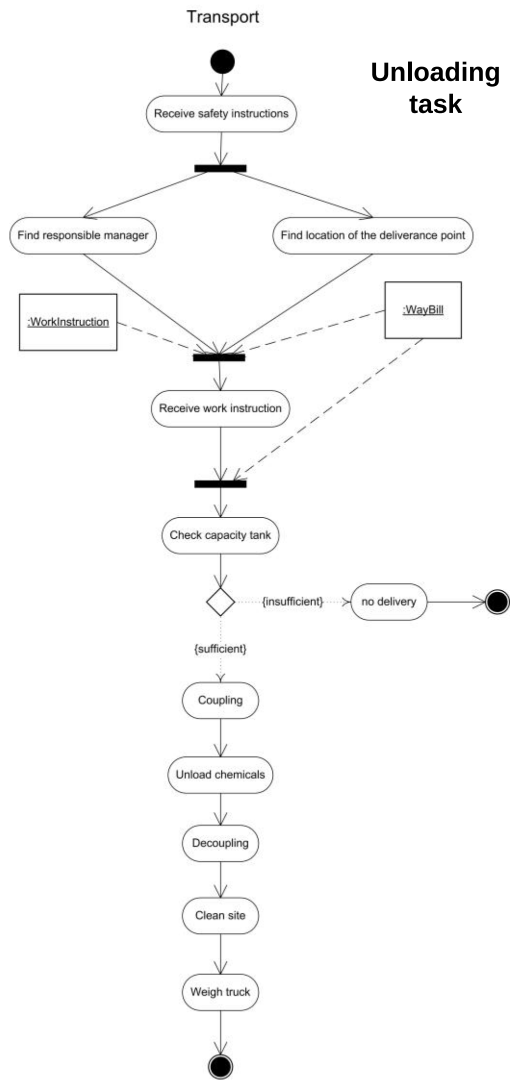

Figure 4 - Unloading task flow model

3.2 Safety assessment task

First, the dangers of the chemical substance(s) used during the task need to be determined. There are different types of dangers occurring under different circumstances. Dangers are for example fire or explosions. A chemical substance can also be dangerous if exposed to skin or eyes, or when inhaled or ingested. Next to that, chemicals are reactive with other chemicals (i.e. chemical leftovers in the paper machine during the cleaning task or leakage of chemicals during the unloading task) and are only stable at certain temperatures, pressures, etc. Even if the task is performed using water as only detergent, dangerous reactions with chemicals can occur. Hence, many parameters have to be taken into account to assess the dangers.

Second, to prevent dangers from happening or to act when a danger occurs, measures need to be taken. There are measures to prevent dangers from happening and measures to be taken when a danger becomes reality (i.e. first aid, fire fighting). The measures are usually logical derivates of a danger, like wearing fire-resistant clothes at the risk of fire. However, many measures are very technical and context-specific as well. Thus, firstly, the worker has to determine the dangers of a task based on the overall situation and secondly, he should fit the measures to the assessed dangers.

Much relevant information about dangers and associated measures can be found on international chemical safety cards (ICSC) and material safety data sheets (MSDS). However, the worker is not a chemical expert: he lacks chemical knowledge and information processing capabilities to fully asses the situation concerning his safety, even though almost all information is available on these safety cards and material safety data sheets. This is a practical example of *knowledge crossover* (see Peters, 2006), at which knowledge from the chemical knowledge domain has to be applied in the domains of cleaning and unloading. To overcome the knowledge crossover problems - i.e. workers are not able to assess the safety situation with the information and knowledge available - the project leader makes a selection and translation of the chemical information and prints this on the working instruction sheet. Here, information is adjusted to the workers knowledge levels, the standard task and a normal situation using symbols and understandable texts. However, by applying the selection, translation and contextualization, much information is lost. This is normally not a cause for problems, because the task is usually performed in a stable environment under normal circumstances. However, when something changes or something unexpected happens, both the chemical knowledge of the worker and the limited information on the working instruction sheets are insufficient to assess the situation.

Without doubt, the working instruction solves a great part of the knowledge crossover issue associated with the difficult and extensive international chemical safety cards and material safety data sheets. However, the instruction sheet is too *static* to support the user assessing their personal safety in all situations. A decision support system is a suitable medium to make the traditional working instruction sheet more *dynamic*. This is the starting point for further analysis, design (section 4) and implementation (section 5). Lastly, I list requirements (functional and non-functional) for the prototype acquired by interviewing Optichem participants. The requirements should be incorporated in the design of the prototype.

- the prototype should make chemical knowledge concerning personal safety accessible for task performers working in the paper industry;
- the prototype should be able to share experiences concerning chemicals and safety;
- the source of information in the prototype should be traceable;
- different types of information should be distinguished;
- the presented information should be understandable;
- the prototype should be ‘enjoyable’ and easy to use;
- the prototype should be accessible through a wireless handheld device or small laptop;
- the prototype should be web-based for wireless access and multi-user support (i.e. platform independent);

4 Prototype Design

The CommonKADS methodology (Schreiber et al., 2000) offers several templates to model knowledge-intensive tasks for a decision support system design. I use the “assessment” task template. The “assessment” task template's objective is to categorize a specific situation based upon a set of domain-specific rules. The goal of the safety assessment task is to find safety measures for a certain situation based on a set of chemical rules. The situation is a mix of attributes and parameters of the location (e.g. paper mill), the chemical substance(s) and assessed dangers. The chemical rules are based on chemical domain knowledge, here, used for assessing dangers and the associated safety measures. The input of the task consists of data about the situation. The task results in dangers and safety measures (output). The assessment task is executed at one particular point in time.

Concerning the knowledge domain of using chemicals in paper making, I identify two central concepts in the safety assessment case, namely working environment and chemical substance. These concepts are depicted in figure 5 together with their attributes. During task performance (i.e. cleaning or unloading) chemical substances are applied or encountered in an environment, here, denoted as the working environment. The working environment consists of machines, materials, workers, chemicals, etc. In reality, the working environment is a domain schema on its own. For clarity, I only depict working environment as a simple concept. Each instance of the relation chemical substance and working environment denotes a safety assessment, depicted by an association class called safety assessment.

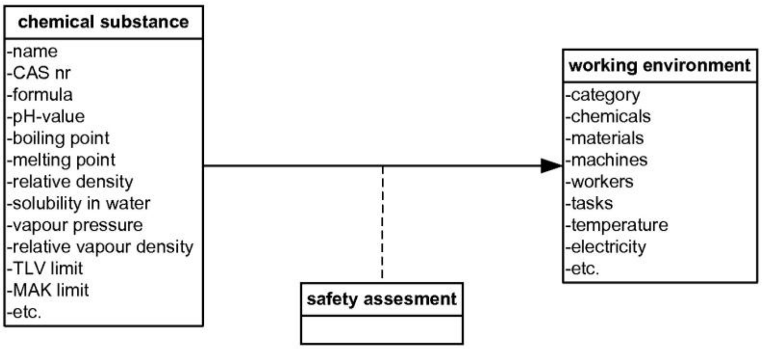

Figure 5 - Domain schema: concepts

The complete domain schema for the safety assessment is depicted in figure 6 and is based on the CommonKADS assessment task template (Schreiber, 2000: p. 133-138). To assess the personal safety, attributes and parameters of the working environment and parameters of the chemical substances are combined. This combination is the definition of a safety assessment case. Abstractions of the safety assessment case data are required to translate some of the data into a format suitable for reasoning. For example a acidic-alkaline-category can be added to the safety assessment case.

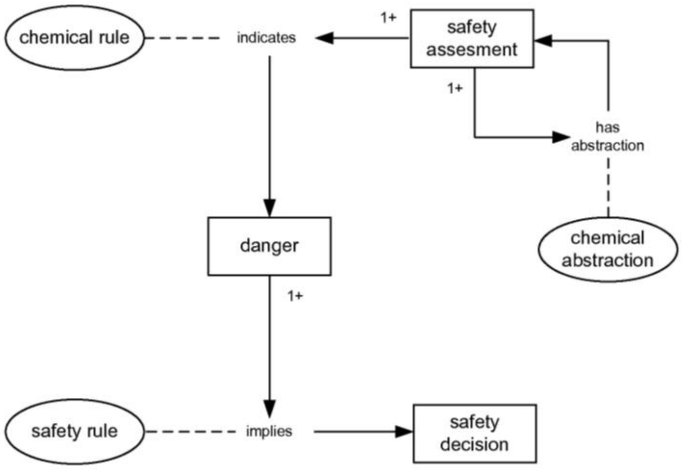

Figure 6 - Domain schema: rule-types

The largest part of the domain knowledge contains chemical and safety rules. Firstly, these rules are used to assess chemical dangers. Secondly, together with the assessed dangers, rules are applied to determine the proper safety measures to be taken. An example of the associated knowledge base (i.e. an instance of the domain schema) consists of rules to indicate an acid-base reaction and its associated dangers and safety measures. Having described the task knowledge and the domain knowledge categories, I continue with the inference knowledge category.

The inference structure (see figure 7) is used to connect the task knowledge and domain knowledge categories. The abstract inference is able to translate case data (input) in new abstracted case data (output). For instance, adding the acidic/alkaline-category to the case data. The ‘specify’ inference finds rules (or criteria) that can be used in the safety assessment case. The specification of rules depends on the case at hand. Therefore, the case is the input of this inference and the outputs are relevant rules. For example, when all chemical substances are categorized and labeled as alkaline during the abstraction steps, no acid-base reaction is possible and hence, the acid-base reaction rule is irrelevant. The ‘select’ inference has as input the set of relevant rules. One rule needs to be selected for evaluation, for example the ‘radical reaction’ rule. This selection can be done randomly, but it is advised to use chemical domain knowledge to select the most important rules (i.e. selecting rules that assess the most threatening and most likely dangers). I have added a selection model component to the inference structure. The ‘evaluate’ inference evaluates the selected rule with respect to the (abstracted) case data. It produces for example as output a truth value. The last inference is the ‘match’ inference. This inference uses the outputs from the evaluate inference, and results in several decisions concerning safety measures.

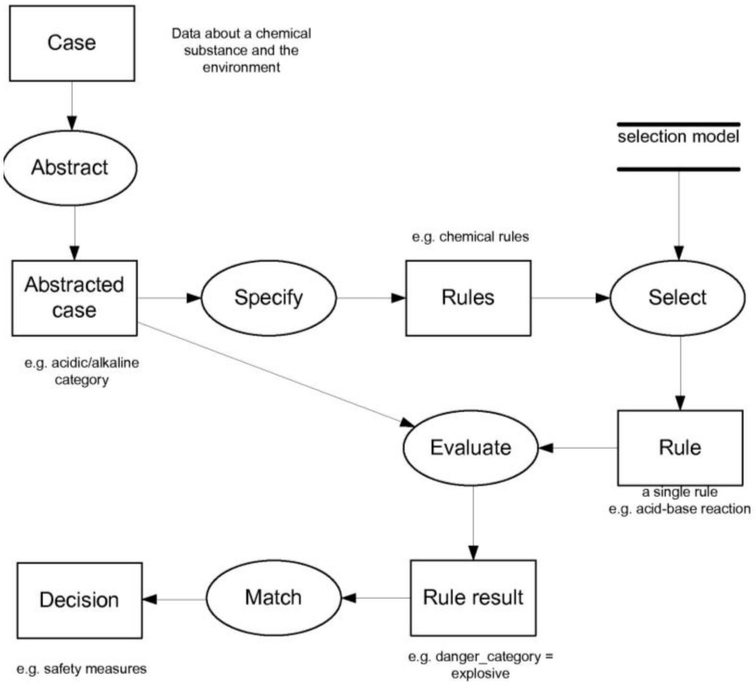

Figure 7 - Inference structure cleaning and unloading tasks

The prototype has two main functionalities, namely assessing dangers and measures associated with one chemical substance and assessing dangers and measures of a reaction between two chemical substances (see figure 8). Practical experiences concerning chemical usage and safety are integrated in the safety measure parts of the report.

With regard to the human-computer interface design, I offer two options: a wizard navigation structure and an expert navigation structure. The wizard navigation structure guides the user through each step of the safety assessment task, and is especially suited for small handheld devices (see Appendix A). The expert structure is implemented using one page that displays all elements that are relevant regarding personal safety in relation to chemicals in the paper industry, and possible measures that can be taken to minimize personal risk (See Appendix B).The expert navigation structure is more suitable for use on tablet PCs or small laptops.

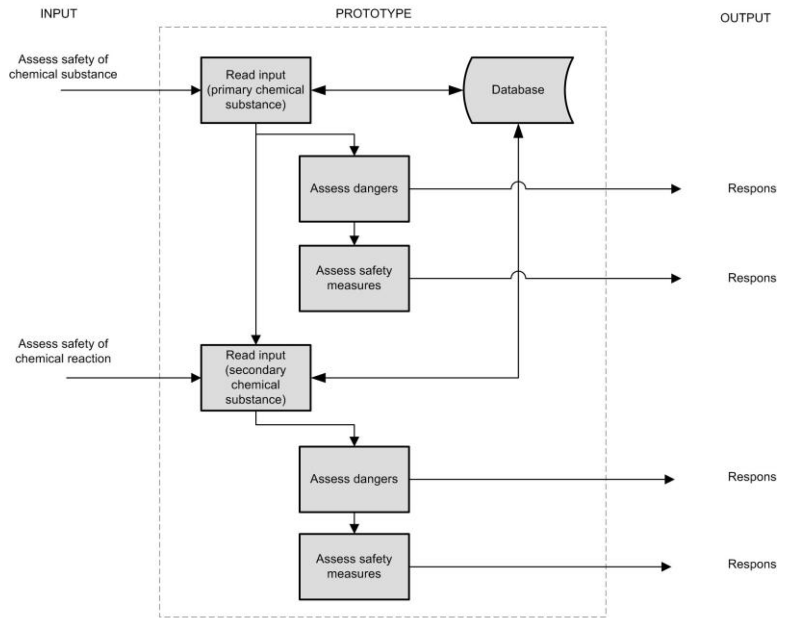

Figure 8- Prototype functionality

5 Prototype Implementation

A web-based, three-tier (a database logic, business logic, and presentation logic layer) decision support system prototype is used (see figure 9). A Microsoft Access database implements the database logic layer. An Algernon rule-base that controls database access, combined with a Tomcat JavaServer Page server form the prototype's business logic and presentation logic layer. A standard web browser is used as a client. The database has been developed using the Protégé ontology and knowledge base editor. A text editor was used to build the JavaServer Pages.

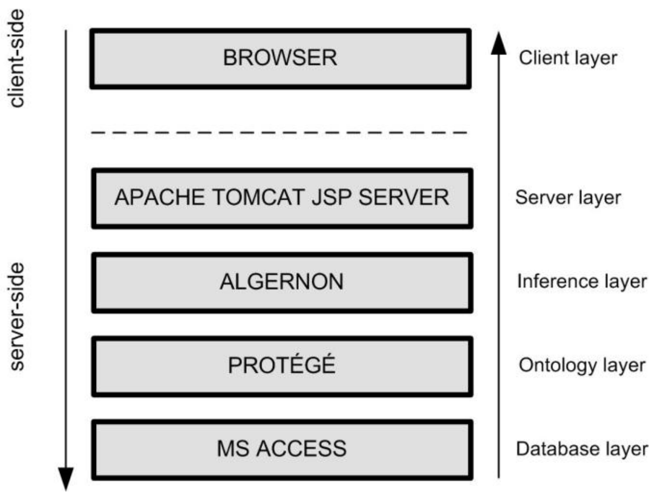

Figure 9 - Web-based three-tier implementation

6 Evaluation

I used the SUMI questionnaire to evaluate the usability of the prototype. SUMI[2] stands for Software Usability Measurement Inventory and is tested and proven method of measuring software usability. The SUMI consists of 50 statements about the prototype which should be answered on a three-point Likert scale: ‘Agree’, ‘Disagree’ and ‘Don’t Know’. There are five subscales (i.e. constructs) underlying the overall measurement. These are efficiency, affect, helpfulness, control and learnability.

The sample consisted of 10 male and 1 female. I asked them to perform a number of assignments that resembled actual transportation and cleaning tasks. Without the prototype, none of the participants was able to complete the assignments. After completing the assignments with help of the prototype, the majority was able to complete 100% of the assignments. Then I asked the participants to fill in the SUMI questionnaire. Based on the results, the overall perceived usability of the prototype was high.

The verbal feedback I received from the participants after the experiment was generally positive. Participants were enthusiastic about the prototype and the majority of the participants realized after the experiment that they knew too little about the chemical domain.

7 Conclusion

The general analysis performed involving all members of the Optichem foundation exposed many problems concerning the lack of chemical knowledge and the lack of knowledge exchange in the paper industry, which are leading to (dangerous) problems. A decision support system could prevent many of these problems. The safety assessment sub-task of many tasks in the paper industry has been identified as the most suitable task for support by a decision support system prototype. The prototype should contribute to the feasibility study of the Optichem-Infonet.

The next step was to select one or two tasks (and companies) for prototype development: cleaning and unloading. Another, more detailed analysis was performed involving these two task resulting in a task analysis and a knowledge analysis (i.e. the requirements for the decision support system prototype). The constructed knowledge model showed the primary structures and mechanisms required for the safety assessment task.

The constructed prototype seems to be a suitable design to solve the problems identified in the analysis. Without the prototype, participants were unable to assess their safety situation when they for instance encountered an unfamiliar substance during their task execution. With help of the prototype, users were able to accomplish the safety assessment task. The prototype was perceived as usable (on average satisfactory or even better) according to the results of the SUMI questionnaire.

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[2] source: http://sumi.ucc.ie/

8 Participants and references

The case discussed in this paper is based on the Optichem Infonet Decision Support System, an idea and initiative of Big River Innovation (Doetinchem, The Netherlands). The report is based on the following references:

Primary source

Peters, K. (2006) "Integrating separate knowledge domains with a Decision Support System: Applying chemical knowledge in the paper industry" - *Master thesis, University of Groningen*

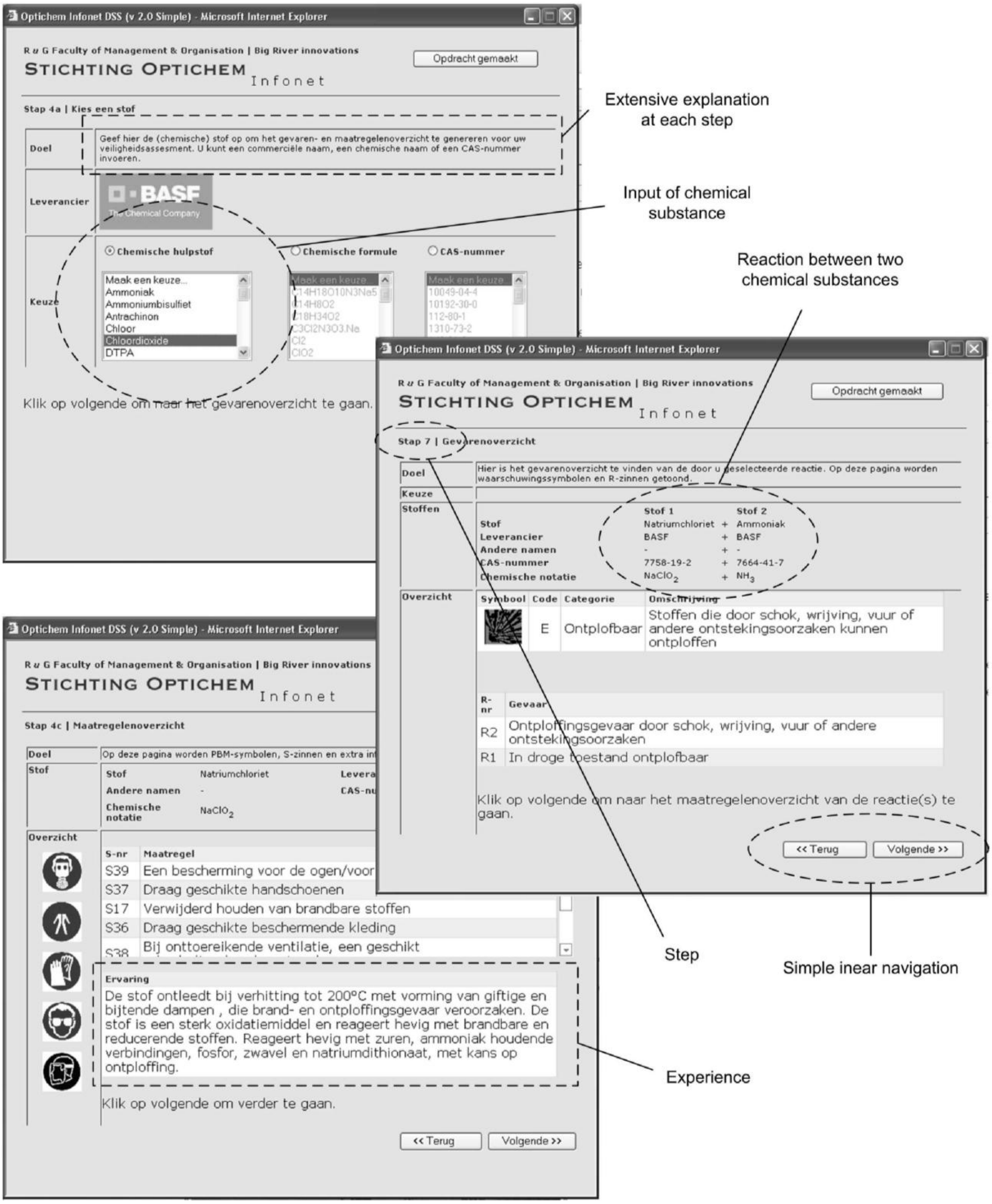
Secondary sources

Faber, N. & Peters, K. (2006) "Know what you're blending! A tool for a sustainable paper industry" in *Sustainable Innovation: the human, organizational and knowledge dimension,* Jorna, R. *(ed.), Greenleaf Publishing Cie*: pp. 165-186

Faber, N., Peters, K. & Jorna, R. (2006) "Technology for Knowledge Crossover: A tool for sustainable paper industry" in *International Congres of Organization Semiotics,* Cecilia, M.; Baranauskas, C. & Liu, K. *(ed.)Capinas, SP: UNICAMP/IC*: pp. 27-36

Schreiber, A., Akkermans, T., Anjewierden, H., de Hoog, A., van der Velde, N., Shadbolt, R. & Wielinga, B. (2000) "Knowledge engineering and management, The CommonKADS methodology" *The MIT Press*

9 Appendix A – Wizard navigation interface



10 Appendix B – Expert navigation interface