Chapter 3

National Research and Technology Audit

This chapter introduces the case study used to illustrate the CILT-MAL system, namely the National Research and Technology Audit commissioned by the Department of Arts, Culture, Science and Technology. Recall from Chapter 1 that this audit was undertaken due to the realisations by the South African Government that science and technology will have a major impact on society in the 21st century and that, if a developing nation wants to compete in the world economy, it should have a robust technology policy. Formulating this policy required a critical assessment of South Africa's existing strengths and weaknesses in science and technology.

It is widely recognised that technology, and the science that supports it, are vital contributors to the well-being and economic competitiveness of a nation. Successful nations are those which develop and nurture 'technologising' policies i.e. policies that stimulate the processes whereby knowledge is gained and embodied in people, products and services [DACST 1997]. The South African Government recognised the contribution that science and technology can make to meet the nations societal needs. Hence, they had to determine whether the country's science and technology system has the capacity and capability to contribute to the national, social and economic well being of the nation.

The forces that shaped the character of science and technology in South Africa have changed significantly over the past six years. New priorities have emerged, placing different demands on the science and technology system. This required an investigation into the capabilities and weaknesses of the system in relation to the new demands. The NRT Audit was commissioned by the government in order to gain an idea of the capacity, capability and limitations of the science and technology system as they relate to the country's current and future needs.

- The objective of the NRT Audit, as accepted by the Ministers' Committee on Science and Technology, was *"to provide data and information to be used as a basis for policies directed at increasing the effectiveness of technological innovation as a contributor to industrial productivity, economic growth, environmental sustainability and international competitiveness by way of sound recommendations and implementation strategies"* [DACST 1997]. The audit was therefore initiated to support the government in formulating a technology policy framework to create a science and technology system that would be effective, efficient and have a positive cultural impact on the South African society. Furthermore, the system should hold all stakeholders accountable and responsible for the execution thereof. Finally, the system should minimise conflicting interests and objectives [DACST 1997].

In order to achieve these objectives, the audit was planned to assess the strengths and weaknesses of South Africa's science and technology system and determine the efficiency, adequacy and value of the system. It was also intended to develop and communicate a better understanding of the forces that will shape the long-term effectiveness of the nation's science and technology system. Lastly, the audit was to provide direction and guidance on how to maximise the effectiveness of the science and technology system to meet the future challenges facing South Africa [DACST 1997].

The NRT Audit was carried out by conducting five surveys. Each survey collected large amounts of data on the science and technology system and was compiled in stand-alone reports. The data have been captured in a data repository, the NRT Audit Data Warehouse. The Foundation for Research and Development produced a synthesis report, Technology and Knowledge [DACST 1998]. This report was produced by human experts who assessed the information and data collected during the audit. The synthesis report describes the current state of science and technology in South Africa and identifies certain trends. This knowledge, as contained in the synthesis report, guides and motivates policy recommendations for the formulation of a Science and Technology Framework for South

Africa. This framework is directed at increasing the effectiveness of technological innovation, as a contributor to industrial productivity, environmental sustainability and international competitiveness [DACST 1997].

The question arises whether the data in the data warehouse support the findings of the synthesis report. It needs to be determined whether the findings are supported by the data, or whether these findings were based on experts' perceptions of the science and technology system in South Africa.

The case study is introduced by describing the five surveys. Furthermore, the conclusions contained in the synthesis report are discussed. Finally the two tasks to be further researched are introduced.

3.1 Survey overviews

The surveys conducted during the NRT Audit were contracted out to individual and separate consulting organisations. Each survey covered one of the following subjects:

- Scientific and technological infrastructure
- Human resources and skills in science, engineering and technology
- Research and development outputs
- Technology base of the South African business sector
- Research and training equipment in South Africa

Using January 1996 as the baseline date data were collected on the science and technology system, from participants (respondents) in the following sectors [DACST 1997]:

- Government: complete population of departments involved in science and technology, science councils and statutory and national heritage science and technology institutions
- Higher education: complete population of universities and technikons
- Private, non-profit organisations serving household and serving business (for example, multi-client industrial and services research institutions)
- Business: sample population of technology-driven production and processing enterprises, private and public, within technology-driven market sectors

The data obtained from the five surveys were integrated and stored in the NRT Audit Data Warehouse, covering the following topics for each sector. For government, higher education and non-governmental organisations data relating to their scientific and technological infrastructure, human resources and skills, research and scholarship outputs as well as their research and training equipment were captured. For the business sector, data relating to their market sector of operation, ownership, market share, exports, innovation, new products and processes, profitability, capitalisation and employment were gathered. Descriptions of their core products, dependence on technological knowledge and capabilities and the level and nature of research and development investment made by the company were also included. Furthermore, data on outputs such as patents and technical publications and the company's current and future needs for technical skills were captured [DACST 1997].

The remainder of this section introduces each of the surveys by describing their particular aim and source of data. A complete description of the audit, as well as the complete reports on all of the surveys is available from the following website:
www.dacst.gov.za/science_technology/nrta.

3.1.1 Survey of the scientific and technological infrastructure

The aim of this survey was to collate, interpret and assess data related to the national pattern of science and technology funding and performing activities in South Africa, excluding the business sector and public corporations. A total of 189 organisations participated in the survey.

For the purpose of this survey scientific and technological infrastructure is defined as *"all activities, which help maintain and/or expand the knowledge base, including, research and development; education and training; the generation of information, development of knowledge, standards and guidelines, patents and licensing"* [DACST 1998].

3.1.2 Survey of human resources and skills in science, engineering and technology

The objective of this survey was to analyse the supply and estimate the demand for science, engineering and technology human resources, as well as to estimate the actual human resources available in research and development. Data supporting this survey were obtained from existing databases of the Human Science Research Council, questionnaires on employment issues completed by organisations actively involved in research and development as well as the GEAR macro-economic strategy.

3.1.3 Survey of scholarship, research and development

The goal of this survey was to collect and analyse data on research projects and their associated resources and funding. It was required to describe South Africa's research projects in terms of key variables, such as objectives, researchers and financial value, and to classify the projects in terms of dimensions such as socio-economic sector and discipline of specialisation, as well as by main performance sectors.

Data supporting the survey were obtained through personal interviews on research policy as well as from documentation on research policy of surveyed organisations, and questionnaires completed by researchers at higher education institutions, science councils and government departments. Research was classified into three types, namely: basic research, applied research and development research. Basic research includes fundamental and strategic research, whereas applied research is the specific application of the basic research and development research is the actual development of a product and/or service.

3.1.4 Survey of the technology base of the South African business sector

The aim of the survey was to determine the extent to which private firms and public corporations depend on technology and related competencies, investment in research and development as well as reliance on external funding.

Data supporting the survey were obtained from 313 of the most economic significant companies by means of questionnaires and buy-in interviews. The companies were grouped into two sectors, namely: the continuous process and discrete products sectors. Companies were broadly classified as follows into these sectors.

Table 3 Industry sectors

Continuous process	Discrete products
Agriculture	Rubber and plastics
Mining	Civil construction
Base metal	Textiles and footwear
Pulp and paper	Electrical and electronic
Power generation	Medical and pharmaceutical
Petrochemicals	Automotive and transport
Glass and non-metallic	Metal products and machinery
Food and beverage	Defence
Water	

3.1.5 Survey of research and training equipment in South Africa

This survey was aimed at obtaining, organising and analysing data related to training and research equipment in South Africa. Data were obtained from higher education institutions, research councils, government established research centres and businesses on a sample basis. This was done by means of questionnaires and personal interviews.

3.2 Summation of the findings

The function of a nation's science and technology system is to contribute to the future of the country by dealing with problems facing the nation as well as growing the country's economy. Spies (1996) argues that all activities within the system should be judged for relevance, quality, effectiveness and efficiency, against the needs and requirements of both the business sector as well as the social development sector.

For the purpose of this study the findings were grouped according to the following categories, the findings relating to the quality of human resources, the findings relating to the relevance of the science and technology system and the findings relating to the effectiveness and efficiency of the science and technology system. The purpose for creating these categories is to integrate the findings of the five surveys, to provide a holistic view of the current status of the country's science and technology system across the partitions created by the surveys and to place the findings within Spies' framework by which the science and technology system should be judged.

3.2.1 Quality of human resources

The findings related to the quality of human resources cover two aspects namely, how well the existing human resources match the needs of the economy and the appropriateness of human resource training. From the five surveys, it is concluded that: The current knowledge and skills of the South African population are altogether inappropriate for a country that aspires to become an industrialised nation; And there is a major mismatch between the needs of the economy and the human resource skills the system is producing. It is crucial that the needs of the economy and the training and development of human resources should be better aligned.

Regarding the appropriateness of human resource training it was concluded that the human resource delivery system is inappropriate. This observation was based on the fact that a large number of new entrants into the job market are not optimally prepared for their new careers. Also, mathematics, technology, science, and language abilities at secondary school level represent an Achilles' heel in the preparation of future generations.

3.2.2 Relevance of the science and technology system

From the five surveys, it is concluded that the science and technology system is increasingly moving towards more relevant types of research. However, applied research, as conducted at higher education institutions, does not directly address the technological and information needs of national priorities or resolve salient national problems. The science and technology system is currently not coherently geared to address the critical problems confronting South African society due to the lack of strategic technology management. Lastly, the implementation of technology from local sources by the business sector is weak.

3.2.3 Effectiveness and efficiency of the science and technology system

From the five surveys, it is concluded that the effectiveness of the science and technology system in attaining the goals of generating new and relevant knowledge. However, the generation of developing technologies is low in terms of the number of technologies reported. It is assumed that mission-oriented research should lead to higher levels of efficiency. However, when the unfavourable ratio of research output to resource input reported by the audit is considered, it must be concluded that the national system is not operating efficiently. The main reason given is that at higher education institutions the teaching load consumes a disproportionate share of the potential research capacity of the staff. Similarly, the amount of effort and time allocated for marketing in science councils is disproportionate to the time spent on research by the staff. It was also found that there is inefficiency in the collaborative use of resources and that both international and inter-institutional collaboration is lacking. Because of the lack of internal and external linkages the current science and technology system does not achieve its maximum potential.

3.3 The two learning tasks

As stated in Section 2.5.1, in the area of machine learning, performance tasks are generally divided into two categories, namely, classification tasks and problem solving type tasks. To determine if the CILT-MAL system is able to analyse context embedded in qualitative data, in a real-world scenario, two experiments to cover each of these task types were formulated.

Firstly, as a classification task, the classification of companies surveyed in the "Survey of the technology base of the South African business sector" into two industry sectors, was investigated. This specific classification task was chosen as all the findings in the synthesis report, based on this survey, were made according to this grouping. An equal important consideration was the completeness and quality of the data collected, which increased the chances of the success of the classification task. Chapter 4 provides a detailed description of the classification task experiment.

Secondly, as a problem-solving type task, the data collected by the surveys dealing with human resources namely the "Survey of human resources and skills in science, engineering and technology", "Survey of the scientific and technological infrastructure" and the "Survey of scholarship, research and development" were used to investigate the quality of the human resources. The fact that this task was supported by data from multiple surveys increased its complexity. The task required a data pre-processing step during which the data from the different surveys had to be integrated into a single data set, as discussed in Section 5.2. Between 50% and 70% of the total time spent on solving a real world problem is typically spent on data pre-processing [Berthold *et al* 1999]. Therefore, it was necessary to include a task that required a significant amount of data pre-processing. Secondly, the task was also within the human learner's field of expertise. As discussed in Section 2.5.7.3, expertise in a problem domain has a major impact on a human's inductive learning process and hence made this task the appropriate choice. This problem solving type task experiment is documented in Chapter 5.

3.4 Conclusion

This chapter introduced the five surveys of the NRT Audit and outlined the findings as reported in the synthesis report of the audit. Subsequently the two learning tasks to be addressed were defined.

This concludes the first part of the thesis. The first part presented the theoretical basis for the development of an intelligent data analysis tool to be used in the experimental work that follows. Part one discussed the concept of co-operative inductive learning as it occurs in co-operative inductive learner teams. These teams were then modelled as multi agent learning systems. Langley's framework for machine learning was used to define the learning mechanisms of the learners that participated in the study. The first part concluded by introducing the NRT Audit case study and formulating the two learning tasks to be addressed.

Part two focuses on the experimental work and the results. Chapters 4 and 5 provide a detailed description of the application of a CILT-MAL system in a real-world scenario. Followed by Chapter 6, which discusses the results and presents appropriate conclusions.