TECHNOLOGY TRANSFER EVALUATION IN THE HIGH TECHNOLOGY INDUSTRY: AN INTERDISCIPLINARY PERSPECTIVE

A thesis submitted in fulfilment of the requirements for the award of the degree of

Doctor of Philosophy

by

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Keywords

Correlators, *'ex-ante'* evaluation, high technology, interdisciplinary, radio astronomy research commercialisation, technology transfer.

Abstract

The underlying objective of this study was to develop a novel approach to evaluate the potential for commercialisation of a new technology. More specifically, this study examined the *'ex-ante'* evaluation of the technology transfer process.

For this purpose, a technology originating from the high technology sector was used. The technology relates to the application of software for the detection of weak signals from space, which is an established method of signal processing in the field of radio astronomy. This technology has the potential to be used in commercial and industrial areas other than astronomy, such as detecting water leakages in pipes. Its applicability to detecting water leakage was chosen owing to several problems with detection in the industry as well as the impact it can have on saving water in the environment.

This study, therefore, will demonstrate the importance of interdisciplinary technology transfer. The study employed both technical and business evaluation methods including laboratory experiments and the Delphi technique to address the research questions.

There are several findings from this study. Firstly, scientific experiments were conducted and these resulted in a proof of concept stage of the chosen technology. Secondly, validation as well as refinement of criteria from literature that can be used for *'ex-ante'* evaluation of technology transfer has been undertaken. Additionally, after testing the chosen technology's overall transfer potential using the modified set of criteria, it was found that the technology is still in its early stages and will require further development for it to be commercialised. Furthermore, a final evaluation framework was developed encompassing all the criteria found to be important. This framework can help in assessing the overall readiness of the technology for transfer as well as in recommending a viable mechanism for commercialisation.

On the whole, the commercial potential of the chosen technology was tested through expert opinion, thereby focusing on the impact of a new technology and the feasibility of alternate applications and potential future applications.

List of abbreviations

AAO	Anglo Australian Observatory
ACTA	Australian Telescope Compact Array
ADC	Analogue-to-Digital Convertor
APL	Applied Physics Laboratory
ANTF	Australian National Telescope Facility
AUTM	Association of University Technology Managers
CCF	Cross-Correlation Function
CEO	Chief Executive Officer
CRADAs	Co-operative Research and Development Agreements
CRO	Cathode-Ray Oscilloscope
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAE	Department of Atomic Energy
DiFX	Distributed FX
F1	Formula One
FFT	Fast Fourier Transform
GPS	Global Positioning System
IRA	Interrater Agreement
KER	Kinetic Energy Recovery
MRG	Medical Research Group
MRI	Magnetic Resonance Imaging
NA	Nada/No response
NASA	National Aeronautics and Space Administration
NMR	Nuclear Magnetic Resonance
NSB	National Science Board
OECD	Organisation for Economic Co-operation and Development
PIMS	Programmable Implantable Medication System
PVC	Polyvinyl Chloride
QUT	Queensland University of Technology
TT	Technology Transfer
UNSW	University of New South Wales
VC	Venture Capital/Capitalist

Statement of Original Authorship

The work contained in this thesis has not been previously submitted for a degree or diploma at any other higher education institution. To the best of my knowledge and belief, the thesis contains no material previously published or written by another person except where due reference is made.

Signed: ________________________________

Dated: ________________________________

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Table of contents

List of figures

List of tables

Chapter 1: Introduction

1.1 Overview

Technology Transfer (TT) is a highly expanding field of knowledge attracting a great deal of interest from institutions and industries alike (Reisman, 2005). Many firms choose to acquire new technologies and capabilities from other firms in different industries to maintain and enhance their competitiveness (Ranft & Lord, 2002). The ability of certain technologies to be applied in other disciplines allows for the possibility of new and improved products and services. There are many documented examples of interdisciplinary transfers, some which have been very successful. For example, satellite imagery, which involves satellites designed to send images back to earth. The related technology in this case is Nuclear Magnetic Resonance (NMR) (also known as magnetic resonance imaging), which is used to scan sections of the human body. Consequently, the technology originally used by NASA to sharpen and enhance the images received from space was applied to NMR used to scan the human body, and this greatly helped in the better diagnosis of cancer by producing cleaner images (Baker, 2000). This is one of the many examples that demonstrate the use of technologies in areas other than that for which they were originally intended. Thus, it is unsurprising that there has been a significant increase in the research on technology transfer conducted to create and modify technology (Autio & Laamanen, 1995).

Technology Transfer (TT) usually involves the participation of two parties, a transferor and a transferee, but in the bigger picture it can involve companies, organisations (including institutions) or even an entire nation, and there can be more than one discipline involved (Reisman, 2005). Furthermore, technology transfer from universities has gained importance in recent years, especially after the introduction of the Bayh-Dole Act in The United States in 1980. This is due to the fact that there is valuable research originating from many universities that has the potential to produce good products; but because the primary goal of universities is not commercialisation, valuable research is sometimes lost. This has led to many organisations getting involved through industry linkages, to encourage universities to continue their research with a commercial goal in addition to the academic milestones.

Universities commercialise their innovations through many mechanisms, even though there are certain mechanisms utilised more than others, such as licensing and spin-offs. It is always required to increase the chances of a successful transfer, therefore it is always necessary to have a framework or set of criteria that can be used to evaluate the usefulness of the technology and predict if its transfer will be successful and beneficial. A successful example of a technology transfer from a university to the market is that of the University of Florida, which commercialised Gatorade, a sports drink developed in the 1960's by a team of researchers, which has earned the university more than $94 million over the years from licensing alone (Dibella, 2005). The example of Gatorade is one of many in establishing the importance of the commercial potential that can be generated from educational institutions. To achieve such success, evaluation is also necessary.

Whether before or after the transfer, technology transfer evaluation is becoming increasingly important, because it is helpful in assessing the value of a technology. As mentioned above, this is especially true for university related research as it is being recognised as an important source of innovation and economic development, and this is verified by the fact that various industries are entering collaborations with universities and funding academic research (The Council on Governmental Relations, 1999; Rahal & Rabelo, 2006).

Based on the increasing importance of university contribution to commercialisation and the requirement of evaluation to reduce risk, the objectives of the study will involve:

- Developing a set of criteria for evaluating the process of technology transfer in the high technology sector, which can also be used across disciplines. This includes the development of a framework encompassing the criteria;
- Evaluating the commercial potential of an emerging technology using the criteria, and;
- Proposing a suitable TT mechanism for commercialisation following the evaluation.

This is further elaborated on in the next section.

1.2 Objectives

The objectives relate to the ever-increasing involvement of universities in the commercialisation process. This only justifies the need for a better evaluation tool that can be used to assess potential transfers from universities. Such a tool can be beneficial as it can aid in better decision making as well as the selection of the right technology, and the subsequent selection of the most favourable mechanisms for commercialisation. This research aims to yield a suitable approach to evaluate the potential for commercialisation of a new technology, by developing and compiling a list of the most important criteria used to evaluate the technology transfer process. More specifically, this study will examine the *'ex-ante'* evaluation of the technology transfer process. To fulfil these objectives, three research components are required. The first involves the accumulation of criteria and mechanisms considered important for commercialisation according to the pertinent literature, followed by the recruitment of experts who will aid in refining these to a more robust collection. The second part is science oriented, whereby an existing technology originally developed for radio astronomy will be studied and an application sought. This will be achieved through laboratory experiments. The experiments will help to establish whether the technology has an application by presenting results with a proof of concept, through a scientific analysis that will be conducted in the laboratory. The last and third part will actually test the refined criteria to evaluate the potential of the technology for transfer, using experts with commercialisation backgrounds. The experts will also play a role in selecting the best mechanism for the commercialisation of this technology.

This study is innovative as it involves an interdisciplinary approach to explore a technology and evaluate its commercial potential. This research is interdisciplinary at two levels. The fist interdisciplinary aspect is that the study involves both scientific and business disciplines. The second interdisciplinary aspect is related to the migration of the technology from its application in one discipline (radio astronomy) to another area (leak detection). This will be further discussed in Chapter Three.

Additionally, the outcomes of the research will not only result in theoretical contributions but also practical implications, as these results could be used by universities when evaluating their research. It is also possible that further development of the chosen technology will yield potential intellectual property value. As mentioned above, the study will employ both technical and business evaluation methods to address the research questions outlined in section 1.3, along with the research problem.

1.3 Outline of the research problem and research questions

There are several gaps in the literature that resulted in the above research objectives. As Harris and Harris (2004) state, there is no current framework to assess the likely success of the transfer of a technology before a product is designed, produced, marketed, and put into use. In this context, the purpose of this study is to evaluate the technology transfer process from an interdisciplinary perspective. This study is beneficial as it combines the science and business disciplines and the evaluation methods involved in conducting experiments, as well as methods used to collect data to contribute to the framework proposed for the business aspect. In other words, the methodology encompassed a science and business component, which is further explained in the methodology outline.

The evaluation of the TT process has generated the greatest interest among technology transfer researchers, because it can determine the feasibility and value of the technology (Autio & Laamanen, 1995). Many studies have particularly focused on evaluating the contribution of universities to the private sector in the TT process (Schimank, 1990; Carlsson & Stankiewicz, 1991; Niosi et al. 1993; Dibella, 2005). The purpose of this research, therefore, is to propose an '*ex-ante'* evaluation tool in an interdisciplinary field focusing on the high technology sector, involving a technology in the area of radio astronomy with a possible application in water leak detection. This objective is also supported by Roper et al's (2004) emphasis on proposing a framework for the '*ex-ante'* evaluation of publicly supported Research and Development (R & D) activities, whose research resulted in an *'ex-ante'* evaluation framework due to their unsuccessful attempts to find existing approaches.

Furthermore, this study explored the current evaluation methods and frameworks as well as various methods and criteria used for evaluating technologies in the high technology sector, by identifying the most influential criteria in evaluating technologies before they are transferred from a university, as well as the most suitable mechanisms for the transfer of high technologies. Along with this, a list of criteria will also be proposed that can be used to evaluate technologies that have potential industry applications, and have the potential to be transferred across industries.

The proposed research questions have been posed to address the identified gaps from the literature so as to contribute to the current research. All three questions are linked to each other and follow a trend, starting from the applicability of the chosen technology and then moving to the criteria that are crucial for *'ex-ante'* evaluation, followed by the possibility of commercialisation through a suitable mechanism. Below are the three research questions:

Research Question 1 (RQ1):

Does the technology in question, initially developed in the field of astronomy, have an application in detecting leakage in pipes used for water transportation?

This question was formulated to explore a possible useful application where the innovative technology could be transferred.

Research Question 2 (RQ2):

What important criteria should be involved in the 'ex-ante' evaluation of the technology transfer process in high technology industries?

The motivation for this question was to filter the best criteria from the available so as to categorise and compile them into a framework.

Research Question 3 (RQ3):

What is the effective mode of transfer to enable efficient commercialisation of the above technology and what would be the most suitable path to commercialisation?

Specifically for this case, it would be beneficial to know what would be the best route to commercialisation, and the reasoning behind the choice could help to determine the most suitable path to commercialisation for the chosen technology.

1.4 Outline of the methodology

The methodology consisted of a combination of methods and these were dependent on each other to obtain the final outcome of the research. The process of data collection and analysis was divided into two parts; a business component and a science component. *Figure 1.1* is an overview of the research design adopted for this study. The figure is a representation of the research journey that began with problem identification and a literature review, which then led to the recognition of research gaps and research questions as well as the generation of a conceptual framework. The methodology was then split into two parts that include a scientific component consisting of laboratory experiments and a business component in which a Delphi study was conducted.

The scientific component consisted of laboratory experiments to determine the feasibility as well as the replicability of the technology, by establishing a proof of concept. The business component involved the compilation of a list of crucial criteria for evaluation and mechanisms for commercialisation from literature. This list was then adopted as the basis on which to conduct a Delphi study, with participants from various areas of expertise that also have commercialisation experience. The experts were chosen using snowball sampling. The Delphi study aimed at gathering the best criteria from the compiled list as well as feedback from the experts. Following this, the refined list was then used to evaluate the technology being investigated, using results from the experiments and the extent of the technology development itself.

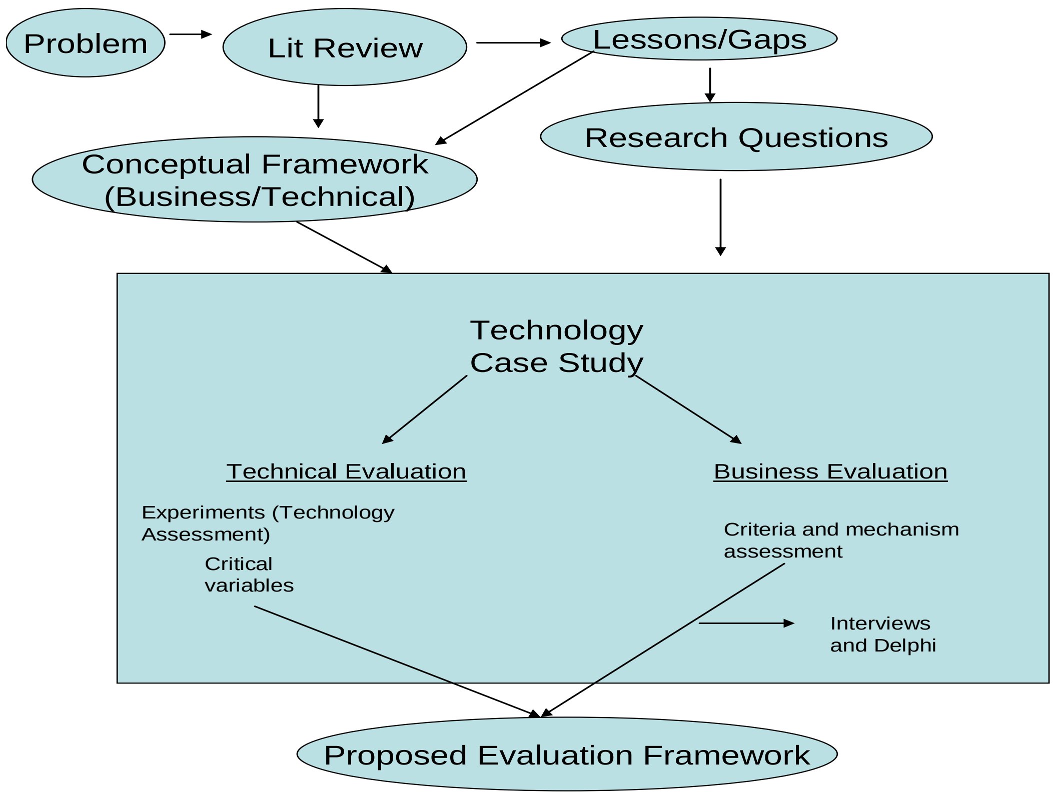

Figure 1-1 Overview of the adopted research design

1.5 The technology

In this case, the technology is software that was modified according to the requirements of this research. Further details about the technology and application can be found in Chapter Three.

1.6 Structure of the thesis

Figure 1.2 is a visual representation of the thesis outline. As the figure illustrates, the thesis consists of eight chapters in total.

Chapter One is the introduction to the research. It will highlight the objectives of the research as well as introduce the research questions shaped from the gaps identified in the literature review. The key components of the methodology adopted for the research will also be explained. There is also a section on the chosen technology and a justification section for the research.

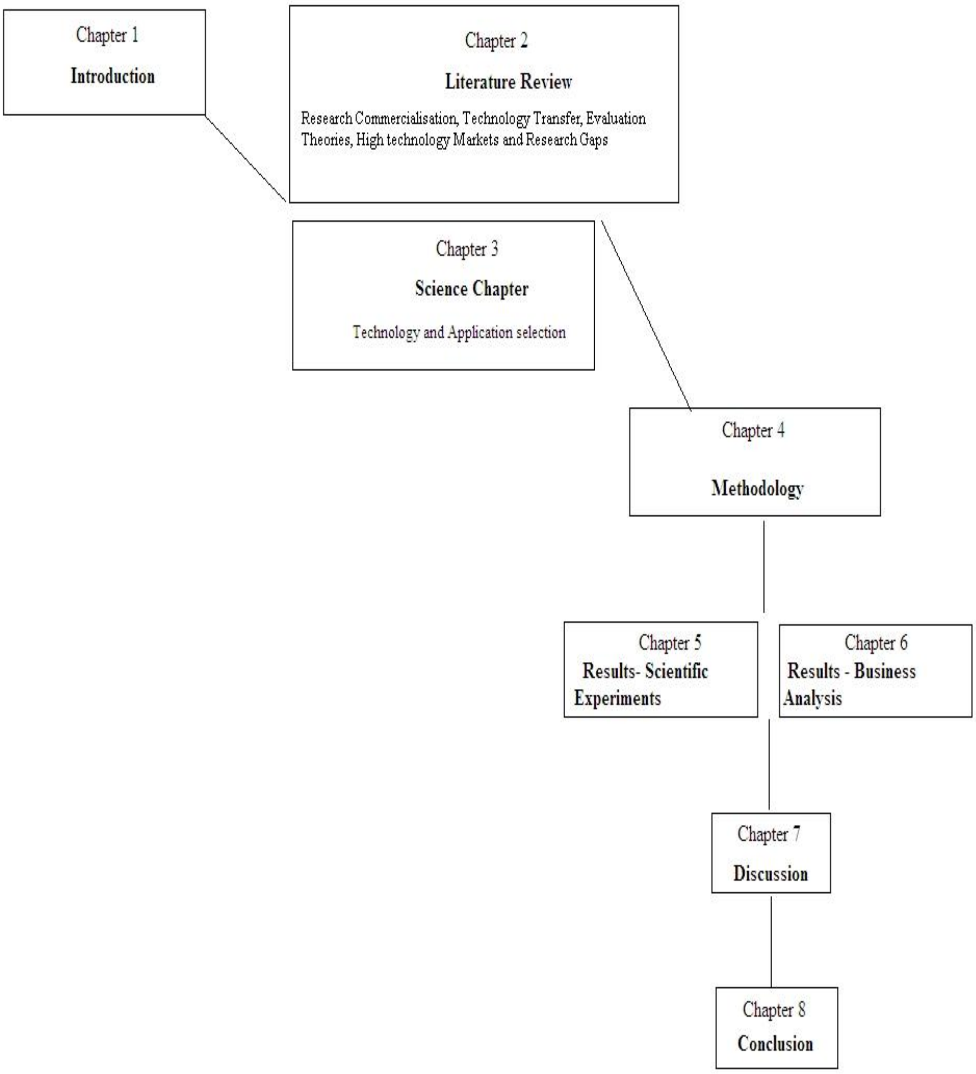

Figure 1-2 Thesis outline

Chapter Two consists of the literature review divided into four separate sub-sections, namely, research commercialisation, technology transfer, theories on evaluation, and markets for high technologies.

The section on research commercialisation contains definitions and discusses the changing role of commercialisation, especially from universities' point of view. The important components of commercialisation are also presented, as is the growing role of educational institutions in research commercialisation is discussed along with related criteria to help improve commercial success.

The section on technology transfer focuses on an appropriate definition for technology transfer as well as the two main streams of research in this area. Literature has identified that one stream focuses on facilitators and barriers to the process, while the other deals with models and frameworks as well as mechanisms that have also been identified from literature. Some examples of mechanisms are licensing and spin-offs. Additionally, in this stream of research, technology transfer can be classified as vertical and horizontal: vertical transfer occurring through the stages of development and horizontal from one area of application to another. The various types and forms of the process are presented, as well as some of the major actors in the process.

The section on evaluation discusses the importance of the process of technology transfer and differentiates the levels of evaluation as recognised from the literature, establishing that *'ex-ante'* evaluation is the one of interest for this research. There is also an elaboration on the different types of criteria that can be used for evaluation.

The last section of the literature review is an overview of the markets that deal with high technology products. It is important to realise that these products are different to those from general markets for a number of reasons, including issues with intellectual property. Literature points out that these markets are competitive owing to the fact that there can be alternate technologies that could be obtained more easily and cheaply. There has also been an increase of products and services that have developed from technologies originating from universities, as previously stated. Hence, due to the important role of markets in technology transfer, it is imperative to investigate the relevant literature.

Chapter Two also has a summary of the findings from the literature review as well as the related research gaps. The main gaps identified from literature include *'ex-ante'* evaluation, which has not been considered as important as evaluation conducted after the transfer of a technology, namely, ex-post evaluation. This sort of evaluation is normally done to assess whether a transfer has been successful or not, and if it is determined successful, the most influential factors that aided in its success are also evaluated. This also relates to the frameworks and assessment criteria used for this purpose. There are not many frameworks that have been developed to evaluate technology transfer before the actual transfer, which is a major gap in the area.

Chapter Three deals with the chosen technology. This chapter will elaborate on the importance of interdisciplinary research and introduce the technology that will be investigated, as well as the justification for choosing the particular application. It will discuss the technology to be used and why it would be beneficial to do so, as well as some of the issues with the current area of application.

Chapter Four provides details of the methods that will be adopted. The chapter will include sampling strategy as well as a justification of the sample size to be used. The methodology is divided into two separate phases; a science phase and a business phase. The chapter will cover scientific methods and business techniques to be used, including the Delphi technique used to generate a list of criteria from the literature that will be analysed and refined using selected experts from different fields with commercialisation experience.

Chapters Five and Six will address the science and business results respectively, to illustrate the results separately. Chapter Five will include the results of the scientific experiments while Chapter Six will contain the results of the Delphi rounds. Chapter Six will also include an assessment of the technology transfer potential of the chosen technology, using the criteria generated from literature and refined by the Delphi conducted with the experts.

Chapters Seven and Eight will consist of the discussions and conclusions respectively. Chapter Seven will include the findings while Chapter Eight will elaborate on the most important lessons to be learnt from this research, and will also include theoretical contributions and practical implications as well recommendations for future research.

1.7 Justification for research

New challenges for the evaluation of technology transfer are posed due to the ongoing shift in research in the technology transfer area, as well as changes in technological innovation dynamics (for example, Autio and Laamanen, 1995; Galbraith et al., 2007). As outlined in Section 1.2, there is a growing interest from universities in commercialising their research. More importantly, there is a need for more research when it comes to the *‘ex-ante’* evaluation of technology transfer.

According to Wang et al. (2003), the different ways that technology transfer occurs, the involvement of a number of people and organisations, and the various processes (technological and organisational) that occur are reasons why it is sometimes difficult to facilitate and evaluate technology transfer. Hence, this research aims to identify the key and crucial factors and criteria related to the high technology industry. Some of the gaps identified from literature included a deficiency of *‘ex-ante’* evaluation frameworks and models for the purpose of determining the commercial potential of technologies. Additionally, the range of criteria included in these frameworks and models normally tend to include a majority of criteria focussed on monetary benefits, and therefore lack an overall diversity and range that needs to cover broader factors such as impacts on society.

Hence, a framework will be proposed that considers existing models and criteria from literature using a technology transfer case from a university setting.

1.8 Summary

This chapter presented the background to the research (Section 1.1) and the related gaps in the literature along with research questions (Section 1.3) and objectives (Section 1.2). Due to the involvement of a technology, a brief description of the chosen technology was also given (Section 1.5). Apart from this, the outline of the thesis (Section 1.6 and *Figure 1.2*) along with the methodology (Section 1.4) and justification (Section 1.7) have also been discussed. The following chapters will describe the components of the thesis with a detailed description.

Chapter 2: Literature Review

2.1 Introduction

The purpose of this literature review is to explore the key concepts of commercialisation, technology transfer, and their related components and theories. The literature review also covers the technology evaluation and high technology market theories, with a particular focus on gaps in the literature. More emphasis will be placed on technology transfer, evaluation, and the markets related to innovation as well as the products and services created through innovation. The literature on commercialisation will be covered so as to introduce the relationship between commercialisation and the technology transfer process.

2.2 Key concepts

Figure 2.1 is a simple visual representation of the relationship between the different areas of the literature investigated for this research. The broader area is that of research commercialisation which encompasses other themes within the literature, namely, technology transfer, evaluation theories and high technology markets. These themes are in turn related to each other. There are many aspects of the literature but this diagram is specifically tailored to this thesis. The aim is to illustrate that these areas have some common literature demonstrated by overlaps in information. However, there are also gaps that will be investigated as the literature is reviewed. Hence, it is important to demonstrate as well as explain the relationship between all the respective themes so as to identify the related gaps.

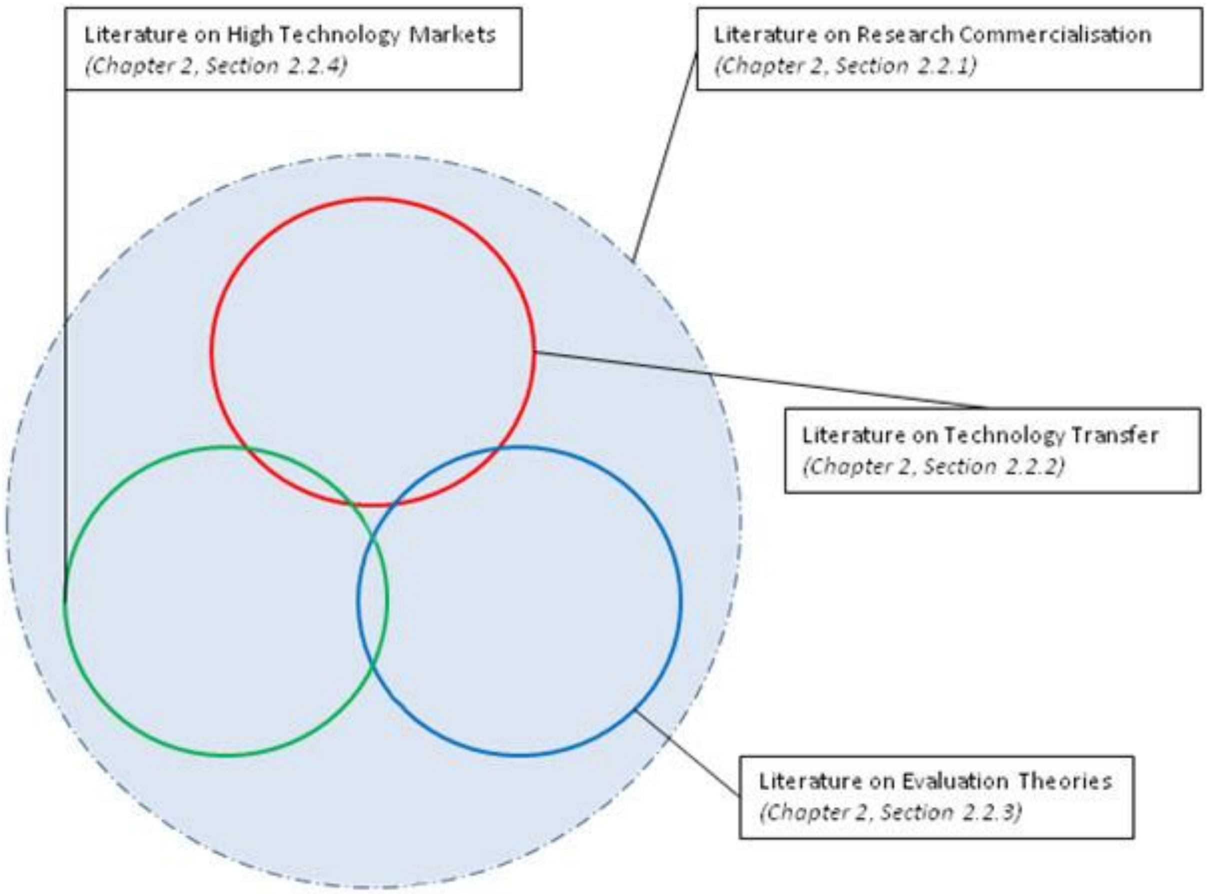

Figure 2-1 Relationships between the key concepts of the literature

2.2.1 Research commercialisation

The broader literature on innovation[1] is extensive[2] and has many streams[3] (Kuznets, 1962; Damanpour, 1991; Utterback, 1994; Bessant & Rush, 1995; Camison- Zornoza et al., 2004; Katila & Shane, 2005; Van der Duin et al., 2006; Miles et al., 2006). The

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1 According to Garcia and Calantone, Innovation is "an iterative process initiated by the perception of a new market and/or new service opportunity for a technology-based invention which leads to development, production, and marketing tasks striving for the commercial success of the invention" (2002:3).

2 Garcia and Calantone's (2002) research on innovation typology and innovativeness terminology is a good example of a literature review on innovation, and covers definitions and typology to identify various technological innovations; for example, incremental innovations and imitative innovations amongst others.

3 Studies on innovation as a separate field of research surfaced in the 1960s, but did so focusing on not only a discipline but, instead on cross disciplinary studies, and this is the essence of this thesis (Fagerberg, 2003).

following discussion is focused on research commercialisation, which is the particular stream of innovation research directly related to this thesis.[4]

To define research commercialisation for the purpose of this research, a definition proposed by Zhao (2004) will be used. Zhao (2004) defines it as "a process of developing new ideas and/or research output into commercial products or services and putting them on the market. It covers intellectual property (IP) transfer and development, as well as the provision of consulting services that rely primarily on technological innovation". This definition was derived from definitions proposed by the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) and the Australian Research Council (ARC). Simply put, the commercialisation of technology involves the introduction of new processes, applications, or the modification of existing production process or services to suit markets needs, or even create a new market involving various actors and resources that include capital and human dimensions. Although research commercialisation and technology transfer are used interchangeably, there are some differences between the two. Research commercialisation involves the converting of scientific innovations into products and services that can be marketed (Harman & Harman, 2004), and Thore (2002, p xii) defines technology commercialisation as "the movement of ideas from the research laboratory to the market". According to Thore (2002), there are three steps leading from research to commercial activities and application for a novel technology that include:

- Transfer of the technology to an interested business party either by the institution itself or with help from a third party
- Further development done by the recipient or transferee and this can involve anything from modifications to the technical and business activities.
- The process of technology commercialisation, which includes the launch of the final outcome; for instance, a product.

4 For the purpose of this study, innovation can be defined as "any change in the application of a product or service away from its original purpose – e.g. using personal computers as a vehicle for communication rather than stand alone items, and eventually using the Internet as a vehicle for commerce as well as more general communication" (Johnson, 2001: 139). In this context, the type of innovation will be an incremental innovation which is basically new applications and products that arise from existing technology and an existing market (Garcia & Calantone, 2002).

Commercialisation can include the generation of ideas, definition of the product, screening which leads to the development of a prototype, marketing and financial analysis, product development and testing, which will then lead to the launch (Cooper, 1993; Dorf & Worthington, 1987; Robertson & Weijo, 1988). The process of commercialisation can be explained using a simplified diagram of the different components involved, as *Figure 2.2* demonstrates.

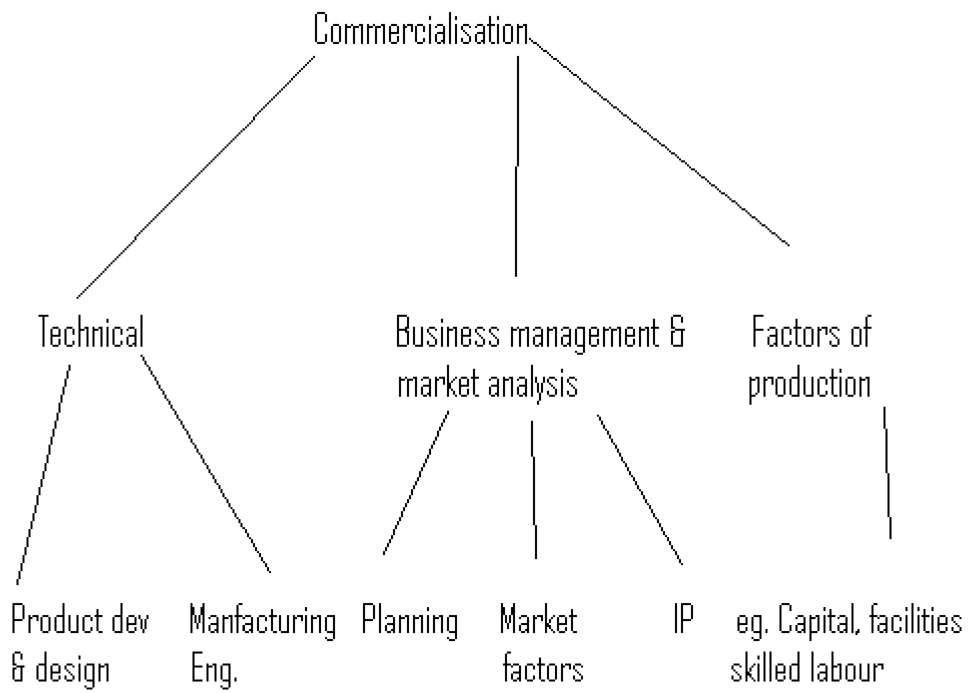

Figure 2-2 Components of commercialisation

The three main components include the technical aspects, the business side, and other factors of production. Apart from these factors, entrepreneurs and networks play an important and influential role. The agents who help to transfer technologies play a crucial part in the process as well, and they include technology consultants and technology transfer offices (TTOs) in universities. An important aspect of commercialisation is IP. It is imperative that staff and students who are looking to commercialise their work know what it is and how to protect their work and this also involves not exposing their IP through publications and presentations at conferences, for instance. In Australia, the main types of IP protection offered are:

- Letter patent, providing protection for a new and improved product or process (Patents Act)
- Registered designs (Designs Act)
- Trademarks, which connect a product or service with the provider (Trade Marks Act)
- Copyright, which provides protection for novel work such as music and computer programs (Copyright Act) and
- Trade secrets or confidential information (Common Law)

Usually, patents are the most relevant when it comes to commercialisation from universities. Patents are a form of motivation that encourage researchers to commercialise their innovations as they know their work is protected for a period of time (twenty years depending on when the fees are paid and the application process), and in this way they can have monopoly for some time (Irvine, 1988; Santer, 1988; Wood, 1992). Owning IP is very important, but it is also necessary to have knowledge of the commercialisation process.

Commercialisation can take place from within an institution such as a university, as well as from one firm to another. Is it important to understand some of the differences between the two as the main focus in this thesis is on transfers from universities to industry. Some of the major differences include transfer channels. Several of the paths adopted by universities include publications, collaborative or contract research, consultancy, licensing, spin-offs, joint ventures, and Technology Transfer Companies (TTC) or Technology Transfer Offices (TTO) (Cripps et al., 1999; Harman & Harman, 2004). Another point to note is that universities’ primary goal is not commercialisation and research is not driven by the market (Lee & Gaertner, 1994). Rahm (1994) also states that universities and firms have different goals, structures, cultures, and research patterns, and one good example is that universities are keen to publish while firms tend to be more discrete to prevent any competitors from getting information. While universities want to make a contribution to research, firms are looking for applications. In addition, universities and firms will have different approaches to handling intellectual property. Lee and Gaertner (1994) describe research commercialisation from universities to the outside world in the form of a model *(see Figure 2.3).* The model below illustrates the different stages involved for basic research to be developed and commercialised to finally reach the market. The model resembles a stage gate process as it has a *go, no go* system, wherein if the previous stage is not fully complete, the research and subsequently its commercialisation will not proceed (*no go*) and the opposite will occur if everything goes well with the stages (*go*). While this is a good representation, it is necessary to know the role of commercialisation in the higher education sector.

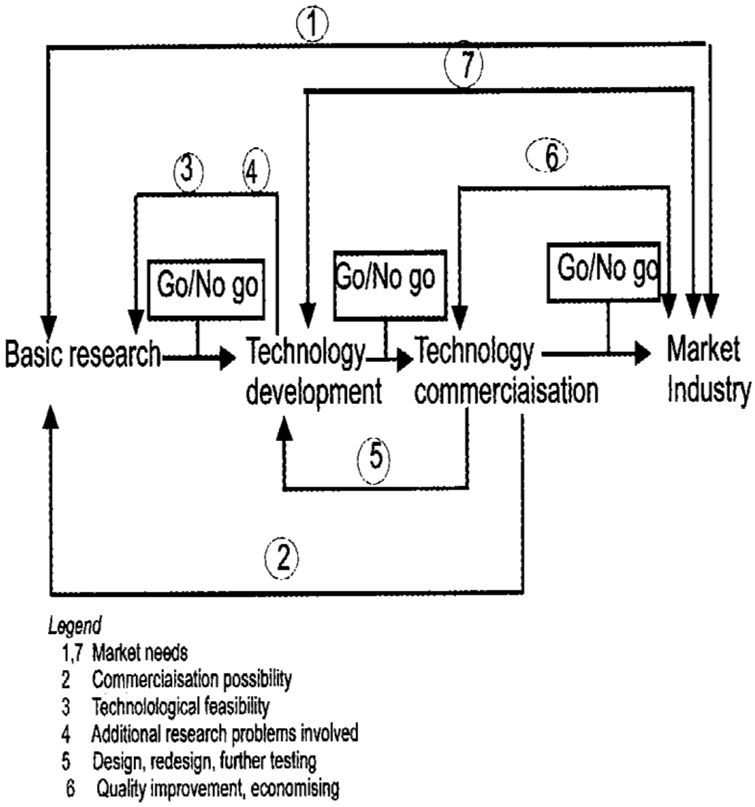

Figure 2-3 Model depicting university research commercialisation (Lee & Gaertner, 1994)

The role of educational institutions such as universities has experienced considerable change in relation to their roles and contributions to innovation, which has led to an increase in the types of relationships leading to knowledge creation and spill over (Gibbons et al., 1994; Howells & McKinlay, 1999).

The Bayh-Dole Act or Small Business Patent Procedures Act adopted in 1980 helped to revolutionise how universities were involved in commercialisation, and helped improve the number of licences and patents originating from universities in the United States. The Bayh-Dole Act was named after Senators Birch Bayh and Robert Dole who cosponsored the Act under President Carter (Nelson, 2001; Mowery & Ziedonis, 2002; Baumel, 2009)

The Act allows universities to patent and own inventions as well as license all inventions arising from federally funded research, and retain any profit resulting from commercialisation. This gave universities control and a sense of motivation to conduct further research for commercial gain. The implementation of the Bayh-Dole Act saw a huge increase in patents from American universities, and some governments followed with their own laws. For instance, countries such as Brazil, China, and South Africa passed acts allowing the patenting of research funded by the government. More recently, India's version of the Bayh-Dole Act labelled "Public Funded R&D Protection of Intellectual Property Bill, 2008" is awaiting the approval of parliament. The Bayh-Dole Act also has helped further, if not created, the biotechnology industry post 1980s (Nelson, 2001; Mowery & Ziedonis, 2002; So et al., 2008; Baumel, 2009).

The advantages of the Act were that universities became involved with industry and this helped to increase research in areas such as biotechnology, which needed collaboration between universities and industry to thrive. However, there are controversies in that the Act might stop the speed and spread of knowledge transfer due to intellectual protection and the fear that universities might lose their academic priorities (Nelson, 2001; Mowery & Ziedonis, 2002; So et al., 2008; Baumel, 2009)

Additionally, it is true that, at present, universities play a role in supporting and contributing to innovation and technology transfer, but this has some downsides. This includes the fact that the primary research and education goals of universities which involves fundamental research and educating students might be affected, and the loss of valuable information may occur by disclosing research prematurely through publications and conferences. However, commercialisation and its subsequent benefits are key motivators for a percentage of research conducted at universities. It is also interesting to see that linkages between universities and industries have resulted in mechanisms such as spin-offs, collaborative research, and licensing of intellectual property rights (IPRs) (Howells & McKinlay, 1999).

As mentioned above, universities have paid much attention to technology commercialisation since the mid-1980s. For example, in 1979, U.S. universities were granted about 264 patents, and by 1997, this number rose to approximately 2,436 (Tidd et al., 2001). This can be attributed to the increasing realisation of the value of such transfers, and that they account for another source of income and contribution to society and industry as well as knowledge spillovers. This is also enforced by the fact that research in universities is no longer constrained to just publishing or academia in general.

Commercialising academic research is widely encouraged and is seen as positive not only because it helps universities to showcase their research to a wider audience, but also because it is an opportunity to establish industry linkages as well as additional funding for research, which can result in the generation of IP and further benefits. Once commercial potential is recognised, universities encourage industry participation and projects so as to increase funding opportunities as well as input from experienced experts. However, this does not always result in a successful outcome, because of reasons such as the inventor being unwilling to spend a lot of time on the project or a lack of funds in the later stages (MacBryde, 1997).

The last few decades have seen an increase in contribution to commercial activity from Australian universities. This is also supported by Lööf and Broström (2008) who state that much attention is given to the influence of universities in literature relating to innovation and technological change. According to statistics, the higher education sector is responsible for more than 25 per cent of all research and development conducted in the last couple of decades (Burgio-Fica, 2001; Zhao, 2004). Statistics reveal that in the five year period between 1992 and 1997, Australian universities increased their funding from industry by some $130 million (Australian Vice-Chancellor's Committee, 1999; Harman, 2001). Additionally, technology transfer from the higher education sector has been economically beneficial and important in the last decade and has lead to academic research being commercialised (Slaughter & Rhoades, 1990; Wood, 1992). Howells and McKinlay's (1999) study on the commercialisation of research from European universities concluded that there was a lack of criteria needed to help with decision making in commercialisation. The literature on the relation of universities and technology transfer provides an insight into the importance of this relationship.

The literature on commercialisation is vast, but it helps to demonstrate the importance of commercialisation and the growing involvement of universities in the process. However, some researchers still argue that the primary role of universities lies in academia, but statistics prove otherwise. Universities are a great source of new innovations and are expected to produce and develop novel ideas and technologies, although there are shortcomings such as intellectual property and lack of expertise that sometimes hinder their involvement. As Lee and Gaertner's (1994) model illustrates (*see Figure 2.3*), there are a lot of factors that can influence the commercialisation process. Hence, the purpose of the following sections will be to further explore the different areas of literature, and seek to accumulate useful criteria that can help to evaluate the potential for a technology to be commercialised before the process is actually initiated.

2.2.2 Technology transfer

The technology transfer process plays an important role not only for universities but also for organisations and economic development (Dority, 2003). The term 'technology transfer' has been defined in various ways in the literature. While a simplified definition by Pankova (2002: 350) is "The diffusion of technology as well as the dispersion of know-how and skills", for the purpose of this study technology transfer can be defined as "the process by which technology, knowledge, and/or information developed in one organization, one area, or for one purpose is applied and utilized in another organization, in another area, or for another purpose" (Winebrake, 1992: 54). The nature of the technology itself is not the only factor that leads to successful technology transfer. There are other factors in the environment of the technology that play a part as well.

Technology transfers can occur in various ways: licensing, direct foreign investments, technical agreements, joint ventures, turnkey projects, and the purchase of equipment amongst others (Wei, 1995). Alternatively, five technology transfer mechanisms have been identified by Göktepe (2004), namely, start-ups, licensing, meetings, publications, and R&D agreements. Göktepe (2004) also states that when technology flows from a certain stage to the next the transition is not smooth, but is usually affected by gaps such as identifying a potential application and when and how this can be turned into a marketable product, and that such gaps can break the flow of the transfer. A framework that could take all of this into consideration can help to minimise gaps and maximise the efficiency of the flow.

Many companies, especially in the high technology industry, decide to obtain technologies from other firms rather than depend on their own research and development (Haspeslagh & Jemison, 1991; Huber, 1991; Kozin & Young, 1994).[5] Attainment activity

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5 High technology industries include those engaged in the design, development, and introduction of new products and/or innovative manufacturing processes through the systematic application of scientific and technical knowledge (Mohr, Sengupta & Slater, 2005). It is comprised of diverse sectors such as electronics, aerospace, telecommunication, and biotechnology and computer software. Additionally, The Organisation for Economic Co-operation and Development (OECD) (2001) identifies five industries as high technology: science-based industries, aerospace, pharmaceuticals, computers and machinery, communication based apparatus, and scientific instruments.

in high technology sectors such as biotechnology, electronics, and software rose considerably in the 1990s (Sikora, 2000). According to Ranft and Lord (2002), it is not enough for a technology just to be bought; it must be nurtured and integrated throughout the process of implementation.

In general, there are two main streams of research on technology transfer. The first stream looks at barriers and facilitators of technology transfer. Kirkland (1999), for example, describes five groups of barriers:

- Legal barriers, mainly intellectual property rights
- Financial barriers, mainly a lack of financial resources
- Limited skilled manpower
- Communication barriers, including the gap between scientists and people on the business side
- Technological barriers and difficulties

Guilfoos (1989), on the other hand, classifies barriers to technology transfer into three main categories: technical, regulatory, and people. Other researchers have also identified and classified barriers (see Carr, 1992; Spann et al., 1993; Greiner & Franza, 2003) (for example, *see Table 2.1*).

Table 2-1 A summary of barriers to technology transfer (Greiner & Franza, 2003)

Technical barriers	
• Technical Risk	• Lack of operational test data
• Lack of a defined requirement	• Risk aversion
• Equivocality	
Regulatory barriers	
• Lack of technical orders for the user	• Long development and procurement lead times
• Lack of regulations defining the use of the technology	• Changing specifications
People barriers	
• Unaware of new technology	• Lack of motivation
• Lack of communication	• Distance (geographical and cultural)
• Lack of information	• Too busy
• Technology push versus market pull	• Unimportant job function (transfer)
• Lack of transfer experience	• Lack of trust

The second stream of research, which is related to this study, looks at models, mechanisms, and frameworks of technology transfer. In this stream, technology transfer can be categorised as horizontal or vertical. Vertical transfer of technology moves through a discovery phase, a creative phase, a validation phase, a development and engineering phase which further leads to function and a technological system involving hardware, processes, or a concept (Roman, 1970). Horizontal transfer occurs when technology from one place is transferred for its application in another place, for example from one firm to another (s*ee Figure 2.4).* Vertical transfer occurs when the process moves from basic to applied research or development and subsequently to commercialisation (Grosse, 1996).

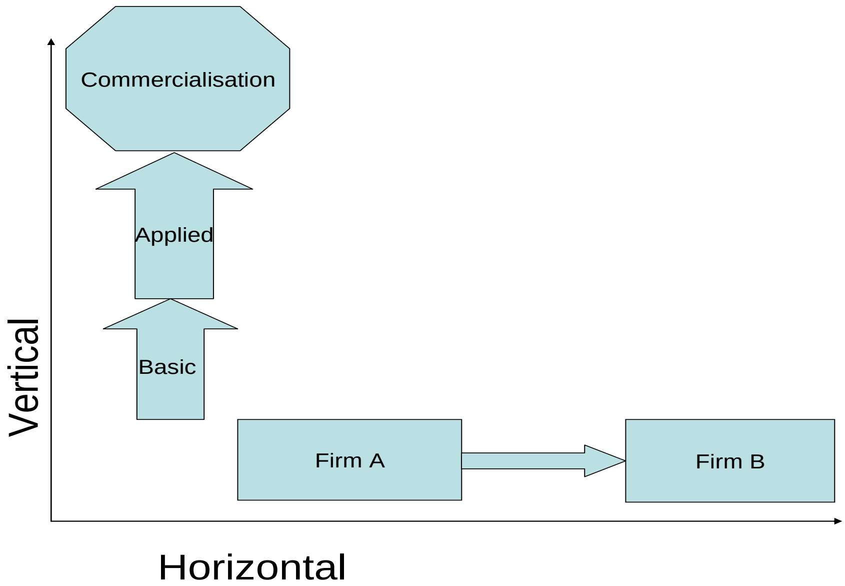

Figure 2-4 Horizontal and vertical technology transfer

In this stream of research, Göktepe (2004) describes the different modes of transfer as "linear", "reverse", and "interactive" modes of technology transfer. The linear mode is inspired by Bush's (1945) linear model of innovation. This is based more on progression from idea generation and technology development through to licensing or forming a spin-off. The reverse linear model occurs when the problem starts within the industry and the technology is developed by university researchers to address the problem. Finally, the third group of studies describes transfer as an interactive process between the various players (Kline & Rosenberg, 1986). Wang et al. (2003) present several key steps that occur in the process of technology transfer (*Figure 2.5)* and maintain that investment is required for this to take place.

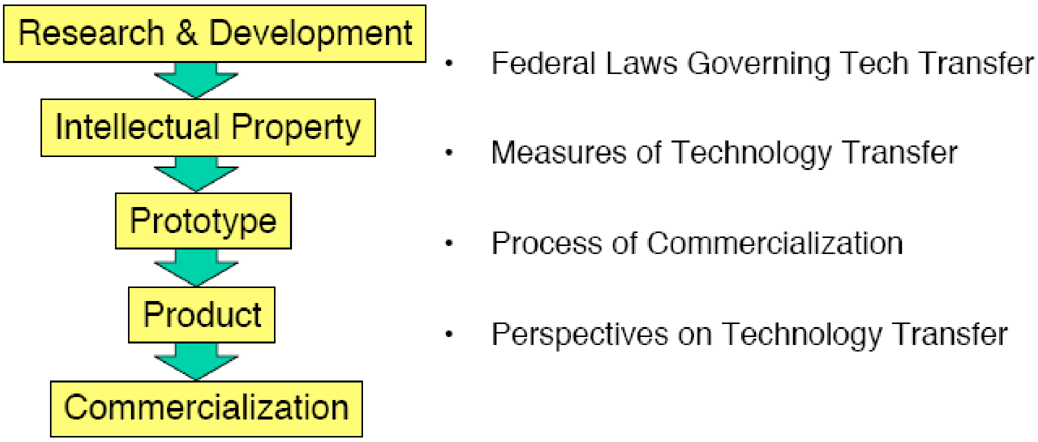

Figure 2-5 Steps involved in the technology transfer process (simplified and modified) (Wang et al., 2003)

Other researchers such as Reisman (2005) represent a taxonomy encompassing the attributes of TT *(see Appendix A).* These include the actors (eg. transferors and transferees), the transaction types (eg. external transfers), motivations for conducting transfer (eg. economic and social), and participating disciplines (eg. management). On the other hand, Spann et al. (1995) classify the major players or roles of the human criterion in technology transfer as:

- Disseminators – make potential users aware of technologies; counsel users and serve as brokers between technologies and adopters
- Sponsors – provide political and financial support
- Developers – conduct laboratory, scale-up, and field trial R & D
- Implementers – cultivate customers and troubleshoot new technology applications
- Adopters – incorporate and use the technologies in their commercial processes or products as well as individual end users of the products.

It should also be noted that technology transfer can occur in many different forms, one of which is tangible; for instance, a working prototype. On the other hand, it could also be a license or the transition of knowledge from one discipline to another that makes it intangible. It is this translucent nature of technology transfer that makes it an area of interest, as there are many ways to transfer the technology as well as policies that accompany it (Bessant & Rush, 1995). Since this research involves the high technology area, an exemplary organisation is The Department of Atomic Energy (DAE) based in

India. Because this study is based on an interdisciplinary study and DAE conducts a lot of technology transfer and manufactures high technology products for other organisations, it is interesting to observe the technology transfer mechanisms that DAE incorporate. These are listed below:

- In-house technology transfer
- Indigenous vendors and spillover of technology
- Technology crossover
- Transfer to external agencies
    - Technologies developed as requested
    - Spin-offs
- Technology diffusion (Grover, 1999)

In addition, Wang et al. (2003, p. ix) state that "the process also typically involves a variety of players, from transferors who create the technology and prove the concept, to those who embed the technology in a useful product, service, tool, or practice, and finally to transferees who embrace it, further develop it, commercialize it, and ultimately use it". These can be classified as the government, funders, performers, and legislation in the early stages, and in the private sector; inventors, entrepreneurs, venture capitalists, industry, and consumers in the later stages (*see Appendix A*). *Figure 2.6* illustrates components of the technology process including the actors involved, and is a good illustration of how the different capabilities, assets, and people are related to one another.

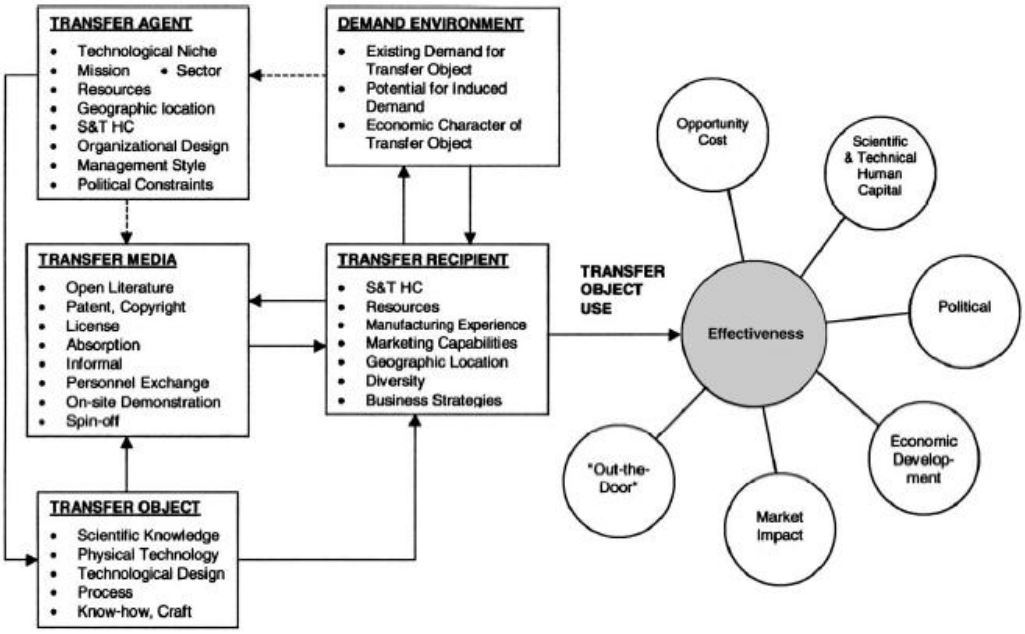

Figure 2-6 Components of the technology transfer process (Bozeman, 2000)

Technology transfer also consists of several stages, and is therefore not an instant event as Bessant & Rush (1995) point out. They state that it consists of the recognition of a need or opportunity, followed by selection and implementation. Technology transfer should be seen as a complex and expensive process, and the transferee should be able to use, reproduce, and be able to transfer the technology if they have access. It includes more than moving equipment, and contains systems and other components inclusive of knowledge, as well as organisational and managerial measures (International Environmental Technology Centre, 2003). To further emphasise, Grover (1999) states that the development of technology alone is insufficient; it has to be ready to the extent that it can be applied in the industry. Furthermore, to be successful in the high technology area, there are two requirements. The first is an understanding between the technology development and the science that makes the technology, and the second is a link between the source developing the technology and the industry that will apply the technology as a product or service. If these do not go hand-in-hand it is difficult to define the technology’s objective and how it can be used, and this can create problems at later stages of the development as well as implementation, thereby affecting the success of the transfer and costing a lot of money or even causing a loss. There is a need for a synergy, and most successful cases of innovations being commercialised require the knowledge or know-how to be synergistic with other capabilities. For instance, when a potential drug is being developed, the scientific knowledge of how the drug will work is not enough. There is a need for the drug to be administered safely and efficiently as well to know the right dosage. This requires a lot of research and many trials before the drug can be put on the market. How the drug is packaged and stored is also important, and once the drug is in the market, consumers need to be educated on how to use it. This is an example of one area, and it is imperative to understand that it is not a simple process (Teece, 1986).

The different stages involved in the technology transfer process, as exemplified by the drug development, require some form of pre-evaluation for the transfer to take place. This is necessary for assessing whether the technology in question is ready to be transferred and whether it would be beneficial. This is normally decided based on the technology meeting certain criteria, which can differ depending on the nature of the industry or discipline in the case of educational institutions where the technology was created and will be utilised. Bozeman's (2000) model (*see Figure 2.6*) aimed to portray the different components of the technology transfer process. These components in turn consist of the different criteria that can be evaluated prior to the transfer taking place. Although it is a useful framework, it is a generalised version of what should be an ideal framework. It may not be possible to create a generalised list of criteria for evaluation across different industries, but it is definitely possible to come close to such a realisation by attempting to gather and refine a set of criteria for this purpose. It can be argued that finding the right criteria might not be accurate, but it can also be justified that if these criteria are chosen and taken through a rigorous process, then it is possible to achieve a handful of criteria that can be used for this purpose, as is the aim of this research.

This is further supported by the Intergovernmental Panel on Climate Change (2000) which states that criteria specific to the creation and utilisation of the technologies are required, as this can help firms to screen innovations and technologies at the concept or transfer stage, as well as help recipient firms to evaluate the technology they might adopt. This could in turn lead to a successful and fruitful transfer and might even help to accelerate the speed of transfer and adoption.

This section has helped to understand what technology transfer is and why evaluation criteria are needed for the transfer to take place smoothly and successfully. Previous studies have claimed that technology transfer can take place smoothly and efficiently, while, others claim that there are always barriers to the process. There is no real evidence demonstrating a successful set of a criteria and subsequent choice of mechanism to support some of these claims completely (see, for example, Asterbo, 2004;

Cooper, 2001; Galbraith et al., 2007). Moreover most of the literature on technology transfer evaluation has been focussed around ex-post evaluation and discussion on successful cases of technology transfer (see Shane & Stuart, 2002) emerging from such research. The next section will elaborate more on this aspect of evaluation in detail and will look at the related evaluation theories.

2.2.3 Evaluation theories

The literature on the evaluation of technologies and technology transfer covers a broad aspect of the assessment procedure. In general, evaluation can be defined as valuing the quality of an explicit methodology that can be scrutinised for its validity or simply the science of valuing (Scriven, 1981). In terms of technology evaluation, Harris and Harris (2004) maintain that technology tends to be evaluated in terms of its usability and functionality from an ergonomic perspective. However, when technology is transferred from one application to another, the wider context needs to be assessed. According to Jasinki (2006), evaluation of the transfer process includes assessing the viability, gains, costs, and risks of the technology. According to the opinions of the OECD (1987) and Luik (2005), the important dimensions of evaluation include the scope of evaluation, the object of evaluation, the level of evaluation, the time span of evaluation, the purpose of evaluation, the criteria for evaluation and the organisation, and the resources and responsibility of evaluation. Some of the general categories of criteria identified in the literature encompass economic value, feasibility, measurement of indicators, and the potential for cross-fertilisation. Some of the methods used range from developing models and conducting surveys to micro and macro-economic case studies and statistical and econometric analyses (OECD, 1987; Luik, 2005). Evaluation can usually occur at three different levels, namely '*ex-ante'* evaluation, interim evaluation, and ex-post evaluation (Piric & Reeve, 1997). Miles et al. (2006) have portrayed this *(Figure 2.7)*.

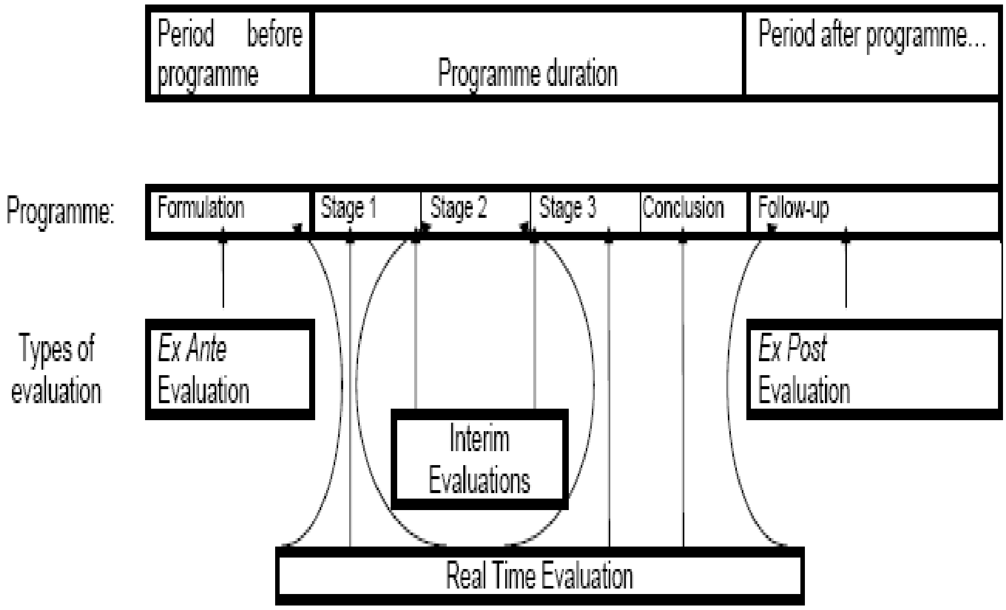

Figure 2-7 Levels of evaluation (Miles et al., 2006)

It is crucial to differentiate '*ex-ante'* evaluation from ex-post evaluation. '*Ex-ante'* evaluation is normally conducted before an option is chosen or implemented, to know whether it will be beneficial and whether it could be a guide on how the required goals can be achieved. On the other hand, ex-post evaluation is concerned with the results or outcomes of a project after it has been implemented and possibly completed (Miles et al., 2006). Geuna and Martin (2003) as well as Kuhlmann (1995) differentiate these by stating that while '*ex –ante'* evaluation is conducted to gauge the significance and chance of success, ex-post evaluation is used to assess the outcome and impact, if any. They further add that evaluation can fulfil two types of functions; namely, summative and formative . In relation to the aims and objectives of this thesis, '*ex-ante'* evaluation can be used to assess or appraise a technology based on a set of different criteria before it is transferred from a university setting to the commercial market.[6] As Miles et al. (2006) point out; '*ex-ante'* evaluation could provide the stepping stones for the other sets of evaluation to be conducted.

In relation to what should constitute the evaluation process, there are different views and opinions from various scholars and academics. According to Spann et al. (1995), measures of technology transfer effectiveness are not well defined or accepted,

6 The terms "Assess" and "Appraise" are used quite interchangeably with evaluation but can have different meanings.

and there is a growing need for a comprehensive framework/model to evaluate and measure the process. Heslop et al. (2001) note that there are several robust tools to help determine which technologies are likely to be successful when commercialised. A few authors have suggested essential tools that can aid technology evaluation to help predict good transfers. For example, Watkins (1990) suggested elements such as the effectiveness of the technology, commercial viability, and whether the technology can be coped with. The Association of University Technology Managers (AUTM) (1994) drew attention to the lack of a protocol to aid in the evaluation of commercial feasibility for research and innovation out of laboratories based in universities. This is backed by Heslop et al. (2001) who adds that no wide-ranging study has been conducted to demonstrate how the producers of technologies evaluate or assess their knowledge for transfer.

The outcomes of technology transfer generally differ from the initial expected goals. In fact, Winebrake (1992) identified some major barriers to transfer from laboratories. For example, both parties usually do not share the same expectations, and there is a lack of knowledge of the value of the technology being transferred. Bozeman and Rogers (2002) assert that putting forward the value for scientific and technical knowledge is not easy and can pose a few problems. The valuing of scientific work only in economic terms fails to capture the reality of such work as well as its social uses (Bozeman & Rogers, 2002). Additionally, Wei (1995) believes that there are several criteria that are important for the technology recipient to be able to assess the results of transfers. Three crucial factors are: cost, assimilation of the acquired technology, and the contribution the transfer will make to the dynamics of the recipient and subsequently the economy.

Bozeman and Rogers (2002) also argue that normally, economic reasoning and methods have been considered as the way to value science, but state that the limitations associated with this approach are becoming more evident (also see US GAO, 1997; National Academy of Sciences, 1999). They also state that once knowledge is put to use, it has some comprehensible value. According to Piric and Reeve (1997), there are certain decisions that need to be made when determining the right evaluation tool. Some of the crucial steps are to first determine what should be evaluated and the appropriate framework or model to use, thus, the timing and placing of the evaluation (Piric & Reeve, 1997). The evaluation of technology transfer demands criteria related to the manufacturing and use of the technology as well as the methods used to conduct the transfer, and consequently, some criteria need to be addressed quantitatively, while others need to be approached qualitatively.

There are also process-related criteria like geographic extent (Intergovernmental Panel on Climate Change, 2000). This indicates the need for a framework that can fulfil these objectives. As mentioned previously, this has led to some universities having their own intellectual property expertise, which is given special attention as it can be a major source of funding and a means to enhance reputation. This leads to actually evaluating some of the research outcomes to recognise value and how it can be further developed to attract patents and interested parties to transfer to. Thore (2002) states that a technology has many facets ranging from technological aspects to marketing attributes, and these often need to be examined and assessed as this can influence decision making. According to Bellais and Guichard (2006), commercialising a technology demands a legal framework that can stimulate the transfer process. Indeed, a conceptual framework is a means to demarcate rights and aid in managing events (Bellais & Guichard, 2006).

According to Arni (1996), the user of an acquired technology can be confused by various questions such as how they are going to utilise the technology, which market to target, where and when to produce, and how much to invest. New ways of valuing science are needed and these should attempt to achieve more than putting a monetary value on what is produced, and be able to create value from applications that make it to the economic markets (Georghiou & Roessner, 2000). Petroni and Verbano (2000) stress that there is a need for a framework that can help to identify the key features of technology transfer. Spann et al. (1995) also state that some of the existing models may fail to tackle the measurement issue due to the fact that all possible outcomes of technology transfer cannot be easily captured, and another difficulty is that the transferor and the transferee generally have different goals and forms of evaluation.

The majority of technologies follow an S-shape curve, and the evaluation of any existing or anticipated technologies and potential applications might be useful in the decision making process of whether to invest and go forward with product development and transfer, as it could shed some light on the technical scope as well as cost and time. Technology forecasting can be helpful for management and could provide perspectives and facilitate communication, especially on an interdisciplinary level. It can also aid management in estimating costs, people skills, product development, and market penetration including competition. “No mechanical process presently exists which will evaluate the information in terms of available technical solutions, cost and value, product applicability and market potential" (Roman, 1970, p.134-135). Also, recipients should be able to identify and adopt a technology or technologies best suited to their purposes. There is no single stratagem to successfully transfer applicable to all situations, therefore evaluations can be useful. It is not only important that the technology fits the specifications, but that it is also sustainable in terms of economic viability and social acceptability (International Environmental Technology Centre, 2003).

Along with evaluating the technology, it is useful if the recipient of a technology has done some research into the technology as well as built a good relationship with the people and environment involved. According to Georghiou (1998), technology transfer does not just involve scientific and engineering knowledge. It has been recognised that firms need to have wider competencies such as management skills, which improves the organisation, information gathering, and distribution. In addition, institutions' intellectual property is valuable and if they do not manage and explore their resources well, it will be difficult or maybe even impossible to transform the IP into market capital. There has always been some debate concerning the right measures for the transfer activity, but mechanisms have been suggested for a successful transfer and these include licensing, technical assistance and consulting, Cooperative Research and Development Agreements (CRADAs), exchange programs, conferences, and publications, but as such no particular metric or tool is suitable for all transfers (Wang et al., 2003). It was pointed out at a conference that took place in 2003 in Washington D.C. that a framework that would include economic, regulatory and commercialisation strategies would be useful and that to successfully commercialise, elements such as management and marketing were necessary (Wang et al., 2003).

The literature related to evaluation consists of various recommendations as to how evaluation should take place. For instance, Luik (2005) conducted extensive research and recommended different dimensions of the evaluation process. On the other hand, some authors have suggested that some criteria such as intellectual property and financial criteria are more important while others emphasised using a number of criteria for evaluation including social and technical criteria (Bellais & Guichard 2006; Thore, 2002).

One important contribution to this area was made by The Office of Technology Assessment (OTA). The OTA was created in 1972 and was part of the United States Congress. The OTA's main purpose was to provide members of the Congress with analysis that was more focused on technical issues. Some of the responsibilities included duties such as assessing and understanding how new and upcoming technologies would influence people and institutions in the U.S. Its innovative model of delivering services to the public, for instance, electronic publishing was highly appreciated and also followed by other countries. It examined science in disciplines such as medicine, transportation and defence amongst others. Moreover, closer to the choice of social benefits as a category of criteria, OTA evaluated and estimated the environmental and social impacts of technological change. The OTA was closed in late 1995 due to reasons related to withdrawal of funding.

Following the abolishment of OTA, various other organisations all over the world, have been working on ways to assess technology and its transfer. The research conducted by OTA resulted in ways of evaluating technology transfer potential including the use of criteria for evaluation purposes (see, for instance, Burnham, 1984; Van den Ende et al., 1998).

As OTA and other findings indicate, it is useful to have a list of the essential criteria but it is indeed more productive to have these criteria examined by experts who could help to decide which set of criteria would be the most effective for evaluation. The same applies for the mechanisms of transfer. Wang et al. (2003) rightly mentioned that there is no one suitable mechanism, but it is also possible though the involvement of highly experienced experts to comprehend why some mechanisms are favoured over others, and potentially learn some of the reasons why some mechanisms are utilised more than others.

While there have been numerous studies on evaluation processes (Miles et al., 2006; Luik, 2005), research particularly aimed at '*ex-ante'* evaluation needs to be conducted more in depth so as to cover the basic requirements for an accurate evaluation. Although, certain criteria have been identified to aid '*ex-ante'* evaluation of technology transfer, there is still no consensus amongst researchers on which established criteria are more important than others. On the other hand, there has been some level of agreement by different researchers as to the different categories of criteria that are essential for evaluation of technology transfer at an *'ex-ante'* level (for instance: readiness of the technology; economic factors and commercial readiness relating to factors such as intellectual property) (see Asterbo, 2004; Galbraith et al., 2007). A relevant example of an assessment model is the cloverleaf model proposed by Heslop et al. (2001) in which determinants were grouped according to different categories that will aid towards commercialisation success. This model will further be discussed in the following sections.

As Galbraith et al. (2007) discuss in their research, there is still a gap when it comes to the scales being self-sufficient in regards to evaluation procedures and this is again due to the fact that they have not been developed solely for the purpose of *'ex-ante'* evaluation. There is postulation that all these models can be used for '*ex-ante*' evaluation and there is also an unconfirmed view that people involved in the evaluation process such as venture capitalists will use such a tool. One step that can be taken is to ensure that such people are involved in the refinement of the criteria so as to help make it more accurate and useful. Therefore one of the aims of this study is to create a set of criteria that is not only valuable in theory but also useful for practitioners in their evaluation and decision making process. To achieve such an objective, various experts involved in the commercialisation process will also be involved in the development of criteria.

Additionally, some authors argued that the evaluation criteria are not comprehensive enough. For example, Becker (2001) states that there has not been an inclusion of criteria related to the social impact that the transfer of technology can create. Typically areas related to economic and market benefits have been looked into in addition to the technology's readiness. Hence, with the growing concern for the environment and other social effects technologies can have, it is essential to consider these aspects in the evaluation of technology transfer.

The selection of a suitable mechanism also plays an integral part in successful technology transfer. Studies such as those conducted by Wang et al. (2003) have shown the importance of the selection of the right mechanism for commercialisation of a technology but there is no definite way of narrowing down this selection after the evaluation process. Hence this research also aims to propose a means of making the selection of the most favourable mechanism of transfer. This can be achieved by incorporating the refined criteria into a framework which can then aid in the selection of a mechanism suited for the particular technology transfer case.

As discussed, many of the early assessment studies have attempted to showcase the technology being beneficial to transfer resulting from most research stemming from ex-post scoring systems and hence, a fresh approach directly aimed at '*ex-ante*' evaluation has not been attempted (see,for example, Asterbo, 2004; Davidsson & Honig, 2003; Shane & Stuart, 2002). Therefore, a critical gap this study seeks out to address is to refine and suggest criteria solely from an 'ex-ante' evaluation perspective.

To sum up, *'ex-ante'* evaluation is necessary if a technology is to be transferred successfully and hence, this study aims to identify the key criteria and mechanisms that can fulfil this purpose. The next section will discuss high technology markets, which are a major driving force and motivation for technology transfer to occur.

2.2.4 High technology markets

This section will focus on the market issues for high technology products that are a result of the technology transfer process. This section will explain why such markets are important and discuss features of the market to evaluate. The National Science Board's (NSB) (2000) report on science and engineering indicators highlights some useful statistics. According to the report, the market for high technology goods was growing at a faster rate compared to most other manufactured products, and during an 18 year review period (1980–1997), the production grew at an annual average rate of about 6.2% in comparison to 2.7% for other products. According to this report, in the year 1997, countries such as Japan, the United States, The United Kingdom, France, and Germany were some of the major high technology goods manufacturers. The NSB report in 2006 had similar findings stating that the market for the products is currently one of the fastest growing markets. It is also mentioned that knowledge-based industries had sales exceeding $14 trillion in 2003. The creation of markets is a determining driver of economic growth, but the marketing of knowledge is not as easy as that of other economic goods (Bellais & Guichard, 2006). On the other hand, a unique attribute of knowledge compared to other economic goods is its cumulativeness (Bellais & Guichard, 2006). Firms in high technology markets need to have constant innovations and know how to commercialise these innovations into products or services that will fulfil consumer needs, and should be competent at doing so (Dutta et al., 1999). Fiet (1995) identified six potential indicators of market risk from previous research and these are highly important in high technology markets:

- Technical obsolescence – when specialised technologies become obsolete they have lower value when used for purposes other than those for which they were previously purchased;
- Many competitors – competition increases inter-firm rivalry, lowers the level of prices that can be charged for a technology, forces down profits, and increases an investor's risk of market losses;
- Many potential, new competitors – the prospect of additional technology providers, and hence the need for more competitive pricing, will increase the risk of market losses;

- Many substitute technologies – the existence of substitutes increases competitive rivalry; lowering the price of one substitute will typically lower the demand for the other; substitutes also increase the power of buyers to set prices; access to substitutes thus increases the risk of competitive losses;
- Weak customer demand for a technology – this causes sellers to offer concessions, increasing the risk of market losses;
- Market attractiveness – the more attractive a market will have a lower level of competitive rivalry within it, meaning profitability for firms will be higher and risks of market losses will be lower.

Markets for technologies by and large require access to accurate and reliable information, including knowledge of technology alternatives. The participation of skilled players is also essential along with property protection and designation. Also, having several financing alternatives with the decision-making autonomy for buyers and sellers is always good (International Environmental Technology Centre, 2003). When it comes to the marketing aspects of technology related applications, Tidd et al. (2001) state that it is important to differentiate between a technology and a product that utilises the technology, and when specifically referring to high technology products, conventional marketing techniques are insufficient. To identify a suitable application and target users, it is recommended to look at the technical and behavioural aspects. This can be achieved by segmentation of both aspects so as to define target users and markets accordingly. In a broader context, Gambardella (2002) highlights that several market failures have to be addressed in regards to technology related markets:

- Unwarranted Research & Development (R & D) duplications
- Externalities in production
- Pricing

Technology contributes to the quality and uniqueness of processes and products. This in turn augments the differentiation of products and increases market demand. According to Cui et al. (2006), multinational companies are increasingly relying on technology to gain competitive advantages in the global market as they expand, and their success is partially determined by the transfer of competitive technologies. The literature reveals shortcomings that limit the perception of how the environment of a firm influences technology transfer amongst other strategies, which has a bearing on performance (*see*

Figure 2.8) (Cui et al., 2006). Studies conducted in the past by Simonin (1999) and Contractor and Sagafi – Nejad (1981) and Marton (1986) overlook the importance of market related issues. For instance, previous studies of the market environment have identified two key market environmental factors in competitive intensity and market dynamism (e.g., Jaworski & Kohli, 1993; Jap, 1999; Grewal & Tansihaj, 2001), but there are currently no studies to compare their effects. Since the transfer of technology is a costly process for a firm, gaining an understanding of the relative influence of markets can aid firms to make more accurate decisions, which will ultimately enhance performance (Cui, 2006). According to Cui et al. (2006), competitive intensity and market dynamism are the two environmental market factors identified as important determinants on strategic decisions (e.g., Jaworski & Kohli, 1993; Jap, 1999; Grewal & Tansihaj, 2001). Competitive intensity is the extent of competition faced by firms in a market, and on the other hand, market dynamism relates to changes in an industry such as demand, technology, and competition structure (Achrol & Stern, 1988; Jap, 1999).

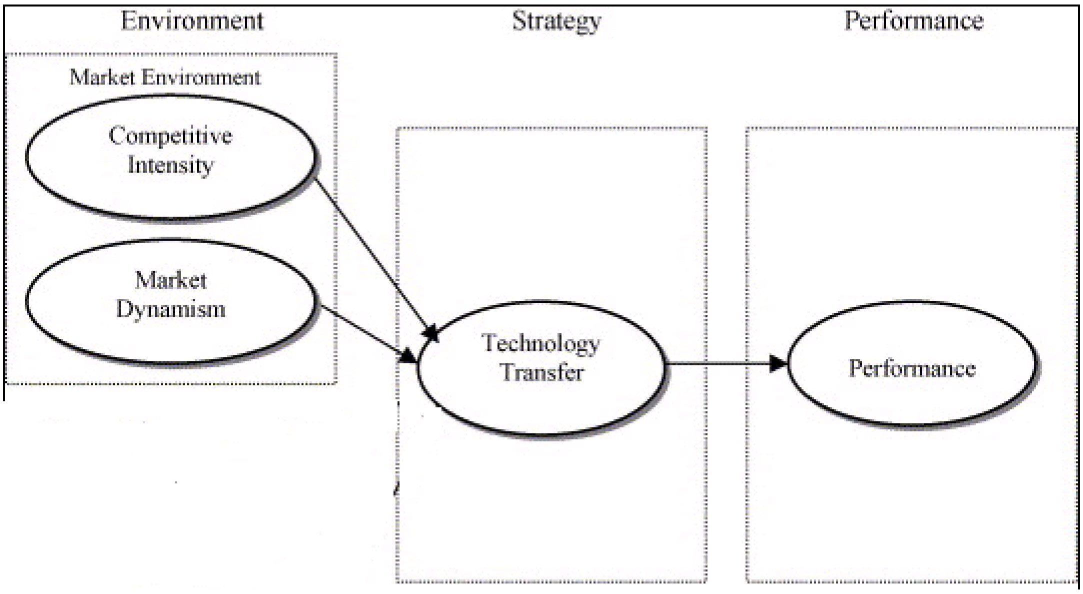

Figure 2-8 The influence of market environment on technology transfer and performance (Cui et al., 2006)

In a broad context, technology should be transferred to another company while helping it to develop a market for innovative processes and products. Varian (2001) states that even though the market forces and factors governing high technology industries are the same as other industries, there are some factors that are particularly relevant to high technology industries. He also states that networks play an important role in these industries. Dutta et al. (1999) go into more detail and propose that marketing; R & D and operations capabilities and their interactions, are important and contribute to the financial performance of the industry (*Figure 2.9*). They also add that marketing is rarely appreciated in comparison to the role of R & D and manufacturing in regards to enhancing a firm's performance (eg. Iansiti & West, 1997), and state that even though a firm might have a good R & D base, they will be unable to generate commercially feasible products or services if they have a poor marketing ability. R & D capability is imperative as such markets usually involve short product life cycles and many new products are regularly introduced due to the dynamic nature of technology, and if the product and its successors have similar quality, they are more likely to hold customers' loyalty (Givon et al., 1995). In addition, operations capability enables smoother functioning and integration of the various tasks and components required to help create a product at the right price (Hayes et al., 1988).

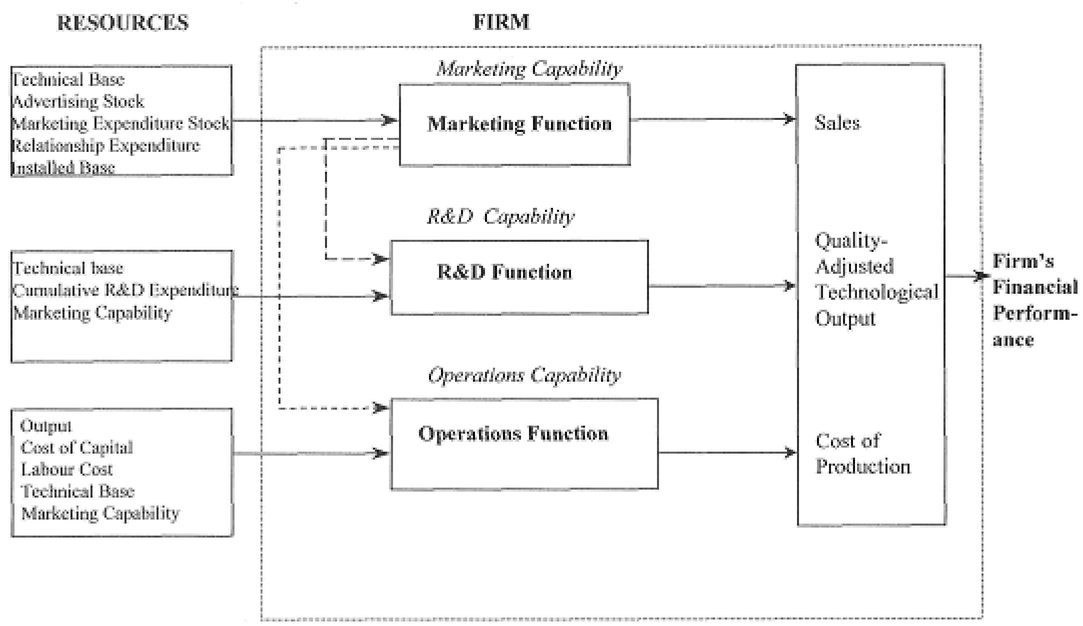

Figure 2-9 Interactions of marketing, R&D and operations (Dutta et al., 1999)

Numerous innovations stem from the high technology industry, and innovations tend to achieve market share as well as create new ones and also utilise resources in a more productive fashion (Tassey, 1995). The firms that are part of this industry are involved in high value added processes and production, which generally results in success in international markets (Tyson, 1992). There is also the possibility that the R & D generated from these industries results in spillover effects and adoption in other disciplines. This can benefit both parties and result in new products and services (Mansfield, 1991; Nadiri, 1993). A technology will not make an impact unless it is practical and economically beneficial, and is able to create new markets or fulfil existing market needs. This sometimes leads to 'technology push' and 'market pull' (Rosenberg, 1982; Kline & Rosenberg, 1986; Lee & Gaertner, 1994). Gaining knowledge about markets is always beneficial as it provides an extra edge, which in turn helps with better decision making.

After examining the literature, it can be concluded that the full potential of the markets is not fully tapped into, in the case of technology oriented products and services. Some technologies will never reach commercial markets because they are owned by defence organisations and therefore sensitive and classified, but on the other hand, there are other technologies that have market potential but are neglected due to lack of assessment and due diligence. Undoubtedly, one of the driving forces for technology transfer and one of the categories of criteria that should be evaluated is the market. Markets are what can make or break a product resulting from commercialisation. Based on the literature, some of the factors to consider for the choice of market-related criteria include market impact, competition, market needs, and the time it takes for a technology to evolve from concept to product. The next section will elaborate on the different sources from literature that helped in putting together a list of criteria and mechanisms that will be further refined through the Delphi technique (see Chapter Four).

2.3 Evaluation criteria

This section deals with the compilation of evaluation criteria from literature, which will be refined using expert involvement. This is further outlined in Chapter Four (Methodology).

Table 2.2 consists of categories of criteria used to evaluate technologies for potential transfer. In addition, mechanisms then used for commercial technologies are also included. The criteria were obtained from different sources. For instance, Durand (2003) reviewed 'Key Technologies 2005', a French technology foresight exercise which included criteria that were utilised to select candidate technologies. In his review, Durand (2003) explains how criteria were grouped to categorise them. The groups range from societal needs to technology dynamics as well as market related factors including the creation of competitive advantage but some groups, such as those to do with societal needs have not been included in evaluation models.

On the other hand, Rahal and Rabelo (2006) also identified and classified 43 determinants that are important in determining successful commercialisation and licensing of technologies from universities. Examples include the nature and sophistication of the technology, the stage of development of the technology, financial risk and exclusitivity of intellectual property amongst others.

Others studies such as those conducted by Roper et al, (2004) identify factors such as costs advantages to customers, knowledge spillover and reputational imagine which can equate to forms of branding.

One model of interest was the cloverleaf model developed by Heslop et al. (2001). This study aimed to identify the main constructs and criteria for the evaluation of technology through surveys. This model as well as some input from practitioners has largely influenced the chosen criteria. The theory deals with obtaining evaluation criteria based on surveys, and suggests that better evaluated projects can lead to a more successful transfer. The theory also originates from the fact that the different criteria involved, for example regulatory issues such as IP and technological criteria related to the application of the technology, influence the choice of transfer, and whether it is worth involving the technology in a new application. The theory generally encompasses innovation literature such as adoption, and the creation of new applications and markets. The procedure involves choosing the criteria and then rating them according to which will help with assessment and evaluation.

As cited in Heslop et al. (2001), according to Galbraith (1982), for an innovation to be successful, a combination of knowledge such as marketing and R & D is required. Entingh et al. (1987) presented a set of criteria to help evaluate whether a technology is good enough to be transferred. In addition, this paper cites another author, Pelman (1998), who suggests that the evaluation of technology and its transfer cannot be fully accurate unless experts and managers from industry contribute. Hence, this particular research adopts this idea and incorporates expert opinion through the recruitment of the Delphi technique.

The Cloverleaf Model consisting of market readiness, technology readiness, commercial readiness, and management readiness (Heslop et al., 2001). It uses three steps ranging from the initial compilation of a list criteria followed by a validation and then finally a refinement. The selection of criteria is largely influenced by this model and other mentioned examples whereby a list of criteria is compiled from existing literature and then refined and validated through expert input. For instance, Schaper and Volery (2007) refer to a framework used in their research as one for analysing opportunities, which is similar to ex-ante evaluation. They also mention technical feasibility and marketing and economic feasibility, which are similar to some of the categories that will be compiled in this thesis.

The criteria listed in *Table 2.2* that were obtained from various sources (see, for example, Heslop et al. (2001); Reisman (2005); Rahal & Rabelo (2006)) will be used for the Delphi method. This has been structured so as to comply with transfers out of a university setting, and that will best relate to the technology in question. The ones highlighted in bold will not be included in the Delphi study because it is necessary to include only the critical ones found to be the most important and best suited to this study. This was achieved by omitting criteria that overlap and choosing criteria that would be best related to university commercialisation and suitable for the *'ex-ante'* stage. Therefore, some informal consultations with industry experts were also conducted following the selection of criteria from literature to confirm the choices. It was essential to have informal consultations with experts so as to validate the final choice of the criteria and also to confirm that the criteria were not repeated throughout due to reasons such different nomenclature given by various researchers for the same criterion. The same applies when selecting criteria for technology transfer mechanisms. For instance, a suggested mechanism within the literature for technology transfer is internal development; however, this is more likely to be used in large organisations such as 3M who transfer their technology to other departments within the company to conduct further research. Therefore, only relevant criteria from the literature suitable for *'ex-ante'* evaluation have been included.

Table 2-2 Criteria compiled from literature

Categories	Criteria
Technological Readiness: This relates to the factors related to the technology to determine how the technology can be more beneficial than other available ones. The criteria here include the complexity of the technology as well as the proof of concept and applicability	**Replicability**: Technological Complexity (the nature and sophistication of the technology); Area of Application; Ready or Not (proof of concept) theory; Proof of application (in practice); Combinatory potential with other technologies; The availability of a functioning prototype; **Availability of resources to implement and leverage the technology (eg. industrial and commercial investments):** Further development of the technology: **Barriers to entry**
Social Benefits: The benefits it could potentially offer to society	**Cost advantages to customers:** Knowledge spillover; Creation of employment; Social infrastructure/networks; Environmental impact; Brand recognition
Economic and Market Factors: This is in relation to how the technology will have an impact on the economy and what sort of markets it can create and penetrate.	**Contribution to economic growth/development:** Access to required resources for eg. Venture capital; Potential return on investment; Market entry (pull/push); determining whether there are any distinguishable competitive advantages; Market impact and need; Time to market; Competition; Size of target market; **Efficiency gains; Financial risk; First to market**
Legal/ regulatory: This includes the criteria related to the protection of intellectual property such as patents covering the technology.	Protection of IP rights; Strength of the IP; Legal contracts Standards, certification and accreditation; Strengths and scope of patent including geographical extent; No interfering patents (no dominant patents); New areas of application; Does

	any other existing technology/method need to be used; IP ownership; Freedom to operate
Manufacturing and Distribution Facilitation	**Increased Capacity; Cost Reduction; Creation of new products and services or improved processes (Platform technology)**
Management Readiness	**Management capabilities are available; the inventor is recognised and established in the field; Technical and commercial experience of team; External resources required**
Selection of the Most Favourable Mechanism for Transfer: Will help to determine what is the most appropriate mechanism or path of transfer for the technology to be commercialised. Every option will be rated based on these criteria and the one with the most suitable response will be chosen. Licensing Spin off Joint venture/collaboration **Trade sales** **Internal development**	Speed; Cost; Control; ROI/Absolute returns; Risk; **Management; Effort; Potential for leveraging existing competencies; Potential for developing new competencies; Potential for accessing other firms' competencies; Skills and expertise; Willingness of the investor to work with the commercial team**

Sources for criteria and mechanisms: Lee & Gaertner (1994); Arni (1996); Heslop et al. (2001); Dority (2003); Durand (2003); International Environmental Technology Centre (2003); Roper et al. (2004); Reisman (2005); Rahal & Rabelo (2006); Schilling (2007)

Problems that need attention if technology creation is not to encumber the technology transfer process include strategic planning and market issues, the science of the technology including knowledge and engineering factors, people skills, assistance from institutions if needed for resources such as finance and others, and further research and development (International Environmental Technology Centre, 2003). The criteria can be linked to the mechanisms in terms of what is beneficial, which provides a way to assess the best mode of transfer. Expert opinion will be used to rate the most relevant criteria for the chosen technology. Once a technology has been created and patented either in the lab or university setting, the best strategy to commercialise it has to be chosen. As mentioned, there are various mechanisms do this and the choice can depend on the nature of the technology as well as the availability of resources (Dority, 2003). The choice of mechanisms can also be influenced by the different sources related to where the technology comes from, the legal issues, and the source of the technology or idea. These can be further broken down to the use and type of technology; who owns the IP and its lifespan. Also, when it comes to sources, the source could sometimes be a good indicator as well, such as if the technology originates from a university, a company, or others such as a third party and government labs. In addition, if funding is needed for the further development of a technology or some patent needs to be licensed, this could be possible with the help of VCs and angel investors amongst other sources. It is also important to show how the criteria can lead to the right choice of mechanisms, but the choice is mainly influenced by the selection of criteria specific to the mechanisms as well.

In conclusion, different categories of criteria are chosen so as to include all the areas related to the transfer process. It is better to choose as many important ones from the literature rather then pick only what is thought to be crucial. In the past, a lot of attention was given to the financial aspects alone when evaluating an opportunity. On the one hand this could seem to be correct as a better financial return is always better, but on the other hand, omitting other important factors such as those related to the market could play a necessary role in determining if the technology is transfer worthy. Other useful criteria are those related to intellectual property and ownership. There are times when there is no due diligence conducted and this can lead to an occasional breach of intellectual property, which results in additional barriers for an institution that were not investigated. Another category of criteria that is included is one that relates to the social impact of technology transfer. It is necessary to include these criteria so as to investigate if the transfer of a technology can be socially beneficial and acceptable. For instance, one of the important elements of social impact is the effect on the environment.

The next section will discuss the conceptual framework that arises from the literature and which is applicable to this research. The framework encompasses various factors that contribute to evaluation of technology transfer process.

2.4 Towards a conceptual framework

The first part of the literature review introduced the concept of commercialisation and different streams of technology transfer focusing on various mechanisms and models. According to the literature, there are three basic transfer models that apply to horizontal and vertical technology transfer (Autio, 1991; Autio & Laamanen, 1995; Grosse 1996) including direct, interactive, and third party. After examining the relevant literature, it can be summarised that technology transfer can occur in three generalised ways. Direct transfers occur when the technology is transferred directly from research to its use or application, for instance, from a university lab to industry. Interactive transfer occurs when both the inventor and the user of the technology work together to develop the technology to specifically suit its application. This can be seen, for instance, between research institutes and industry. Finally, third party transfer usually occurs when the technology is transferred with the help of an agent or a medium such as licensing agents or third party facilitators (Autio, 1991; Autio & Laamanen, 1995; Grosse 1996), and *Figure 2.10* illustrates this. Literature also highlights the various actors involved in the process apart from the transferor and the transferee (*see Appendix A).*

Additionally, there are several stakeholders involved in the process (International Environmental Technology Centre, 2003). These include entrepreneurs, scientists such as developers, customers and recipients including users, financial sources such as investors, as well as venture capitalists, and these vary according to the technology in question as well as the chosen mechanism of transfer. Essential communication is imperative to successful technology transfer and it is useful to have efficient two-way communication as this will help to reduce barriers. It is good to ensure that stakeholders have the capacity and ability (potential and realised) to commit to and fulfil their responsibilities. The government plays a big part in providing the right environment. According to the research conducted, some circumstances helpful to technology transfer are:

- Open and competitive market;
- Comprehensive and credible specifications on the technology performance;
- Financers who are at the least technology-neutral;
- The most cost competitive technology also has the most favourable environmental and social performance specifications; and
- Policy risks are addressed (International Environmental Technology Centre, 2003) (This is applicable to technologies within and outside a country).

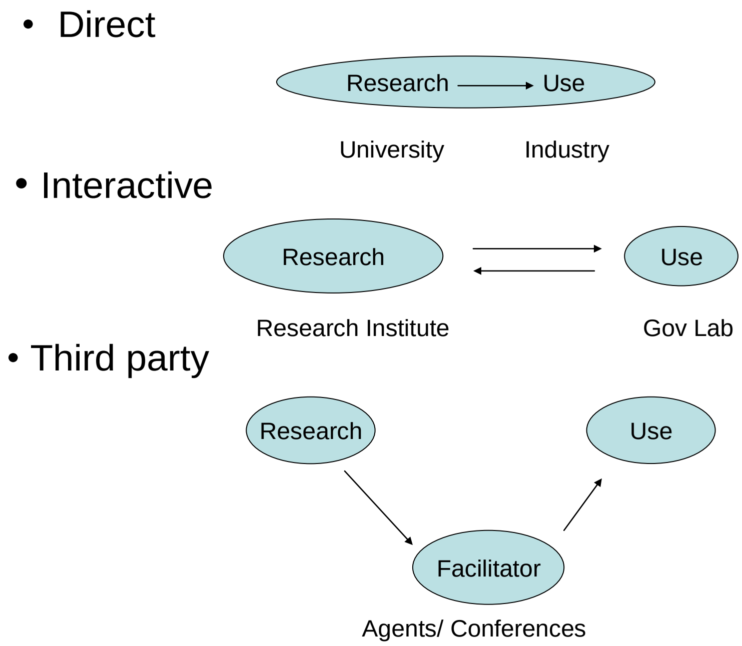

Figure 2-10 Technology transfer models (Autio, 1991; Autio & Laamanen, 1995; Grosse 1996)

As mentioned, *'ex- ante'* evaluation is an important element in this process and has been overlooked in the past, with the focus mainly on outcomes and output. Even if there has been evaluation it has mainly been related to financial aspects. As explained in the literature review, other factors have not been given much attention. Some of these factors are crucial and it is necessary to take them into consideration when making decisions. For instance, factors other than economic ones are not always thought of as important, and these range from social to market-related factors. One of the tasks of this research is to encompass a diversity of criteria that span beyond economic factors (see Section 2.3).

After exploring literature, gaps in the evaluation of the technology transfer process within the high technology industry emerged. According to Grant (1996), much needs to be done at the empirical and theoretical level, especially in understanding the organisational processes through which the technology is integrated. As mentioned previously, evaluating technology transfer outcomes is complicated by the variety of paths through which technology can move from producer(s) to user(s) (Bozeman, Coker & Kingsley, 1996). In fact, the structure and organisation of technology transfer mechanisms and evaluation of the transfer process are determinants of success for the transfer process (Rao, 1991; Simpson, 2002). Having examined the literature, it can also be added that the '*ex-ante*' evaluation of technologies has not been given as much importance as it deserves and contrarily, a lot of work has been done on '*ex-post'* evaluation (Harris & Harris, 2004). Also, Georghiou and Roessner (2000) remark that: "Evaluation work has probably had less of an impact in the literature than it deserves, in part because much of the detailed work is not easily obtainable. There is a disturbing tendency for evaluation data that could form a valuable reference point for future studies to be lost in the grey literature" (p. 674).

It can also be noted that most of the work primarily focuses on the economic and monetary benefits and not as much on other factors or criteria such as social and market-related factors, as otherwise recommended by some authors. Although there have been different criteria suggested in previous research, this study also demonstrates the importance of social aspects when it comes to evaluation of technology transfer. As mentioned previously, while previous studies have shown that evaluation is beneficial, none of them have actually demonstrated the inclusion of social criteria as part of a framework along with other criteria. Criteria such as environmental impact and benefits to the consumer are necessary as this helps demonstrate that if a technology is transferred it will have benefits beyond just monetary (Becker, 2001).

Therefore, as mentioned above, one of the objectives is to identify a range of diverse criteria from literature and those that are recommended by experts. The fact that more than one discipline is involved is also a factor. The criteria need to be robust enough to span disciplines and at the same time cover the evaluation needs of technology transfer. More on interdisciplinary research can be found in the next chapter.

Furthermore, the choice of technology transfer mechanism is also crucial. As there are many types of mechanisms, it is necessary to include those used for university commercialisation and then let the experts decide on what they think would be the most suitable for the chosen technology for this thesis.

Hence, after reviewing literature and identifying the important factors as indicated above, a conceptual framework can be suggested. *Figure 2.11* is the conceptual framework that can be applied for this research and is specifically designed to illustrate the technology transfer evaluation process in respect to *'ex-ante'* evaluation. The process involves evaluating a technology using certain criteria and proposing an appropriate mechanism for commercialisation.

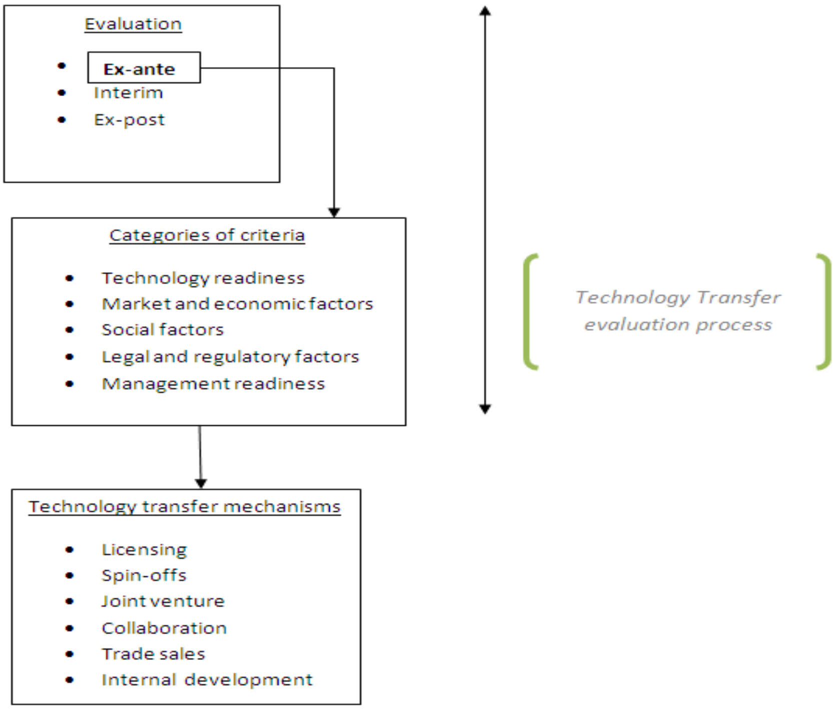

Figure 2-11 Conceptual framework

As indicated, the main elements in this research include *'ex-ante'* evaluation, the criteria that are used for evaluation and mechanisms of technology transfer. The fundamental theories of research commercialisation have shown gaps in relation to the criteria that need to be used specifically for *'ex-ante'* evaluation. There are different forms of evaluation but as mentioned before the one of focus for this research is *'ex-ante'* evaluation.

'Ex-ante' evaluation is a crucial step in the transfer of technology because it helps determine if a technology is ready for transfer as well as what areas need to be improved if this is not the case by determining a technology's strengths and weaknesses. Following this, theories related to mechanisms of transfer are applied as they help inform which mechanism is most appropriate for a technology to be transferred based on the outcome of the evaluation.

Therefore, *Figure 2.11* illustrates that *'ex-ante'* evaluation involves the use of criteria that are required for the process. These criteria fall under different classifications as elaborated in the previous section. As mentioned above, the outcome of evaluation in turn influences the type of mechanism which can then be used to commercialise the technology.

2.5 Summary

The literature review consisted of four parts, namely, research commercialisation, technology transfer, evaluation theories, and high technology markets, which are the underpinning components of this research. The literature review was then followed by a discussion on the compilation of evaluation criteria and technology transfer mechanisms that will be used in this study. The last section in this chapter discussed the gaps in the literature and finally, a conceptual framework was suggested for this study. The next chapter will discuss interdisciplinary research as it is the essence of this thesis, as well as the technology that is being investigated.

Chapter 3: The Technology

3.1 Introduction

This section will discuss the importance of interdisciplinary research and introduce the chosen technology as well as the chosen application. Due to the fact that this research involves more than one discipline, namely, science and business, an understanding of interdisciplinary research is necessary. This will be followed by details on the technology and finally the application.

3.2 Interdisciplinary research

Interdisciplinary research is best described as the coming together of two or more disciplines, and examples include areas such as biotechnology and engineering. According to Qin et al. (1997), the merging of different disciplines can lead to the generation of new information and products. Research that spans beyond one discipline opens up more possibilities and allows for innovative ideas to be formulated and investigated. Research is said to be interdisciplinary when there is more than just the bringing together of two or more disciplines. It involves the integration and co-ordination of ideas and methods (COFIR & COSEPUP, 2004).

Interdisciplinary research can provide new pathways and bridges between disciplines that can result in the creation of new knowledge and ideas. It often involves information, ideas, skills, concepts, and theories from more than one discipline to find a solution to a problem that cannot otherwise be solved. It involves approaching a problem from a different angle to find a solution that may not lie just in one area. It is important for researchers to appreciate the new area being investigated to gain a better understanding of the overall problems associated, as well as the best way to find a solution.

This research falls into the interdisciplinary category as it involves two disciplines that will be studied together to address the research questions and also because technology transfer is taking place over two areas of application. Research that involves a number of disciplines generally results in technology transfer.

Many people are still unaware that technology transfer takes place from space technologies to technologies and products for everyday use. Many examples can be cited: for example, Baker (2000) compiled cases of technologies invented by the National

Aeronautics and Space Administration (NASA) for space and military use that have found applications in various areas on earth. One technology made an impact in the medical field, which was a pump used to deliver insulin to diabetic patients.

NASA’s micro-engineering technology used in space flights was used to manufacture a pump that was small enough to be implanted into patients, making it more convenient to use and enabling better control of the delivery of medication. The technology was originally developed at John Hopkins University in the Applied Physics Laboratory (APL) and was sponsored by the NASA Goddard Space Flight Centre. In fact, Goddard classifies it as one of their top ten technology spinoffs. MiniMed Technologies (California) then licensed and refined the technology labelled PIMS, which is Programmable Implantable Medication System. PIMS is programmed to deliver measured quantities of insulin over a period of time when implanted in humans (*Figures 3.1* and *3.2*). Below is a history of its development:

- Between 1980 to 1983, Alfred Mann (then CEO of Pacesetter Systems) develops a partnership with APL at John Hopkins University and NASA to develop insulin pumps that can be implanted into the human body. The team is known as Pacesetter Systems Infusion Division.
- In 1983, Pacesetter introduces the MiniMed 502 followed by the MiniMed 502A which is a breakthrough product for insulin delivery
- MiniMed Technologies Limited is then officially born in 1985 as a spin-off from Pacesetter Systems
- In 1986, the first MiniMed implantable pump for insulin delivery is implanted in a patient at Johns Hopkins Hospital
- Following this period there were several developments at MiniMed, including the introduction of new technologies and products as well the new spin-offs arising from MiniMed due various research outcomes
- In 2001, Medtronic Diabetes which is a merger of MiniMed and Medical Research Group (MRG) is formed
- This is followed by Medtronic Diabetes launching new models of pumps, and adding components such as LCD screens and expanded memory
- More recently, in mid 2006, MiniMed Paradigm REAL-Time Insulin Pump and Continuous Glucose Monitoring System was introduced (Baker, 2000; Medtronic, 2009; NASA, 2009)

The above example demonstrates a technology transfer that resulted in a new area of application, which in turn resulted in a range of products and spin-offs: initially, the spin-off from Pacesetter Systems to MiniMed, followed by MiniMed’s division into three spin-offs. The resulting products have had a huge impact in the medical areas dealing with diabetes and insulin delivery. This example is one that illustrates the importance of interdisciplinary technology transfer.

Figure 3-1 The PIMS implantable pump and catheter (NASA, 2009)

Figure 3-2 MiniMed implantable pump system (NASA, 2009)

Another example is the use of NASA’s technology for search and rescue from space using a technology incorporated in a watch. A transmitter fitted in the watch sends signals to the nearest satellite which then directs it to a rescue centre (Baker, 2000).

There are other examples like technologies being transferred from their original use in aircrafts to vehicles such as cars. Some have been developed and others are still in production. Those that have been successfully implemented in road vehicles include navigation systems (GPS) and cruise control (Harris & Harris, 2004). Another interesting aspect is the transfer of technology from Formula 1 (F1) to road vehicles. There are a number of examples but several that have made an impact are:

- Computerised engine management systems: the combustion process is varied by the push of a button to vary the performance of the car
- Active suspension systems: the aim of this technology is to gather information on the movement of the body of the vehicle. This information is used to dampen the force on each wheel so as to adjust the body movement, providing better control.
- Traction control: ignoring the complexity in F1 cars, this technology was transferred to road vehicles for the purpose of controlling the power supplied to the wheels, thereby providing better stability. This has now been banned in F1
- Direct petrol fuel injection: used to help with more efficient combustion of fuel and reduce carbon emissions, therefore providing better fuel economy and less pollution

More recently, F1 has made numerous technological contributions that could filter down to everyday road vehicle technology. For example, the rules that govern F1 have been changed to allow the kinetic energy usually lost as heat in breaking to be recovered and put back into the propulsion system of the car. McLaren-Mercedes, and Ferrari are some of the teams that have started using Kinetic Energy Recovery (KER) in the 2009 season. The rationale behind the change in the F1 rules is that, in the F1 season, there is a very short cycle time between races (two weeks) during which intensive innovation takes place in an attempt to reduce lap times by a few thousandths of a second. Many of these incremental changes do not have any relevance to regular cars: however, it is argued that if F1 cars were allowed to recover kinetic energy this would lead to the rapid development of KER systems which would eventually be incorporated into commercial vehicles. A concept for a KER system is shown in *Figure 3.3*. The advantages include more efficient fuel usage and better performance. Apart from this, there are hopes of one day having a major adoption of road and race cars that are hybrid (fossil fuel/electric) through technology enhancements and their subsequent transfer (Trabesinger, 2007; MSN Cars, 2008).

Figure 3-3 Concept diagram for a kinetic energy recovery system (Gizmag, 2007)

In addition, there are numerous other examples and instances, cited in journals and on the Internet that list instances of technology transfers and ideas, whether successful or not. NASA has a website dedicated to transfers that have occurred, for example, highway control systems and heart pacemakers. It is important to point out the relevance of interdisciplinary research and what it can achieve. The next section will highlight some examples of technology transfer from astronomy to medicine and the impact that they have. It is also important to know that technologies alien to some industries can find a use in others.

Interdisciplinary research can be challenging due to the fact that it spans the boundary of more than one area, but it can be a rewarding and fruitful experience. The merging of two disciplines in this thesis will be a learning process and it will be interesting to observe the results of the experiments being analysed by experts from various backgrounds.

To better understand the relationship between the above mentioned disciplines, it is necessary to illustrate and portray the common relationship shared by the different elements of this study. In particular, for this genre of research that involves disciplines such as business and science, it is pertinent to make the relationship between the two areas eminent (see *Figure 3.4)*.

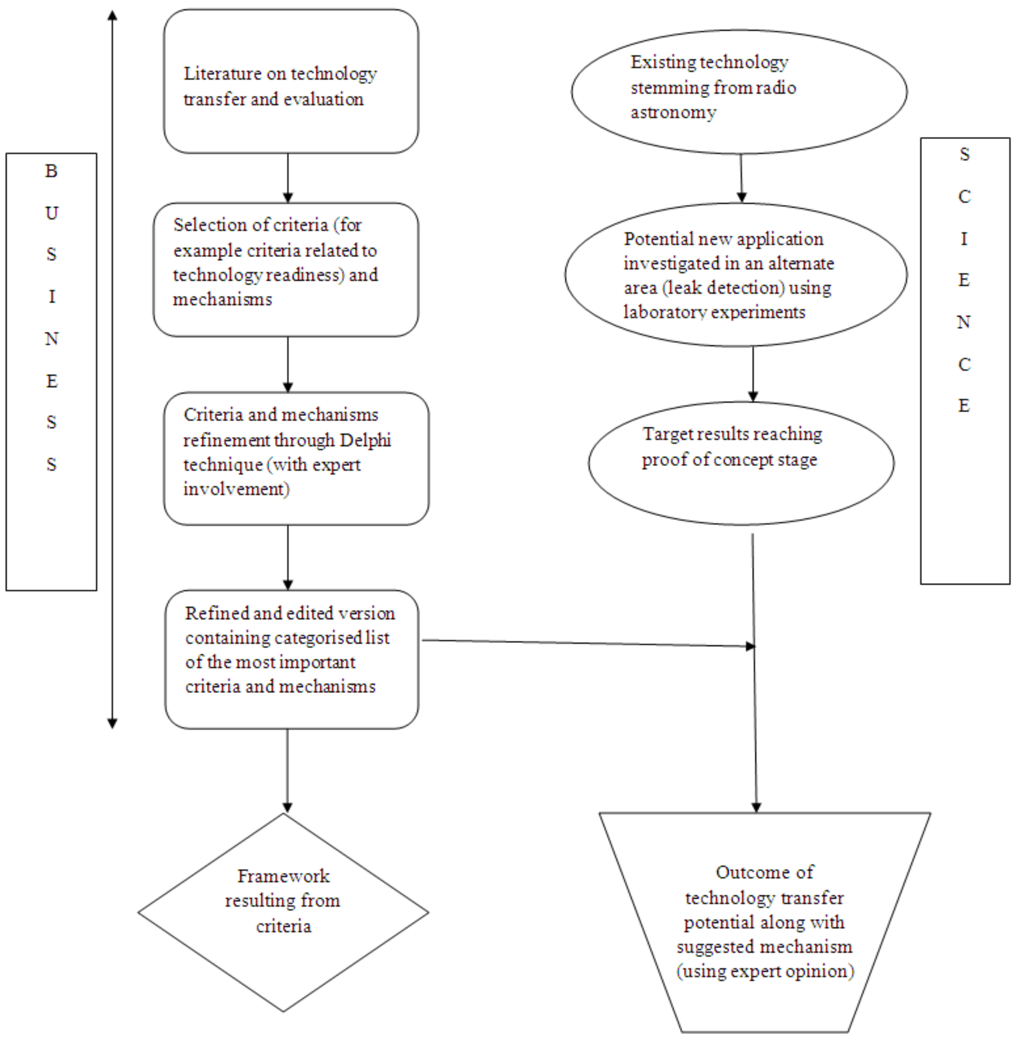

Figure 3-4 Relationship shared by different elements of this study

Figure 3.4 outlines two aspects of the research, namely, business and science disciplines. The business aspect highlights the criteria that are required for the '*ex-ante*' evaluation of technology transfer and mechanisms for commercialisation that will be selected from technology transfer, evaluation and related literature (discussed in the next section). The criteria and mechanisms will be then refined using the Delphi method with the involvement of experts. This will result in a set of refined criteria and mechanisms that are deemed important in the '*ex-ante* 'evaluation process. Following this, the set of refined criteria will serve two purposes:

- To test the commercial potential of the new application and to choose the most suitable mechanism for commercialisation as suggested by experts and
- To create a suitable framework encompassing the refined criteria.

On the other hand, the science aspect demonstrates a technology that is taken from an existing application (radio astronomy) to create a potential new application (water leak detection in pipes) which will be tested through laboratory experiments. The outcome of the experiments will be tested for its commercial potential using the revised set of criteria along with a suitable mechanism chosen predominantly for the technology in question. Furthermore, it is useful to understand the background of the technology as this will help in better understanding the purpose of the research and experiments.

3.3 The technology

Even though astronomy in Australia has generated several technologies such as the Square Kilometre Array, most have not been transferred to the private sector although they are freely available for public use. Making technologies available to the public can be beneficial as certain technologies that are otherwise unavailable to the general public are accessible, thereby allowing for certain transfers to occur. In Chapter Two, the increasing role of universities in commercialisation and technology transfer was discussed, but it is also important to mention their involvement with organisations such as the Anglo Australian Observatory (AAO), the Australian National Telescope Facility (ATNF), and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). The collaboration aids in creating new ideas and spinning off new and improved technologies. One notable example is the University of New South Wales (UNSW), which has played a leading role in setting up experiments related to astronomy in the Antarctic by helping supply equipment that can operate in low temperatures. In addition, a Low-Intensity X-Ray Imaging Scope has its origins in astronomy as does Magnetic Resonance Imaging (MRI). Both are technology transfers from astronomy that occurred on an international scale. The previous section also focused on interdisciplinary research, and it is therefore interesting to note that some PhDs in astronomy have been employed in areas such as business and IT (Jackson et al., 2005).

Currently, possible applications in Australia that can arise from the transfer of technology are from astronomy to medicine; for example, include spectroscopic imaging, signal analysis, and submillimeter imaging. This is possible due to the advances in astronomy research in Australia and the presence of organisations such as AAO, ATNF, and CSIRO (http//:www.atnf.csiro.com.au). AAO developed technologies in optical instrumentation, photonic devices and smart focal planes, and *Echidna*, which is a fibre positioning system (Jackson et al., 2005).

Signal analysis will be the focus of this study owing to the fact that there is a need for equipment that can detect very faint sounds amongst a mixture of noise, and one possible solution could be the use of correlators of the type used in radio astronomy. An example is the correlator developed for Very Long Baseline Interferometry (VLBI) and implemented in software. The VLBI technique was developed in the 1960s to study signals from celestial radio sources. The concept involves obtaining collected data from sources placed at various locations, such as widely spaced telescopes, and transporting the digitised data to a correlator at a different location where the data is combined in a coherent manner. A correlator's task is to align the streams of data obtained, adjusting any changes caused by instrumental disturbances and time lags (Tingay et al., 2007). A major advantage of VLBI is that very sharp images can be obtained. The sharpness of the images obtained is proportional to the distance between radio telescopes. For example, the radio telescopes that make up the Australia Telescope Compact Array at Narribri can be linked to radio telescopes at Coonabarabran, Parkes, Ceduna, and Tasmania in a phased array. These telescopes can also be linked to telescopes in South Africa to form a very long baseline. This is about the largest baseline that can be formed on Earth as all radio telescopes have to observe the same region of the sky simultaneously. Synchronised atomic clocks at each telescope are used to time stamp the data tapes allowing the data to be correlated. More specifically, correlators are used to extract weak signals from background noise on the assumption that signals of interest are correlated and noise uncorrelated. In astronomy, weak signals have to be detected. Radio signals from cosmic objects are difficult to detect as they are combined with a lot of noise, which is why there is a need for radio telescopes to have some means of extracting extremely weak signals from noise. A device called a correlator can achieve this. The Australia Telescope Compact Array (ATCA) at the Paul Wild Observatory, 23km west of the town of Narribri in NSW, Australia (http//:www.narribri.atnf.csiro.com.au) is composed of six 22m dishes on a railway track 6km in length *(Figure 3.5)*.

Figure 3-5 Radio dishes at the Australia Telescope Compact Array (ATCA) in Narrabri, NSW

Signals are collected at the dishes and transferred to a correlator room in the control building. Time tag information is used to match the signals prior to processing by the hardware correlator *(Figure 3.6)* (Hughes, 2007), and the receiving dishes are arranged in a certain fashion and referred to as a '*phased array'.* A group of antennas in which the relative phases of the respective signals feeding the antennas are varied in such a way that the effective radiation pattern of the array is reinforced in a desired direction and suppressed in undesired directions, known as '*phased array*' (Trinh et al., 1997) *(see Figure 3.7).*

Phased arrays are used in a variety of applications, for example in radar systems where linear radar antennae can be effectively used as a curved dish to transmit and receive radar signals. For example, phased arrays are used in ships' radar systems and are seen on a rotating bar somewhere above the bridge on a ship. Another advantage of a phased array is that a beam of radiation can be transmitted and received in different directions. Phased arrays are commonly used in the field of medical ultrasound.

Figure 3-6 Hardware version of correlators at the ATNF, Narrabri, NSW, Australia

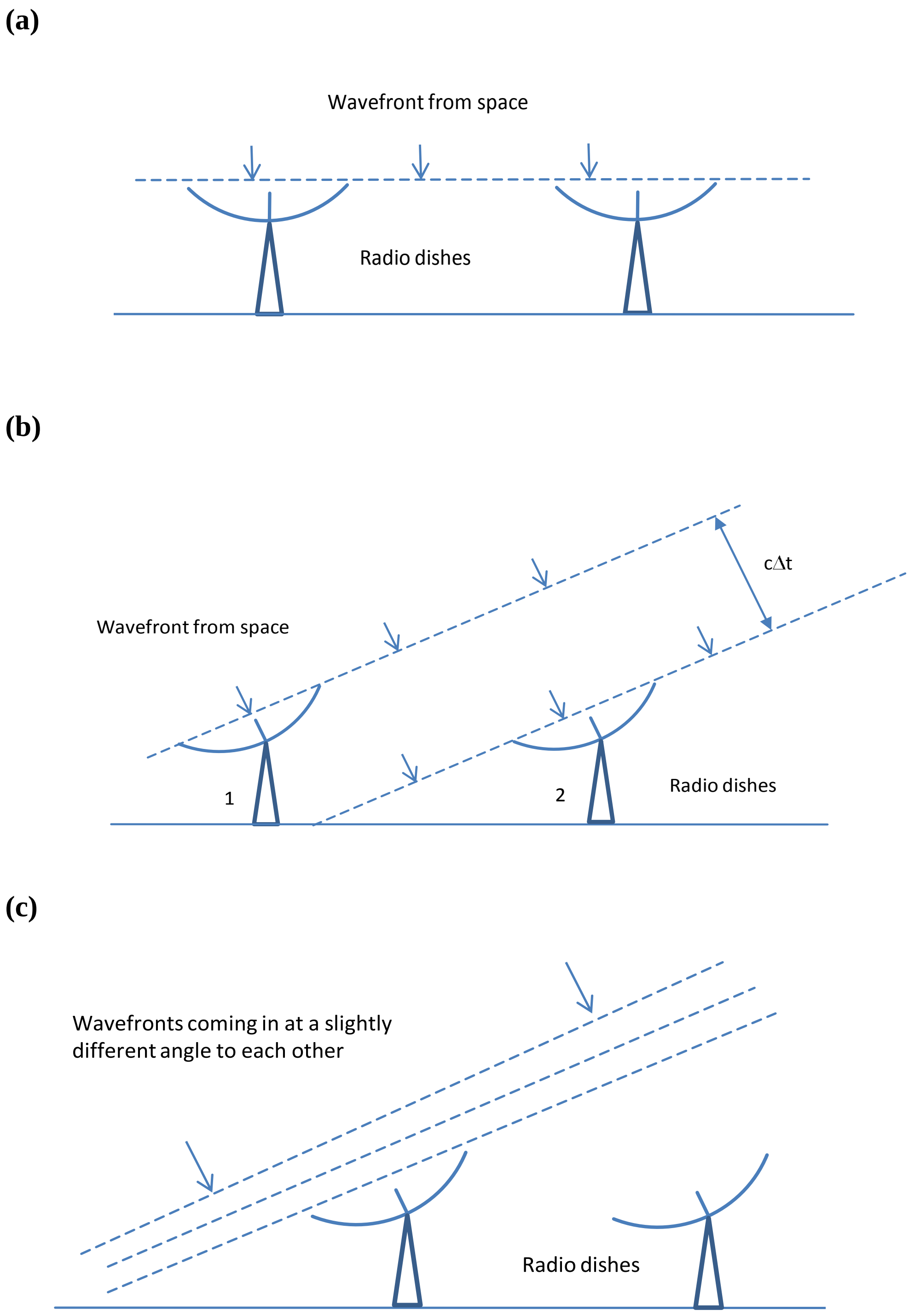

Figure 3-7 (a) Parallel wavefronts arriving at radio telescope issue pointing up at the zenith arrive at arrive at the focal point at the same time. (b) When the object is away from the zenith, a wavefront is focused at different times. The path length difference is cΔt. (c) If the radio emission is from an extended source, the wavefronts arrive at the earth at the dishes at a slightly different angle, and so there is a different time delay between dishes. The difference in the time delay (phase) of the signals enables an image to be generated

In radio astronomy, large dishes are used to concentrate the radio signals and the signals are combined using a correlator. These signals are much weaker than those utilised for more general purposes like telecommunications. The signals are time shifted so that they are aligned when processed by a correlator, and the phase shift between dishes is known, or at least can be accurately calculated, and the calculated phase shift between dishes is used to combine pairs of signals in the correlator. Each pair of dishes is known as a *baseline*. Random signals, for example, Gaussian noise tends to cancel whereas correlated signals tend to add and therefore increase in amplitude relative to the noise. The overall effect is to increase the signal to noise ratio. In some case, radio signals are effectively a point source, for instance, quasars in the distant reaches of the universe. In other cases, radio sources are distributed and therefore the wavefronts come into the dish at a slightly different angle to each other, and will therefore have a slightly different phase shift. The difference in phase shift can be used to form an image of a distributed radio object.

The technology can be used in applications other than astronomy, and one possible application of interest would be to detect water leakage. This could be a particularly useful application owing to water shortage problems in Australia. Initially, CSIRO in Sydney was visited, and meetings with scientists as well as a commercial officer were conducted. The outcome of the meetings included a recommendation to contact Steven Tingay who had developed a software version of the correlator. My supervisor contacted him and further explained to him the aim of the research. He was happy to help and sent us his version. With regards to IP, it was available in the free market.

The software sent to us by Steven Tingay was written in a computer language called PERL and translated into Matlab by computer staff at QUT. A Scilab version was then written and used to analyse the data obtained. More details on the methodology can be found in Chapter Four, and details of the results are presented in Chapter Five.

The principle involves sound arriving at the closest receiver first followed by a time delay and then received at further sensors. The time delay, as well as other details such as the distance between the receivers and the velocity of sound in that environment will help to pin-point the position of the leak. This will be tested and replicated on a small scale in a laboratory using four microphones in a line forming a phased array. Sound signals will be digitised and analysed using correlator software. This is feasible because noise created from a leak will be different from background noise as well as the noise from normal water flow. Leaks can make different sounds and sometimes might go unnoticed, and at other times are masked by background and surrounding noise. The level of the sound of these leaks can be influenced by the amount of water and its pressure in the pipe, the physical nature of the pipe, and location of the pipe. Fortunately, the sound of the leak is sometimes conducted along the material of the pipe allowing for remote detection. The mechanism will involve pinpointing the location of the leak by the increasing the intensity of the sound as it gets closer and closer to the device (SubSurface Leak Detection, Inc., 2006).

Once the basic proof of concept is tested, more components can be added to increase the accuracy of the device and make it more user-friendly. For example, this could include connectivity to computers to log information, display of information on a screen, and power supply to make it portable. It might be possible to make the equipment water resistant so that it could be used in humid environments. The idea is to see if this is possible and propose a feasible product while looking at all areas, and then studying the whole process from origin to new product, keeping in mind that the technology has moved from one area of application to a totally new one.

As highlighted previously, the hardware version has conventionally been utilised in astronomy, but in this case the software version will be used as it has several advantages over the hardware version. For example, software correlators are more flexible, quicker to implement, and cheaper to use. The software version is also more compatible and expandable and has the possibility of being modified and further developed (Deller, 2006) (*see Figure 4.6* for software version). The next section will focus on the chosen application for this technology.

3.4 The application

As stated previously, the study will focus on a technology from the astronomy discipline, and an alternate application will be sought in a totally different area. The basic concept comes from using existing technologies to find applications elsewhere through adoption of the technology, which can be done by modifying certain concepts and components of the source technology. It is a good case to study as a mature technology avoids the need for new research to be conducted in another field where it could be applied. This is very useful in terms of saving resources and the time taken to develop the technology, as the base technology is already functional. Additionally, if an external technology is utilised, its performance and potential can be evaluated if required.

The chosen technology can have many possible applications: for example, security and the medical field - such as detecting the growth of tumours by picking up sounds of irregularities in the blood flow. For instance, there has been research on using non-invasive acoustic methods to detect coronary heart disease (Yasemin et al., 1993). For this thesis, only one application was chosen as it is to be studied in detail. The application related to water leakage was chosen owing to the water problems in Australia, which will be explained below. Like many of the examples stated there could be numerous applications. Sometimes the most suitable one is chosen owing to many reasons such as availability of information, and the most beneficial one will be chosen. Another reason is the gap in detecting leak sounds accurately in plastic pipes as compared to better success in metal ones.

Loss of water frequently occurs in distribution systems. A large percentage is lost while it flows through pipes from one point to another due to leakage which is generally the major cause amongst other causes such as public usage and theft. The amount of water lost can amount to 50 percent depending on the age and durability of the pipes. Leaks can be caused by corrosion, installation issues, faults in the materials, and in some cases ground movement due to drought, freezing, and vibrations from road traffic (*see figures 3.8* and *3.9*). One particular problem with domestic water pipes is that the number of leaks increases at night when the mains pressure increases due to reduced demand. This leads to loss of money and natural resources, especially in Australia where there is a severe water shortage, leading to water restrictions in the country. Another problem is that leaks can give access to contaminants entering the water network, thereby endangering public health (Hunaidi et al., 2000).

Figure 3-8 Burst in pipe caused due to undetected leak (BBC London, 2009)

Figure 3-9 Leaks in pipe carrying water (KillickPlumbing, 2008)

The standard equipment used to locate leaks in pipes is acoustic devices. Leaks are detected by vibrations produced by water flowing out of pipes, pinpointing the position of the leak. Leak detection methods have been classified into three main categories, namely:

1. Biological methods: using observation, odour, or sound to locate leaks. This can be achieved by experienced manpower or trained dogs
2. Hardware methods: using devices to detect leaks. Devices such as acoustic sensors, ground penetrating radar (*see Figure 3.10*) and infrared thermographs are examples.
3. Software methods: using software to detect leaks (Bose and Olson, 1993; Carlson, 1993; Tuner, 1991; Zhang, 1996).

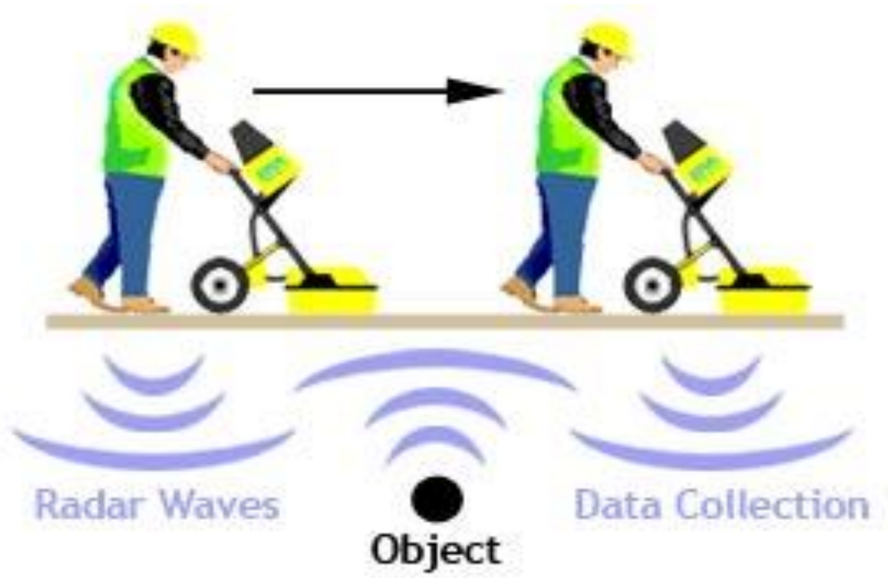

Figure 3-10 Example of ground penetrating radar used for leak detection (Worksmart, Inc., 2007)

The hardware based method is the most widely used method for leak detection amongst the three. One of the issues in using acoustic detection is that it is only efficient for metal pipes and not for PVC ones, because plastic pipes only transmit low frequency sounds heavily attenuated in the wall of the pipe, making the sound very difficult to detect at a distance. On the other hand, there is a possibility that leaks in both metal and plastic pipes can be detected using non-acoustic methods, but these techniques are still limited in their utility and are not as reputable as acoustic ones (Hunaidi et al., 2000; Kiss et al., 2007). Therefore, the experiments conducted will be aimed at demonstrating a proof of concept that the software correlator has an application in water leak detection. Further information about the experiments will be discussed in the next chapter.

3.5 Summary

This chapter began with an explanation of interdisciplinary research followed by details of the technology chosen for the study. This included an introduction to correlators and how they function, and last section of this chapter focused on the chosen application. The next chapter (Chapter Four) will highlight the methodology adopted for the experiments and criteria refinement, as well the evaluation of the commercial potential of the technology.

Chapter 4: Methodology

4.1 Introduction

In order to address the research gaps, a suitable combination of methods was adopted. The gaps recognised included a need to identify the right criteria to be used for evaluation purposes. An existing technology was chosen along with a suitable application, as well as its commercial potential evaluated using the list of criteria developed using the Delphi technique. The focus of this chapter is to outline the research design adopted to approach the research questions along with the combination of chosen methods.

4.1.1 Research design

Owing to the interdisciplinary nature of the research, more than one method was utilised so as to cover both the science and business disciplines. The collection of adopted methods included interviews, questionnaires, and scientific experiments, which was suitable as a specific technology transfer was being studied. It was imperative to identify and propose assessment criteria that would help in evaluating the technology transfer process of a high technology application. Certain specific criteria and mechanisms of transfer were initially chosen from existing literature as discussed in Chapter Two. Using the Delphi technique, the criteria previously obtained from literature as well as some commercialisation mechanisms were sent to experts who rated them and made recommendations and comments. Parallel to this, results from scientific experiments including proof of concept were collected. Once the list of criteria was finalised and the results from the experiments accumulated, the final evaluation was conducted. Details on the experiments can be found in Sections *4.2.1, 4.2.2*, and *4.2.3,* while details on how the Delphi was conducted can be found in Sections *4.2.4 and 4.2.5*. Finally, details on how the refined list of criteria was applied to results of the technology in question can be found in Section *4.2.6* (see also *Figure 1.1*).

4.2 Methodology

This section will cover the methodology chosen for the purpose of this study. This will include data collection and analysis. As mentioned above, a combination of methods was used and this was particularly useful when data was to be obtained through different sources such as experiments and Delphi (Feagin, Orum & Sjoberg, 1991; Yin, 1993 & 1994).

The technology chosen for this thesis was analysed by multiple sources of data; some obtained from interviews and questionnaires and others by experiments. The research questions to be answered required the conscription of various methods to be employed, and since opinions of experts were required, some interviews were conducted to gain input from them. Experiments were also conducted for the technology assessment. The methodology was divided into different phases, namely:

1. Phase 1: Technology assessment (R.Q. 1)
2. Phase 2: Business evaluation (R.Q. 2& 3)

4.2.1 Phase 1: technology assessment (R.Q.1)

Phase 1 is related to RQ1 and was conducted to test that the technology has an application in water leak detection.

The technology originates from radio astronomy and the principle is based on a mathematical process called correlation, as discussed in Chapter Three. To achieve the necessary results, experiments were conducted at the QUT laboratories to determine the feasibility and applicability of the technology in question. According to Cavana et al (2001), lab experiments are those conducted in an artificial or contrived environment. Experiments were necessary as technical data needs to be screened.

A basic proof of concept was initially conducted to verify whether further experiments could be conducted, and the results indicated that this was possible. This test was initially performed with one microphone followed by two microphones, with the results put through the software to determine whether the sound of interest was being picked up. At this point, the sound was just a finger click and whistling. Once these tests were confirmed, then a circuit was built consisting of four microphones each having the same component. The circuit board was put in a metal box to minimise noise. The set-up will be explained following an explanation of how phase shifts will be calculated.

One method of finding the phase shift between two signals is to plot the signals and measure the time difference between a common feature of the signals, for example, the rise of the signals or a peak/trough. This could work with signals with a clearly defined structure such as a hand clap, as shown later in Chapter Five, but will not work well when there is no clearly defined structure as could be the for signals buried in noise. Also, even in cases where the structure of a signal can be clearly seen, the manual method is time consuming and impracticable in cases where several signals are to be analysed.

The time delay between two signals can be determined more efficiently by calculating the cross-correlation function (CCF). This entails multiplying one signal by a time-shifted version of the other and integrating, i.e. summing the point-by-point multiplications for the overlapping portion of the signals. The second signal is shifted one point each time and the integral calculated. In most situations, the cross-correlation function will have low value except at one point where the function rises to a maximum. The distance of this point from the origin of the time axis gives the time delay between signals.

The cross-correlation function can be evaluated more efficiently in the frequency domain rather than in the time domain. A Fast Fourier Transform (FFT) is performed on each signal. The equation for calculating the cross-correlation function for two signals is:

$$R_{ij}(\tau) = \mathcal{F}^{-1}\left\{X_i(f)X_j^*(f)\right\}$$

where $R_{ij}(\tau)$ is the cross-correlation function which is a function of the time delay between signals. The distance of the peak of the function from the origin of the time axis represents the time delay between the two signals. The two subscripts i and j indicate that two signals are involved in the correlation, so the correlation is a cross-correlation as opposed to an autocorrelation which involves a signal being correlated with a time-shifted version of itself. $\mathcal{F}^{-1}$ = the inverse Fourier Transform of the function between the curly brackets. $X_i(f)$ = the Fourier Transform of one of the signals. A FT contains the amplitude of cosine and sine terms as a function of frequency – hence the f in brackets. $X_j^*(f)$ = the complex conjugate of the FT of the second signal.

The * indicates the complex conjugate. A frequency spectrum contains a real and imaginary component of the form ($x + yi$) where x refers to the cosine components and y the sine components of a waveform. The complex conjugate involves reversing the sine of the imaginary component, therefore the complex conjugate of ($x + yi$) is ($x - yi$) and ($x - yi$) is ($x + yi$). Prior to multiplying two spectra together, the imaginary component of one is reversed – i.e. if the imaginary component is positive it becomes negative and *vice versa*.

The product of two complex numbers is found as follows:

$$(x + yi)(u + vi) = xu + xvi + iyu + i^2 yv$$

$$= (xu - yv) + i(xv + yu)$$

Real part of CCF spectrum

Imaginary part of CCF spectrum

This process is the equivalent of performing a cross-correlation on two signals where one signal is multiplied by all of the time-shifted versions of another signal. The expression on the right is the frequency spectrum, or cross spectrum, of the cross-correlation function. Performing an inverse FFT reveals the time-domain function.

Another advantage of calculating the CCF using the FFT method is that both signals can be filtered prior to calculating the CCF. When an FFT is performed, a spectrum is obtained. The first term in the spectrum corresponds to the amount of 0 Hz or DC in the signal. The second term is a number proportional to the amplitude of the fundamental frequency in the signal. The fundamental frequency (f_0) is the inverse of the total sampling period, which can be found by calculating the product of the number of samples (n) and the sample period (Δt), i.e. $f_0 = {}^{1}/_{n\Delta t}$. So, for example, if 100 000 samples are collected at a sampling frequency of 100 000 Hz (therefore the sample period is 10 µs or 10^{-5} s), the fundamental frequency (f_0) is equal to ${}^{1}/_{(10^{-5} \times 10^{5})}$ or 1 Hz.

When the spectrum is produced, the number of spectral bins is equal to the number of points in the sample. When viewing a spectrum, it is apparent that the latter half of the spectrum is a mirror reflection of the first half. Therefore, the frequency range or bandwidth of the spectrum is equal to half the number of sample points multiplied by the fundamental frequency. So, for example, in the case of 100 000 sample points acquired at 100 kHz, the bandwidth of the spectrum is 50 000 × 1 which is equal to 50 KHz. An electronic signal is likely to contain a certain amount of 50 Hz noise. In the case of calculating the CCF, this could confuse the issue as there will be a peak for every 20 ms shift. 50 Hz noise can be removed from a spectrum by determining which peak in the spectrum and mirror reflection of the spectrum corresponds to 50 Hz. In the case of the example cited above, the fundamental frequency is 1 Hz, therefore the coefficient corresponding to the amount of 50 Hz in the signal will occur at the 51st position. It occurs at the 51st position rather than the 50th, as the first position is for 0 Hz and therefore 50 Hz occurs 50 places on from the first position.

The 51st entry is set to zero and the entry in the mirror reflection of the spectrum corresponding to 50 Hz. In this case, 50 Hz is found at 50 places from the end of the spectrum (not the 51st as there is no 0 Hz term in the mirror reflection). So, in the case of a spectrum of 100 000 sample points acquired at 100 kH, 50 Hz will occur at position 100 000 – 50 = 99 950. A flow diagram of the processing algorithm is shown in *Figure 4.1*.

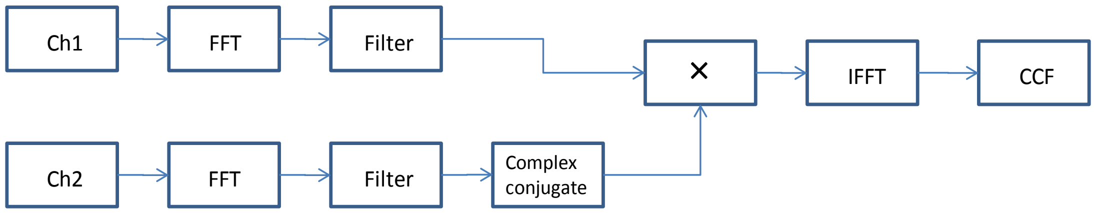

Figure 4-1 Block diagram of the process used to calculate the cross-correlation function of two signals

The CCF can be performed between any two pairs of signals. In the case of a square array shown in *Figure 4.2*, there are six possible combinations. To find the time delay between each pair of signals, the FFT of each signal is multiplied by the complex conjugate of the opposite signal, i.e. A B^*, AC^*, AD^*, BC^*, BD^*, CD^* where the capital letters in this case represent the FFT of the signal acquired at the designated location.

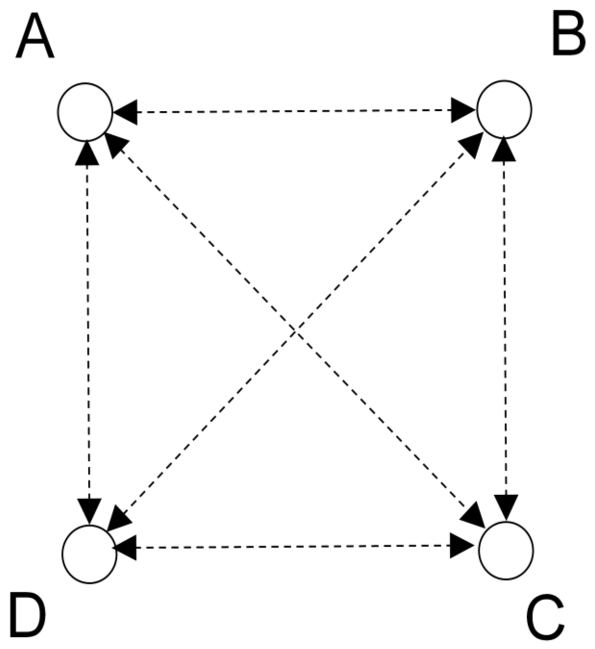

Figure 4-2 Schematic diagram of an array of four detectors. The arrowed dotted lines indicates the possible pairings

4.2.2 Materials required and initial set-up procedure for data collection

The first phase involved setting up the necessary equipment for data collection. A 4-channel Analogue-to-Digital Converter (ADC) capable of digitising signals at a rate of up to 100 KHz/channel was acquired from National Instruments. A particular advantage of this ADC is that signal channels can be acquired simultaneously. This enabled precise correlation of the signals and the direction of a sound source to be determined. The ADC was interfaced to four microphones using four audio amplifiers assembled in the laboratory (*Figure 4.3*). The basic idea was to create a leak in a water pipe that can be detected using a simulated model in the laboratory.

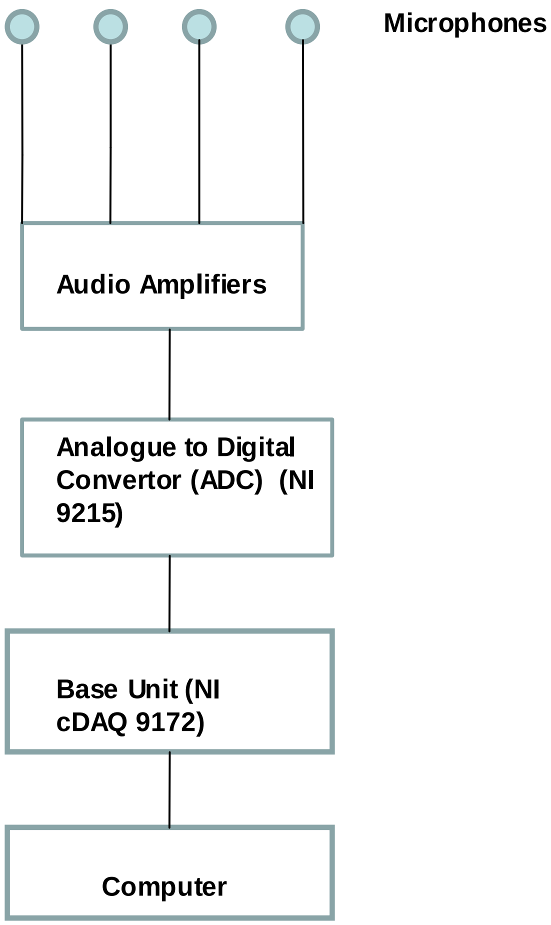

Figure 4-3 Set up for data collection

The next step involved building the circuit for one microphone and this was replicated for a total of four microphones. The circuit had a quad audio amplifier chip (LM324N) that can amplify four signals simultaneously. In addition to the audio chip, the circuit contains resistors and capacitors and two 9V batteries for power, as shown in *Figure 4.4*. The components were soldered onto a Vero board. The circuit was then placed in a diecast metal box to reduce electrical interference, and four electret microphones were connected to the amplifier chip using shielded cable. The four outputs of this circuit were connected to the inputs of a National Instruments NI 9215 4-channel 16-bit ADC, which in turn was connected to a Toshiba notebook computer running Windows XP.

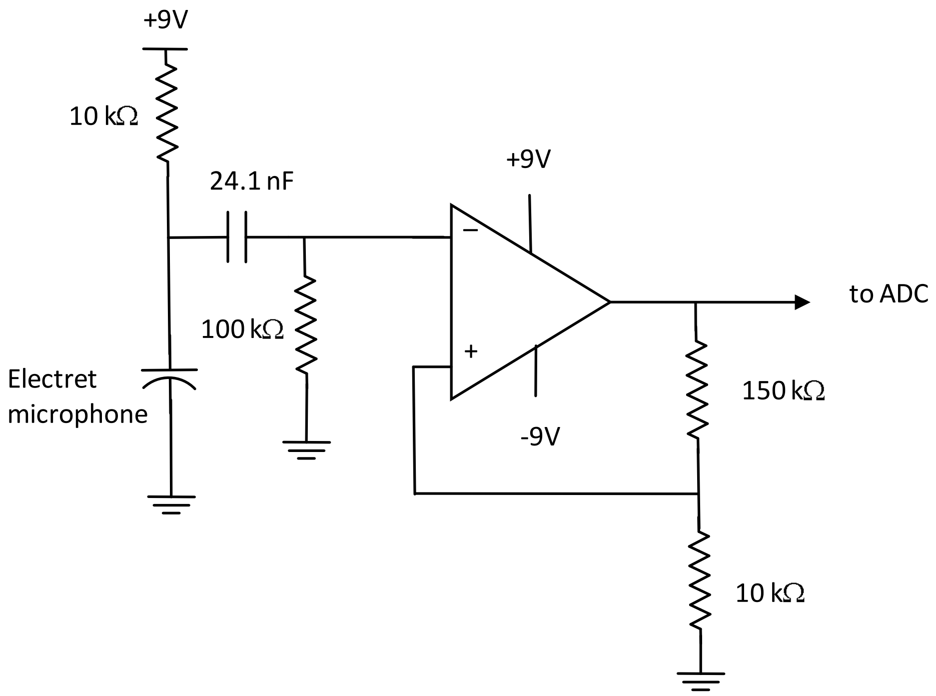

Figure 4-4 Circuit diagram for connecting each electret microphone into the LM324N audio amplifier. The circuit is powered by two 9 V batteries in series to provide a bipolar 9 V power supply. The LM324N chip contains four audio amplifiers allowing four electret microphones to be connected

For the initial tests, an array of microphones was placed in strategic locations around a sound source, and a faint sound that normally cannot be detected by a single microphone was the source. The phased array also helped to determine the direction of the sound. This was then followed by the water leak detection. *Figure 4.5* illustrates this set-up.

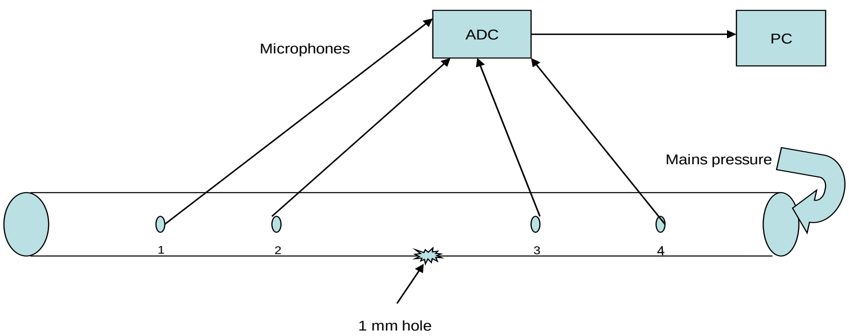

Figure 4-5 Positioning of microphones on the pipe

A computer program called LabView (developed by National Instruments) assisted with data collection. A water leak model was constructed in the laboratory and the acoustic signal generated acquired using one, two, three, and four microphones.

Further set-up details and findings will be discussed in Chapter Five as further modifications were made.

4.2.3 Analysis

The original software version of the correlator is based on DiFX (Distributed FX) and was developed by Steven Tingay (Tingay et al., 2007). *Figure 4.6* illustrates an overview of the software correlator architecture. For this study, a program written in Scilab was used. Scilab is a freely available software package similar to Matlab.

The digitised data was collected and analysed by the software (processing) and combined in a coherent manner. The correlator aligned and combined the data from the different microphones, which also involved the calculation of the delays between the microphones. Then, the time-series data was converted to frequency-series data and this was followed by cross multiplication, integration, and the export of visibility data, which was processed data required for generating images (Tingay et al., 2007).

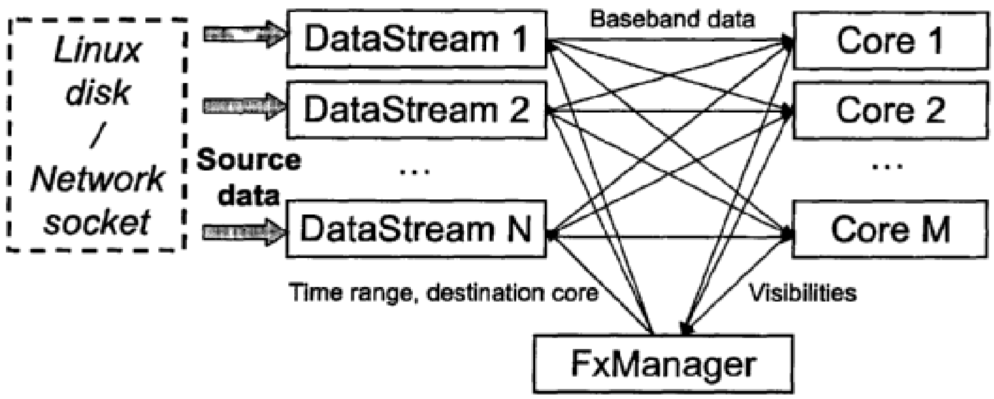

Figure 4-6 Overview of the software correlator architecture which demonstrates that data streams are combined and distributed to multiple cores (parallel processing) (Tingay et al., 2007)

4.2.4 Phase 2: business evaluation (R.Q. 2 & 3)

This phase involved the refinement of criteria obtained from literature, as well the evaluation of the commercial potential of the technology using the refined criteria and selecting the most suitable mechanism for commercialisation. The approach involved a series of steps. An initial compilation of criteria from literature was used to build a table of criteria, and this list was further refined and validated using the Delphi technique consisting of interviews and online questionnaires with experts involved in commercialisation. Subsequently, the commercial potential of the chosen technology was then assessed using these criteria. Therefore, in this phase, the application of the above technology was evaluated based on existing criteria from literature along with some of the main mechanisms of transfer.

It was first necessary to compile a list that could highlight the important criteria to be evaluated. To rate the aforementioned criteria, the Delphi method was well suited as it helped to achieve a satisfactory level of convergence with the participation of experts (Kaynak et al., 1994; Roest, 2002). Furthermore, the Delphi method is chosen because an exploratory approach was needed so as to find out the importance of the criteria as well as to obtain expert's opinions and validate the importance of the criteria obtained from literature. Another benefit of using Delphi is that recommendations can also be obtained from experts at the same time for any other criteria that could be added with a rating (Van den Ende et al., 1998; Ortt et al., 2006). This section will be divided into sampling strategy and stages consisting of collection and analysis techniques.

4.2.5 Sampling strategy

The chosen sample strategy is purposive sampling, which is non-probability sampling. This was a good option as information from specific targets needed to be obtained. This type of sampling is confined to certain people who can provide the information needed (Cavana et al., 2001). Judgement sampling and snowball sampling, which are major types of purposive sampling, were utilised. In judgement sampling, the subjects are chosen based on their ability to provide the required information (Cavana et al., 2001). In this case, the special expertise and knowledge of the study sample was used to select targets for the study. Judgement sampling was appropriate as it helped to target the experts in the area and this resulted in the collection of accurate data. Snowball sampling is a method whereby the chosen sample population has specific information or knowledge and might be difficult to contact. The initial group chosen gave references for new subjects who in turn had the required information (Cavana et al., 2001).

This was an appropriate approach to take because the relevant contacts were not found at first, and the study population that was initially contacted made referrals to more relevant and appropriate experts who assisted in obtaining appropriate information. The respondents in turn made referrals to more experts. Hence, this process helped as it directed to some information that would have otherwise been hard to get.

These sampling methods were applicable for this research because in-depth information was needed as this is a very specialised area, and a limited sample size exists. For this study, the experts were classified into categories related to the areas of expertise in order to obtain a variation in the sample. According to Roest (2002), an expert is a key person who has important knowledge about the area of interest and a background in that field as well.

The categories were chosen in a manner in which all of the relevant required areas were addressed *(Table 4.1).* An interesting aspect of the use of Delphi in this thesis was the recruitment of a multi-disciplinary team of experts. This added to the area of Delphi research by demonstrating that the Delphi study could be conducted by involving experts from various fields using a virtual medium (Skulmoski et al., 2007). The experts were divided into categories according to whether they were experts on transfer mechanisms, high technologies, technology consultants, and commercialisation officers. This guaranteed a wide knowledge base and a better range of alternatives. The chosen sample size was 21. The relevant research literature revealed that there is no fixed rule as to how many experts are required for the Delphi panel, nor is there an understanding on how much expertise or knowledge one needs to be chosen as an expert (Kaynak et al., 1994). Dalkey (1969) stresses that 15-20 members is the minimum number required. Ludwig (1997) agrees by stating that the majority of Delphi studies have consisted of 15 to 20 participants. It was also reported that the reliability of group responses increases as the size of the group increases: for instance, with a group size of 13, reliability with a correlation coefficient close to 0.9 was found (Dalkey et al., 1972).

Hence, the sample size chosen here was appropriate because there was a minimum of five experts from each category and this provided more validity. In addition, replicability of this study is also possible as the process is highlighted in this chapter and there is a considerable amount of literature on Delphi.

Table 4-1 Selection of experts based on area of expertise in relation to the study

Area of expertise	Number of experts
Mechanisms of transfer (licensing executives, spin-off managers, etc…) venture capitalist	5
Commercialisation officers (university commercialisation offices, legal experts, etc.)	6
Scientists (physicists, astronomers, etc…) and academics	5
Technology consultants	5

4.2.6 Collection and analysis

The respondents/experts were initially contacted by phone or email and were briefed about the procedure. This was followed by sending them more information about the technology and research topic, and they were then given time to familiarise themselves with the area. The next step was to arrange suitable times for the interviews and to send out the questionnaires by email. The following sections will discuss the different stages involved to collect data for the business related phase.

Stage 1: Obtaining criteria for literature

A general list was compiled from literature identifying the major categories that were essential for the evaluation. The important sub-categories were also identified and listed. The refining was done according to previous models used in this area of research as well as experts in commercialisation through interviews. The experts were then asked to review this list by rating the criteria in the Delphi stages.

Stage 2: The Delphi method (Round 1)

The Delphi method was developed during the early 1950s and is based on a structured process for collecting and distilling knowledge from experts in several rounds combined with controlled opinion feedback (Roest, 2002). Delphi is a way of obtaining information from a set of experts with the aim of achieving consensus. The experts are asked a number of questions, which are then summarised and sent back to the experts anonymously to check if they would like to reconsider their answers based on the means of the ratings. The process can be repeated a number of times and this can help to augment the reliability of the results. The process involves obtaining experts' opinions and summarising them, and they are allowed to change their results so as to agree with the consensus, or their results can remain unchanged with a justification.

Generally, there is no interaction between the experts, decreasing any chance of bias. They also have some time to decide on their answers. Expert opinion is helpful as the experts are aware of the developments in their area and can therefore reliably contribute accurate information. Therefore, in this case, having a range of experts was useful in obtaining a clearer result (Ludwig, 1997; Ortt et al., 2006).

Generally, in the Delphi method, a group of experts are individually asked for their opinion. The process involves:

1. Each expert giving his or her opinion about a list of questions.
2. The opinions of each expert being collated and any extreme opinions discarded. Following this, an initial view (consensus) is formulated.
3. The initial view is then passed on to the experts for further comments, and depending on how they respond, the initial view might be changed.
4. This process will continue until a consensus has been reached, which has the acceptance of all/most of the panel (Roest, 2002).

However, based on the suggestions by Skulmoski et al. (2007) in relation to the design of the Delphi technique, below is a description of the altered and specific version of Delphi that was adopted for this research:

1. Mixed method approach, that is, qualitative and quantitative due to the fact that the experts were asked to rate as well as justify/comment on their choice
2. The choice of experts was based on their knowledge, experience, and willingness to participate in and contribute to the research
3. The number of participants chosen was 21. The recruiting of experts for the Delphi consisted of a simple yet efficient system, and snowball sampling was used.

   Furthermore, the choice of experts was also based on their experience and area of expertise. The participants were expected to satisfy certain requirements listed below:

   - Relevant knowledge to the research
   - Experience

- Willingness to participate
- Time to spend on the multiple rounds if required
- Effective communication skills (Adler & Ziglio, 1996; Skulmoski et al., 2007)

The number of rounds depended on the outcome, but for this research, it was two rounds as satisfactory convergence was achieved. The next round of questionnaires was dependent on the results from the previous round.

4. The mode of interaction with the experts was through online questionnaires and interviews. As Skulmoski et al. (2007) point out, the Delphi method can be used with a series of questionnaires to obtain and narrow down feedback from experts. It was decided that email would be used as the medium to send out the questionnaires for the Delphi rather than standard mail. This gave the participants more privacy, freedom, and time to answer at their leisure (Lindqvist & Nordanger, 2007).
5. The results were analysed using means, standard deviation, and interrater agreement (IRA), which will be discussed below.

Additionally, the first round of Delphi consisted of six interviews and fifteen online questionnaires. The interviews were used as a means of consultations with the experts to confirm with them the list of criteria obtained from literature as well as to collect data for the Delphi study. The experts were requested to rate each criterion on a 5 point Likert scale, 1 being *least important* and 5 being *very important*. In this round, the experts were told to be as general as possible, and the same applied for the mechanisms. The experts also had the opportunity to make any comments as well as recommendations for the criteria and mechanisms if they felt something had been left out, while rating them so as to demonstrate their importance. It was assumed that the experts did not know who else had been approached even though snowball sampling was used, as they recommended several others but were unaware of those who agreed to participate. Some advantages to using this technique are that no direct interaction is required and it is reliable as it helps to form opinions and build theories (instructions and template can be found in *Appendix B*).

Stage 3: The Delphi method (Round 2)

In the second round, each expert was contacted by email with instructions as to what was to be done. The second round involved only the use of online questionnaires. Each expert was sent their previous results from round 1 as well as the mean of all results, and a breakdown of how many experts gave a particular rating for each criteria and mechanism. The experts then had to study the information provided and decide whether they would like to remain on the same rating or change their results. The experts were informed that if they chose to maintain the same rating or changed their rating and it was considerably different from the mean, they were to justify why; whereas, if they chose to move closer to the mean or to the same number, this was not required. There was also room for additional comments if they wanted to add anything further (instructions in *Appendix C*).

The analysis included the calculation of the means of the results as well as standard deviation. *Figure 4.7* illustrates the above-explained stages.

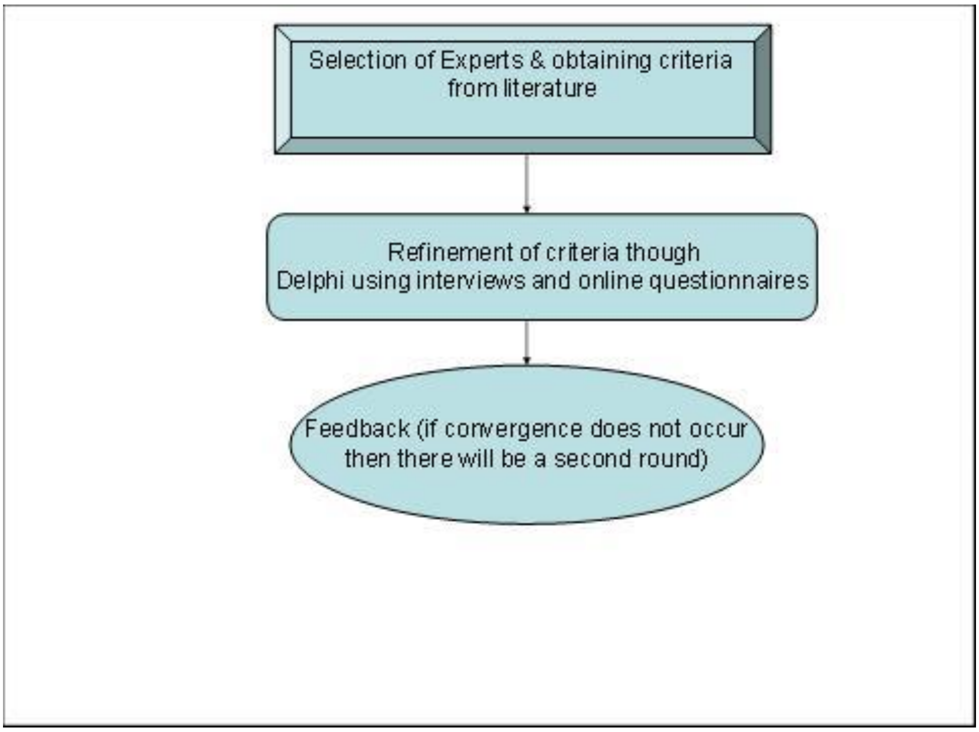

Figure 4-7 Steps for data collection

Furthermore, the interrater agreement (IRA) for the ratings of the experts was obtained using r_{WG} indices for both rounds of the Delphi. This was done as part of the analysis to investigate the agreement amongst experts in their rating, and to check if there was an emerging pattern of convergence, especially from the ratings in the second round as compared to the first. The r_{WG} index was calculated as follows:

$$r_{WG} = 1 - \frac{S_X^2}{\sigma_E^2}$$

where S = standard deviation and

$$\sigma_{EU}^2 = \frac{[(A]^2 - 1)}{12}$$

where A is the scale adopted (for example 5 point or 7 point scale) (James et al., 1984 & 1993; LeBreton & Senter, 2008).

The Delphi was followed by a final stage which consisted of the evaluation of the technology transfer potential of the chosen technology using the refined set of criteria from the Delphi as outlined below.

Stage 4: Evaluation of the technology transfer potential using the new set of criteria

This stage was the final part of the data collection procedure and was based on the results of the Delphi and the experiments. The aim here was to evaluate the technology's commercial potential and decide which would be the most suitable mechanism for its transfer. To achieve the necessary results, experts with commercialisation experience were approached. This set of experts was different to the one used for the Delphi, and 30 experts were contacted with a minimum requirement of between 15 and 20 experts (Dalkey, 1969; Ludwig, 1997; Skulmoski et al., 2007). This was appropriate as the experts were from the same field of expertise, and a total of 18 participated.

An online questionnaire (7 point scale) was sent to them via email as a link. When they accessed the provided link, they were first asked to agree to a consent form and a confidentiality agreement. The confidentiality agreement was required so as to protect any potential intellectual property that could be generated in the future. As a precaution, no disclosing information was sent to them. Once the experts accepted these conditions, they were able to view a brief about the research. This included:

- The aims of the project
- Background of the technology
- How the criteria were obtained
- Information about the intellectual property and potential markets for the technology.

The experts were then able to attempt the questionnaire. Initially, they were asked about their professional background, followed by the evaluation of the commercial potential of the technology using the criteria and recommendations for the mechanism that would be the most suitable.

Finally, they were asked to comment on what they felt was the position of the technology in terms of its commercial potential. This was important as their comments were crucial in analysing the final outcome of the research. The ratings were also analysed using means and standard deviation. Additionally, the IRA was also estimated using the r_{WG} index as done previously with the Delphi (instructions, confidentiality agreement, and template can be found in *Appendix D*). While stage 1, 2, and 3 were done to answer RQ 2, stage 4 was essential to answer RQ3.

4.3 Ethical considerations

In order to minimise any risk associated with the research, the participants were required to sign a consent form (for the interviews) and/or agree to the online questionnaires, and were also informed about the objectives of the research. They also had the right to withdraw at any time if they wished.

In addition, the participants were kept anonymous and any data collected was only available to the researcher and the supervisors. This was considered to be a low risk research as acknowledged by the University Research Ethics Committee.

4.4 Summary

This chapter provided insight into the methods adopted to answer the research questions in this thesis. It began by outlining the research design tailored for the thesis owing to the interdisciplinary nature of the research encompassing scientific and business disciplines. The methodology was divided into technology assessment (address RQ1) and business assessment (address RQ2 and RQ3).

The technology assessment introduced the concepts of phase shifts, cross-correlation function, and FFT, which are all essential in helping to analyse the data collected through laboratory experiments. This was followed by an explanation of the set-up and components required to conduct the experiments, and the analysis of the data collected using software.

Following this, the methods implemented for the business evaluation were outlined. This began with the explanation of the sampling strategy used for the selection of the experts. One set of experts was used for the Delphi study and a second set for the evaluation of the commercial potential of the technology. The next sections expanded on stages involved in refining the list of criteria, which included acquiring criteria from relevant literature (stage 1) and using the Delphi method (stages 2 and 3) to refine the list using expert opinion. This also included details on which experts were recruited for the Delphi. The last stage (stage 4) which consisted of the evaluation aspect was then explained, and the ethical issues finally discussed. The following two chapters will outline the results of the scientific experiments and business phase respectively.

Chapter 5: Results of the Scientific Experiments

5.1 Introduction

This chapter will outline the results of the scientific experiments conducted to establish a proof of concept for the application. The chapter will also outline additional information on how the data was collected and results of the key experiments performed.

5.2 Supplementary information about the experiments

The experiments were comprised of several rounds of testing and modification to obtain satisfactory results. Initially, simple tests of sound detection were conducted using hand claps and mouse clicks as sound sources, and a Cathode-Ray Oscilloscope (CRO) was utilised to check if the microphones were picking up sound. Following this, the equipment was put together and a circuit board built as discussed in Chapter Four, and this was improved upon and tested over time (*see Video Clips 1, 2, 3 and 4; provided separately on CD*).

Once the equipment and circuit board were ready, simple tests using clicks and claps were again conducted to check if data was being collected. Results from the hand clap test are discussed in Section 5.4.1. The last step was to write an algorithm that could correlate the data obtained from the four microphones.

However, analysis of the data at that time did not result in leak detection. Part of the problem may have been that water from the leak generated a significant amount of noise when it hit the sink. Several modifications were made which then resulted in successful leak detection. These are outlined below:

- The existing small hole in the PVC leak pipe was widened to 2.5 mm in diameter. The pipe was oriented so that the hole pointed vertically.
- A strip of foam was draped over the hole and held in place using plastic pegs to prevent the strong jet from splashing on the side of the sink. This allowed noise created by the leak to be heard by a stethoscope placed on the pipe. When the sponge became saturated, the stream of water falling from the sponge down onto the floor of the sink could be heard. An attempt was made to reduce this noise by placing a piece of foam on the bottom of the sink and using a plug to prevent sound caused by the water draining away. The foam was very effective at removing all sounds except for the leak sound (this was checked using a stethoscope) (see Figure 5.1)

- It was discovered that when a finger was interposed between the stethoscope and pipe, the sound was greatly magnified. However, circulatory sounds were mixed with leak sounds. A small piece of flattened Blu-Tak was placed on the diaphragm of the stethoscope, which had the same effect as the finger but without body sounds. It may be that if the electrets microphones are placed on a small piece of Blu-Tak on the pipe, the sound of the leak will be intensified and the amount of ambient noise entering the microphone will be reduced.
- However, the Blu-Tack and gel arrangement was not very stable and the microphone moved after a minute or so. Some small plastic tubes used as connectors in irrigation systems were obtained from a local hardware store (Mitre 10 in the Brisbane CBD), that were just the right diameter for inserting an electrets microphone. These were cut to a more convenient height in the Faculty of Science workshop. These plastic holders were placed onto the surface of the PVC leak pipe using Blu-Tack.
- Additionally, it was discovered that the interposition of ultrasound gel between the front face of the microphones and pipe was very effective at excluding ambient sound (see Video clip 1 and Figure 5.2). For example, with a CRO set at a certain gain, a loud clap a metre or so away from the microphones could not be detected but a tiny tap on the pipe with the end of a screwdriver showed a very strong signal. With the microphones placed in the cylinders just touching the pipe with no gel, normal speech could be detected with the same CRO gain.

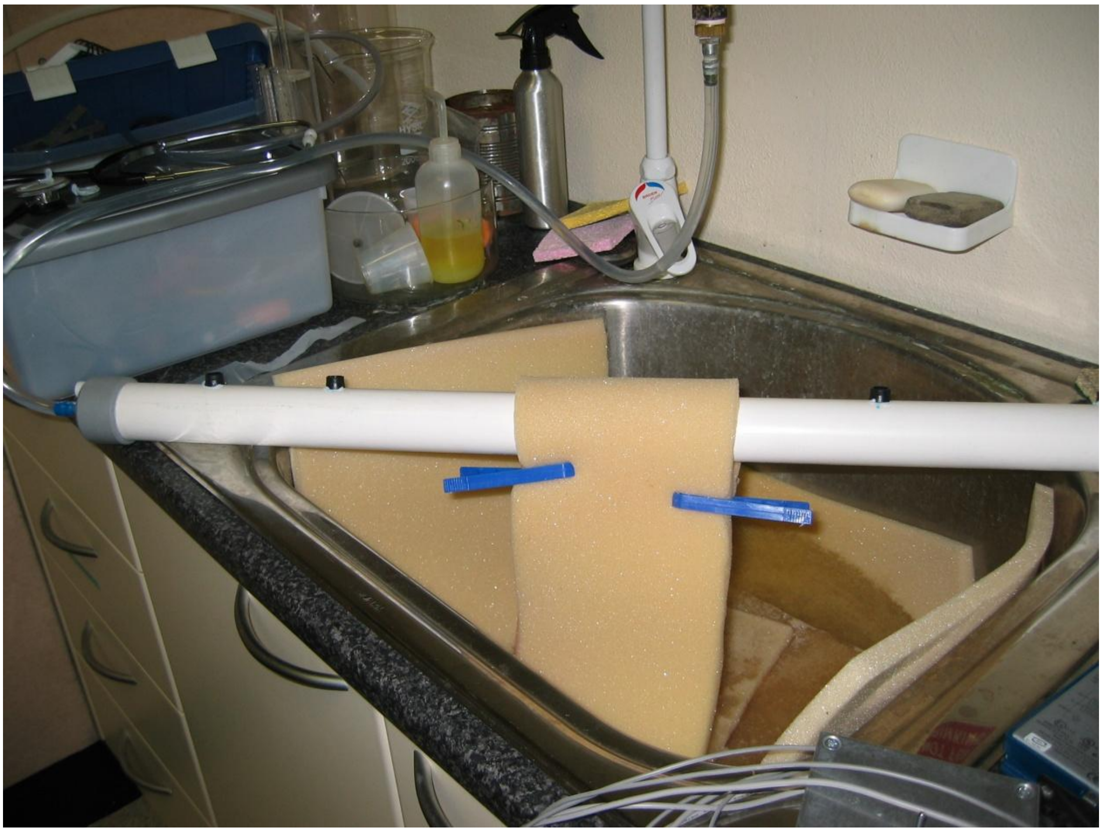

Figure 5-1 Using foam around the leak and on the sink

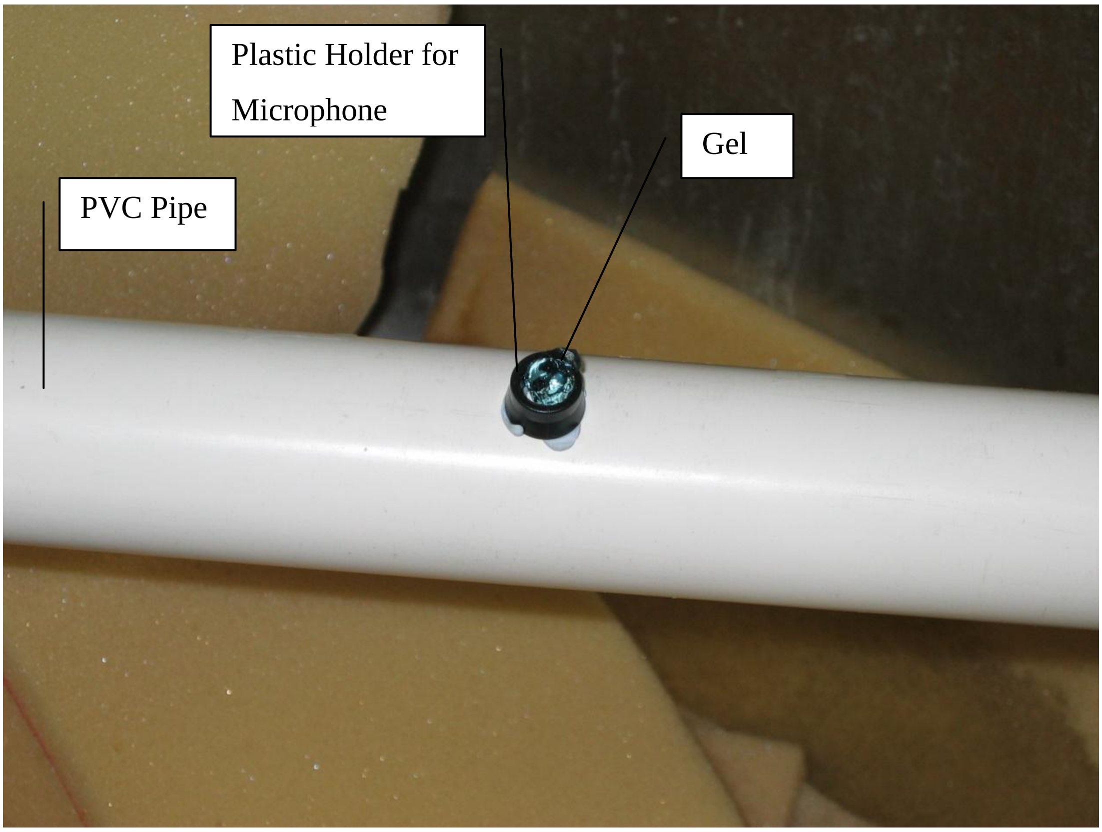

Figure 5-2 Interposition of the gel between the front face of the microphone and the pipe

Once the set-up was modified, each channel was sampled at 100 kHz. Data was acquired using a virtual instrument developed using the *LabView* 8.2 (NI) program. For trial purposes, 10s samples were acquired and stored on a disc in “csv” (comma separated variable) format. The csv data files were saved on a USB stick and transferred to a desktop PC[7]. The csv files were loaded into Microsoft Excel and each channel of one million points copied and pasted into a Microsoft Windows program called *Notepad* and saved as a text file. Following this, data was loaded into a correlation program developed using Scilab (Scilab is very similar to Matlab but is a shareware program and therefore free). The program loads in two channels at a time (equivalent to a baseline in radio astronomy) and performs a Fast Fourier Transform (FFT) on each channel. The complex conjugate of one of the channels was calculated and the two sets of complex numbers produced by the FFT multiplied to produce a real and imaginary term, which represents the frequency spectrum of the Cross Correlation Function (CCF).

An inverse FFT was performed to reveal the CCF. The position of the peak of the CCF was calculated and used to calculate the time delay between the two signals. The speed of sound in air is 330 ms^{-1} and using a sampling frequency of 100 kHz, the distance travelled by a sound wave in the sampling interval of 10 µs is $= 330 \times 10^{-5} = 3.3 \times 10^{-3}$ m, i.e. 3.3 mm.

5.3 Calculation of source position

The angle of the acoustic wavefront with respect to each pair of microphones can be calculated as shown in *Figure 5.3*. As a fairly good approximation an acoustic wavefront can be considered as straight; the further away the source of sound the better the approximation. The calculation of the phase shift between microphone pairs A and B and C and D enables the horizontal angle of the sound source to be calculated. The phase shift between microphone pairs A and B and C and D, enables the vertical angle to be calculated.

7 Analysis of the signals could have been performed on the notebook, but since it had a small keyboard and screen it was easier to use a desktop PC

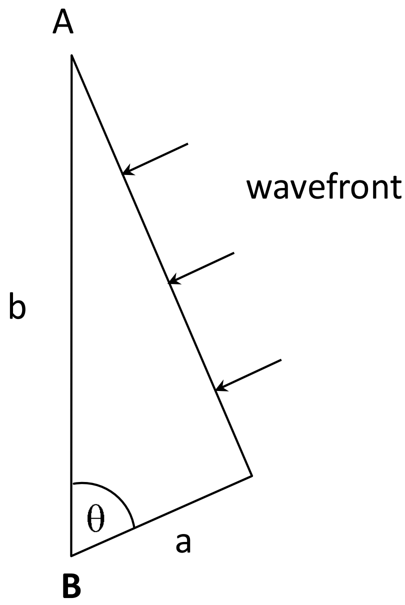

Figure 5-3 Diagram showing an acoustic wavefront arriving at two microphones A and B

The equation for calculating the angle (θ) between the wavefront and a plane passing through microphones A and B is:

$$\cos\theta = \frac{a}{b} = \frac{vt}{b}$$

Therefore:

$$\theta = cos^{-1}\left(\frac{vt}{b}\right)$$

where *b* is the distance between A and B and *a* is the distance between the wavefront and microphone B when the wavefront impinges on A. This distance is approximated by the time delay (*t*) between the arrival of the wavefront at A and B multiplied by the speed of sound in air (*v*). More sophisticated methods of calculating the direction of a sound source have been presented in the literature (for example, Brandstein et al. (1995, 1997); Birchfield (2001)), but the method described above is adequate for a proof of concept because necessary results for this study were achieved and were sufficient for the evaluation.

5.4 Theoretical test

Excel was used to generate two files containing test data. One of the files contained a sequence of 1,000 “0” with a “1” replacing the 300th “0”. The second file also contains 1,000 zeros but with the 400^{th} zero replaced by a “1”, which was the same as the first except with the “1” replacing the 59th “0”. *Figure 5.4* shows a plot of the two test signals. In this case, the time between samples was 10 µs as it is with the real data. Therefore, the total length of time covered by the test data is 1,000 times 10 µs which is 0.01 s (10 ms). The time shift between the two peaks is 1 ms.

When a CCF is performed, the output will be zero for all time shifts except for a shift of 100 places when the two peaks (ones) coincide, in which case the output is unity. *Figure 5.5* shows the CCF. Note that the peak is exactly where it is expected to be, i.e. at a delay of 1 ms. This is *plus* 1 ms as the first signal (with a unity pulse at position 300) is in advance of the second signal (with a unity pulse at position 400) by 100 samples or 1 ms. When the test data files are specified in reverse order in the Scilab computer program, the delay is -1 ms.

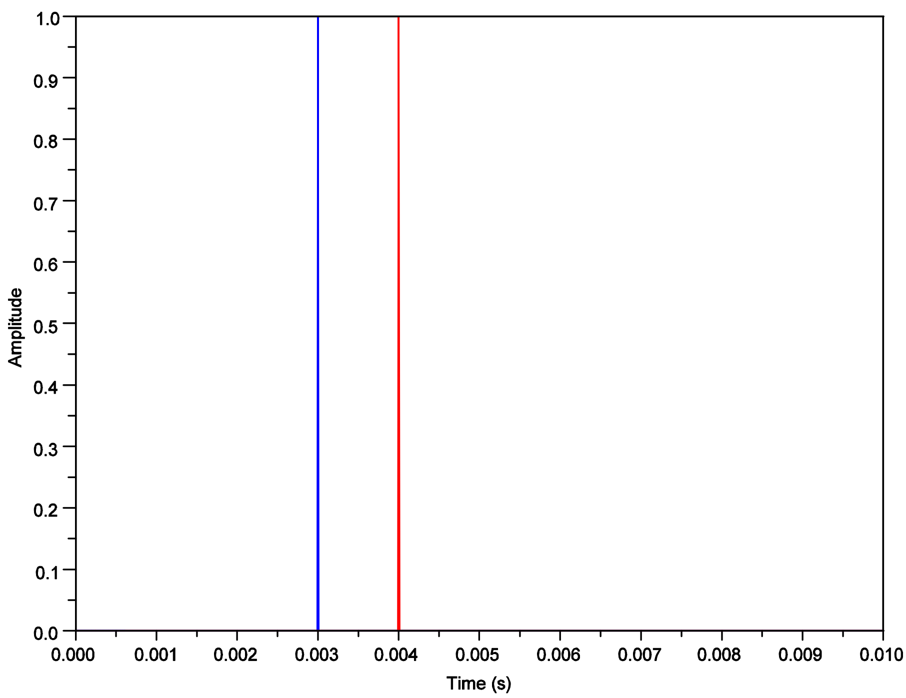

Figure 5-4 Two unity pulses separated by 10 ‘time’ positions.

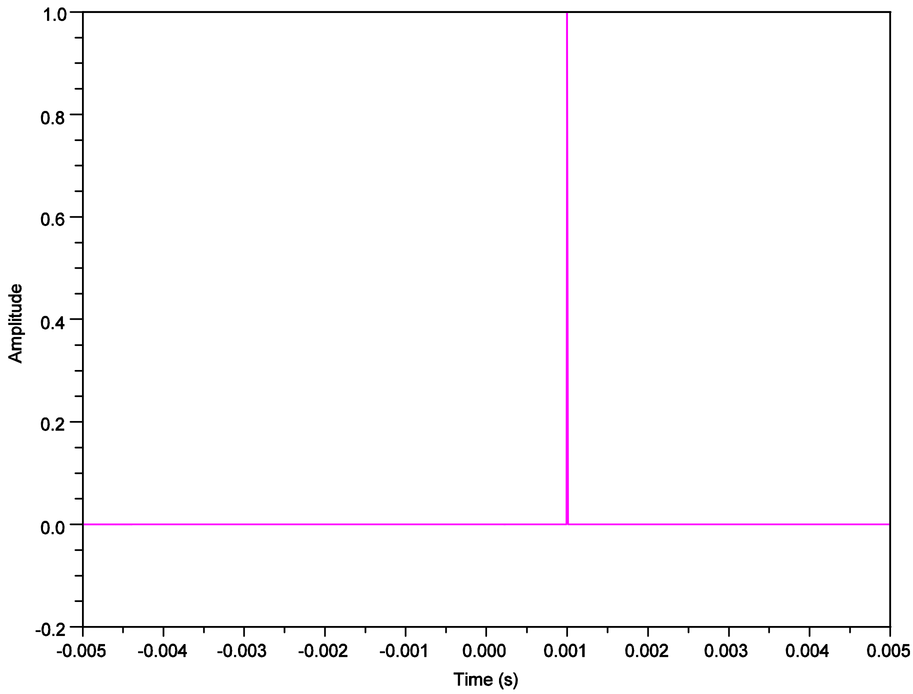

Figure 5-5 Cross correlation function of the two unity pulses shown in figure 5.4.

5.4.1 Clap test

A hand clap was performed to one side of the microphone array, and the acoustic signal of a clap is shown in *Figure 5.6*. The blue (darker in black and white print) trace corresponds to microphone 1 and the red (lighter in black and white print) trace to microphone 2. Notice that the amplitude of channel 2 is slightly smaller than channel 1, which is expected as the clap was closest to microphone 1.

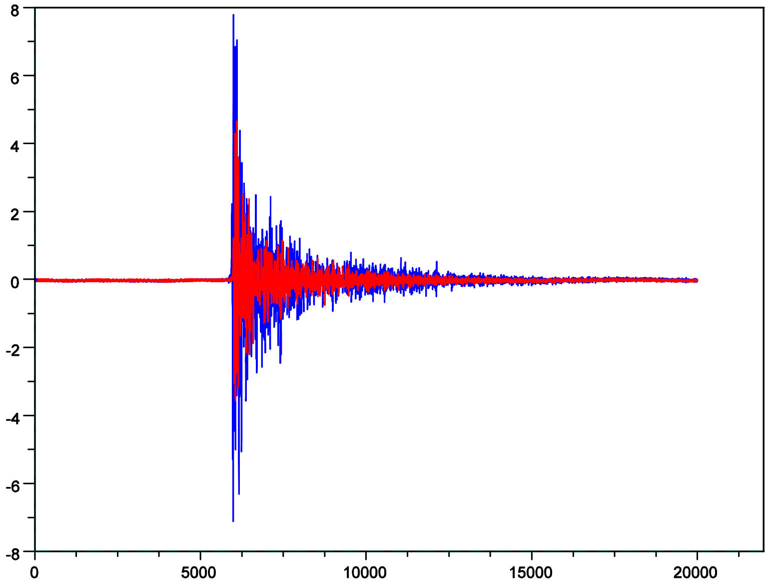

Figure 5-6 Acoustic signals of a clap received by two microphones. Data was sampled at 100 kHz. 0.2 s of data are displayed.

The cross correlation function is shown in *Figure 5.7*. The peak is 46 points from the origin indicating a time delay of 0.46 ms, representing a path length difference of 15.2 cm. Using the equation above, this give an angle between the acoustic wavefront and a plane passing through microphones 1 and 2 of:

$$\theta = cos^{-1}\left(\frac{vt}{b}\right) = cos^{-1}\left(\frac{3.30 \times 10^{2} 4.6 \times 10^{1} \times 10^{-5}}{1.8 \times 10^{-1}}\right) = 32.5°$$

The angle made with the plane through microphones 1 and 3 was 23.5º. Similar angles were obtained for microphone baseline pairs 3 and 4 and 2 and 4.

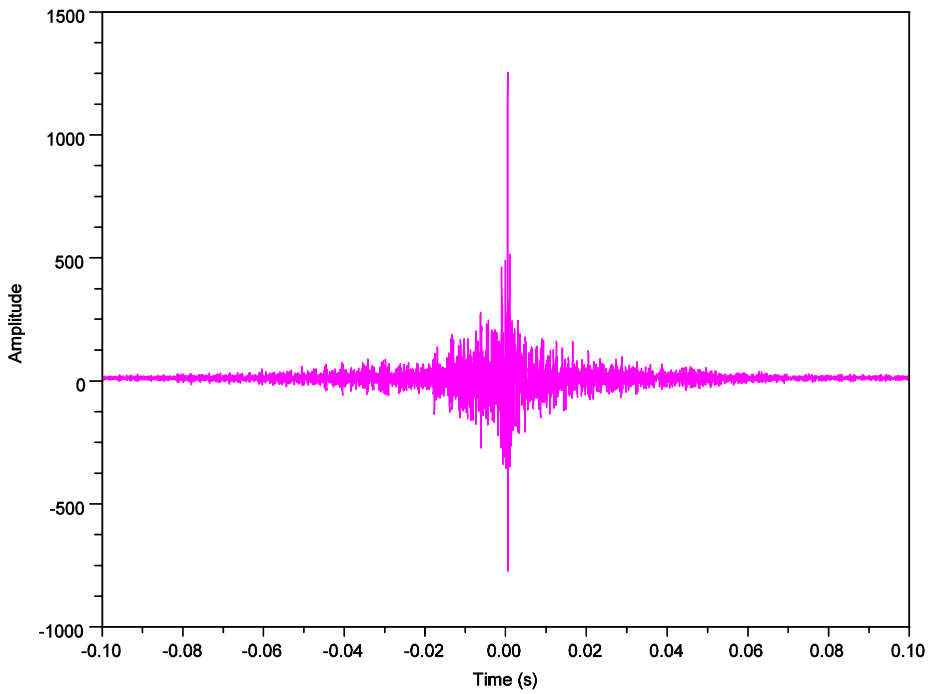

Figure 5-7 The Cross correlation function (CCF) of the clap shown in Figure 5.6. The peak is 46 points from the origin indicating a time delay of 0.46 ms, representing a path length difference of 15.2 cm

5.5 Leak tests

The technique can then be used to determine the location of a fluid leak in a pipe (i.e. liquid or gas) if microphones or accelerometers are set up as shown in *Figure 5.8*. Sensors are placed on the pipe a known distance apart and the CCF calculated for a signal sample. If the CCF shows that there is no time shift between the signals, then the source of the sound (e.g. leak) must be exactly half way between the two sensors. This is assuming that the speed of sound in the material of the pipe is constant along the length. *Figure 5.8* shows the situation of a leak in a fluid-filled pipe that is not half way between sensors. In the case shown, sensor B is closer to the leak than A, therefore the sound from the leak will arrive at sensor B before sensor A. The equivalent feature in the sound arrives at sensor A at a time Δt later, and in this time the sound has travelled a distance Δtc where c is the speed of sound in the material of the pipe. This distance is the *extra* distance the sound has travelled from the leak to sensor A. The sound has already travelled a distance d_l between the leak and sensor A. The distance between the leak and the closest sensor to the leak is found using:

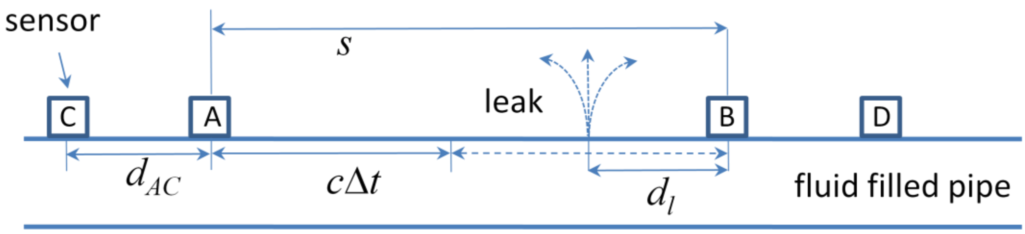

Figure 5-8 Schematic diagram of use of a phased array to find the location of a leak in a pipe

If two pairs of sensors are placed on the pipe as shown in *Figure 5.8*, then the same calculation can be performed using sensors CD, AD, and CB, possibly providing a more accurate measurement of the location of the leak. Another important advantage of using pairs of microphones is that the speed of sound (c) in the material of the pipe can be calculated. For example, if the distance between sensors A and C is d_{AC} and the time delay between the arrival of the sound at sensors A and C is Δt_{AC}, the speed of sound in the material of the pipe is: $c = d_{AC}/\Delta t_{AC}$ The same calculation can be performed using sensors A and D.

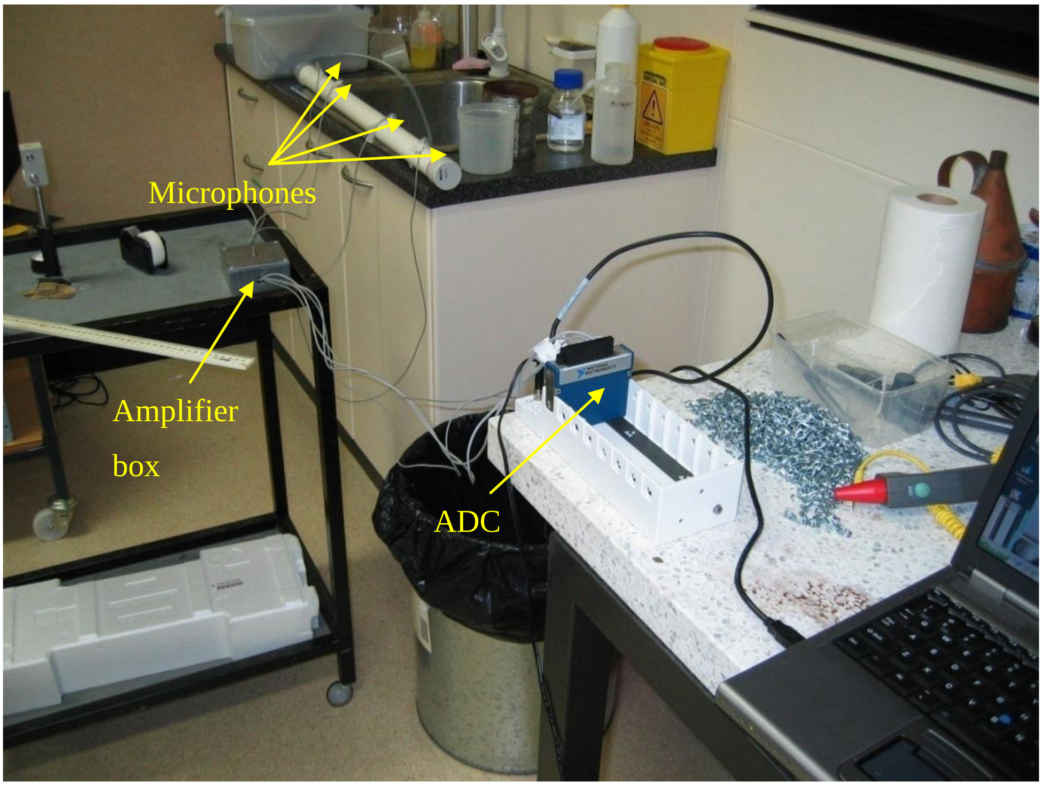

Figure 5-9 Photo showing the notebook PC, ADC, amplifier box and microphones

As previously explained, some modifications were made to the original set-up (*see Figure 5.9*). A length of PVC pipe was obtained, and a cap was placed on either end of the length of test pipe with a barbed-tail connector inserted into one end. A 2.5 mm diameter hole was drilled into the middle of the pipe to provide a leak, and a piece of flexible plastic tube was used to connect the barbed-tail connector to a tap at mains pressure. The pipe was oriented so that the leak was pointing vertically. A piece of foam was draped over the pipe and pieces of foam placed on the bottom of the sink to dampen the sound of water flowing away from the leak area (*Figure 5.1*). The tap was turned on so that a jet of water projected against the foam. Sound was recorded for a total of 10 seconds. The leak was turned on about three seconds after the commencement of data acquisition.

For the test, microphones A and C were separated by 9.5 cm and the distance between A and B was 37.5 cm. *Figure 5.10* shows the 10 second recording. One second of data (100,000 samples) between the 8th and 9th second of the data was used to calculate the CCF. Both samples were band limited to 10 – 6,000 Hz by applying a digital filter to the spectra produced as an intermediate step in calculating the CCF. *Figure 5.11* shows the CCF for one second of data from microphones A and C before the leak was switched on.

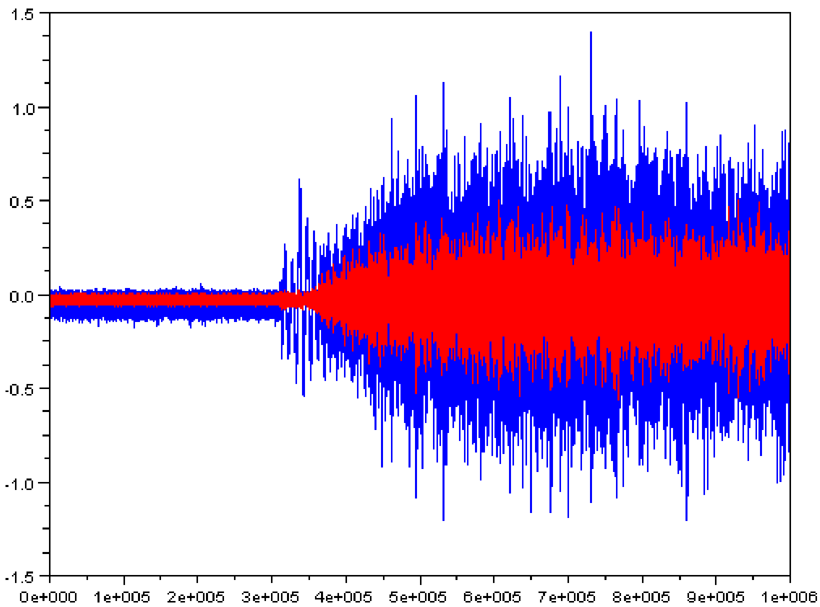

Figure 5-10 Sound data recorded from microphones A and B on the test pipe with a leak. The leak was turned on after three seconds

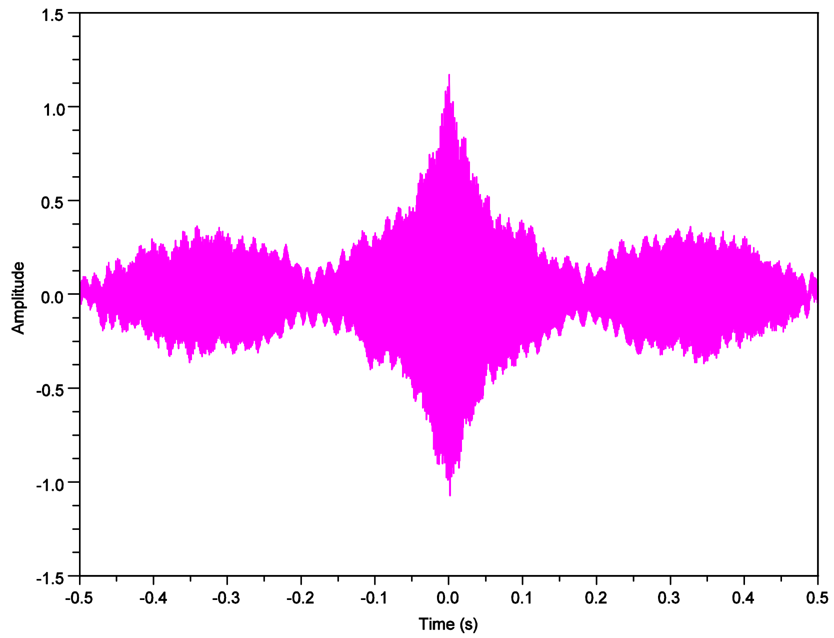

Figure 5-11 CCF for 1 second of noise from microphones A and C. The positive peak is displaced by 60 samples (0.6 ms).

The positive peak of the CCF was displaced 60 samples (0.6 ms) from zero time. This could be due to a dominant source of external noise arriving at microphones A and C at slightly different times. This was the CCF of the noise – internal and external electronic noise and external acoustic noise (lab equipment, air conditioning, and the south east freeway about 100 m away). Notice that the amplitude of the CCF is much smaller than for the leak CCFs shown in *Figures 5.12 and 5.13*. The peak is much broader indicating general un-correlation, as expected from random noise. *Figure 5.12* shows the CCF for microphones A and B used to estimate the position of the leak. *Figure 5.13* shows the CCF for microphones A and C used to calculate the shear wave velocity for PVC.

The time delay for CCF of microphones A and C was 42 samples or 42×10^{-5} s = 0.42 ms, and the delay for microphones A and B 39 samples or 0.39 ms. As mentioned above, the equation $c = {d_{AC}}/{\Delta t_{AC}}$ can be used to measure the speed of sound. In this case, d_{AC} is 9.5 cm and Δt_{AC} is 0.42 ms, so $c = {9.5 \times 10^{-2}}/{4 \times 10^{-4}} = 226\ ms^{-1}$. This value is consistent with theoretical values.

The shear wave velocity (v) in any material is given by $v = \sqrt{G/\rho}$ where G is the shear modulus and ρ is the density. (N.B. the equation for the velocity of longitudinal (compression) waves is the same as above, except that the shear modulus G is replaced by the bulk modulus (B)).

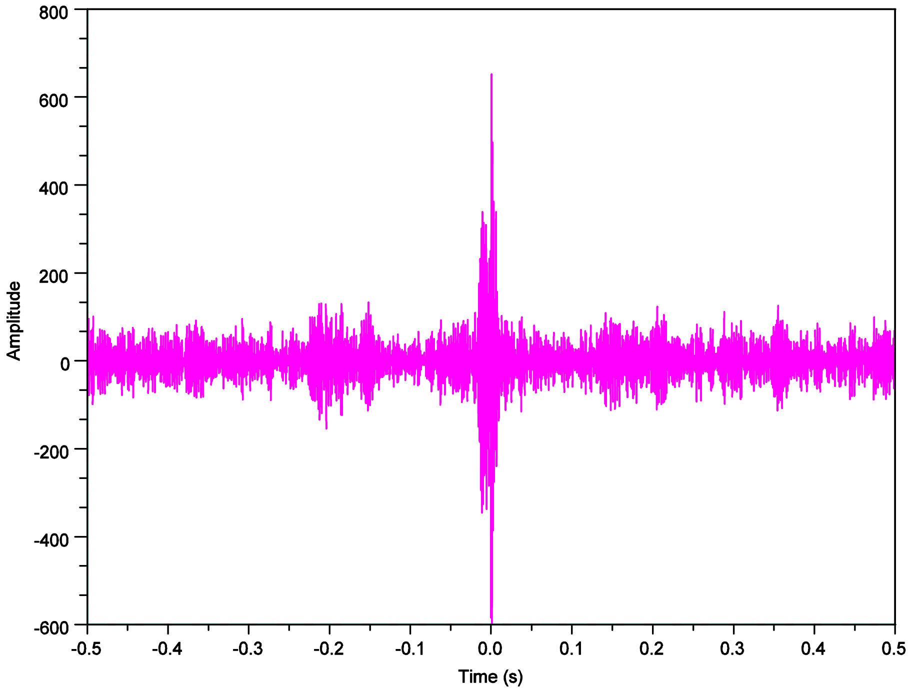

Figure 5-12 CCF for microphones A and C used to calculate the speed of sound in the wall of the PVC pipe

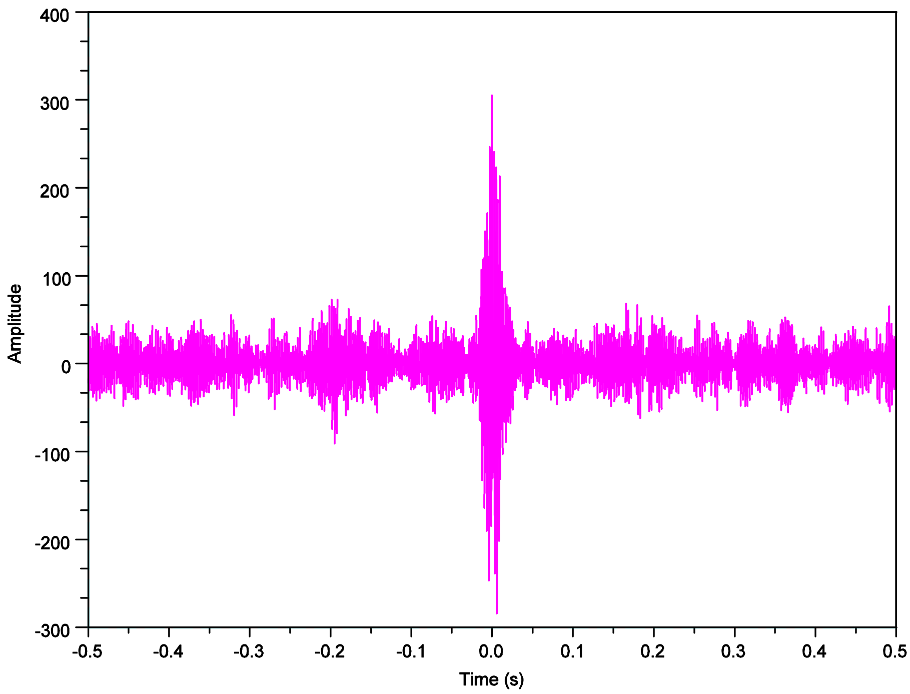

Figure 5-13 CCF for microphones A and B used to calculate the position of the leak between the microphones on either side

According to the Matbase website (2009), the shear modulus of PVC is 80 MPa and the density of PVC is in the range of 1.38 – 1.41 g cm^{-3}. Therefore, an estimate of the shear wave velocity in PVC is (taking an intermediate value for the density of PVC) $v = \sqrt{8 \times \frac{10^7}{1.4} \times 10^6} = 239 \text{ ms}^{-1}$. Note that the value calculated above, using the CCF approach, is within 6% of the theoretical value.

The next step was to calculate the distance of the leak from the closest microphone (the Scilab computer program has been written to indicate which microphone is closest to the leak). As mentioned above, the equation to use is $d_l = {(s - \Delta tc)}/{2}$. In this case, the distance (s) between the microphones A and B on either side of the leak was 37.5 cm, and the delay (Δt) was 0.39 ms, therefore the distance of the leak from microphone A is:

$$[(3.75 \times 10^{-2}) - (3.9 \times 10^{-4} \times 2.26 \times 10^{2})]/_2 = 14.3 \text{ cm}$$.

The distance between the near edge of microphone A and the centre of the leak hole was measured with a ruler as 14.3 ± 0.1 cm – i.e. exactly as calculated using the CCF within the limits of experimental error.

Calculating the CCF using 100,000 points for each microphone data sample took 22 minutes and 39 seconds using an 2.33 GHz Intel core duo PC with 3.23 GB of RAM. A lot more work could be done on optimising and compiling the code.

5.6 Summary

In summary, the experiments were successful in proving the proof of concept for this application within the laboratory environment. There are various other experiments that require attention after obtaining the results such as conducting experiments with pipes buried, for instance, in sand or mud, and field experiments to assess usability in real situations. There are also other factors that need to be assessed such as the diameter and length of the pipe. More discussion on this will follow in Chapter Seven. The next chapter will discuss the findings of the Delphi and evaluation.

Chapter 6: Results of the Business Phase

6.1 Introduction

The literature review resulted in several gaps in relation to the 'ex-ante' evaluation of technology transfer. This chapter will summarise the results from the two rounds of Delphi. This will be useful in refining the criteria and mechanisms deemed important from literature, as well as the evaluation of the chosen technology with the refined set of criteria.

The sections will be ordered according to the results of the first and second round of Delphi. This will be followed by the comparisons of both rounds as well as the different groups of chosen experts. Finally, the results of the evaluation will be outlined.

6.2 Results of the Delphi study

The Delphi study helped with understanding which criteria and mechanisms of transfer were necessary as well as important. The experts were engaging in terms of providing a rating along with useful comments on the criteria and mechanisms. All the experts participated by rating the criteria, while only some provided comments for most criteria and mechanisms.

The analysis of the ratings given by the experts was conducted using standard deviation and averages to compare results, and the accompanying comments from experts helped to establish which criteria were more important than others. In addition, the interrater reliability (IRA) was also measured using the   index as outlined in the methodology chapter.

The two round Delphi consisted mainly of online questionnaires with the 21 experts from four areas of expertise as highlighted in Chapter Four. The experts each had between 5 to 50 years experience in commercialisation, and their positions included CEOs, professors, and investors amongst others (*see Table 6.1*). The rationale was to use experts with commercial experience who were employed in different areas so as to add variance and to investigate if each group of experts would answer differently.

In the first round, the experts were asked to rate a number of criteria and mechanisms based on their importance to '*ex-ante'* evaluation and mechanisms for commercialisation. In this round, six interviews and fifteen online questionnaires were conducted with a total of 21 experts with commercialisation experience. The interviews were conducted so as to refine criteria for the '*ex-ante*' evaluation of technology transfer of high technologies obtained from literature as well mechanisms used for transfer. Few recommendations for additional criteria and mechanisms were made including one that was considered important, namely, involvement of the inventor. A majority of the experts recommended consulting as a useful mechanism for the transfer of technologies.

Some experts spent more time discussing the criteria while a few were brief. One expert emphasised that the use of criteria will depend on the type of technology but rated the criteria in a more general sense. While most of the criteria were rated important, there were some that belonged to the social factors category that were not considered as important. However, environmental impact and cost advantages were given an average borderline rating and will be considered, as the chosen application can be helpful in terms of the environmental impact. The interviews helped by providing insight into the criteria used to rate a potential transfer. Overall, there was mostly a consensus amongst the experts, even in some of the recommendations they gave. Statistical analyses comprised of means and standard deviations were then performed. Although the results of most responses and recommendations were similar, the analysis indicated that at least one further round was required to confirm a pattern of convergence.

The second round consisted of sending the experts their responses from the first round as well the means obtained. They were then asked to reconsider their responses and either move towards the mean or justify their choice if they chose to stay with their previous response. Only 1 expert out of the 21 did not respond in the second round. The experts' comments will be added where necessary to help with justification.

6.2.1 Round 1 of Delphi

This section will highlight the results from the first round of Delphi. This includes the position of each expert in the industry as well as their respective cumulative experience in commercialisation. For the sake of anonymity, the experts will be referred to as A1 – A6 respectively for those who were interviewed in the first round, and B1-B15 for those whose were sent online questionnaires. The same system will be used for the second round, keeping in mind that all were sent online questionnaires.

Table 6.1 contains the various roles of the chosen experts and the duration of their current positions as collected when interviewing them or when they replied to the questionnaire. In addition, their cumulative experience until the time of the Delphi exercise is also displayed.

Table 6-1 Summary of experts' background information

Expert	Role in organisation	Duration in current organisation	Cumulative experience in commercialisation
A1	General Manager (Physical sciences)	1 yr, 4 mths	18 yrs
A2	Commercialisation Manager (Physical sciences)	1 yr	7 yrs
A3	Manager (Innovation and commercialisation)	9 yrs	30 yrs
A4	Managing Director	7yrs	20 yrs
A5	Deputy CEO	4yrs, 4 mths	17 yrs
A6	Senior Commercialisation Consultant	6 mths	5 yrs
B1	Chief Scientific Officer	2yrs, 6 mths	20 yrs
B2	Managing Director and President	15 yrs	36 yrs
B3	Senior Lecturer	7 yrs	14 yrs
B4	Investment Manager	2 yrs	5 yrs
B5	Managing Director	4 yrs	10 yrs
B6	Lecturer and Scientist	13 yrs	32 yrs
B7	Technology Consultant and Retired Professor Emeritus	4 yrs	50 yrs
B8	CEO and Managing Director	2 yrs	15 yrs
B9	Investment Manager	6 mths	10 yrs
B10	Partner	6 yrs	25 yrs
B11	Partner and Director	11 yrs	11 yrs in Venture Capital and 35 yrs in Biotech
B12	Engineer	8 yrs	8 yrs
B13	CEO and Managing Director	3 yrs	11 yrs
B14	CSIRO Fellow	1 yr	40 yrs
B15	Director of Research and Training	3 yrs, 2 mths	22 yrs

Table 6.2 contains the recommendations of the experts for criteria they feel should be included, while *Table 6.3* has recommendations for the mechanisms. They were also asked to rate each recommendation on a 1-5 scale so as to indicate their importance (5 being most important). For those who did not give recommendations or ratings, N/A will be used.

Table 6-2 Individual recommendations of criteria by experts along with rating

Expert	Criteria	Rating
A1	IP ownership	5
	Encumbrances	5
A2	Continued support of inventor to commercialise	5
A3	N/A	N/A
A4	Champion	4
	Cost to market	4
	Manufacturing cost vs. alternates	4
	Market size	5
A5	Cost of development, production and market	4
	Extent or requirement for regulation	4
	Involvement of inventor	3
A6	Company's capacity to adopt the technology (including skills, financial and market)	4
B1	N/A	N/A
B2	N/A	N/A
B3	Scientific Complexity	N/A
B4	N/A	N/A
B5	N/A	N/A
B6	N/A	N/A
B7	N/A	N/A
B8	N/A	N/A
B9	Willingness of Inventors to participate in the transfer process	5
	Attitude of the source of the technology and commercial office towards technology transfer	4
B10	N/A	N/A
B11	N/A	N/A
B12	Additional time to develop applications based on market need	N/A
B13	N/A	N/A
B14	N/A	N/A
B15	N/A	N/A

Table 6-3 Individual recommendations of mechanisms by experts along with rating

Expert	Criteria	Rating
A1	Contract research	5
	Consulting	5
A2	Patent aggregators	4
A3	Research collaborations with industry	5
A4	Consulting	3
A5	Abandonment	1
	Incubation	2
	Consulting	3
	Contract research	3
	Stepping stone	4
A6	Consulting	5
B1	N/A	N/A
B2	N/A	N/A
B3	N/A	N/A
B4	N/A	N/A
B5	N/A	N/A
B6	N/A	N/A
B7	N/A	N/A
B8	N/A	N/A
B9	N/A	N/A
B10	N/A	N/A
B11	N/A	N/A
B12	N/A	N/A
B13	N/A	N/A
B14	N/A	N/A
B15	N/A	N/A

Table 6.4 is a compilation of all the averages, standard deviations, and index (2 decimal places) for all the criteria and mechanisms obtained from the first round. The number of experts who chose a certain rating for each criteria and mechanism is also included. For instance, in the first round, the criterion Stage of development of the technology had 15 experts (out of 21 experts) rate it a 5, therefore, the majority of the experts thought this was very important. On the other hand, for the criterion Enhancement of social infrastructure/networks, most experts gave it a rating of 1 and 2, implying that this particular criterion was not so important. Section 6.2.3 has further analysis and comparisons between both rounds of Delphi.

Table 6-4 Averages, standard deviations and r_{WG} for all criteria and mechanisms as well as a breakdown of responses for each rating for the first round

				Breakdown of responses showing count of number of experts that rated each criteria				
Criteria	**Averages**	**St. Dev**	r_{WG}	**1**	**2**	**3**	**4**	**5**
1.Technological Readiness								
Stage of development of the technology	**4.33**	**1.24**	**0.23**	1	2	1	2	15
Replicability possible	**4.10**	**1.00**	**0.50**	1	0	3	9	8
Technological Complexity (the nature and sophistication of the technology)	**2.24**	**1.34**	**0.10**	8	6	3	2	2
Scope for alternate applications	**3.30**	**0.86**	**0.63**	0	2	13	2	3
Ready or Not (proof of concept in theory)	**3.86**	**1.28**	**0.19**	2	1	3	7	8
Proof of application (in practice)	**3.76**	**1.26**	**0.20**	2	1	4	7	7
Combinatory potential with other technologies	**2.71**	**1.01**	**0.49**	3	5	8	5	0
Prototype availability	**3.90**	**1.21**	**0.27**	0	4	3	4	9
Technical Feasibility	**4.52**	**0.81**	**0.67**	0	1	1	5	14
Potential for further development	**3.62**	**1.16**	**0.33**	1	2	7	5	6
Newness of the technology (uniqueness)	**4.00**	**1.10**	**0.40**	1	1	3	8	8
2. Economic and Market Factors								
Contribution to economic growth/ development	**2.62**	**1.24**	**0.23**	4	6	8	0	3
Potential for attracting required resources, for example venture capital	**4.62**	**0.67**	**0.78**	0	0	2	4	15
Potential return on investment	**4.67**	**0.73**	**0.73**	0	0	3	1	17
Financial risk	**3.74**	**1.10**	**0.40**	1	1	5	7	5
Market needs (pull/push)	**4.33**	**1.02**	**0.48**	1	0	2	6	12
Distinguishable competitive advantages	**4.65**	**0.59**	**0.83**	0	0	1	5	14
Market impact	**4.14**	**0.79**	**0.69**	0	0	5	8	8
Level of Competition	**4.24**	**0.70**	**0.75**	0	0	3	10	8
Time to market	**4.24**	**1.00**	**0.50**	0	1	5	3	12

3. Social Benefits								
Knowledge spillover	**2.33**	**1.20**	**0.28**	7	4	7	2	1
Creation of employment	**2.33**	**1.15**	**0.33**	6	7	3	5	0
Enhancement of Social infrastructure/networks	**2.00**	**1.22**	**0.25**	10	5	3	2	1
Environmental impact	**3.05**	**1.28**	**0.18**	4	2	6	7	2
Cost advantages to customers/users	**3.81**	**0.87**	**0.62**	0	2	4	11	4
Brand creation	**2.90**	**1.22**	**0.25**	2	7	6	3	3
Potential for new useful applications	**3.48**	**1.21**	**0.27**	1	4	5	6	5
4. Legal and Regulatory								
Protection of IP rights	**4.33**	**1.02**	**0.48**	0	2	2	4	13
Strengths and scope of patent including geographical extent	**4.29**	**1.10**	**0.39**	1	1	1	6	12
Patent exclusitivity	**4.14**	**1.06**	**0.44**	0	2	4	4	11
New areas of application (not infringing any other patents)	**3.90**	**1.00**	**0.50**	1	0	5	9	6
Need for complimentary technologies (availability of licenses, for example to use other technologies)	**3.76**	**1.04**	**0.45**	0	2	8	4	7
Freedom to operate, for example, open innovation	**4.48**	**0.93**	**0.57**	0	1	3	2	15
Mechanisms								
Licensing	**3.81**	**1.17**	**0.32**	1	2	4	7	7
Spin-off	**3.86**	**1.24**	**0.24**	0	5	2	5	9
Joint venture	**2.81**	**1.17**	**0.32**	3	5	8	3	2
Trade sales	**2.70**	**1.38**	**0.05**	4	7	3	3	3
Collaborations	**3.86**	**1.28**	**0.19**	1	2	6	2	10
IP assignment	**2.95**	**1.24**	**0.23**	3	4	8	3	3

6.2.2 Round 2 of Delphi

Table 6.5 is a compilation of all the averages, standard deviations, and index (2 decimal places) for all the criteria and mechanisms obtained from the second round. The number of experts who chose a certain rating for each criteria and mechanism is also included. As explained in the previous section, the breakdown of experts helps to demonstrate how many experts gave a certain rating for each criterion and mechanism. For example, in the first round, the criterion Stage of development of the technology had 15 experts rate it a 5, whereas, in this round it dropped to 13 experts who rated it a 5. This helps to make comparisons between both rounds, to demonstrate the pattern to which experts changed their responses in the second round. The next section has further analysis on both the Delphi rounds.

Table 6-5 Averages, standard deviations, and r_{WG} for all criteria and mechanisms as well as a breakdown of responses for each rating for the second round

				Breakdown of responses showing count of number of experts that rated each criteria				
Criteria	**Averages**	**St. Dev**	r_{WG}	**1**	**2**	**3**	**4**	**5**
1.Technological Readiness								
Stage of development of the technology	**4.30**	**1.22**	**0.26**	1	2	0	4	13
Replicability possible	**4.25**	**0.55**	**0.85**	0	0	1	13	6
Technological Complexity (the nature and sophistication of the technology)	**2.25**	**1.12**	**0.38**	5	9	3	2	1
Scope for alternate applications	**3.20**	**0.83**	**0.65**	0	3	12	3	2
Ready or Not (proof of concept in theory)	**3.90**	**1.29**	**0.16**	2	1	2	7	8
Proof of application (in practice)	**3.95**	**1.05**	**0.45**	1	0	5	7	7
Combinatory potential with other technologies	**2.70**	**0.98**	**0.52**	3	4	9	4	0
Prototype availability	**3.95**	**1.10**	**0.40**	0	3	3	6	8
Technical Feasibility	**4.55**	**0.76**	**0.71**	0	1	0	6	13
Potential for further development	**3.55**	**1.10**	**0.40**	1	2	6	7	4
Newness of the technology (uniqueness)	**4.00**	**0.97**	**0.53**	1	0	3	10	6

2. Economic and Market Factors								
Contribution to economic growth/development	**2.45**	**0.94**	**0.55**	3	7	9	0	1
Potential for attracting required resources, for example venture capital	**4.70**	**0.66**	**0.78**	0	0	2	2	16
Potential return on investment	**4.70**	**0.66**	**0.78**	0	0	2	2	16
Financial risk	**3.70**	**1.03**	**0.47**	1	1	5	9	4
Market needs (pull/push)	**4.55**	**0.60**	**0.82**	0	0	1	7	12
Distinguishable competitive advantages	**4.70**	**0.47**	**0.89**	0	0	0	6	14
Market impact	**4.15**	**0.75**	**0.72**	0	0	4	9	7
Level of Competition	**4.20**	**0.62**	**0.81**	0	0	2	12	6
Time to market	**4.30**	**0.86**	**0.63**	0	1	2	7	10
3. Social Benefits								
Knowledge spillover	**2.25**	**1.12**	**0.38**	6	6	6	1	1
Creation of employment	**2.60**	**0.99**	**0.51**	2	9	4	5	0
Enhancement of Social infrastructure/networks	**1.95**	**1.10**	**0.40**	8	8	2	1	1
Environmental impact	**3.05**	**1.15**	**0.34**	3	2	7	7	1
Cost advantages to customers/users	**3.85**	**0.75**	**0.72**	0	1	4	12	3
Brand creation	**2.85**	**1.04**	**0.46**	2	4	11	1	2
Potential for new useful applications	**3.42**	**0.96**	**0.54**	1	2	5	10	1
4. Legal and Regulatory								
Protection of IP rights	**4.35**	**0.88**	**0.62**	0	1	2	6	11
Strengths and scope of patent including geographical extent	**4.35**	**0.93**	**0.56**	0	2	0	7	11
Patent exclusitivity	**4.20**	**0.95**	**0.55**	0	1	4	5	10
New areas of application (not infringing any other patents)	**4.10**	**0.55**	**0.85**	0	0	2	14	4
Need for complimentary technologies (availability of licenses, for example to use in other technologies)	**3.80**	**0.95**	**0.55**	0	1	8	5	6
Freedom to operate, for example, open innovation	**4.55**	**0.83**	**0.66**	0	0	4	1	15
Mechanisms								
Licensing	**4.00**	**0.97**	**0.53**	1	0	3	10	6
Spin-off	**4.10**	**1.07**	**0.43**	0	3	1	7	9
Joint venture	**2.90**	**1.17**	**0.32**	3	3	9	3	2
Trade sales	**2.75**	**1.21**	**0.27**	2	8	6	1	3
Collaborations	**3.85**	**1.23**	**0.25**	1	2	4	5	8
IP assignment	**3.25**	**1.02**	**0.48**	1	2	11	3	3

6.2.3 Comparisons of both rounds of Delphi

Table 6.6 is a summary of the averages, standard deviations, and index of the ratings of criteria and mechanisms for both rounds along with the percentage differences of the averages and standard deviations. The results of round 1 are in bold so as to differentiate them from the results of round 2.

It is useful to observe any major differences in the results obtained from the first and second round. The analysis between both rounds resulted in no major differences between the average ratings of criteria or mechanisms. The highest difference was an increase in the average rating for the criterion Market needs from 4.33 in the first round to 4.55 in the second round, and the mechanism IP assignment from 2.95 in the first round to 3.25 in the second round. This indicates that the experts were happy with most of their initial responses in round 1, and only a few made changes in the second round.

In addition, interrater reliability (IRA) was also measured by calculating the index. A value of 0.70 is considered an acceptable number but this can vary depending on circumstances (LeBreton & Senter, 2008). Below are standards for interpreting IRA estimates as found in LeBreton and Senter (2008):

- .00 to .30 – Lack of agreement
- .31 to .50 – Weak agreement
- .51 to .70 – Moderate agreement
- .71 to .90 – Strong agreement
- .91 to 1.00 – Very strong agreement

Starting with the criteria, some did not have much difference in IRA levels between the two rounds. However, there was an increase in agreement in criteria such as:

- Replicability possible from an of 0.50 (weak agreement) in round 1 to 0.85 (strong agreement) in round 2
- Technological complexity from 0.10 (lack of agreement) in round 1 to 0.38 (weak agreement) in round 2
- Proof of application (in practice) from 0.20 (lack of agreement) in round 1 to 0.45 (weak agreement) in round 2
- Prototype availability from 0.27 (lack of agreement) in round to 0.40 (weak agreement) in round 2

- Newness of the technology from 0.40 (weak agreement) in round 1 to 0.53 (moderate agreement) in round 2
- Contribution to economic growth/development from 0.23 (lack of agreement) in round 1 to 0.55 (moderate agreement) in round 2
- Market needs from 0.48 (weak agreement) in round 1 to 0.82 (strong agreement) in round 2
- Time to market from 0.50 (weak agreement) in round 1 to 0.63 (moderate agreement) in round 2
- Knowledge spillover from 0.28 (lack of agreement) in round 1 to 0.38 (weak agreement) in round 2
- Creation of employment from 0.33 (weak agreement) in round 1 to 0.51 (moderate agreement) in round 2
- Enhancement of social infrastructure/networks from 0.25 (lack of agreement) in round 1 to 0.40 (weak agreement) in round 2
- Environmental impact from 0.18 (lack of agreement) in round 1 to 0.34 (weak agreement) in round 2
- Cost advantages to customers/users from 0.62 (moderate agreement) in round 1 to 0.72 (strong agreement) in round 2
- Brand creation from 0.25 (lack of agreement) in round 1 to 0.46 (weak agreement) in round 2
- Potential for new useful applications from 0.27 (lack of agreement) in round 1 to 0.54 (moderate agreement) in round 2
- Protection of IP rights from 0.48 (weak agreement) in round 1 to 0.62 (moderate agreement) in round 2
- Strength and scope of patent from 0.39 (weak agreement) in round 1 to 0.56 (moderate agreement) in round 2
- Patent exclusitivity from 0.44 (weak agreement) in round 1 to 0.55 (moderate agreement) in round 2
- New areas of application from 0.50 (moderate agreement) in round 1 to 0.85 (strong agreement) in round 2
- Need for complimentary technologies from 0.45 (weak agreement) in round 1 to 0.55 (moderate agreement) in round 2

Out of the 33 criteria, there was an increase in agreement in 20 of the criteria (listed above). After the second round, there were 10 criteria with strong agreement. In the case of mechanisms, four had an increase in IRA levels:

- Licensing from 0.32 (weak agreement) in round 1 to 0.53 (moderate agreement) in round 2
- Spin-off from 0.24 (lack of agreement) in round 1 to 0.43 (weak agreement) in round 2
- Trade sales from 0.05 (lack of agreement) in round 1 to 0.27 (lack of agreement) in round 2
- IP assignment from 0.23 (lack of agreement) in round 1 to 0.48 (weak agreement) in round 2

Overall, there was an increase in agreement for the criteria and mechanisms when looking at the IRA levels. Even though all criteria and mechanisms did not have a strong agreement, the majority had some level of agreement which is a good outcome following the Delphi. This in turn is related to convergence of results which is necessary in a Delphi study, and consequently in the choice of criteria and mechanisms.

Generally, convergence was achieved after the second round. This is firstly indicated by very little difference in individual ratings of criteria and mechanisms between both rounds, and secondly, by the results based on standard deviation and IRA. For instance, the standard deviation after the second round was between and including 0.47 and 1.29 as compared to a range of and including 0.59 – 1.34 in the first round, indicating that there was an increase in agreement between experts and that the spread of responses was smaller after the second round of Delphi. Convergence is important as it implies that there is a level of agreement amongst experts.

Table 6-6 Comparison of the averages and standard deviations of the ratings of criteria and mechanisms for both rounds along with percentage differences

Criteria	Round 1 Avg	Round 1 Stdev	Round 1	Round 2 Avg	Round 2 Stdev	Round 2	% Avg Difference	% Stdev Difference
1.Technological Readiness								
Stage of development of the technology	**4.33**	**1.24**	**0.23**	4.30	1.22	0.26	-0.67%	-0.40%
Replicability possible	**4.10**	**1.00**	**0.50**	4.25	0.55	0.85	3.10%	-8.90%
Technological Complexity (The nature and sophistication of the technology)	**2.24**	**1.34**	**0.10**	2.25	1.12	0.38	0.24%	-4.40%
Scope for alternate applications	**3.30**	**0.86**	**0.63**	3.20	0.83	0.65	-2.00%	-0.62%
Ready or Not (proof of concept in theory)	**3.86**	**1.28**	**0.19**	3.90	1.29	0.16	0.86%	0.35%
Proof of application (in practice)	**3.76**	**1.26**	**0.20**	3.95	1.05	0.45	3.76%	-4.22%
Combinatory potential with other technologies	**2.71**	**1.01**	**0.49**	2.70	0.98	0.52	-0.29%	-0.57%
Prototype availability	**3.90**	**1.21**	**0.27**	3.95	1.10	0.40	1.00%	-2.21%
Technical Feasibility	**4.52**	**0.81**	**0.67**	4.55	0.76	0.71	0.52%	-1.09%
Potential for further development	**3.62**	**1.16**	**0.33**	3.55	1.10	0.40	-1.38%	-1.24%
Newness of the technology (uniqueness)	**4.00**	**1.10**	**0.40**	4.00	0.97	0.53	0.00%	-2.44%
2. Economic and Market Factors								
Contribution to economic growth/ development	**2.62**	**1.24**	**0.23**	2.45	0.94	0.55	-3.38%	-5.99%
Potential for attracting required resources for example venture capital	**4.62**	**0.67**	**0.78**	4.70	0.66	0.78	1.62%	-0.24%
Potential return on investment	**4.67**	**0.73**	**0.73**	4.70	0.66	0.78	0.67%	-1.47%
Financial risk	**3.74**	**1.10**	**0.40**	3.70	1.03	0.47	-0.74%	-1.33%
Market needs (pull/push)	**4.33**	**1.02**	**0.48**	4.55	0.60	0.82	4.33%	-8.23%
Distinguishable competitive advantages	**4.65**	**0.59**	**0.83**	4.70	0.47	0.89	1.00%	-2.34%
Market impact	**4.14**	**0.79**	**0.69**	4.15	0.75	0.72	0.14%	-0.95%
Level of Competition	**4.24**	**0.70**	**0.75**	4.20	0.62	0.81	-0.76%	-1.70%
Time to market	**4.24**	**1.00**	**0.50**	4.30	0.86	0.63	1.24%	-2.61%

3. Social Benefits								
Knowledge spillover	**2.33**	**1.20**	**0.28**	2.25	1.12	0.38	-1.67%	-1.58%
Creation of employment	**2.33**	**1.15**	**0.33**	2.60	0.99	0.51	5.33%	-3.20%
Enhancement of Social infrastructure/networks	**2.00**	**1.22**	**0.25**	1.95	1.10	0.40	-1.00%	-2.51%
Environmental impact	**3.05**	**1.28**	**0.18**	3.05	1.15	0.34	0.05%	-2.75%
Cost advantages to customers/users	**3.81**	**0.87**	**0.62**	3.85	0.75	0.72	0.81%	-2.55%
Brand creation	**2.90**	**1.22**	**0.25**	2.85	1.04	0.46	-1.10%	-3.62%
Potential for new useful applications	**3.48**	**1.21**	**0.27**	3.42	0.96	0.54	-1.10%	-4.96%
4. Legal and Regulatory								
Protection of IP rights	**4.33**	**1.02**	**0.48**	4.35	0.88	0.62	0.33%	-2.83%
Strengths and scope of patent including geographical extent	**4.29**	**1.10**	**0.39**	4.35	0.93	0.56	1.29%	-3.37%
Patent exclusitivity	**4.14**	**1.06**	**0.44**	4.20	0.95	0.55	1.14%	-2.22%
New areas of application (not infringing any other patents)	**3.90**	**1.00**	**0.50**	4.10	0.55	0.85	3.90%	-8.85%
Need for complimentary technologies (availability of licenses for example to use other technologies)	**3.76**	**1.04**	**0.45**	3.80	0.95	0.55	0.76%	-1.86%
Freedom to operate, for example, open innovation	**4.48**	**0.93**	**0.57**	4.55	0.83	0.66	1.48%	-2.06%
5. Mechanisms								
Licensing	**3.81**	**1.17**	**0.32**	4.00	0.97	0.53	3.81%	-3.87%
Spin-off	**3.86**	**1.24**	**0.24**	4.10	1.07	0.43	4.86%	-3.30%
Joint venture	**2.81**	**1.17**	**0.32**	2.90	1.17	0.32	1.81%	-0.03%
Trade sales	**2.70**	**1.38**	**0.05**	2.75	1.21	0.27	1.00%	-3.44%
Collaborations	**3.86**	**1.28**	**0.19**	3.85	1.23	0.25	-0.14%	-1.01%
IP assignment	**2.95**	**1.24**	**0.23**	3.25	1.02	0.48	5.95%	-4.49%

6.2.4 Comparison of the different groups of experts

A comparison of averages and IRA between the responses from the first and second rounds was done between groups of experts, namely:

- Commercialisation experts (six in total and shown as C in table)
- Venture capitalists (five in total and shown as VC in table)
- Scientists and academics (five in total and shown as S&A in table)
- Technology consultants (five in total shown as TC in table)

The comparison was performed to determine if there was a difference in responses between the different groups of experts. Looking at the averages, the difference between each group was very minimal, but when the r_{WG} index was examined for comparison of agreement levels there were some differences between groups. For instance, the criterion Potential for attracting required resources was given a high average by all groups of experts but differed in terms of agreement for one group. While commercialisation experts, scientists, academics, and technology consultants had strong to very strong agreement, venture capitalists agreed weakly. This was unexpected as VCs normally look for opportunities that have the potential to attract required resources, and they were expected to agree strongly. On the other hand, for the criterion Potential return on investment, the group of VCs had an average of 5 as well as the highest level of agreement (1.00). This connects well with the interests of VCs.

However, there were criteria of interest to specific groups that had higher levels of agreement and lower levels of agreement in the groups that would not be particularly interested in those criteria. Overall, the level of agreements for the groups did not vary much between the first and second round of the Delphi study (*Table 6.7*).

The final part of analysis for the Delphi, which deals with the choice of criteria and mechanisms to be used as part of the evaluation, will be outlined in the next section.

Table 6-7 Comparison of averages and r_{WG} (in italics) between groups of experts for both rounds (Round 1 in bold)

Criteria	**C**	**VC**	**S&A**	**TC**	C	VC	S&A	TC
1.Technological Readiness								
Stage of development of the technology	**4.83**	**4.40**	**4.00**	**4.00**	3.83	4.40	4.20	4.00
	0.92	***0.00***	***0.10***	***0.00***	*0.85*	*0.00*	*0.10*	*0.15*
Replicability possible	**4.17**	**4.60**	**3.40**	**4.20**	3.67	4.60	4.00	4.00
	0.52	***0.65***	***0.85***	***0.10***	*0.85*	*0.75*	*0.85*	*1.00*
Technological Complexity (the nature and sophistication of the technology)	**2.00**	**1.60**	**3.60**	**1.80**	2.00	1.60	3.20	1.80
	0.20	***0.65***	***0.85***	***0.00***	*0.35*	*0.65*	*0.85*	*0.15*
Scope for alternate applications	**3.50**	**2.20**	**3.80**	**3.00**	2.83	3.00	3.60	2.80
	0.65	***0.75***	***0.88***	***0.40***	*0.35*	*0.65*	*1.00*	*0.60*
Ready or Not (proof of concept in theory)	**3.67**	**3.60**	**4.60**	**3.60**	2.83	4.00	4.60	3.60
	0.00	***0.00***	***0.10***	***0.85***	*0.00*	*0.00*	*0.00*	*0.85*
Proof of application (in practice)	**3.83**	**4.40**	**3.00**	**3.80**	3.50	4.40	3.20	4.00
	0.00	***0.40***	***0.85***	***0.00***	*0.65*	*0.50*	*0.85*	*0.00*
Combinatory potential with other technologies	**2.67**	**2.20**	**3.40**	**2.60**	2.17	2.20	3.40	2.60
	0.47	***0.60***	***0.40***	***0.60***	*0.60*	*0.60*	*0.40*	*0.60*
Prototype availability	**4.33**	**3.20**	**3.40**	**3.80**	3.67	4.00	3.40	4.00
	0.67	***0.15***	***0.00***	***0.00***	*0.85*	*0.25*	*0.50*	*0.00*
Technical Feasibility	**4.67**	**4.60**	**4.20**	**4.60**	3.83	4.60	4.20	4.80
	0.87	***0.60***	***0.85***	***0.15***	*0.85*	*0.90*	*0.85*	*0.15*
Potential for further development	**3.00**	**3.20**	**4.20**	**4.20**	2.33	3.40	4.00	4.00
	0.00	***0.65***	***0.40***	***0.65***	*0.15*	*0.25*	*0.60*	*0.75*
Newness of the technology (uniqueness)	**4.17**	**3.80**	**4.40**	**3.60**	3.50	3.80	4.20	3.80
	0.72	***0.10***	***0.00***	***0.85***	*0.90*	*0.40*	*0.00*	*0.90*
2. Economic and Market Factors								
Contribution to economic growth/ development	**2.33**	**2.20**	**2.40**	**3.60**	1.83	2.20	2.60	2.80
	0.00	***0.10***	***0.65***	***0.60***	*0.65*	*0.00*	*0.65*	*0.85*
Potential for attracting required resources for example venture capital	**4.83**	**4.80**	**4.60**	**4.20**	4.17	4.80	4.80	4.20
	0.92	***0.40***	***0.90***	***0.85***	*1.00*	*0.40*	*0.90*	*0.90*
Potential return on investment	**4.67**	**5.00**	**4.00**	**5.00**	3.83	5.00	4.20	5.00
	0.67	***1.00***	***1.00***	***0.50***	*0.60*	*1.00*	*1.00*	*0.65*
Financial risk	**3.17**	**3.40**	**3.60**	**3.40**	2.50	4.00	3.60	4.20
	0.12	***0.54***	***0.54***	***0.60***	*0.25*	*0.65*	*0.50*	*0.60*
Market needs (pull/push)	**5.00**	**4.60**	**3.60**	**4.00**	4.17	4.60	4.20	4.40
	1.00	***0.50***	***0.85***	***0.00***	*1.00*	*0.60*	*0.85*	*0.90*
Distinguishable competitive advantages	**4.67**	**3.80**	**5.00**	**4.20**	3.83	4.80	4.80	4.60
	0.87	***0.65***	***0.88***	***1.00***	*0.85*	*0.85*	*0.90*	*0.90*
Market impact	**4.00**	**4.40**	**4.00**	**4.20**	3.17	4.40	4.20	4.20
	0.60	***0.65***	***0.60***	***0.75***	*0.65*	*0.65*	*0.60*	*0.90*
Level of Competition	**4.33**	**4.40**	**4.20**	**4.00**	3.50	4.40	4.40	3.80
	0.87	***0.50***	***0.85***	***0.65***	*0.90*	*0.65*	*0.85*	*0.85*
Time to market	**4.67**	**3.80**	**4.20**	**4.20**	3.67	3.80	4.60	4.40
	0.67	***0.65***	***0.15***	***0.40***	*0.60*	*0.85*	*0.15*	*0.85*

3. Social Benefits								
Knowledge spillover	**1.83**	**2.00**	**3.20**	**2.40**	1.50	1.80	3.20	2.20
	0.52	***0.60***	***0.25***	***0.00***	*0.65*	*0.65*	*0.65*	*0.00*
Creation of employment	**1.50**	**2.60**	**2.80**	**2.60**	1.50	2.60	3.00	3.00
	0.65	***0.10***	***0.60***	***0.15***	*0.65*	*0.50*	*0.60*	*0.50*
Enhancement of Social infrastructure/networks	**1.50**	**1.60**	**2.80**	**2.20**	1.33	1.40	2.60	2.20
	0.65	***0.40***	***0.60***	***0.00***	*0.85*	*0.40*	*0.85*	*0.00*
Environmental impact	**3.00**	**2.40**	**3.60**	**3.20**	2.33	2.40	3.60	3.40
	0.00	***0.00***	***0.10***	***0.85***	*0.15*	*0.35*	*0.10*	*0.85*
Cost advantages to customers/users	**3.50**	**3.80**	**4.00**	**4.00**	3.17	3.80	3.80	4.00
	0.45	***0.75***	***0.40***	***0.75***	*0.65*	*0.75*	*0.40*	*0.90*
Brand creation	**2.33**	**2.80**	**3.00**	**3.60**	2.00	2.80	3.20	3.00
	0.47	***0.35***	***0.00***	***0.25***	*0.60*	*0.75*	*0.00*	*0.40*
Potential for new useful applications	**3.00**	**3.40**	**4.20**	**3.40**	2.50	3.00	3.80	3.20
	0.00	***0.10***	***0.35***	***0.65***	*0.25*	*0.40*	*0.54*	*0.90*
4. Legal and Regulatory								
Protection of IP rights	**5.00**	**4.40**	**4.00**	**3.80**	4.00	4.40	4.00	4.20
	1.00	***0.15***	***0.60***	***0.25***	*0.90*	*0.65*	*0.60*	*0.25*
Strengths and scope of patent including geographical extent	**4.83**	**4.60**	**3.60**	**4.00**	3.83	4.80	3.80	4.20
	0.92	***0.00***	***0.85***	***0.35***	*0.85*	*0.15*	*0.90*	*0.40*
Patent exclusitivity	**4.67**	**4.20**	**3.60**	**4.00**	3.67	4.60	3.60	4.20
	0.67	***0.25***	***0.65***	***0.10***	*0.60*	*0.65*	*0.85*	*0.10*
New areas of application (not infringing any other patents)	**3.67**	**4.00**	**4.00**	**4.00**	3.50	4.20	4.00	4.00
	0.00	***0.50***	***0.75***	***1.00***	*0.90*	*0.50*	*0.90*	*1.00*
Need for complimentary technologies (availability of licenses, for example to use other technologies)	**4.33**	**3.80**	**3.40**	**3.40**	3.33	4.00	3.60	3.60
	0.67	***0.00***	***0.65***	***0.60***	*0.75*	*0.10*	*0.50*	*0.60*
Freedom to operate, for example, open innovation	**4.83**	**4.20**	**4.40**	**4.40**	4.00	4.20	4.60	4.60
	0.92	***0.10***	***0.40***	***0.60***	*0.90*	*0.60*	*0.40*	*0.60*
5. Mechanisms								
Licensing	**4.50**	**3.40**	**3.20**	**4.00**	3.67	3.80	3.80	4.00
	0.85	***0.50***	***0.00***	***0.15***	*0.85*	*0.50*	*0.00*	*0.90*
Spin-off	**4.50**	**3.80**	**4.20**	**2.80**	4.00	4.40	4.00	3.20
	0.65	***0.15***	***0.40***	***0.15***	*0.90*	*0.15*	*0.85*	*0.25*
Joint venture	**2.33**	**2.40**	**3.20**	**3.40**	2.00	2.80	3.20	3.20
	0.67	***0.00***	***0.10***	***0.65***	*0.60*	*0.00*	*0.40*	*0.65*
Trade sales	**3.17**	**2.80**	**2.00**	**2.20**	3.00	2.80	2.00	2.60
	0.00	***0.54***	***0.00***	***0.50***	*0.10*	*0.85*	*0.00*	*0.75*
Collaborations	**3.00**	**4.00**	**4.40**	**4.20**	2.50	4.00	4.80	3.60
	0.20	***0.15***	***0.50***	***0.10***	*0.25*	*0.00*	*0.50*	*0.90*
IP assignment	**2.33**	**3.60**	**3.20**	**2.80**	2.50	3.80	3.40	2.80
	0.47	***0.40***	***0.00***	***0.40***	*0.75*	*0.40*	*0.15*	*0.60*

6.2.5 Choice of criteria and mechanisms

After having achieved convergence from both rounds, it was then necessary to decide which criteria and mechanisms were deemed important and which ones would not be included in the finalised set of criteria and mechanisms. It was also necessary to consider recommendations made by experts. The following section will discuss which criteria and mechanisms were considered unnecessary for the refined list as well as whether any were added as part of the recommendations from experts.

The guideline for the selection of criteria and mechanisms is based on averages of the results obtained from the Delphi. It was decided that any criteria and mechanisms with averages of 3 and above would be selected for the next round, because any criteria and mechanisms with an average below 3 is considered unimportant and can thus be discarded, as discussed with the experts. Where required, the comments from experts will be included as justification (comments are italicised and bracketed along with experts' references as assigned previously).

Along with the criteria selected according to the averages, any recommendations that were rated high by the experts and are considered important will be added to the list. As it happens, there are several that were common amongst most experts. Totally, seven of the criteria and two of the mechanisms were found to be below the average of 3, the criteria being:

- Technological complexity (2.25)
- Combinatory potential with other technologies (2.70) (B2 – *"too big a question for initial TT."*)
- Contribution to economic growth/development (2.45)
- Knowledge spillover (2.25) (B9 - *"not a key motivator."*)
- Creation of employment (2.60) (B13 - *"Entrepreneurs in general don't care. It's all about their 'baby'.")*
- Enhancement of Social infrastructure/networks (1.95) (B2 -*"too complex to consider, onerous burden for a particular Technology."*)
- Brand creation (2.85) (B13 - *"A good brand means premium prices and resiliency."*)

In the case of the types of mechanisms, it was:

- Joint ventures (2.90) (A3 - *"JVs are hard for universities because they are not primarily commercial entities.";* B4 *"Difficult to engineer."; B7 - "can cause problems over IP ownership."*)
- Trade sales (2.75) (B2 - *"selling off the farm - selling the Technology short.";* B4 - "*Rare as starting point for unis."*).

Some were very close to the average of 3, therefore, it was decided to check the experts' comments for these criteria. Based on the comments, only Brand creation was noted to be important, therefore the others were dropped. Regarding the above criteria, the experts reasoned that they were not the key ones used by them when evaluating a technology's commercial potential. However, in the case of Brand creation, after studying the comments from experts, it was learnt that creating a brand or an entity for the technology early in the process could create better value.

In the case of the mechanisms, Joint ventures and Trade sales were thought to be an incompatible choice for universities due to several reasons such as problems with IP ownership. Additionally, based on experts' recommendations, one criterion, namely, involvement of the inventor (*see Table 6.2*) and one mechanism, consulting (*see Table 6.3*) were added because several experts recommended the same and rated them highly. The next section will highlight the results of the evaluation of the commercial potential of the technology.

6.3 Results of the evaluation of the commercial potential of the technology

This section will highlight the results of the evaluation of the commercial potential of the technology. A total of 18 experts participated. All are involved in commercialisation and some are based in Australia, while others are in countries such as the United Kingdom and the Netherlands. *Table 6.8* contains the various roles of the chosen experts as well as the duration of their current positions. Again, due to anonymity, the experts in this section will be referred to as C1 – C18. All experts were contacted by email and the questionnaire was administered online.

Table 6-8 Summary of experts' (for evaluation) professional background information

Expert	Role in organisation	Duration in current organisation	Cumulative experience in commercialisation (till date)
C1	IP and Licensing Associate	2 yrs	12 yrs
C2	Business Development and Commercialisation	7 yrs	18 yrs
C3	Managing Director	4 yrs	5 yrs
C4	Business Manager	3 years	1.5 years
C5	Analyst	2 yrs	6 yrs
C6	Director, Commercialisation Office	10 yrs	25+ yrs
C7	Managing Director	3.75 yrs	22 yrs
C8	Managing the delivery of Innovation programs to industry	3 yrs	8 yrs
C9	Business Development Manager responsible for building contract research business	6 mths	5 yrs
C10	Director of Commercial Research	1.5 yrs	9 yrs
C11	Negotiation of research contracts with industry, including identification of new partners	2 mths	3.5 yrs
C12	Business Development Manager (assess IP disclosures, advise on IP provisions in agreements, development commercialisation plans, oversee patent applications, seek industry partners to license technology, etc.)	10 mths	10 mths
C13	Research Officer - IP Transfer	3 mths	1 yr
C14	Marketing and Commercialisation Manager	2 yrs, 2 mths	2 yrs, 6 mths
C15	Director	2 days	8 yrs
C16	CEO	6 yrs	14 yrs
C17	Associate, Transactions and Operations Group	2 yrs	5.5 yrs
C18	Technology Manager	9 mths	4+ yrs

The experts were asked to review the information provided on the technology and then evaluate its commercial potential using a 7 point Likert scale. They were also asked to suggest which mechanism would be highly suitable if the technology were to be commercialised. *Table 6.9* is a summary of the averages, standard deviations, and index of all the criteria and mechanisms based on the pooled results of the experts (where required comments from experts are included and italicised and bracketed along with experts' references as assigned previously). As the technology is still a proof of concept, it was expected that the criteria under technological readiness would not be given a very high rating. This is reflected in the results obtained for some of the criteria. For instance, stage of development of the technology had an average response of 2.83, and in relation; potential for further development had an average of 4.78. This translates to the technology being at a certain stage of development and needing further development as suggested by the experts' responses. Additionally, the experts also acknowledged that the technology was ready to a certain extent in terms of proof of concept, theoretically and practically. There was a higher rating for criteria related to the further development and feasibility of the technology as well as replication being possible. This demonstrates that the experts understood the position and value of the technology in accordance with the information provided and that the technology is still in concept stages *(*C1 – *"Conceptually the idea has merits.";* C11 – *"The technology looks interesting and potentially has value, but is at a very early stage.").*

In relation to the economic and market criteria, the experts mainly suggested that further due diligence be conducted in regards to the relevant markets and competition, as the related criteria were given an average to above average rating.

With criteria related to social benefits, the highest rating was given to Cost advantages to customers/users (4.35) and this goes to show that the technology can help in the production of cheaper options when further developed. In relation to further development, brand creation was one of the criteria considered important after the Delphi. The experts only gave an average rating of 2.94 for the technology and this implies that further work has to be done to establish a more defined purpose of the application, which will help to create a brand.

All of the legal and regulatory criteria were given an average rating of about 3. This implies that the experts are aware that there is a possibility of obtaining protection for the related intellectual property, but because nothing has been protected yet, it is recommended that this area should be addressed.

Furthermore, IRA levels for the responses were investigated. Most of the IRA values were interpreted as few being in weak agreement and the majority being between moderate and strong agreement. Out of the 28 criteria used for the evaluation, five had a strong agreement, 11 had a moderate agreement, seven had a weak agreement, and five had a lack of agreement.

Interestingly, the five criteria that had a lack of agreement all fell under the legal and regulatory category. This can be attributed to the fact that the experts were not given any detailed information about the process and equipment used to conduct the experiments as well as any information about the algorithms written for the correlation process owing to the sensitive intellectual position of the technology. This resulted in experts rating all the criteria related to IP in a highly skewed fashion, consequently resulting in a lack of agreement. Information on the interpretation of IRA levels can be found in Section 6.2.3.

When it came to the choice of the mechanism best suited for the commercialisation of this particular technology, licensing got the highest average rating (5.56), with the most agreement amongst the experts with a standard deviation of 1.34 and also of 0.55. This was followed by collaborations (average of 4.88). Surprisingly, spin-off had the lowest average rating (2.33). Usually, the creation of spin-offs is one of the popular choices of mechanisms along with licensing when it comes to the commercialisation of university research. In this case, it is an inappropriate mechanism because at the present stage, the technology is not developed to the extent that a company can be created around it.

Table 6-9 Averages, standard deviations, percentage standard deviations and r_{WG} of the criteria and mechanisms

Criteria	Average	Stdev	Percentage Stdev	r_{WG}
1.Technological Readiness				
Stage of development of the technology	2.83	0.79	11%	0.85
Replicability possible	4.12	1.22	17%	0.63
Scope for alternate applications	4.61	1.20	17%	0.64
Ready or Not (proof of concept in theory)	3.61	1.54	22%	0.41
Proof of application (in practice)	2.67	1.46	21%	0.47
Involvement of inventor	3.25	0.93	13%	0.78
Prototype availability	3.33	1.46	21%	0.47
Technical Feasibility	4.11	1.02	15%	0.74
Potential for further development	4.78	1.48	21%	0.45
Newness of the technology (uniqueness)	2.94	1.30	19%	0.58
2. Economic and Market Factors				
Potential for attracting required resources for example venture capital	2.78	1.06	15%	0.72
Potential return on investment	3.18	1.29	18%	0.59
Financial risk	3.94	1.56	22%	0.39
Market needs (pull/push)	3.28	1.23	18%	0.62
Distinguishable competitive advantages	3.22	1.11	16%	0.69
Market impact	3.28	1.13	16%	0.68
Level of Competition	4.00	1.06	15%	0.72
Time to market	3.24	1.25	18%	0.61
3. Social Benefits				
Environmental impact	3.35	1.58	23%	0.38
Cost advantages to customers/users	4.35	1.32	19%	0.56
Brand creation	2.94	1.12	16%	0.68
Potential for new useful applications	4.18	1.24	18%	0.62
4. Legal and Regulatory				
Protection of IP rights	2.88	2.00	29%	0.00
Strengths and scope of patent including geographical extent	2.47	1.46	21%	0.47
Patent exclusitivity	2.40	1.68	24%	0.29
New areas of application (not infringing any other patents)	2.87	1.96	28%	0.04
Need for complimentary technologies (availability of licenses for example to use other technologies)	3.69	1.82	26%	0.18
Freedom to operate, for example, open innovation	3.00	1.81	26%	0.18
5. Mechanisms				
Licensing	5.56	1.34	19%	0.55
Spin-off	2.33	1.53	22%	0.41
Consulting	3.61	1.72	25%	0.26
Collaborations	4.88	1.45	21%	0.47
IP assignment	3.67	1.61	23%	0.35

An analysis was also performed for each category of criteria, and an overall score was acquired to investigate the commercial status of the technology (*Table 6.10*). The experts' comments suggested that the technology had potential and was interesting, but further development was required as expected.

The technological readiness had an overall average rating of 3.63. The economic and market factors had an average of 3.36, social benefits 3.70, and legal and regulatory 2.88. The standard deviation for these ranged from 0.41 to 0.75, which implies that the experts' ratings and comments were in agreement to a certain extent.

The overall score, which can be an indication of where the technology stands, is 3.39 out of 7, which implies that the technology is about halfway ready and needs further development to be commercially ready. This demonstrates that the application is still a proof of concept (C2 – *"from limited info provided, it appears to be about Proof of Concept = 3 on US DOD Technology Readiness Level (TRL) scale of 1 through 9."*).

Table 6-10 Averages, standard deviation, and percentage standard deviation for each category of criteria and overall score

Category	**Average**	**Standard deviation**	**Percentage standard deviation**
Technological Readiness	3.63	0.75	11%
Economic and Market Factors	3.36	0.41	6%
Social Benefits	3.70	0.67	10%
Legal and Regulatory	2.88	0.46	7%
Overall score	3.39	0.77	11%

6.4 *Summary of key findings*

This section is the summary of key findings from this chapter:

- Overall, the Delphi helped in the decision of which criteria and mechanisms were important.
- Most of the criteria and mechanisms were considered important with the exception of six criteria and two mechanisms that were then taken off the list used for the evaluation. Additionally, one criteria and one mechanism were added to the list as per experts' recommendations (see Section 6.2.5).
- A comparison between the responses of the different groups of experts who participated in the Delphi study indicated that their responses were very similar when it came to the averages given by them for the criteria and mechanisms, but differed in terms of levels of agreement. However, this is useful in providing a variance across the results, and could also suggest alternate ways of involving specific groups of experts in collecting data related to specific categories of criteria. This will be further discussed in the recommendations for future research.
- The evaluation of the commercial potential of the technology concluded that the technology was still in proof of concept stages and needed further development.
- At the current stage, the recommended mechanism of transfer is licensing.

The next chapter is the discussion of the findings for the research questions posed.

Chapter 7: Discussion

7.1 Introduction

This chapter is the interpretation of the findings from Chapters Five and Six. Having identified several gaps in the research area after reviewing literature, several objectives were formulated. To reinstate, the objectives of this research are:

- To develop a set of criteria for evaluating the technology transfer (TT) process in the high technology sector which can also be used across disciplines
- To evaluate the commercial potential of an emerging technology using the criteria along with the development of a framework
- To propose a suitable TT mechanism for commercialisation following the evaluation.

To achieve the above objectives and subsequently answer the research questions, it was necessary to divide the research into a scientific component and business component followed by the evaluation of the commercial potential of the technology using the above outcomes. Therefore, to simplify the findings for each component, the chapter will be divided based on findings for each of the three research questions posed, which are:

1. Does the technology in question, initially developed in the field of astronomy, have an application in detecting leakage in pipes used for water transportation?
2. What important criteria should be involved in the '*ex-ante'* evaluation of the technology transfer process in high technology industries?
3. What is the effective mode of transfer to enable efficient commercialisation of the above technology and what would be the most suitable path to commercialisation? Following this, a proposed framework will be discussed.

7.2 Research Question 1 (RQ1)

Does the technology in question, initially developed in the field of astronomy, have an application in detecting leakage in pipes used for water transportation?

A simple answer to this question is yes. This application has been proven using laboratory experiments, but only to a proof of concept stage. There is definitely scope for further development as highlighted below and in Section 8.5. The experts' evaluation confirms this, which will be discussed in the other two research questions.

Before moving on to more details, it is necessary to highlight recent cases relating to water loss due to leaks in pipes that were undetected and resulted in pipes bursting. Recently, there was a crack in one of Brisbane's[8] (Queensland, Australia) main pipelines that resulted in the wastage of approximately 150 million litres of water. In a separate incident, a pipe burst in Los Angeles (California, the United States of America) causing floods. These catastrophic events could have been prevented through better leak detection techniques and constant monitoring of pipelines.[9] These cases are a good justification for conducting research on technologies that can help to minimise such events such as the technology chosen in this research.

The experiments conducted for this study resulted in a system being developed that was comprised of four electret microphones that feed into a four channel amplifier, which in turn feeds into a four channel 16-bit analogue-to-digital converter (ADC) connected to a notebook PC. Additionally, a computer code has also been written that calculates the Cross Correlation Function (CCF) for pairs of signals. The computer code is based on a code developed for radio astronomy applications, and so technology transfer has occurred at this basic level. In particular, the code developed divides a data sample into sub-samples and generates a CCF based on averages spectra. This code is fully

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8 The total length of 'active' reticulation pipes within Brisbane is 5927km. Approximately 20% of the total water pipes are made of PVC. Brisbane's leak detection program relies on monitoring District Meter Areas (DMAs) to identify anomalies in flow. If there are concerns of leakage, listening sticks/correlators are used to locate leaks (Brisbane City Council, personal communication, October 06, 2009).

9 An interesting compilation of facts about water and its value was compiled by the Bundaberg (Queensland, Australia) Regional Council with information provided by the Co-operative Research Centre for Water Quality and Treatment and organisations such as Sunwater, Wide Bay Burnett Regional Plan, and Healthy Waterways.

functional. The hardware and software has been tested on computer generated data and acoustic signals (e.g. hand claps, clicks, leaks, etc.) and CCFs produced. Code has also been developed that uses the CCF to calculate the direction of the chosen sound source.

In relation to this thesis, technology transfer has been demonstrated in two ways. The first is that a computer program used in a radio astronomy software correlation written originally in PERL was translated into Matlab and then translated into Scilab. The software has been used to correlate acoustic signals instead of radio signals.

The second is that a technology originally used in radio astronomy is now being applied for water leak detection and this could further result in technology transfer from lab to market if the technology is further developed and commercialised. A handful of studies have tried to investigate leakages in plastic pipes. Even though a common method to detect leaks in plastic pipes is to use cross-correlation, it has been done using two sensors and not four (Gao et al., 2004). An advantage of using additional pairs of microphones placed on a pipe is that the delay in the arrival of a leak sound at the two microphones can be used to calculate the speed of sound in the pipe as demonstrated in Chapter Five. This in turn helps to locate the direction and approximate location of the sound source.

Muggleton and Brennan (2004) along with Gao et al. (2004) also mention in their research that correlation techniques are popular because of clear-cut technique. The experiments described in this thesis, which were conducted to verify whether the technology could be transferred, used a similar concept whereby signals are transmitted from sensors placed at either end of pipes with a suspected leak and signals were sent to a remote computer for cross-correlation.

The main application chosen was to detect leaks in PVC pipes, as this was a major problem cited by experts working in the water industry. To achieve a satisfactory result, several other basic steps were also conducted such as using hand claps and mouse clicks as sound sources. Since leaks in water pipes produce sound, it was possible to locate the sound using correlation, which is why a known correlation technique was chosen from radio astronomy. Even though it is not possible to fully investigate the technique in this study, experiments have been done including the development of algorithms that help to move one step closer to the development of this technology. However, important lessons were learnt during this process that can possibly help in similar areas of research.

Initial tests for leaks proved unsuccessful due to the fact that a lot of background noise was picked up. To overcome this issue, several steps were taken as described in

Chapter Five. To reiterate, a sponge-like foam was used to soak the water and this was also helpful in significantly minimising noise. A more novel approach was the application of ultrasound gel on the pipe where the microphones had contact. The amplified signals from the microphones were connected to an analogue CRO. When the water flow was turned on and water escaped through the leak, it was immediately apparent that the signal was much cleaner than when the gel was not applied. This process led to the frequency content being much lower, i.e., the signal-to-noise ratio was higher when the gel was used.

A digitised sample of the leak signal with and without the gel was obtained and a Fast Fourier Transform (FFT) performed to elucidate the frequency content of both signals, and this again demonstrated that the use of gel resulted in much cleaner signals (*see Video clip 1*). Also, the equipment was relatively cheap to assemble. The most expensive item was the ADC which cost $700. Cheaper ADCs can be obtained, and the electronic components only cost a few dollars.

With further development, the technology could be made more sophisticated to enable the automatic processing of a batch of files. There is also scope for a lot more research, for example, developing a more sensitive amplifier system, producing a printed circuit board with a ground plane to further reduce noise, analogue filtering of the signals prior to digitisation, and digital filtering (in the frequency domain prior to performing the inverse FFT to remove noise – e.g. 50 Hz).

Further experiments can also be conducted to ascertain how well the technology will work in real life situations. This will be the next logical step following the results obtained in this research. For instance, experiments can be conducted with a pipe buried in sand, to mimic buried pipes in real situations. Tests can also be done to determine the extent of detection using variables such as the maximum length of pipe in which a leak can be detected, as well as the smallest leak that can be detected and whether sound can be picked up with pipes placed around corners. The system can also be made more robust whereby the electrical components can be installed in corrosion and water proof casings to avoid damage when used in adverse conditions.

Furthermore, the technology transfer demonstrated in this thesis could have a number of applications. For example, acoustic sensors could be attached at multiple places to a network of water pipes. Data samples would be then sent via a mobile phone network for instance, to a central, powerful software correlator. An array of acoustic sensors could also be placed in the environment to record the sounds of animals and birds to monitor environmental health. More details on related future research and applications can be found in Chapter Eight under the future research section. In summary, satisfactory results have been achieved so far to demonstrate a proof of concept.

7.3 Research Question 2 (RQ2)

What important criteria should be involved in the '*ex-ante*' evaluation of the technology transfer process in high technology industries?

Evaluation can occur in three ways, namely, '*ex-ante',* interim, and ex-post evaluation. Criteria used for each of these differ. While *'ex-ante'* evaluation is done to assess the commercial potential of a technology before it is actually commercialised, interim evaluation is conducted while the transfer process is taking place to assess the progress so as to achieve success. On the other hand, ex-post evaluation helps in assessing the outcomes once the transfer has been completed (Geuna & Martin, 2003; Miles et al., 2006).

One of the aims in this research was to identify the important criteria for *'ex-ante'* evaluation in relation to high technologies. *Table 7.1* is a collection of all criteria found to be important following the Delphi study. Heslop et al. (2001) suggested four categories that can be useful in assessing the likelihood of a successful technology transfer or the early assessment of a technology. These are:

- Market readiness
- Technology readiness
- Commercial readiness
- Management readiness

The outcome of this research suggests a similar set of categories and criteria, although the Management readiness category proposed by Heslop et al. (2001) is replaced by Social benefits in this study. This is because societal expectations from technologies have changed over the years with organisations aiming to be more socially responsible with the technologies they use, adopt or transfer. The social impact that technologies have can greatly influence its development and subsequent use. The importance of social benefits created from technology transfer has been overlooked in the past and this explains one of the reasons previous models and frameworks did not incorporate it. Therefore, it is necessary that this category be included as previously suggested by some researchers (see Rahal & Rabelo, 2006; Roper et al., 2004).

Using a series of steps to refine criteria obtained from literature, which included two rounds of the Delphi technique and expert involvement, the proposed categories are:

- Technological Readiness
- Economic and Market factors
- Social benefits
- Legal and Regulatory

It was imperative to cover all major aspects related to technology commercialisation, from the technology itself to the potential markets it can have. This is emphasised by Thore (2002) who discusses the importance of the many aspects related to a technology and its commercialisation, such as the different factors that can influence whether a technology is ready to be commercialised and what factors could result in its success. This includes several dimensions such as aspects related to the readiness of the technology, the applications a technology can have, and what intellectual property the technology could generate. While some authors such as Luik (2005) recommended approaching evaluation based on specific factors such as market and economic related factors, others like Bellais and Guichard (2006) recommend using a combination of criteria all at once with an emphasis on intellectual property and market related criteria. Additionally, if there are still doubts as to which particular criteria or variables can help in assessing the success of commercialisation, the selection of categories of criteria chosen for the evaluation can be justified as there is an agreement in the literature about which dimensions of criteria including technology, environment, and the markets should be used by many researchers (see Astebro, 2004; Heslop et al., 2001; Galbraith et al., 2007).

This was the approach taken in this research, as it was necessary to pool all of the important criteria and mechanisms so as to get the experts to rate them all at once. It is crucial in discussing the criteria considered to be the most important in each category, and is discussed next.

Table 7-1 A collection of all criteria found to be important following the Delphi study

1.Technological Readiness
Stage of development of the technology
Replicability possible
Scope for alternate applications
Ready or Not (proof of concept in theory)
Proof of application (in practice)
Involvement of inventor
Prototype availability
Technical Feasibility
Potential for further development
Newness of the technology (uniqueness)
2. Economic and Market Factors
Potential for attracting required resources, for example venture capital
Potential return on investment
Financial risk
Market needs (pull/push)
Distinguishable competitive advantages
Market impact
Level of Competition
Time to market
3. Social Benefits
Environmental impact
Cost advantages to customers/users
Brand creation
Potential for new useful applications
4. Legal and Regulatory
Protection of IP rights
Strengths and scope of patent including geographical extent
Patent exclusitivity
New areas of application (not infringing any other patents)
Need for complimentary technologies (availability of licenses, for example to use other technologies)
Freedom to operate, for example, open innovation

7.3.1 Importance of criteria and further discussion on RQ2

Even though most of the criteria and mechanisms have been considered important, it is necessary to have knowledge of which criteria are more important than others in each category. Each category is discussed below.[10] The most important as well least important criteria in each category will be discussed along with their average ratings in brackets following the second round of the Delphi (where helpful experts' comments will be added

10 References to the work of the following authors are made: Lee & Gaertner, 1994; Arni, 1996; Heslop et al., 2001; Durand, 2003; Roper et al., 2004; Rahal & Rabelo, 2006; Schilling, 2007.

for further rationalisation, and these are bracketed and italicised with experts' references as discussed in Chapter Six):

1. Technology Readiness - readiness of the technology is crucial to help establish the position of the technology in terms of feasibility and usefulness:

- Technical feasibility (4.55) was given the highest importance in this category. Feasibility is important to determine whether there is enough experience and knowledge to build and use the technology. As discussed by several authors, if a technology is not feasible then its transfer will most likely not occur or result in failure. Therefore, feasibility is a key criterion to be considered when evaluating commercial potential.
- The stage of development (4.30) can largely influence whether the technology is ready to be commercialised. The technology normally needs to be in an advanced development stage to be commercial ready. Past studies agree that the stage of development of a technology is one of the key factors that can make or break a decision to commercialise or further develop a technology. This is due to the fact that a technology's value can be realised through its development.
- Replicability possible (4.25) is another criterion that was rated high. The ability for a technology to be replicable is crucial to enable the process to be repeated in the case of commercialisation (B8 - *"Ability to replicate is very important in order to commercialise"* and *"essential if you want to obtain theoretical & commercial benefit";* B13 - *"Important for investors.").* For instance, it should be possible for the application of the technology to be duplicated by the transferee otherwise it would be expensive to recruit additional expertise, and getting the inventor involved in the process is not possible in most cases.
- Technology complexity was given the lowest rating (2.25) owing to the fact that it is important for the technology to be as ready as possible, and more complex technologies require more skills and therefore could be expensive. While some researchers argue that the level of complexity can equate to the quality of a technology, others argue that adding layers to a

technology could result in difficulty with its applicability in areas other than its place of origin.

2. Economic and Market Factors: in this category, three criteria, namely, Potential to attract funding, Potential return on investment, and Distinguishable competitive advantages received the highest rating (4.70). This demonstrates that the due diligence of the market and competitors is as important as attracting funds. This is further verified by past research that gave importance to the monetary value a technology can create, which is in turn related to the competitive edge a technology has. Having core competencies adds further value to the technology.

On the other hand, the contribution to economic growth or development was given the least average rating (2.45). This is due to the fact that when commercialising from universities, the interested parties look for possible gain from the technology.

3. Social Benefits: In this category, Cost advantages to consumers (3.85) received the highest average. This is because if customers are given a better price, then there will definitely be a market for the commercial product. For instance, a product resulting from the transfer of a technology that can offer a cost benefit to consumers is always beneficial, as it can result in a huge market and dominance in its respective market.

Interestingly, out of the seven criteria in this category, only three were above an average of 3 with one of them barely crossing the 3 mark (Cost advantages to consumers – 3.85; Potential for new applications – 3.42 and Environmental impact – 3.05). As observed in past models, criteria related to benefits to society and environment are not generally considered important unless the technology is aimed at these areas, because of the fact that organisations that commercialise usually aim to make a profit.

4. Legal and Regulatory: as expected, the ratings for these criteria were high given the importance of intellectual protection. Freedom to operate was rated the highest (4.55) and Need for complementary technologies was rated the lowest (3.80). Indeed, freedom to operate is important as technologies need to be used without infringing any other patents, so as to avoid any legal complications for the organisation or organisations involved.

One point of significance is that some of the highly-rated criteria were similar in importance to those obtained by Heslop et al. (2001) in their development of criteria that can be used to assess the readiness of technology. Criteria or readiness conditions as referred to by Heslop et al. (2001) were 54 in total and were ranked based on the ratings received by them. For instance, distinct competitive advantage was given a high rating with a mean of 4.70 on a five point scale, and correspondingly was ranked second (out of 54) in Heslop et al's findings. Comparisons to exemplify similarities between both studies can be found in *Table 7.2*.

Table 7-2 Similarities in the types of criteria and their significance between results obtained though data collection and Heslop et al. (2001) findings

Transfer readiness conditions	**Rank (out of 54)**	**Criteria refined through the Delphi**	**Average (out of 5)**
Distinct competitive advantages	2	Distinguishable competitive advantages	4.70
Expected positive Return On Investment (ROI)	5	Potential return on investment	4.70
Defined marketable product	6	Market needs (pull/push)	4.55
New, non-obvious invention	8	Newness of the technology (uniqueness)	4.00
Has future uses	9	Potential for further development and scope for alternate applications	3.55
No other dominant patents	10	Patent exclusivity	4.20
Inventor will champion	11	Involvement of inventor	Added due to experts' recommendation with importance
Immediate market uses	18	Time to market	4.30
Functioning prototype	36	Prototype availability	3.95

As *Table 7.2* shows, the importance of the corresponding criteria are similar. The table contains the averages obtained from the data collection with the ratings out of 5, as well as Heslop et al.'s findings (2001) with their ranking out of 54 (where 1 is highest). This demonstrates that the findings from the experts can be validated.

Additionally, there was only one criterion, namely involvement of the inventor that was added through the Delphi. As discussed in the literature review, this is a good recommendation by the experts as unwillingness of the inventor(s) to participate in commercialisation can result in an unsuccessful outcome (MacBryde, 1997).

The aim here was to refine criteria obtained from literature and explore their importance for *'ex-ante'* evaluation. Therefore, based on the Delphi study, these criteria are deemed to be crucial in evaluating the commercial potential of high technology. The outcomes also help with understanding what criteria are of more importance than others in each category, as explained above. This is useful when a technology is to be evaluated based on the importance of criteria (Heslop et al., 2001). A framework has also been proposed that can aid in evaluating the commercial potential of a new technology (see Section 7.5).

7.4 Research Question 3 (RQ3)

What is the effective mode of transfer to enable efficient commercialisation of the above technology and what would be the most suitable path to commercialisation?

Technology transfer consists of several stages before commercialisation can actually occur. For commercialisation to occur, a suitable choice of transfer mechanism is necessary (Wang et al., 2003).

There are various ways in which a technology can be transferred. These include licensing, spin-offs, and the sale of intellectual property amongst others (Wei, 1995; Göktepe, 2004). The choice of mechanism best suited to the commercialisation of a particular technology depends on various factors such as the value of intellectual property generated by the technology (Pries & Guild, 2005).

To decide on the most suitable mechanism for the technology evaluated in this research, questionnaires were sent to experts involved in commercialisation. The evaluation of the technology transfer potential resulted in an overall score of 3.39 out of 7 (7 point scale used for the evaluation). Along with the experts' comments, this can be interpreted as the technology having reached the proof of concept stage as indicated by experts.

The experts thought that there is potential in the technology, but the due diligence for the market needed more work along with establishing the relevant IP and its subsequent protection. This was expected as the technology is still in its early stages. Before discussing the mechanism suggested by the experts for the technology evaluated, the mechanisms deemed the most important in the Delphi will be discussed.

The most important mechanism as rated by experts in the Delphi (average indicated for each along with comments from experts where necessary) was spin-offs

(4.10). The Australian Centre for Innovation et al. (2002) further supports this, stating that spin-offs are an important, useful commercial path as they involve retaining IP generated, and this can help with further development and possibly higher returns.

Licensing was the next suggested mechanism (4.00) (B10 - *"bread and butter transaction for universities."*). Licensing is normally a suggested mechanism when a technology may be unsuitable for a spin-off company (Bray & Lee, 2000).

Traditionally, spin-offs and licensing are the most commonly used mechanisms of transfer from universities. Major advantages in creating a spin-off include continued involvement of the inventors in most cases, complete control and ownership of IP, and continuity of interest in improving the technology. Disadvantages include additional access to more skills and capital (Gregory & Sheahen, 1991; Perez & Sanchez, 2003; Pries & Guild, 2005).

On the other hand, some of the advantages of licensing include possible access to markets otherwise inaccessible, the possibility of sharing IP with established firms experienced in marketing and selling subsequent products and services, incorporation of the technology with another technology to enhance its effectiveness and possible access to capital, and additional know-how through the licensee. Some of the disadvantages of licensing include partial or total loss of control of IP and decision making in the commercialisation process. *Table 7.3* is a collection of all mechanisms found to be important following the Delphi study.

Table 7-3 A collection of all the mechanisms found to be important following the Delphi study

Mechanisms
Licensing
Spin-off
Consulting
Collaborations
IP assignment

As mentioned above, the commercialisation of a technology requires certain factors to help with the transfer process such as the choice of a suitable mechanism (Bellais & Guichard, 2006).

Following the outcome of discovering the current commercial position of the technology, it was then necessary to explore which mechanism was the most suited for this particular technology.

Following the evaluation, the suggested mechanism was licensing with an average of 5.56 and the most agreement with an IRA level of 0.55. This could be due to the fact that the licensee could improve further on the technology and there could be long term benefits as indicated by some of the experts. Alternatively, if the technology to be transferred was developed in one more areas then its current stage, the choice of mechanism could differ. This will be influenced by which area the technology is stronger in when it is being considered for transfer.

The evaluation was conducted so as to determine the commercial position of the technology in question, as well as to suggest an appropriate mechanism. Although the creation of a spin-off would be one of the appropriate choices, the experts recommend licensing. This could be because, at this stage, licensing could provide access to further resources that could help to develop the technology further in terms of technical readiness, as well as establishing the IP position and due diligence of competition and markets (Bray & Lee, 2000; Pries & Guild, 2005).

The outcomes of these findings helped to better understand the importance of the different mechanisms that can be used to commercialise a new technology, and that the choice of mechanisms is not only technology specific but also industry specific and dependant on the source; in this case, a university. The next section will discuss the proposed framework.

7.5 'Ex-ante' evaluation framework

Based on the findings, a conceptual framework can be proposed for the *'ex-ante'* evaluation of technology transfer. The model was placidly inspired by Bickerton's (2000) context diamond which deals with corporate branding, and Dorf and Byers's (2008) diagram designed to be used for the review of an opportunity. Dorf and Byer's diagram uses a percentage rather than a scale and is about evaluating an opportunity.

The proposed model will be referred to as the Commercialisation Predictor Model (CPM). This will help to address some of the problems that Harris and Harris (2004) and others previously mentioned concerning the lack of such a model or tool. Hence, this will help to shape how we approach our decisions regarding a new technology or any new applications it might have in other disciplines.

As *Figure 7.1* demonstrates, the idea is to position each of the four categories of criteria at each of the ends of the diamond. A 7 point scale will be used for each category that consists of the criteria as outlined in Chapter Six. Once the total score for each category is calculated, the score is positioned according to the scale and category on the diamond.

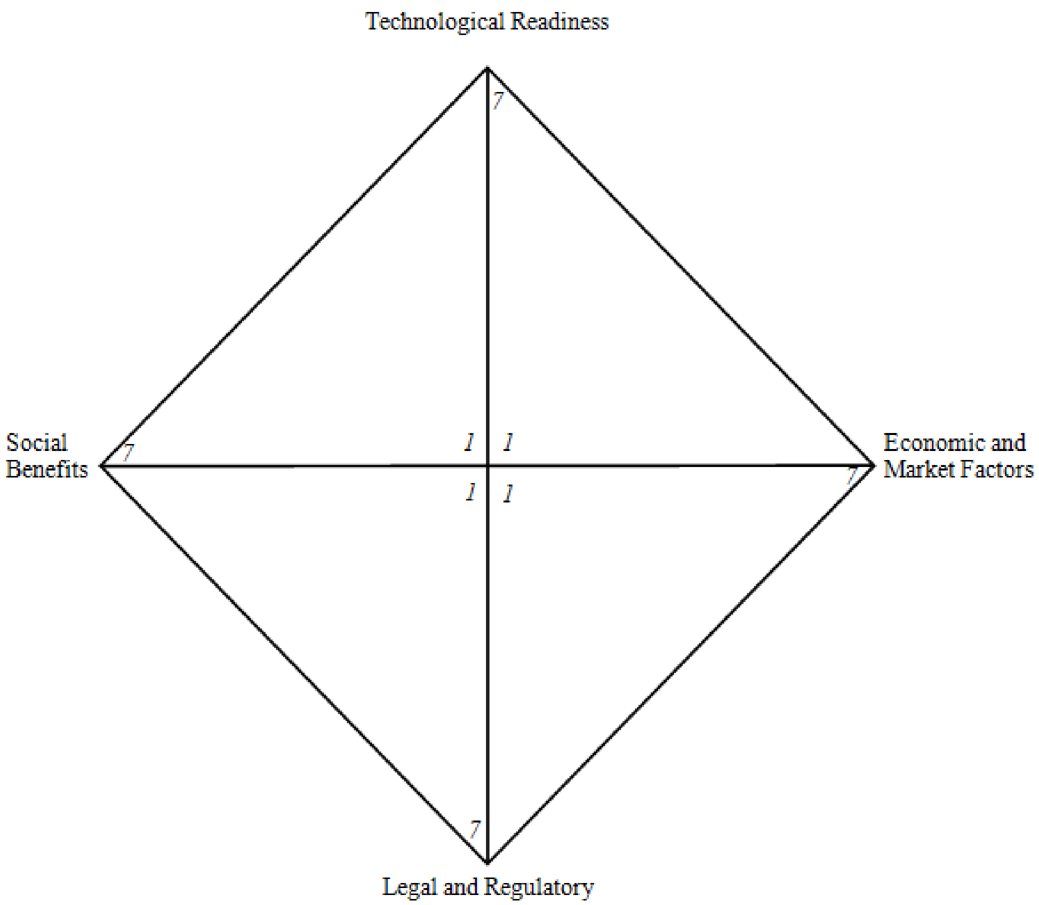

Figure 7-1 Commercialisation Predictor Model (CPM)

The evaluation of the commercial potential of the technology used in this thesis will be demonstrated as an example. The scores obtained for each of the categories are:

- Technological readiness – 3.63
- Economic and Market factors – 3.36
- Social benefits – 3.70
- Legal and Regulatory – 2.88

Figure 7.2 demonstrates (to an approximate scale) the values stated above marked on the relevant scales of the respective categories, which are then connected. This can be first interpreted mathematically. The diamond consists of four triangles each with a 90^0 angle.

Using basic mathematics, the area of each triangle is simply calculated by multiplying the scores of the two factors (the two factors are the catheti of a rectangular triangle) and dividing it by 2. Doing this for all four triangles and adding the areas of each triangle results in the total area of the diamond covered by the shape formed due to the respective scores. The principle behind this is, the closer the covered area is to the original diamond, the more ready the technology is.

In the model, the maximum area is 4*(7*7*0.5) =98, which would mean the technology is considered to be 100% ready for transfer. The area of the diamond that resulted from the evaluation of the technology was calculated as 22.9 (rounded figure):

3.63*3.36*0.5=6.1

3.36*3.70*0.5=6.2

3.70*2.88*0.5=5.3

<u>2.88*3.63*0.5=5.2 +</u>

22.9

22.9 then equates to 23% readiness (as 98 equals 100%). This in itself is not an unambiguous notion of readiness, as the percentage leaves space for interpretation. It should be used as a guide to inform overall readiness for technology transfer. The percentage should be used together with the visual representation in the figure, to remove ambiguity of the result. For example, a 50% readiness can be obtained by fulfilling three categories, while lacking totally in one. The percentage does not represent this: however, using the visual representation, it can be seen that the technology is significantly lacking in one category, even though a 50% score is reached. A measure of standard deviation could also be used to detect ambiguity. A high standard deviation would indicate that some categories have scored notably different to others. Combining the mathematical score with the visual representation in the model will give an indication of which categories still need to be addressed. Therefore, a combined procedure should be used, where first the total area is calculated and second the visual outcome is studied.

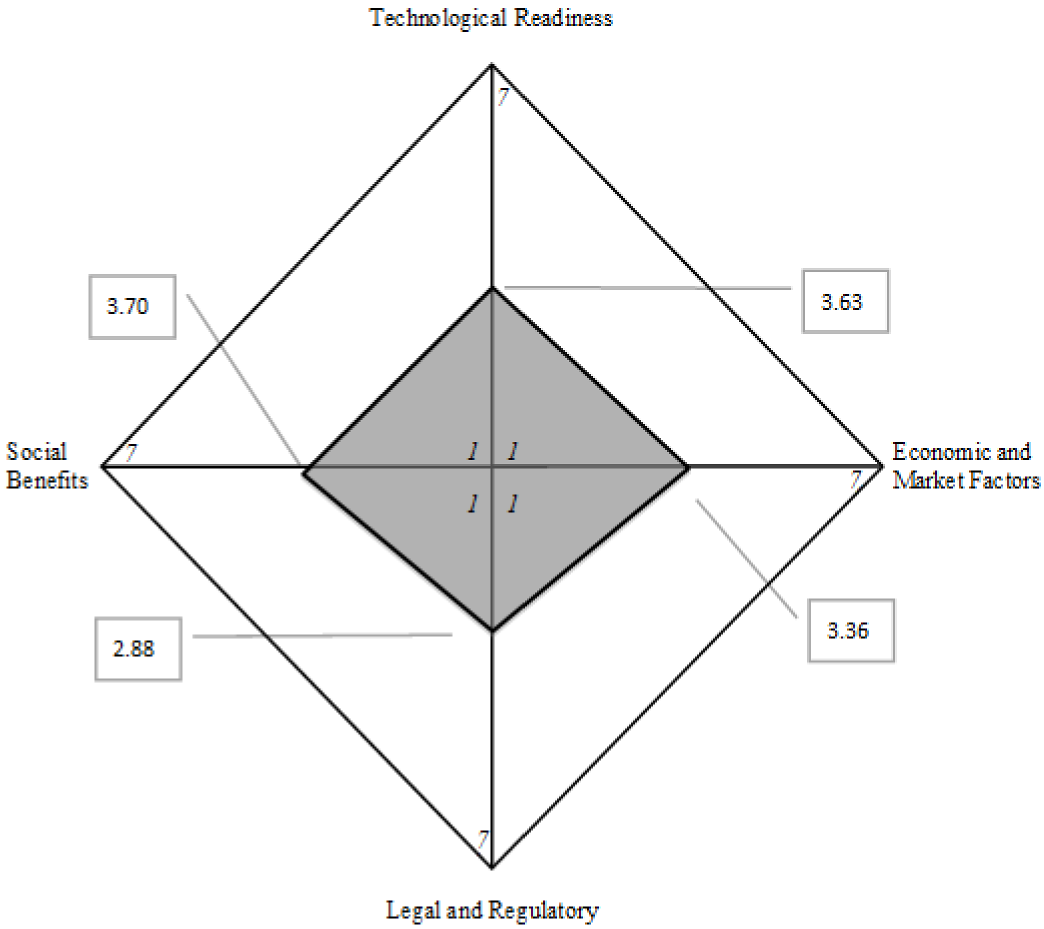

Figure 7-2 Commercialisation Predictor Model (CPM) using values from the evaluation outcome of this study

If different industries want to adopt this model, it might be possible to do so. There are two options to do this. Certain criteria can be added to the existing categories or, on the other hand, the shape can be modified as categories are added or taken out. For instance, in the case of medical technologies a category for ethics can be added. The resulting shape would be a pentagon. This will in turn require a change in the mathematical equations used to calculate the area.

The framework can also demonstrate areas in which improvements are needed. For example, *Figure 7.3* (example only) illustrates that the technology has a strong readiness and fulfils most of the economic and market factors, but lacks in the legal and regulatory and social benefits categories. This information can then be used to address the relevant issues by investigating individual criterion in each category, which will then contribute to the betterment of the categories. This results in the change of shape of the internal coordinates, which can once again indicate if there are any improvements to be made to make the technology 100% commercial ready.

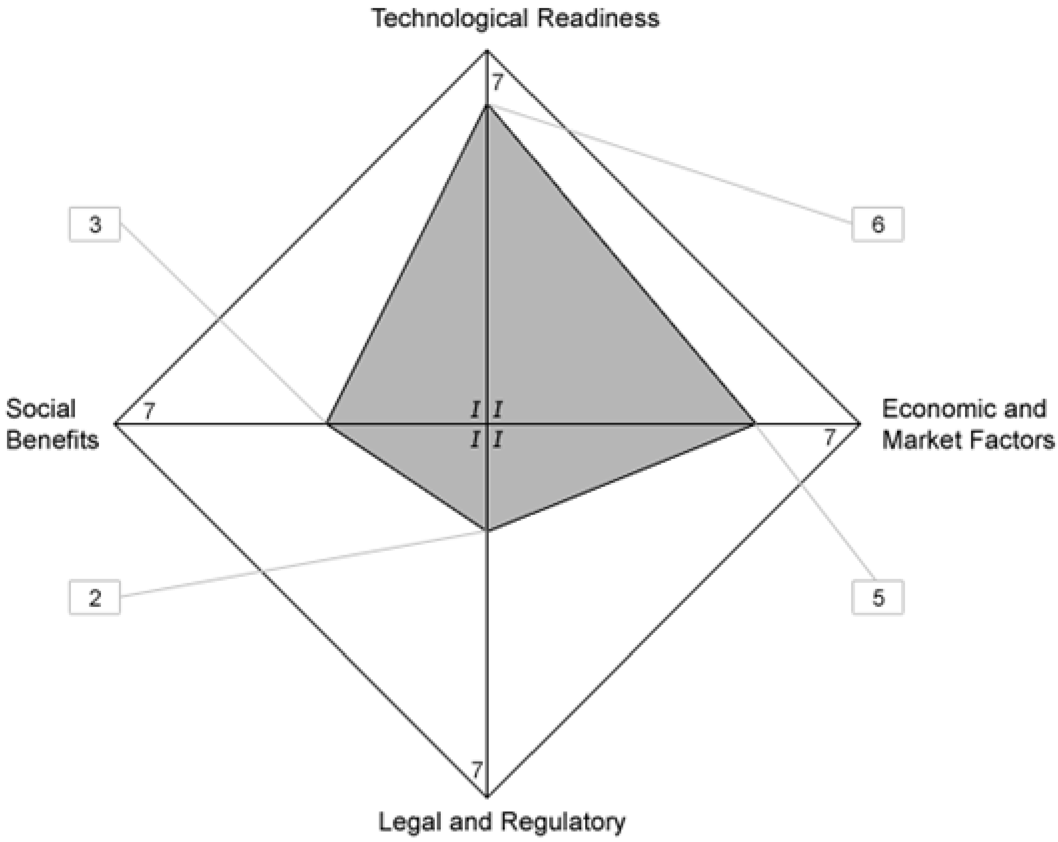

Figure 7-3 Commercialisation Predictor Model (CPM) example scenario 1

In addition, theoretically, the shape obtained can help to narrow down the choice of mechanisms for commercialisation. For instance, if the shape skews more towards the Legal and Regulatory category, then an option to commercialise would be by IP assignment due to the fact that the technology is strong in its IP, and selling it would be a suitable option. On the other hand, if the shape skewed more towards the economic and market factors (*Figure 7.4*) (example only), this can imply that the technology has a strong market and could result in a lucrative financial outcome, therefore, it could attract venture capital and result in licensing or trade sales.

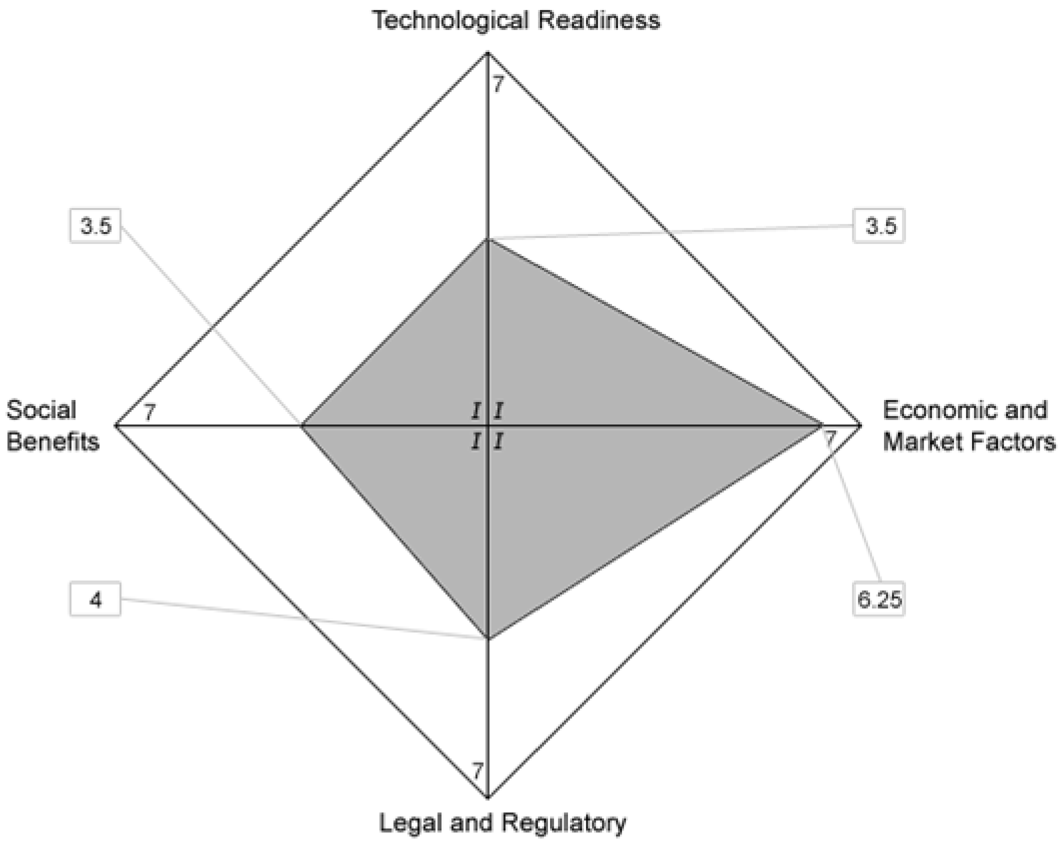

Figure 7-4 Commercialisation Predictor Model (CPM) example scenario 2

This framework has been designed based on the findings, but further work can be done to improve the accuracy as well bridge a connection to the choice of commercialisation mechanism. [11] For instance, a weighting system can further be added to the framework if necessary. An example of how this can be achieved is by assigning a weight to each criterion under each category based on the ratings given by experts following the Delphi. The higher the averages of the particular criteria, the higher the weight assigned.

11 Future development of the framework could use a categorisation system for commercialising new technologies similar to the one suggested by Pries and Guild (2005). *Build, Rent, or Sell* are three options that can be used to commercialise new technologies. *Build* involves creating a new venture, *Rent* lets other firms use the technology through ongoing development, and *Sell* is the outright sale of the technology. The choice of which would be best for the commercialisation of the new technology depends on criteria related to the technology itself, such as intellectual property. Further research can be done to better relate to the choice of mechanisms to commercialise a new technology.

7.6 Summary

This chapter began by stating the objectives followed by the research questions. This was succeeded by the discussion of each research question, and a framework emerging from the criteria was proposed. The next chapter (conclusion) will have an overall summary of the research as well as contributions, limitations, and future research.

Chapter 8: Conclusion

8.1 Overview of findings

A basic proof of concept for this technology has been proven using scientific experiments. This includes the development of a working prototype device that can be used for recording sound from four microphones simultaneously, and calculating the difference in the arrival time of the sound at each microphone (i.e. the phase difference). Software correlators developed relatively recently for analysing radio astronomy signals inspired the development of this device. Several steps were needed to test the feasibility of the technology for water leak detection. This included conducting simple tests such as using a hand clap as a sound source and calculating phase shifts.

Additionally, a Delphi study with the participation of experts helped to refine criteria and mechanisms chosen from literature that are important for the *'ex-ante'* evaluation for the transfer of high technologies.

The refined list was then used again as an evaluation tool with the participation of experts to assess the commercial potential of the developed technology. These findings have several contributions as outlined in the next section.

8.2 Theoretical contributions

This study contributes to the ongoing research on improving technology transfer models, particularly in the high technology industry and for universities looking to commercialise. A contribution made is the identification of the core categories of criteria and their incorporation into a framework (Section 7.5) for the '*ex-ante*' evaluation of the technology transfer process, along with suitable mechanisms to assist with the transfer. The framework can be applied in the evaluation procedures of potential technology transfer. While numerous frameworks and models mainly arising from technology transfer and evaluation literature have been developed, the majority of them focus on ex-post evaluation and therefore encompass criteria suitable for evaluating the transfer of a technology after the commercialisation process. On the other hand, a gap in the related literature indicated a lack of comprehensive criteria that could be used to assess the commercial potential of a technology. Creating a diverse checklist will ensure that any important opportunities are not left out (Anthony, Eyring & Gibson, 2006). This concept is the essence of this study due to the fact that the list of developed criteria covers different aspects related to the transfer of a technology. They also add that if the checklist is satisfactory it can be used and altered when needed to suit the needs of a particular transfer of technology. Keeping this concept in mind, criteria were refined and validated and presented in the form of a framework. The addition of a category dealing with criteria relating to social aspects is a contribution made by this research. Although previous research has mentioned social impacts of technology transfer, there has not been an eminent addition of these criteria in evaluation frameworks. The importance of the social impact of technologies and its transfer has been recognised over the years allowing for assessment forms dealing not just with technology and economic assessment but also environmental impact for instance (Becker, 2001). Moreover, attempts have been made to churn technological developments into social directions that are desirable and acceptable. After consulting experts and conducting the Delphi study, a certain number of social criteria have been found to be important in evaluating technology transfer. Subsequently, as per experts' recommendations it is useful to add these as part of the *'ex-ante'* evaluation framework.

Therefore, the proposed framework developed from this research is a platform to be built upon to further enhance and refine criteria that can be used for the '*ex-ante*' evaluation of technology transfer. The findings were achieved by consulting experts and getting their opinions, as well as researching relevant literature about the specific criteria and how they can help to achieve successful transfer. Additionally, the important criteria in each category have been discussed, thereby informing literature about the specific criteria considered more crucial than others.

Hence the suggested framework and refined criteria are a contribution to the relevant literature because they address gaps in the literature relating to a lack of *'ex-ante'* frameworks as compared to frameworks used for ex-post evaluation.

In addition, the framework could further narrow down the choice of mechanisms after a technology has been evaluated, as discussed in Chapter Seven. The idea is to visually represent the core competencies of a technology and determine its strengths, and use the developed areas of the technology to narrow down what sort of mechanism would be best suited to its commercialisation.

Another contribution is to the literature on the Delphi method, particularly when adopted for interdisciplinary research. Although, Delphi studies have been conducted for many years now, e-Delphi or conducting a Delphi study over the internet is still not as common. This study has shown that conducting a Delphi study online can be as effective as using traditional mediums for Delphi.

Additionally, this study has demonstrated the complexity of knowledge required for technology transfer, so in future research in this field, a similar approach will be valuable for optimising all necessary information obtained (Roest, 2002; Durand, 2003, Skulmoski et al., 2007).

This study has also demonstrated the importance of interdisciplinary research by combining two disciplines and integrating their respective research outcomes. There were two levels of interdisciplinarity demonstrated; the higher level was the combination of scientific and business disciplines. At a more specific level, the original application of the technology was in the field of radio astronomy and this was then applied to water leak detection resulting in some practical implications discussed in the next section. The coming together of different disciplines can lead to new ideas and knowledge generation, which is useful due to the fact that interdisciplinary research can lead to certain innovations that would not otherwise be possible, and this is in turn can lead to other benefits such as economic growth, welfare of society, and the creation of new markets or products (Qin et al., 1997; COFIR & COSEPUP, 2004). The techniques and combinations of methods adopted for this research to achieve an interdisciplinary outcome are necessary for studies focused on similar objectives. The next section will outline the practical implications arising from this study.

8.3 Practical implications

A potential new application of an existing technology was studied: in this instance the possible application for technology transfer in detecting water leakages in PVC pipes. This is useful because of the ongoing drought problems in Australia and water shortages elsewhere in the world. The proof of concept achieved in this study can be a basis for further development of the technology, and new applications could be investigated as discussed in Section 8.5.

Furthermore, the transfer of algorithms used to correlate the collected data is another contribution. The algorithms developed in this study are a variation of the original correlator software designed to work with the equipment utilised to collect data. After multiple rounds of modification and experimentation, the correlation function of the software to detect leaks and other sounds buried in noise was successful. There is further potential for the development and application of the technology and this will be discussed in Section 8.5

Additionally, the range of criteria incorporated into a framework could be adopted by industry and universities in their evaluation procedures. The suggested framework could be tailored according to a specific industry's need, and implemented in their technology evaluation process following further enhancement of the framework as discussed in Section 8.5.

8.4 Limitations and delimitations

There were some limitations faced and these will be outlined below. Concerning the Delphi study, it is possible that the selection of experts may not be fully accurate and their opinions could be biased, especially when they were asked to change their ratings in the second round of the Delphi method. There was also a possibility of increasing the number of experts but the results obtained indicate that the experts agreed overall (Adler & Ziglio, 1996; Skulmoski et al., 2007).

Other limitations may be related to the generalisability of the final criteria as they may not be applicable to all technologies across all industries, but it can be argued that this technology is being analysed in depth, which helps to get a more focused, specific, and accurate set of criteria. This in turn makes the criteria more generalisable for high technologies.

Furthermore, the study only looks at one technology and an application that could have a positive outcome, and therefore the full potential of the criteria might not have been exploited. However, this is justified by the fact that, initially, a more generalised list of criteria from literature was compiled and expert opinion was sought, thereby adding credibility to the chosen and applied criteria.

Additionally, due to the interdisciplinary nature of this research, only limited time could be spent on developing the technology for the application. More R&D would have been possible but as this research is focused on *'ex- ante'* evaluation, the results obtained suffice for the purpose of evaluation. A stronger investigation of the intellectual property concerned could also have been useful, but this is currently not possible as the technology is in its early stages. The next section will discuss possible future recommendations for this research.

8.5 Recommendations for future research

There are some recommendations for further work that could be made for the technology and the evaluation process. To begin with, in relation to the experiments conducted, there could be an improvement in the efficiency of performing calculations by utilising faster computers with more processing power, as well as a fast wireless network that can transfer data collected from the source.

Another possibility is to send data to computing centres where digital correlators have been implemented (e.g. Swinburne University in Melbourne) for processing. The CCFs would be sent back over a network for further local calculations. In a sense, this kind of facility would be analogous to a power station providing power to many users. It is a lot more efficient to generate power using a single large power station rather than many small power stations. Another major advantage of the remote processing approach is that high performance computing hardware only dedicated to the phased array equipment is not required. If dedicated equipment was used it would not be required all the time, and therefore the dedicated computer resources would be wasted when not in use. Software correlators such as DiFX developed at the Swinburne University of Technology are optimised for performing the intensive calculations required. Therefore, it would make sense for acoustic phased array samples to be sent over the internet for rapid processing at such facilities.

There is also scope for more development of the technology: for example, developing a more sensitive amplifier system, producing a printed circuit board with a ground plane to further reduce noise, analogue filtering of the signals prior to digitisation, and digital filtering (in the frequency domain prior to performing the inverse FFT to remove noise – e.g. 50 Hz). Also, the use of other sensors could be explored, such as accelerometers and hydrophones. Perhaps even a combination of different types of sensors would be more effective than one type of sensor alone. More robust algorithms could also be written for the correlation of the collected data. Basically, the essential features of a commercially viable system are that the system should comprise stand-alone units with a built-in vibration sensor (e.g. microphones, accelerometers, hydrophones), an ADC, most probably built into a microcontroller, memory for storing digitised signals, an accurate clock for time stamping the data, and a method of transmitting the data over large distances (e.g. mobile phone, radio, satellite, fibre optic) to a central computing facility for calculating multiple CCFs. In addition, the sensors should be robust enough to withstand rain and winds and should have a reliable source of power, for example, solar energy.

Alternate applications for the technology could also be explored. Detecting water loss in other forms of water transport can also be monitored: for instance, in Australia, transportation to rural areas in times of severe drought can be difficult and expensive, and done by road and rail. Saving even a few drops of water can be crucial. Leak detection in dams and reservoirs could also be a possibility.

Other examples include the use of the technique in focus groups or meetings where digital minutes could be created. This could be useful in determining the location of someone in the room speaking. This could further be incorporated into software that could show a three-dimensional blueprint of the room and identify the location of the person speaking as well as their information such as background and photo. Another example of an application could be to study birds. Microphones could be placed in an environment inhabited by a certain species of birds. The microphones can help to pick up the sounds of these birds amongst surrounding noise and the results can then help to indicate the direction of the sound.

Regarding expert selection for the Delphi study, difference in agreement within the different groups of experts as discussed in Chapter Six could suggest that particular experts can be targeted for particular categories of criteria, and this could increase accuracy and knowledge about these criteria.

In relation to the evaluation process, further studies on the criteria used for *'ex-ante'* evaluation can be conducted to investigate the relationship between the different categories of criteria and their use across various industries. Research on the choice of the most suitable mechanism based on the evaluation outcome should also be investigated. This can be achieved through further development of the proposed *'ex-ante'* evaluation framework, which could involve the creation of a more detailed and automated evaluation software. The software could be used to calculate the totals for each category of criteria, as well as automatically display the relevant shape depending on the number of categories, and highlight which category or specific criteria still need improvement. Additionally, suggested mechanisms based on the shape and results could be proposed.

8.6 Summary

This study has demonstrated the importance of interdisciplinary research as well as the importance of *'ex-ante'* evaluation in the technology transfer process. A framework based on the findings has been proposed. Furthermore, a new application to detect water leaks from an existing technology originating from radio astronomy has been developed to a proof of concept stage with a working prototype. Additionally, several theoretical contributions and practical implications have been made and the possibility for related future research recommended.

It is important in this highly competitive and technologically dynamic world to demonstrate that a technology developed at educational institutions or originally developed for a single use can have potential applications elsewhere. For the success of such transfers, *'ex-ante'* evaluation is a necessary and beneficial tool. It is hoped that this research has provided some insight into this concept by demonstrating a practical example, and also in bridging the gap between science and business skills essential in taking innovation to the market through invention.

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Appendices

Appendix A: Taxonomy of technology transfer literatures (Reisman, 2005)

Key 1: **Actors: .**

- 1.1 Transferors
  - 1.1.1. Scientific disciplines
  - 1.1.2. Professions
  - 1.1.3. Corporate or institutional entities
  - 1.1.4. Industries
  - 1.1.5. Economic sectors
  - 1.1.6. Geographic regions
  - 1.1.7. Societies/countries.
- 1.2. Transferees
  - 1.2.1. Scientific disciplines
  - 1.2.2. Professions
  - 1.2.3. Corporate or institutional entities
  - 1.2.4. Industries
  - 1.2.5. Economic sectors
  - 1.2.6. Geographic regions
  - 1.2.7. Societies/countries.

Key 2: **Transaction Types**

2.1 External Transfers

- 2.1.1. Information exchange
  - 2.1.1.1 Programs: (Sabbaticals, scholarship programs such as the Fulbright awards, work- study arrangements, internships)
  - 2.1.1.2 Conferences and Symposia:
  - 2.1.1.3 Technical Correspondence:
  - 2.1.1.4 Free Technical Services:
  - 2.1.1.5 Professional-Journal Publications:
  - 2.1.1.6 Software programs:
  - 2.1.1.7 Internet/Web usage related exchanges:

2.1.2. Sales

2.1.2.1 Sales of Equipment and/or Intellectual Properties: (A single piece of equipment or an entire system such as a factory, turn-key projects, etc., a formula, new designs, drawings, blueprints, procedures, market surveys, demographic statistics)

2.1.2.2 Sales of Services: (Consulting assistance, user manuals, equipment maintenance)

2.1.3 Cooperative agreement

2.1.3.1 Co-production: (The GE (USA) - SNECMA (French)) collaboration in the aerospace industry

2.1.3.2 Co-research (the U.S. Human Genome Project, a 13-year effort coordinated by the Department of Energy and the National Institutes of Health)

2.1.3.3 Co-design (Arrow anti missile system (USA and Israel), The UK "Watchkeeper" unmanned spy plane project (UK, USA, Israel)

2.1.4 Arm's length licensing

2.1.4.1 Licensing: Conveyance of manuals, blueprints, design drawings, or data; provision of technical and managerial assistance.

2.1.4.2 Cross Licensing: (same as above)

2.1.5 Franchising (McDonald's hamburgers in USSR, Holiday Inn Hotels in USA).

2.1.6 Joint venture

2.1.6.1 Equity Joint Venture:

2.1.6.2 Contractual Joint Venture:

2.2 Internal Transfers

2.2.1 Internal information exchange

2.2.1.1 Meetings:

2.2.1.2 Correspondence:

2.2.1.3 Publications:

2.2.2 Cooperative agreement

2.2.3 Arm's length licensing

2.2.4 Internal joint venture

2.2.5 Wholly owned subsidiary

2.3 Time duration

2.3.1 Short term

2.3.2 Long term

2.4 Payment requirement

2.4.1 None

2.4.2 Required

2.5 Network

2.5.1 Two nodes

2.5.2 Multi nodal

2.6 Flow

2.6.1 Unidirectional

- 2.6.2 Bi-directional
- 2.6.3 Multidirectional
- 2.7 Nature of TT
  - 2.7.1 Proprietary
  - 2.7.2 Non-Proprietary

Key 3 **<u>Motivations</u>**

3.1 Economic Factors

- 3.1.1 Cost savings
- 3.1.2 Economic growth
- 3.1.3 Increased earnings in hard currency
- 3.1.4 Generation of foreign exchange (other than hard currency)
- 3.1.5 Improved balance of trade
- 3.1.6 Generation of exports
- 3.1.7 More equitable trade agreements
- 3.1.8 Increased tax revenues
- 3.1.9 Increased sales
- 3.1.10 Taking advantage of. tax and tariff laws
- 3.1.11 Increased royalties
- 3.1.12 Increased sales of technology
- 3.1.13 Improved profitability
- 3.1.14 Improved knowledge/database

3.2 Social Factors

- 3.2.1 Improved quality of life
- 3.2.2 Improved physical health status
- 3.2.3 Increased employment
- 3.2.4 Elevation of social or political status
- 3.2.5 Cultural enrichment, cultural evolution
- 3.2.6 Advancement of society
- 3.2.7 Improved environment through improved/new technology
- 3.2.8 Improved crime-fighting capabilities

3.3 Operational Factors

- 3.3.1 Changes in scale of production or service
- 3.3.2 Improved input material
- 3.3.3 Improved reliability of delivery dates
- 3.3.4 More efficient use of capital and labor
- 3.3.5 Upgraded labor skills
- 3.3.6 Access to alternative sources of supply
- 3.3.7 Increased production capacity
- 3.3.8 Working out trade deals under constraints
- 3.3.9 Reducing risk of over-demand forecast
- 3.3.10 Improved problem solving skills
- 3.3.11 Better purchasing capability

- 3.3.12 Increased mechanization/automation
- 3.3.13 Improved process yields
- 3.3.14 Changing from intermittent to mass flow processes
- 3.3.15 Improved communication capabilities
- 3.3.16 Temporal improvement: ability to do work faster
- 3.3.17 Moving towards standardization
- 3.3.18 Long-term arrangements that feed technology enhancement
- 3.3.19 Designing for market segments
- 3.3.20 Long-term arrangements that feed technology enhancements
- 3.3.21 Larger market for participating multinational companies
- 3.3.22 Improved R&D
- 3.3.23 Vertical and horizontal integration of an industry
- 3.3.24 Improved access to new technology and know-how
- 3.3.25 Exposure to future technical innovations
- 3.3.26 Improved sales opportunities
- 3.3.27 Gaining access to new markets
- 3.3.28 Accelerated introduction of a new product model
- 3.3.29 Opportunity to start new business
- 3.3.30 Productivity gains
- 3.3.31 Improved user satisfaction
- 3.3.32 Improved process innovation
- 3.3.33 Improved quality of conformance
- 3.3.34 Greater degree of computerization resulting in higher accuracy and speed
- 3.3.35 Improved communications (e.g., in satellite technology transfer)
- 3.3.36 Improved Internet or web hosting capabilities

3.4 Strategic Factors

- 3.4.1 Improved product and service quality of design
- 3.4.2 Improved product innovation
- 3.4.3 Entry into international market
- 3.4.4 Improved volume flexibility
- 3.4.5 Improved product/service flexibility
- 3.4.6 Improved managerial flexibility
- 3.4.7 Improved handling customer complaints/ after sales service
- 3.4.8 Improved agility: reduction in idea. to- market time
- 3.4.9 Improved product and service design
- 3.4.10 Improved physical properties of the product
- 3.4.11 Improved performance characteristics of products/services
- 3.4.12 Entry barrier mitigation through Internet
- 3.4.13 Technology management (to respond to changes)
- 3.4.14 Web-enabled services

3.5 Global factors

- 3.5.1 Improved reconnaissance capabilities
- 3.5.2 Improved war/defense capabilities
- 3.5.3 Improved space technological capabilities
- 3.5.4 Improved transportation capabilities
- 3.5.5 Improved political image

3.5.6 Enhanced influence

3.6 Personal Factors
- 3.6.1 Benefits from learning
- 3.6.2 Gratification from teaching/sharing knowledge
- 3.6.3 *Quid pro quo* with colleagues
- 3.6.4 Enhanced status in the discipline/profession
- 3.6.5 Enhanced marketability
- 3.6.6 Increased entrepreneurship skills
- 3.6.7 Improved personal benefits-higher personal income
- 3.6.8 Enhanced travel opportunities

Key 4 **Disciplines and Professions**

4.1: Economics
- 4.1.1 Vertical TT
- 4.1.2 Horizontal TT
- 4.1.3 Physical item TT
- 4.1.4 Information TT
- 4.1.5 Industry– industry TT
- 4.1.6 Sector-sector TT
- 4.1.7 Region-region TT
- 4.1.8 Domestic TT
- 4.1.9 International TT
  - 4.1.9.1 West-East TT
  - 4.1.9.2 North-South TT

4.2: Anthropology Cross-cultural TT
- 4.2.1 Group program
- 4.2.2 Community program
- 4.2.3 Village program
- 4.2.4 Rural program
- 4.2.5 Urban program

4.3: Sociology
- 4.3.1 Diffusion of innovation
- 4.3.2 Adoption of Innovation
- 4.3.3 Diffusion of social technology
- 4.3.4 Diffusion of non-social technology
- 4.3.5 Centralized diffusion
- 4.3.6 Decentralized diffusion

4.4: Management, engineering and other professions
- 4.4.1 Vertical TT
- 4.4.2 Horizontal TT
- 4.4.3 Physical item TT
- 4.4.4 Information TT
- 4.4.5 Industry-industry TT
- 4.4.6 Sector-sector TT
- 4.4.7 Region-region TT
- 4.4.8 Domestic TT
- 4.4.9 International TT
- 4.4.10 Material TT
- 4.4.11 Design TT
- 4.4.12 Capacity TT
- 4.4.13 TT imparts operational capability
- 4.4.14 TT imparts duplicative capability
- 4.4.15 TT imparts innovative capability
- 4.4.16 Market level TT
- 4.4.17 Production level TT
- 4.4.18 R&D level TT
- 4.4.19 Inter-firm TT
- 4.4.20 Intra-firm TT
- 4.4.21 Internal TT
- 4.4.22 Arms-Length TT
- 4.4.23 TT to wholly owned subsidiary
- 4.4.24 TT to joint venture
- 4.4.25 TT to independent company
- 4.4.26 Web-based innovations
- 4.4.27 Web-based customer interactions

Appendix B: Delphi round 1 instructions and template

Instructions

There are 3 parts that include general information, criteria, and mechanisms. Please rate them considering the criteria are used to evaluate the transfer of a high technology from a university setting. For the mechanisms, please rate them according to the most utilised (from your experience) in this case.

Please ensure:

- That you rate every criteria and make comments for each in the justification box
- Make recommendations for the criteria and mechanisms if you feel that some were missed and please give them a rating if so.

Background to the research and the methodology

Research overview

Technology is an important aspect for the growth and development of an economy (Grosse, 1996). Technology comprises the ability to recognise technical problems, develop new concepts as solutions, and the ability to exploit the concepts in an effective way (Winter, 1988; Autio, 1991). Technology by itself does not provide the benefit: in fact, it is the applications of the technology that are important, and it is the technology-transfer process that takes the technology from the laboratory to then be developed into practical products and services (Gressani & Sonneborn, 1993; Spencer, 2001).

Technology Transfer (TT) is a highly expanding field of knowledge that is attracting a great deal of interest from institutions and industries alike (Reisman, 2005). Many firms choose to acquire new technologies and capabilities from other firms in different industries to maintain and enhance their competitiveness (Ranft & Lord, 2002). In fact, the ability of certain technologies to be applied in other disciplines opens the possibility of new and improved products and services. Thus, it is unsurprising that there has been a significant increase in the research on technology transfer conducted to create and modify technology (Autio & Laamanen, 1995). Technology Transfer (TT) usually involves the participation of two parties, a transferor and a transferee, but overall it can involve companies, organisations (including institutions), or even an entire nation and there can be more than one discipline involved (Reisman, 2005).

There are many documented examples of interdisciplinary transfers, some that have been very successful. Take, for example, the case of a satellite developed to send images back to earth. The related technology in this case is Nuclear Magnetic Resonance (NMR), which is used to scan sections of the human body. This can be helpful in the diagnosis of cancer for example. The technology used by NASA to sharpen and enhance images received from space was applied to the one used to scan the human body, and this greatly helped in better diagnosis (Baker, 2000). An example of university to market is that of the University of Florida, which commercialised Gatorade, a sports drink developed by a professor which has earned the university about $94 million from licensing alone (Dibella, 2005).

The above examples demonstrate that technologies can be used in areas other than those for which they were originally intended. As mentioned above, a similar approach will be taken in this research where a technology is studied, and a recommendation will be presented as to how it should be commercialised for use in areas it was not originally intended for.

The evaluation of technology transfer, whether before or after the transfer, is becoming increasingly important. This is especially true for university-related research as it is being recognised as an important source of innovation and economic development, and this is verified by the fact that various industries are entering collaborations with universities and funding academic research (Rahal & Rabelo, 2006). “This dynamic involvement with industry has created new demands on the university to manage these activities so that the institution’s primary goals of education, research, and dissemination of knowledge are not compromised but rather augmented, with conflicts minimized and managed” (COGR, 1999). This justifies the need for a better evaluation tool that can be used to assess potential transfers from universities as well as other sources. Such a tool can be beneficial as it can aid in better decision making as well as the selection of the right technology, and subsequent selection of the most favourable mechanism for commercialisation.

Therefore, the approach adopted in this research will involve using a technology originally developed for radio astronomy, to detect water leakages in pipes that are part of water networks in various infrastructure systems. This is innovative research as it involves an interdisciplinary approach to explore a technology and evaluate its commercial potential.

Template of the Delphi as used on the website

PARTICIPANT INFORMATION for QUT RESEARCH PROJECT

Techology transfer evaluation in the high technology industry: an interdisciplinary perspective

Research Team Contacts	
Laxman Samtani	Dr. Kavoos Mohannak
31388003	31382508
l.samtani@qut.edu.au	k.mohannak@qut.edu.au

Description

This project is being undertaken as part of a PhD project by Laxman.A.Samtani. The project is funded by QUT and CIEAM. The funding body will not have access to the data obtained during the project.

The purpose of this project is to develop an ex-ante evaluation framework for technology transfer stemming from the high technology sector.

The research team requests your assistance because your input will help in shaping the framework by contributing to the necessary criteria and evaluating the commercial potential of a chosen technology.

Participation

Your participation in this project is voluntary. If you do agree to participate, you can withdraw from participation at any time during the project without comment or penalty. Your decision to participate will in no way impact upon your current or future relationship with QUT.

Your participation will involve interviews and questionnaires.

Your participation will involve a face to face interview expected to last for an hour approximately and will be conducted in the workplace. It will be followed by two rounds of questionnaires (Delphi) which will be sent via email.

Expected benefits

This project maybe beneficial by contributing to the criteria that can be used for the evaluation of the transfer of high technologies. It might also have an indirect benefit for you and the researchers.

Risks

There are no risks beyond normal day-to-day living associated with your participation in this project.

Confidentiality

All comments and responses are anonymous and will be treated confidentially. The names of individual persons are not required in any of the responses.

With the participants' consent the interview will be audio recorded for transcription. Only the researcher and supervisors will have access to the recording and anonymity of participants will be protected at all times. The contents of the interview will be verified by the participants.

Consent to Participate

We would like to ask you to sign a written consent form (enclosed) to confirm your agreement to participate.

Questions / further information about the project

Please contact the researcher team members named above to have any questions answered or if you require further information about the project.

Concerns / complaints regarding the conduct of the project

QUT is committed to researcher integrity and the ethical conduct of research projects. However, if you do have any concerns or complaints about the ethical conduct of the project you may contact the QUT Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au. The Research Ethics Officer is not connected with the research project and can facilitate a resolution to your concern in an impartial manner.

CONSENT FORM for QUT RESEARCH PROJECT

"Techology transfer evaluation in the high technology industry: an interdisciplinary perspective"

Statement of consent

By signing below, you are indicating that you:

- have read and understood the information document regarding this project
- have had any questions answered to your satisfaction
- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- agree to participate in the project
- understand that the project will include audio and/or video recording

Name ....

Signature ....

Date ________ / .... / ....

Interview

Title: “Techology transfer evaluation in the high technology industry: an interdisciplinary perspective”

Section A: Professional background information

1. What is your role in your organisation?

2. How long have you been in this position?

3. How many years of experience and expertise do you have in this area?

Section B: Criteria for ex-ante evaluation

Please rate the below criteria based on their importance for the *ex ante* evaluation of technology transfer of high technologies.

List of criteria

Criteria	**1 Least important**	**2**	**3**	**4**	**5 Very important**	**Justification/additional comments**
1.Technological Readiness						
Stage of development of the technology	☐	☐	☐	☐	☐	
Replicability possible	☐	☐	☐	☐	☐	
Technological Complexity (the nature and sophistication of the technology)	☐	☐	☐	☐	☐	
Scope for alternate applications	☐	☐	☐	☐	☐	
Ready or Not (proof of concept in theory)	☐	☐	☐	☐	☐	
Proof of application (in practice)	☐	☐	☐	☐	☐	
Combinatory potential with other technologies	☐	☐	☐	☐	☐	
Prototype availability	☐	☐	☐	☐	☐	
Technical Feasibility	☐	☐	☐	☐	☐	
Potential for further development	☐	☐	☐	☐	☐	
Newness of the technology (uniqueness)	☐	☐	☐	☐	☐	

2. Economic and Market Factors						
Contribution to economic growth/ development	☐	☐	☐	☐	☐	
Potential for attracting required resources for example venture capital	☐	☐	☐	☐	☐	
Potential return on investment	☐	☐	☐	☐	☐	
Financial risk	☐	☐	☐	☐	☐	
Market needs (pull/push)	☐	☐	☐	☐	☐	
Distinguishable competitive advantages	☐	☐	☐	☐	☐	
Market impact	☐	☐	☐	☐	☐	
Level of Competition	☐	☐	☐	☐	☐	
Time to market	☐	☐	☐	☐	☐	
3. Social Benefits						
Knowledge spillover	☐	☐	☐	☐	☐	
Creation of employment	☐	☐	☐	☐	☐	
Enhancement of Social infrastructure/networks	☐	☐	☐	☐	☐	
Environmental impact	☐	☐	☐	☐	☐	
Cost advantages to customers/users	☐	☐	☐	☐	☐	
Brand creation	☐	☐	☐	☐	☐	
Potential for new useful applications	☐	☐	☐	☐	☐	
4. Legal and Regulatory						
Protection of IP rights	☐	☐	☐	☐	☐	
Strengths and scope of patent including geographical extent	☐	☐	☐	☐	☐	
Patent exclusitivity	☐	☐	☐	☐	☐	
New areas of application (not infringing any other patents)	☐	☐	☐	☐	☐	
Need for complimentary technologies (availability of licenses for example to use other technologies)	☐	☐	☐	☐	☐	
Freedom to operate, for example, open innovation	☐	☐	☐	☐	☐	

Would you like to add any other criteria? If yes, please give your reasons and rate them:

Section C: Mechanisms of transfer

Please rate the mechanisms of transfer (from universities).

Criteria	1 Least important	2	3	4	5 Very important	Justification /additional comments
Licensing	☐	☐	☐	☐	☐	
Spin-off	☐	☐	☐	☐	☐	
Joint venture	☐	☐	☐	☐	☐	
Trade sales	☐	☐	☐	☐	☐	
Collaborations	☐	☐	☐	☐	☐	
IP assignment	☐	☐	☐	☐	☐	

Would you like to add any other mechanisms? If yes, please your give reasons and rate them:

Appendix C: Delphi round 2 instructions

Instructions for the second round of the Delphi

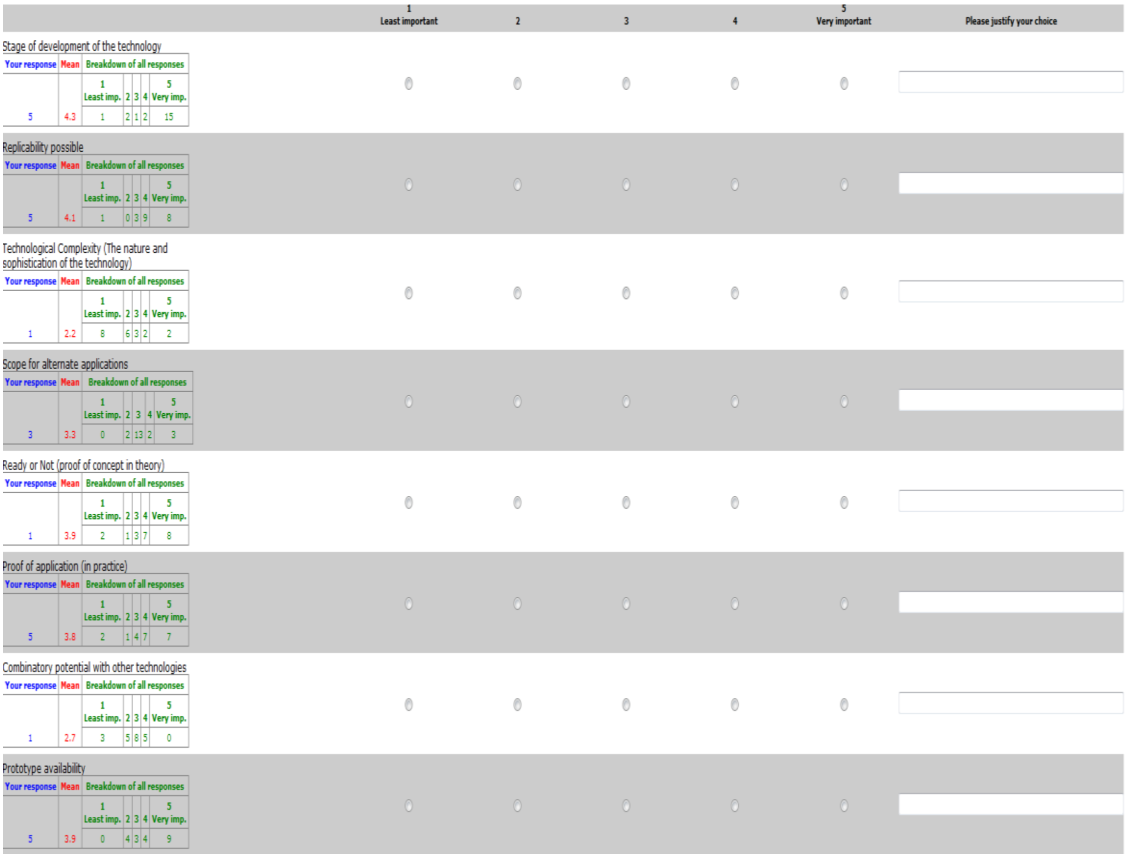
Please refer to the screenshot below and carefully read the instructions.

- Once you enter the password and your name, you will find a similar layout as to what was sent previously. In addition, on the far left hand side *(refer to screenshot),* you will see your previous ratings *(in blue)* as well as the mean of all responses (a total of 21 experts) *(in red)* and a breakdown showing how many experts gave a certain rating for each criteria *(in green).*

- I would be grateful if you could take some time to look at the results, taking particular care to compare your own previous ratings to those provided by other experts. After having compared the ratings, please rate the criteria once again. In light of the others' ratings, you may choose to change your rating, or keep it the same. If your **previous rating was different** from the majority of previous ratings, and you **decide to KEEP your rating**, then you need to **provide a reason** for maintaining your previous rating.

- On the other hand, if your **previous rating was different** from the majority of previous ratings, and you **decide to CHANGE your rating toward the majority rating**, then you do not need to provide a reason for maintaining your previous rating. For example, if for a criterion your previous response was a rating of 2 and the mean is 4.5, and you choose to change your rating closer to the mean, then you do not need to justify your rating for that criterion. But if you choose to keep your previous results, then please justify why you chose to do so. If your rating was consistent with the majority, and you are happy to maintain that current rating, then you do not need to provide a reason.

- The idea is to either agree with the majority or to stay with your initial rating. The same applies to the mechanisms of transfer. **Please justify** if you decide not to go with the modal score as this contributes to the findings. There will also be a section in which to enter any additional comments.



Criterion	Your response	Mean	Breakdown of all responses: 1 Least imp.	2	3	4	5 Very imp.	1 Least important	2	3	4	5 Very important	Please justify your choice
Stage of development of the technology	5	4.3	1	2	1	2	15						
Replicability possible	5	4.1	1	0	3	9	8						
Technological Complexity (The nature and sophistication of the technology)	1	2.2	8	6	3	2	2						
Scope for alternate applications	3	3.3	0	2	13	2	3						
Ready or Not (proof of concept in theory)	1	3.9	2	1	3	7	8						
Proof of application (in practice)	5	3.8	2	1	4	7	7						
Combinatory potential with other technologies	1	2.7	3	5	8	5	0						
Prototype availability	5	3.9	0	4	3	4	9						

Screenshot of the questionnaire

- **Please note** that some criteria were left unrated in the previous round. In this case you will not receive a previous rating for those criteria but please rate them in this round and do not hesitate to contact me if you have any queries about them. Thank you!

Appendix D: Evaluation of the technology transfer potential

Instructions and Template

PARTICIPANT INFORMATION for QUT RESEARCH PROJECT

Techology transfer evaluation in the high technology industry: an interdisciplinary perspective

Research Team Contacts	
Laxman Samtani 31388003 l.samtani@qut.edu.au	Dr. Kavoos Mohannak 31382508 k.mohannak@qut.edu.au

Description

This project is being undertaken as part of a PhD project by Laxman.A.Samtani. The project is funded by QUT and CIEAM. The funding body will not have access to the data obtained during the project.

The purpose of this project is to develop an ex-ante evaluation framework for technology transfer stemming from the high technology sector.

The research team requests your assistance because your input will help in shaping the framework evaluating the commercial potential of a chosen technology.

Participation

Your participation in this project is voluntary. If you do agree to participate, you can withdraw from participation at any time during the project without comment or penalty. Your decision to participate will in no way impact upon your current or future relationship with QUT.

Your participation will involve an online questionnaire.

Expected benefits

This project maybe beneficial by contributing to the criteria that can be used for the evaluation of the transfer of high technologies. It might also have an indirect benefit for you and the researchers.

Risks

There are no risks beyond normal day-to-day living associated with your participation in this project.

Confidentiality

All comments and responses are anonymous and will be treated confidentially.

Only the researcher and supervisors will have access to data and anonymity of participants will be protected at all times.

Consent to Participate

We would like to ask you to agree to the consent form (enclosed) to confirm your agreement to participate.

Questions / further information about the project

Please contact the researcher team members named above to have any questions answered or if you require further information about the project.

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CONSENT FORM for QUT RESEARCH PROJECT

"Techology transfer evaluation in the high technology industry: an interdisciplinary perspective"

Statement of consent

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- understand that if you have any additional questions you can contact the research team
- understand that you are free to withdraw at any time, without comment or penalty
- understand that you can contact the Research Ethics Officer on 3138 2340 or ethicscontact@qut.edu.au if you have concerns about the ethical conduct of the project
- agree to participate in the project
- understand that the project will include audio and/or video recording

Name ....

Signature ....

Date ________ / .... / ....

The information you receive with this survey in the briefing document entitled "Information for the questionnaire" (the Briefing Document) is of unique value to QUT, CIEAM and the author and QUT, CIEAM and the author will be prejudiced by any unauthorised use or disclosure of the information and may suffer financial or other loss as a result of unauthorised disclosure of the information.

Information for the questionnaire

Please take some time to go through the provided information first and then attempt the online questionnaire (link and password will be provided via email). For any queries, please contact Laxman Samtani by emailing l.samtani@qut.edu.au.

1. General information about the research

Objectives of the PhD

- Develop a set of criteria for evaluating technology transfer (TT) process in the high technology sector which can also be used across disciplines
- Evaluate the commercial potential of an emerging technology using the criteria
- Propose a suitable TT mechanism for commercialisation following the evaluation

Technology Background

- There are many documented examples of cross-disciplinary transfers, some that have been very successful
- In radioastronomy, radio signals from space are collected and focused by metal dishes. In some cases, an array of dishes is used to receive signals from a common source
- The signals are time shifted so that they are aligned when processed by a correlator. The rationale behind a correlator is that the scientific signal will be common to each receiver whereas the random noise will not. Correlation involves multiplying two time-shifted signals together
- Originally, hardware versions of correlators have been used, but a software version was developed recently
- The technique can be used to determine the location of a fluid leak in a pipe (i.e. liquid or gas) if microphones or accelerometers are set up.

Achievements of the research till present at QUT

- A prototype device has been constructed for recording sound from four microphones simultaneously and calculating the difference in the arrival time of the sound at each microphone (i.e. the phase difference). The development of this device was inspired by software correlators developed relatively recently for analysing radio astronomy signals

- A programme was written in Scilab (a numerical computational package) to cross correlate the results obtained from the experiments by first using different sound sources; for example, a clap and then doing some experiments on a pipe with a created leak
- Results indicate that the technique if further developed can result in a cheaper product. Additionally, it is also possible that further R & D can result in a more efficient, accurate, and faster technique than those available currently in the market
- Criteria were obtained from corresponding literature
- A Delphi study (the Delphi method was developed during the early 1950s and is based on a structured process for collecting and distilling knowledge from experts in several rounds, combined with controlled opinion feedback (Roest, 2002)) was conducted using experts with commercial knowledge to refine these criteria as well important mechanisms (the refined criteria are the ones included in the questionnaire).

2. Technology specific information

The information provided is at a high level due to confidentiality, therefore algorithms and circuit layout are not provided.

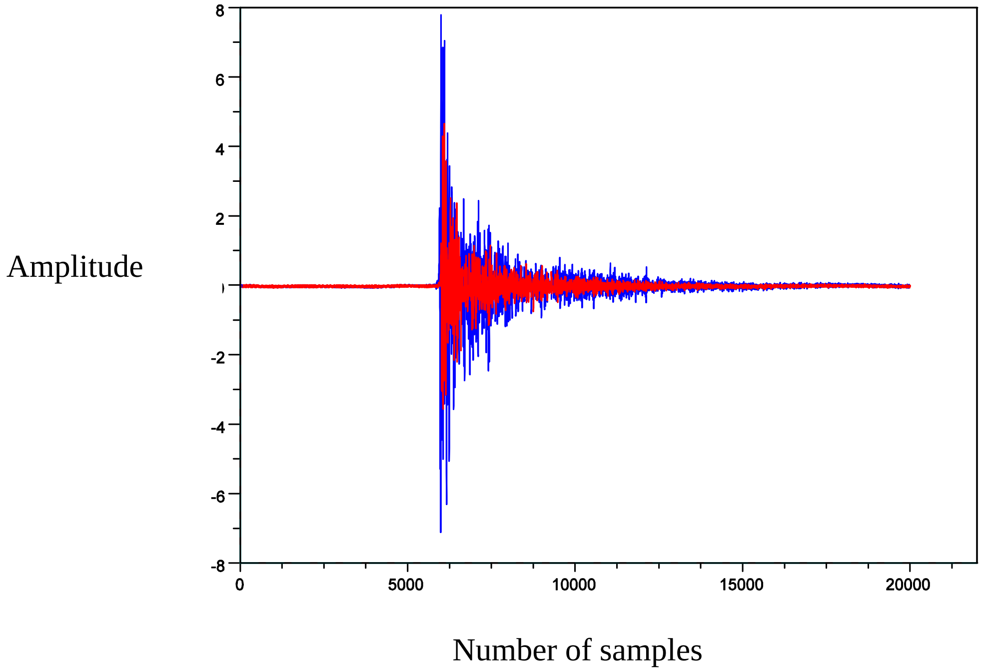
Intellectual Property

- No Patent protection filed for as of yet
- Protection can be obtained for the algorithms written using the software as well as the technique of combining hardware and software to collect and analyse data.

Potential markets

- Water industry for residential and commercial water transportation pipes
- Further research and development of the correlation technique can have uses in areas such as security and tumour growth detection, amongst others
- The technology can also be combined with imaging technologies to convert acoustic signals to visual output

Additionally, an example of the results is included below:



The acoustic signal of a clap is shown in the above figure. The blue trace corresponds to microphone 1 and the red trace to microphone 2. Notice that the amplitude of channel 2 is slightly smaller than channel 1, which is to be expected as the clap was closest to microphone 1.

Please enter your name

Section A: Professional background information

1. What is your role in your organisation?
2. How long have you been in this position?
3. How many years of experience and expertise do you have in technology transfer and commercialisation?

Section B: Evaluation criteria

4. Please read the provided information on the technology (sent separately)
5. Using the criteria below, please rate the commercial potential of the technology where 1 is the lowest score and 7 is the highest.

List of criteria

Criteria	1	2	3	4	5	6	7
1.Technological Readiness							
Stage of development of the technology	☐	☐	☐	☐	☐	☐	☐
Replicability possible	☐	☐	☐	☐	☐	☐	☐
Scope for alternate applications	☐	☐	☐	☐	☐	☐	☐
Ready or Not (proof of concept in theory)	☐	☐	☐	☐	☐	☐	☐
Proof of application (in practice)	☐	☐	☐	☐	☐	☐	☐
Involvement of inventor	☐	☐	☐	☐	☐	☐	☐
Prototype availability	☐	☐	☐	☐	☐	☐	☐
Technical Feasibility	☐	☐	☐	☐	☐	☐	☐
Potential for further development	☐	☐	☐	☐	☐	☐	☐
Newness of the technology (uniqueness)	☐	☐	☐	☐	☐	☐	☐
2. Economic and Market Factors							
Potential for attracting required resources for example venture capital	☐	☐	☐	☐	☐	☐	☐
Potential return on investment	☐	☐	☐	☐	☐	☐	☐
Financial risk	☐	☐	☐	☐	☐	☐	☐
Market needs (pull/push)	☐	☐	☐	☐	☐	☐	☐
Distinguishable competitive advantages	☐	☐	☐	☐	☐	☐	☐
Market impact	☐	☐	☐	☐	☐	☐	☐
Level of Competition	☐	☐	☐	☐	☐	☐	☐
Time to market	☐	☐	☐	☐	☐	☐	☐
3. Social Benefits							
Environmental impact	☐	☐	☐	☐	☐	☐	☐
Cost advantages to customers/users	☐	☐	☐	☐	☐	☐	☐
Brand creation	☐	☐	☐	☐	☐	☐	☐
Potential for new useful applications	☐	☐	☐	☐	☐	☐	☐
4. Legal and Regulatory							
Protection of IP rights	☐	☐	☐	☐	☐	☐	☐
Strengths and scope of patent including geographical extent	☐	☐	☐	☐	☐	☐	☐
Patent exclusitivity	☐	☐	☐	☐	☐	☐	☐
New areas of application (not infringing any other patents)	☐	☐	☐	☐	☐	☐	☐
Need for complimentary technologies (availability of licenses, for example to use other technologies)	☐	☐	☐	☐	☐	☐	☐
Freedom to operate, for example, open innovation	☐	☐	☐	☐	☐	☐	☐

Section C: Mechanisms of transfer

What would be, according to you, the most suitable choice of mechanism for the transfer of this particular technology? Please select from the options below, 1 being the least suitable and 7 being highly suitable.

Mechanism	**1 Least suitable**	**2**	**3**	**4**	**5**	**6**	**7 Highly suitable**
Licensing	☐	☐	☐	☐	☐	☐	☐
Spin-off	☐	☐	☐	☐	☐	☐	☐
Consulting	☐	☐	☐	☐	☐	☐	☐
Collaborations	☐	☐	☐	☐	☐	☐	☐
IP assignment	☐	☐	☐	☐	☐	☐	☐

Section D: Overall recommendations and additional comments

Based on the provided information and evaluation, where do you think the technology stands in terms of commercialisibility?

Additional comments