CRITICAL SUCCESS FACTORS (CSFs) FRAMEWORK FOR NANOTECHNOLOGY INDUSTRY DEVELOPMENT IN MALAYSIA

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ABSTRACT

Malaysia focuses on several industrial areas for rapid development, through selective cores for development in all Malaysia Plans. Nanotechnology received governmental support with its first inclusion in 2001 under the Eighth Malaysia Plan (2001-2005). However, its development of nanotechnology has its issues, such as slow development, lack of collaboration, etc. Many industry-based reports highlighted the need for more comprehensive effort to facilitate development. This study aimed at developing a framework of critical success factors (CSFs) for effective nanotechnology development in the Malaysian nanotechnology industry. This research has identified problems from available resources related to current practice and knowledge in the nanotechnology industry, followed by identification of best practices, tools, and principles toward achieving better nanotechnology development. The Modified Delphi Technique was employed with two iterations, beginning with data collection interviews involving nanotechnology players in the industry, and ending with validation interviews with Malaysian nanotechnology bodies/agencies. In between the two interview rounds, thematic analysis of the data collection interviews was combined with factors identified in the literature review to develop a framework of CSFs that was verified in the validation interviews. Resource Based View (RBV) theory and Diffusion of Innovation (DOI) theory were identified as underpinning theories to explain the findings. The final framework highlighted four element factors, namely human resource and infrastructure (as explained by RBV), and consumer awareness and regulatory framework (as explained by DOI). This framework can be used as a term of reference for both Malaysian nanotechnology practitioners and academicians toward achieving greater nanotechnology development in Malaysia.

ABSTRAK

Malaysia memberi tumpuan kepada beberapa kawasan perindustrian untuk pembangunan pesat, melalui teras terpilih untuk pembangunan dalam semua Rancangan Malaysia. Nanoteknologi menerima sokongan kerajaan dengan kemasukan pertama pada tahun 2001 di bawah Rancangan Malaysia Kelapan (2001-2005). Walaubagaimanapun, perkembangan nanoteknologi mempunyai isu tersendiri, seperti perkembangan lambat, kekurangan kerjasama, dan lain-lain. Banyak laporan berasaskan industri menonjolkan keperluan untuk usaha yang lebih komprehensif bagi memudahkan pembangunan. Kajian ini bertujuan untuk membangunkan rangka kerja faktor kejayaan kritikal (CSFs) untuk pembangunan nanoteknologi berkesan dalam industri nanoteknologi di Malaysia. Kajian ini telah mengenal pasti masalah daripada sumber-sumber yang ada berkaitan dengan amalan dan pengetahuan semasa dalam industri nanoteknologi, diikuti dengan mengenal pasti amalan terbaik, alat, dan prinsip untuk mencapai pembangunan nanoteknologi yang lebih berkesan. Teknik Delphi Diubahsuai digunakan dengan dua ulangan, bermula dengan temu bual pengumpulan data yang melibatkan pemain nanoteknologi dalam industri, dan berakhir dengan temu bual pengesahan dengan badan/agensi nanoteknologi Malaysia. Di antara dua pusingan temu bual, analisis tematik temu bual pengumpulan data digabungkan dengan faktor-faktor yang dikenal pasti dalam kajian literatur untuk membangunkan rangka kerja CSF yang telah disahkan dalam temu bual pengesahan. Teori Pandangan Berasaskan Sumber (RBV) dan teori Difusi Inovasi (DOI) telah dikenalpasti sebagai teori pendukung untuk menerangkan hasil kajian. Kerangka akhir ini menyerlahkan empat faktor, iaitu sumber manusia dan infrastruktur (yang diterangkan oleh RBV), dan kesedaran pengguna dan rangka kerja pengaturan (yang diterangkan oleh DOI). Rangka kerja ini boleh diguna sebagai terma rujukan untuk kedua-dua pengamal dan ahli akademik nanoteknologi Malaysia ke arah mencapai pembangunan nanoteknologi yang lebih baik di Malaysia.

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ABBREVIATIONS

A3G	Applied Algebra and Analysis Group
AMNL	Advanced Materials and Nanotechnology Laboratory
AMREC	Advanced Materials Research Centre
CNPAM	Centre for Nanotechnology, Precision and Advanced Materials
CST	Catalytic Science and Technology
DOI	Diffusion of Innovation
FDI	Foreign Direct Investment
GDP	Gross Domestic Product
IIS-UTM	Nanochem and Nanophys Lab
INEE	Institute of Nano Electronic Engineering
ISC	Industrial and Scientific Computation
ICT	Information Communication Technology
IT	Information Technology
MINE	Material Innovations and Nanoelectronics Research Group
MSIG	Mathematics Statistic Industrial Group
NAMBAR	Nano & Mesoporous Materials for Biological Applications
NANOCEN	Centre for Research in Nanotechnology and Catalysis
NNI	USA National Nanotechnology Initiative
NoMPTec	Novel Materials and Process Materials
PCAs	Program Component Areas
QuaSR	Quantum Nanostructures Research
R&D	Research and Development
RBV	Resource Based View
SCM	Supply Chain Management
SCNI	Scientific Computational and Industrial
TCM	Theoretical and Computational Modeling for Complex Systems
TM	Technology Management
UKM	Universiti Kebangsaan Malaysia
UM	Universiti Malaya
UPM	Universiti Putra Malaysia
USM	Universiti Sains Malaysia
UTP	Universiti Teknologi Petronas

CHAPTER 1

INTRODUCTION TO THE RESEARCH

1.1 Introduction

This chapter contains eight parts, which are: (i) background of the study, (ii) problem statement, (iii) research questions, (iv) research objectives, (v) significance of the study, (vi) scope of the research, (vii) definition of terms, and (viii) organisation of thesis.

1.2 Background of the Study

The importance of developing new technologies via various methods and strategies is no longer a subject of debate, since the very technology itself has been observed time and time again to be drivers of civilisations (Sueb, 2013; Arber, 2009). Moreover, technologies that have the potential of life-changing impact, such as nanotechnology and other disruptive technologies, need to be developed carefully in order for it to benefit society (Manyika, Chui, Bughin, Dobbs, Bisson, & Marrs, 2013; Ramsden, 2008).

However since the initial drive by the government to push nanotechnology into the forefront of scientific research in 2001 (Hashim, Nadia, & Salleh, 2009), many years has passed without witnessing significant societal-wide impact, which it has been touted to be able to do (Manyika et al., 2013). This research, therefore, investigates how to integrate industry players to work together more efficiently and effectively in the Malaysian nanotechnology industry. As initially stated, this chapter introduces the research, where it describes the research background, frames the problem of the study while providing the study justification to rationalise the need for this research, established the key research objectives to assist in guiding this research to its goals, and last but not least, outlines the chapters in this dissertation.

Meanwhile, nanotechnology has become a buzzword in recent years, to the point where industry players have predicted the nanotechnology business to be capable of rivalling the biotechnology industry and even perhaps forecasted to be at par with information communication technology (ICT) by 2014 (Hebert, 2004). It is said that nanotechnology is the next “disruptive technology”, meaning that it will influence across industries and affect our very lives, similar to previous technologies like “atomic” was for the 1950s, “micro” was for the 1980s, and “.com” was for the 1990s (Tan, 2010). Its forecasted impact is slowly blurring out the lines that separate reality with fantasy, whereby certain technologies that were only imaginary several decades ago, have now been physically demonstrated in laboratories today and even commercialised, such as spill proof clothing, golf balls that have less wobble and fly straighter, and air purifying pavements (Mongillo, 2007).

According to Thomas (2006), on the world scene, the European Union (EU), Japan, and the United States (US) are the leading investors of nanotechnology, while China comes second to the US in purchasing nanotechnology research. Thomas also reported that, at that time, about 60 countries have already initiated some form of national nanotechnology research programmes, half of which are located in Europe. The US has spent more than US$5 billion on research funding since 2001, and thus making it the next big publicly funded scientific endeavour since the Apollo Project moon-landing (ETC Group, 2005). The ETC Group also reported that globally, both public and private sector nanotechnology investment was estimated at US$8.6 billion in 2004 alone.

Such funding by the major power player countries clearly shows the confidence of these countries in this technology, which is estimated to be yielding US$1 trillion per year by 2015, of nanotechnology related products that would need approximately 2 million workers to support the industry (National Nanotechnology Initiative - NNI, n.d.). The ETC Group (2005) and Thomas (2006) both reported that the US National Science Foundation (NSF) has predicted the nanotechnology market to reach US$1 trillion even earlier, by 2011 or 2012. Lux Research puts nanotechnology as being capable of even more within more or less the same timeframe; US$2.9 trillion by 2014 (Berger, 2007). As with other predictions and forecasts by prominent players in the industry, nanotechnology shows much promise.

However, with the surrounding hype and champions of nanotechnology, what really is nanotechnology? The general public would view nanotechnology as a completely new area or field of study (Reid, n.d.), but it is actually a question of studying the convergence of various fields at a nano-scale. Burke (2009, p. 32) had stated nanotechnology to be "a general term for the ability to very specifically manipulate matter at the atomic and molecular scale and create products that were heretofore impossible". Thus, this would give birth to a plethora of theoretically viable nanotechnology products and applications that could possibly exist sooner than expected. However, it must be pointed out here that although the research into the materials and applications of these materials is paramount to the growth of this promising industry, there must also be research into the management of this industry in order for it to flourish and aid in the betterment of mankind.

1.3 Problem Statement

Not wishing to take the wait-and-see approach, the Malaysian government has taken up the challenge of exploring the vast potentials of nanotechnology by launching its own National

Nanotechnology Initiative on 4 July 2005 in Johor Bahru, Malaysia (Asia Pacific Nanotech Weekly, 2005). In order to remain competitive, Malaysia has to have its own nanotechnology policies, as well as strategic plan to manage this viable technology, as extensively stressed by the then Deputy Prime Minister, now the Prime Minister, in several of his public appearances regarding the research and management of nanotechnology.

Hashim et al. (2009) had provided the current outlook of the nanotechnology industry in Malaysia through their research. The study had concluded that the Malaysian scenario required much work in the management of such high technology. Some of the highlighted problems within the nanotechnology industry include lack of linkages between various projects, no central facility, there is no definitive plan to realise and develop the nanotechnology industry, there is no clear overall road-map for nanotechnology research, and lack of effort in promoting awareness of nanotechnology.

Furthermore, Hashim et al. (2009) also revealed a Strength, Weakness, Opportunity, and Threat (SWOT) analysis of the nanotechnology industry in Malaysia, as formulated by the Malaysian Industry-Government Group for High Technology (MIGHT), which is placed under the supervision of the Economic Planning Unit (EPU) of the Malaysian Prime Minister's Department. Some of the weaknesses identified were, no dedicated policy for nanotechnology, need for human resource planning, lack of private sector investment and participation, lack of facilities, and lack of world-class companies to raise the standard.

Meanwhile, the report by the Asian Technology Information Program (ATIP) had identified the infrastructure components for supporting the nanotechnology industry, namely R&D infrastructure, human resource, industry infrastructure, and industry readiness (ATIP, 2006).

From the comparison performed in 2006, it was highlighted that the Malaysian nanotechnology industry still requires more development in R&D infrastructure and human resource development, as compared to the other ANF countries; ANF being a network organisation that is supported by 13 countries, including Australia, China, Hong Kong, India, Indonesia, Korea, Japan, Malaysia, New Zealand, Singapore, Taiwan, Thailand, and Vietnam.

From the perspective of utilising a model for application in the industry, Phaal, Farrukh, and Probert (2001) had concluded that few companies appeared to actually manage technology explicitly in terms of a framework. They also established that even though a framework is useful for application in the industry, its application can be challenging.

Thus, based on the preliminary review of material, this researcher has been compelled to look into the issues surrounding the development of the Malaysian nanotechnology industry (Bürgi & Pradeep, 2006; Hipkin, 2004; Ghazinoory & Farazkish, 2010) in order to manage the development of this potentially viable industry to become more focused and successful by identifying the factors which may be of influence in facilitating the growth of this industry.

As such, this research effort shall attempt to look into the barriers and challenges facing the nanotechnology industry, by extracting information from industry players as well as the authoritative bodies that regulate and develop this industry. This research also had attempted to provide viable recommendations in order to address these problems identified by the players, and confirmed by the governing bodies, in the industry.

1.4 Research Questions

i. What is the existing scenario of the nanotechnology industry, particularly in current and future outlook as well as barriers to its development in Malaysia?

ii. What are the critical success factors (CSFs) required for successful nanotechnology development in Malaysian nanotechnology industry?

iii. How to develop a framework of critical success factors (CSFs) for nanotechnology development in Malaysian nanotechnology industry?

iv. How to validate these critical success factors (CSFs) for nanotechnology development in Malaysian nanotechnology industry?

1.5 Research Objectives

The specific objectives of this research were:

i. to investigate the existing scenario of the nanotechnology industry, particularly in current and future outlook as well as its barriers to implementation in the Malaysian industry;

ii. to identify the critical success factors (CSFs) associated with nanotechnology development in the Malaysian nanotechnology industry;

iii. to develop a framework of critical success factors (CSFs) for nanotechnology development in the Malaysian nanotechnology industry; and

iv. to validate the critical success factors (CSFs) for nanotechnology industry development in the Malaysian nanotechnology industry.

1.6 Significance of the Study

In this context, this research aims to develop a framework of critical success factors (CSFs) for effective nanotechnology development in Malaysian nanotechnology industry. It will also determine the applicability of the proposed framework in a Malaysian setting. Therefore, the expected contributions to knowledge from this research are as follows.

1) As the nanotechnology industry is an integral part of the national development process, it needs to be explored and documented to ensure effective development and management. Looking at it from a Malaysian perspective will make it the first such study to be investigated.
2) This research has compiled the definition, chronology of adoption (history), drivers and barriers in the Malaysian nanotechnology industry for future reference. This compilation is one of the strategies to improve the perceptions of nanotechnology industry through the extension of a range of existing theories surrounding the issues of Malaysian nanotechnology industry.
3) The validated and confirmed critical success factors (CSFs) reflecting the development of a framework for effective nanotechnology industry development to be applied to the Malaysian nanotechnology industry could also be used for education, training, and practice for either academia or practitioners.

The following section will briefly discuss the overall research structure of this dissertation.

1.7 Scope of the Research

This research has selected Malaysian nanotechnology stakeholders which include nanotechnology companies that develop and sell nanotechnology-based products, as well as the organisations responsible for the monitoring and development of the nanotechnology industry. This was done based on the importance of these nanotechnology stakeholders and the roles that they play in maintaining and sustaining the nanotechnology industry. According to Osman (2013), “delivering a new approach requires action from … stakeholders that engage in" the industry, thus it was deemed necessary to involve these types of respondents in this study.

In order to achieve a valid result, and meet the established objectives of this study, this research has applied a qualitative approach where the Modified Delphi Technique was employed to extract important information through a series of face-to-face interviews with the nanotechnology industry players during the first iteration. This information was then codified and analysed using thematic analysis in order to identify the main CSFs that are pertinent for nanotechnology development to thrive. During the second iteration, these identified issues and barriers were then validated and confirmed by representatives from research institutions and regulatory bodies to yield the final CSF framework for the development of the nanotechnology industry.

1.8 Definition of Terms

i. Nanotechnology

The latest accepted definition of nanotechnology was by the National Nanotechnology Initiative, as was stated in Bayda, Adeel, Tuccinardi, Cordani, and Rizzolio (2020), "nanotechnology is the understanding and control of matter at the nano-scale, at dimensions between approximately 1 and 100 nanometers, where unique phenomena enable novel applications".

Encompassing nano-scale science, engineering, and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale. Matter such as gases, liquids, and solids can exhibit unusual physical, chemical, and biological properties at the nano-scale, differing in important ways from the properties of bulk materials and single atoms or molecules. Some nanostructured materials are stronger or have different magnetic properties compared to other forms or sizes of the same material. Others are better at conducting heat or electricity. They may become more chemically reactive or reflect light better or change colour as their size or structure is altered.

ii. Nanotechnology Industry

According to Ramsden (2013), "the nanotechnology industry is the (predominantly manufacturing) industry based on nanotechnology". Nanotechnology is applied in a wide range of industry sectors in Malaysia, but mainly in the manufacturing sector with application in other industries. According to AZoNano (2015), main players are companies involved in nano-photocatalyst energy and environmental engineering, and research and design (R&D) in poultry, agro-based products, water treatment, and others.

iii. Critical Success Factors

According to Osman (2013), critical success factors can be defined as, "the term for an element that is necessary for an organisation to achieve its objectives. It is a critical factor requires for ensuring the success of an organisation". Raravi, Bagodi, and Mench (2013), further added that these elements, "could affect the performance in a either positive or negative direction".

1.9 Organisation of Dissertation

This dissertation is structured into five chapters, as outlined below.

1) Chapter 1 presents the introduction to thesis. This first chapter covers the introduction, background, problem statement, research questions, research objectives, significance, scope, and organisation of the thesis.

2) Chapter 2 presents the literature review on the topic of interest, namely nanotechnology, nanotechnology industry in Malaysia, and the challenges faced by the nanotechnology industry. This is followed by a literature review on critical success factors, and underpinning theory.

3) Chapter 3 discusses the research methodology. This chapter includes the explanation and justification of the decisions that have been made in the selection of research methodology for framework development and validation process. This chapter elaborates on the methodological framework, data sources, interview process, data analysis, and framework definition.

4) Chapter 4 presents the research primary findings gathered via the data collection interviews involving Malaysian nanotechnology practitioners. This consisted of results from the data collection interview, framework development process, and validation interviews. The chapter includes the identification of all relevant CSFs for the development of effective nanotechnology industry development framework in the Malaysian nanotechnology industry.

5) Chapter 5 presents and discusses the development of a framework of critical success factors (CSFs) for effective nanotechnology industry development in Malaysian nanotechnology industry. It is based on the triangulation of the key findings of data collection interviews in Chapter 4, with the findings of the literature review in Chapter 2.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter describes nanotechnology, which has been highlighted as the next emerging technology that has the capability of giving a huge impact on our daily lives through the invention or reinvention of new and enhanced products, thus is has been dubbed as being the next potentially disruptive technology. Nanotechnology has become a new industrial revolution and many countries are investing heavily in this technology to maintain their market competitiveness. Since this is new yet growing and emerging, there is still a scarcity of research in this area, particularly in developing countries like Malaysia, which is the driving factor behind this research.

2.2 Nanotechnology

Nanotechnology has caused a stir in worldwide because of its potential. Big countries has invested in nanotechnology and taken a full concern over the development of nanotechnology. Malaysia has to have its own nanotechnology policies and initiative as well as strategic plan to manage the technology, as extensively stressed by the Deputy Prime Minister in his several meetings about the management of nanotechnology. To sustain the technology, major agencies are also needed to guide the direction of nanotechnology industry development. Currently, Malaysia is lack behind in this aspect because of the technology is still new to the Malaysian expertise. The Ministry of Science, Technology and Innovation (MOSTI) oversees the nanotechnology development in this country, and particularly to develop policies, initiatives and strategic plans for nanotechnology.

According to Malaysia's S&T Policy for the 21st Century, to sustain technology support for Malaysian industries, there is a need to develop a secure knowledge base in key technology areas such as nanotechnology. To this extent, the relatively small numbers of applications of nanotechnologies that have made it through the industrial application represent revolutionary rather than evolutionary advances (Kearns, Taylor, & Hull, 2005; Putranto et al., 2003). Current applications are mainly in the areas of determining the properties materials, the production of chemicals, precision manufacturing and computing. Food industry for instance, is also interested in nanotechnology such as Kraft Foods and Nestle in packaging, and food safety and processing and amongst others (Dunford, 2017). The application of nanotechnology such as precision farming and smart delivery system has major impact in the industry. Precision farming makes use of computers, global satellite positioning systems and remote sensing devices. It helps reduce agricultural waste and minimise the environmental pollution. Consequently, accurate and comprehensive management of nanotechnology at micro (organisational), semi micro (regulatory) and macro (economy) levels are virtually impossible, especially in high-tech regulated sectors and developing economies. However, based on the previous studies (Bürgi & Pradeep, 2006; Hipkin, 2004) there is a need of research to look into the management aspects of nanotechnology in order to understand more about this area, to ensure a sustainable competitive advantage of the nanotechnology industry.

2.2.1 History of Nanotechnology

The history of this promising technology which has wide implications on society can be summarised in the following timeline. The first description of ideas that formed the basis of nanotechnology was described by Feynman (1960) in his after-dinner talk describing molecular machines building with atomic precision. He described a field, in which little has been done, but in which an enormous amount can be done in principle. This field is not quite the same as the other fields in physics in that it will not contribute much of fundamental physics, but it is more like solid-state physics in the sense that it might tell much of great interest about strange phenomena that occur in complex situations. Furthermore, a point that is most important is that it would have an enormous number of technical applications in other fields. He further describes of the need to miniaturise components even further, which needs equipment capable of viewing and controlling these components at a very small scale. He also touched upon the biological system and other applications of nanotechnology, such as in lubrication and computing.

Nanotechnology is one of the more difficult nanowords to pin down and define fully in order for it to be accepted by all. Taniguchi (1974) first used this term to refer to the "production technology to get the extra high accuracy and ultra-fine dimensions, i.e. the preciseness and fineness on the order of 1 nm (nanometer), 10^{-9} meter in length". His paper described the process of on ion-sputter machining.

Due to an outgrowth of studies of naturally-occurring molecular machines, Eric Drexler (as an undergraduate student) originated the official and essential concept of nanotechnology at MIT. He has been labelled as the "undisputed godfather of nanotechnology" with the idea that was not imaginable at the time. However, being an undergraduate student with grand and controversial ideas, Drexler had faced strong criticisms and opposition by his peers in other fields, who viewed his idea as being impossible to implement. This field of opposition included a Nobel Prize winner, and this made Drexler an eventual outcast as his idea was taken up by the more prominent scientists in the various scientific fields that had taken up the challenge of managing nanotechnology (Regis, 2004).

He came up with the mind-boggling concept in which he had imagined a sea of minute robots that are able to quickly move and precisely position molecules so that they can produce virtually any substance or material by using ordinary ingredients in a matter of hours. This vision inspired a generation of scientists, chemists, computer scientists, and engineers to shift their focus to science at the nano-scale.

However, only in 1981 did he write his first technical paper on molecular nanotechnology engineering as an inspiration for building a machine using atomic precision (Drexler, 1981). His dream and vision were approaching closer to reality with the invention of STM (Scanning Tunnelling Microscopy) by Gerd Binnig and Heinrich Rohrer in the same year, which was the first machine, developed using nanotechnology in its construction (Binnig & Rohrer, 1986).

STM allows scientists to see and manipulate individual atoms. More specifically, it is widely used in both industrial and fundamental research to obtain atomic-scale images of metal surfaces. It provides a three-dimensional profile of the surface which is very useful for characterising surface roughness, observing surface defects, and determining the size and conformation of molecules and aggregates on the surface. Several other recently developed scanning microscopes also use the scanning technology developed for the STM. The STM inventors were then recognised for the efforts when they received the Nobel Prize in Physics in 1986 (OECD, 2010).

A precursor instrument, the topografiner, was invented by Russell Young and colleagues between 1965 and 1971 (Young, Ward, & Scire, 1972) at the National Bureau of Standards (NBS) (currently the National Institute of Standards and Technology – NIST).

As narrated by Farnsworth, Fernandez, and Sabbatini (2007), Richard Smalley, Robert Curl, and Harold Kroto discovered fullerenes (also called buckyballs) in 1985, but the special properties of the buckyballs took a few years to prove and categorise. Although by 1996 no practical applications of buckyballs had been produced, scientists appreciated the direction this discovery based in organic chemistry had led scientific research, as well as its specific contributions to various other fields. The accidental discovery of fullerenes also emphasises the benefits and unexpected results which can arise when scientists with different backgrounds and research aims collaborate in the laboratory.

British chemist Harold W. Kroto at the University of Sussex was studying strange chains of carbon atoms found in space through microwave spectroscopy, a science that studies the absorption spectra of stellar particles billions of kilometres away to identify what compounds are found in space. This is possible because every element radiates a specific frequency of light that is unique to that element, which can observed using radio-telescopes. The elements can then be identified because a fundamental rule of matter stating that the intrinsic properties of elements apply throughout the universe, which means that the elements will emit the same frequency regardless of where they are found in the universe. Kroto took spectroscopic readings near carbon-rich red giants, or old stars with very large radii and relatively low surface temperatures, and compared them to spectrum lines of well-characterised substances. He identified the dust to be made of long alternating chains of carbon and nitrogen atoms known as cynopolyynes, which are also found in interstellar clouds. However Kroto believed that the chains were formed in the stellar atmospheres of red giants and not in interstellar clouds, but he had to study the particles more closely.

At the same time, Richard Smalley was doing research on cluster chemistry, at Rice University in Houston, Texas. "Clusters" are aggregates of atoms or molecules, between microscopic and macroscopic sizes, that exist briefly. Smalley had been studying clusters of metal atoms with the help of Robert Curl, using an apparatus Smalley had in his laboratory. This laser-supersonic cluster beam apparatus had the ability to vaporise nearly any known material into plasma using a laser, which is a highly concentrated beam of light with extremely high energy.

Through an acquaintance with Curl, Kroto contacted Smalley and discussed the possibility of using his apparatus to recreate the high-heat conditions of a red giant's atmosphere in order to study the clusters of carbon produced, which might give Kroto insight as to the formation of the carbon chains. Smalley conceded and Kroto arrived in Smalley's laboratory in Rice University on September 1, 1985, whom began working on the experiment along with graduate students J.R. Heath and S.C. O'Brien. Through this collaboration, these scientists were able to make one of the significant scientific discoveries in nanotechnology.

Buckyballs are giving scientists information about allotropes of carbon never before conceived. More importantly, these buckyballs allow engineers and doctors do what was never before possible, and some of the applications for buckyballs currently in research include medicine more specifically in drug treatments and scanning, and in engineering, through various applications in circuits, lubrication, superconductors, and as catalysts.

In 1986, the beginnings of the nanotechnology movement were observed. The spectrum of development which was initially sparked off by Feynman had culminated in the first book ever being published by Drexler, titled "Engines of Creation: The Coming Era of Nanotechnology" (Drexler, 1986).

The field of nanotechnology was also being recognised as a major field that needs to be coordinated. This eventuated in the formation of the Foresight Institute, based in California, USA. This institute is a leading think tank and public interest organisation focused on transformative future technologies. Founded in 1986, its mission is to discover and promote the upsides, and help avoid the dangers, of nanotechnology, artificial intelligence, biotechnology, and similar life-changing developments.

In order to facilitate research and development in nanotechnology, scientists had invented the Atomic Force Microscopy (Blanchard, 1996). Extending from his previous work in STM, Greg Brinnig worked with Christoph Gerber and Calvin Quate had produced the AFM or scanning force microscopy (SFM), which is a very high-resolution type of scanning probe microscopy, with demonstrated resolution on the order of fractions of a nanometer, more than 1000 times better than the optical diffraction limit. The AFM uses a tiny needle made of diamond, tungsten, or silicon, much like those used in the STM. While the STM relies upon a subject's ability to conduct electricity through its needle, the AFM scans its subjects by actually lightly touching them with the needle. Like that of a phonograph record, the AFM's needle reads the bumps on the subject's surface, rising as it hits the peaks and dipping as it traces the valleys. Of course, the topography read by the AFM varies by only a few molecules up or down, so a very sensitive device must be used to detect the needle's rising and falling.

The discovery of nano-tubes in 1991 by S. Iijima has been by far the buckyball's most significant contribution to current research. Nano-tubes, both single- and multi-walled, can be thought of as sheets of graphite rolled into cylinders and sometimes capped with half-fullerenes. Nano-tubes, like fullerenes, possess some very unique properties, such as high electrical and thermal conductivity, high mechanical strength, and high surface area. In fact, carbon nano-tubes provide a clear example of the special properties inherent at the quantum level because they can act as either semi-conductors or metals, unlike macroscopic quantities of carbon molecules. These properties make nano-tubes extremely interesting to researchers and companies, who are already developing many potentially revolutionary uses for them.

Table 2.1
Summary of Significant Events in Nanotechnology According to Year

Year	Event
1991	• Japan's MITI announces bottom-up "atom factory" • IBM endorses bottom-up path • Japan's MITI commits $200 million
1992	• First textbook published • First Congressional testimony
1993	• First Feynman Prize in Nanotechnology awarded for modeling a hydrogen abstraction tool useful in nanotechnology • First coverage of nanotechnology from White House • "Engines of Creation" book given to Rice administration, stimulating first university nanotechnology centre
1994	• Nano-systems textbook used in first university course • US Science Advisor advocates nanotechnology
1995	• First think tank report • First industry analysis of military applications • Feynman Prize in Nanotechnology awarded for synthesis of complex three-dimensional structures with DNA molecules
1996	• $250,000 Feynman Grand Prize announced • First European conference • NASA begins work in computational nanotechnology • First nanobio conference
1997	• First company founded: Zyvex • First design of nanorobotic system • Feynman Prize in Nanotechnology awarded for work in computational nanotechnology and using scanning probe microscopes to manipulate molecules
1998	• First NSF forum, held in conjunction with Foresight Conference • First DNA-based nanomechanical device • Feynman Prize in Nanotechnology awarded for computational modeling of molecular tools for atomically-precise chemical reactions and for building molecular structures through the use of self-organisation

1999	• First Nanomedicine book published • First safety guidelines • Congressional hearings on proposed National Nanotechnology Initiative • Feynman Prize in Nanotechnology awarded for development of carbon nano-tubes for potential computing device applications and for modeling the operation of molecular machine designs
2000	• President Clinton announces U.S. National Nanotechnology Initiative • First state research initiative: $100 million in California • Feynman Prize in Nanotechnology awarded for computational materials science for nanostructures and for building a molecular switch
2001	• First report on nanotechnology industry • U.S. announces first centre for military applications • Feynman Prize in Nanotechnology awarded for theory of nanometer-scale electronic devices and for synthesis and characterisation of carbon nano-tubes and nanowires
2002	• First nanotechnology industry conference • Regional nanotechnology efforts multiply • Feynman Prize in Nanotechnology awarded for using DNA to enable the self-assembly of new structures and for advancing our ability to model molecular machine systems
2003	• Congressional hearings on societal implications • Call for balancing NNI research portfolio • Drexler/Smalley debate is published in Chemical & Engineering News • Feynman Prize in Nanotechnology awarded for modeling the molecular and electronic structures of new materials and for integrating single molecule biological motors with nano-scale silicon devices
2004	• First policy conference on advanced nanotechnology • First centre for nanomechanical systems • Feynman Prize in Nanotechnology awarded for designing stable protein structures and for constructing a novel enzyme with an altered function
2005	• At Nanoethics meeting, Roco announces nanomachine/nano-system project count has reached 300 • Feynman Prize in Nanotechnology awarded for designing a wide variety of single molecular functional nanomachines and for synthesizing macromolecules of intermediate sizes with designed shapes and functions
2006	• National Academies nanotechnology report calls for experimentation toward molecular manufacturing • Feynman Prize in Nanotechnology awarded for work in molecular computation and algorithmic self-assembly, and for producing complex two-dimensional arrays of DNA nanostructures
2007	• Feynman Prize in Nanotechnology awarded for construction of molecular machine systems that function in the realm of Brownian motion, and molecular machines based upon two-state mechanically interlocked compounds
2008	• Technology Roadmap for Productive Nano-systems released • Protein catalysts designed for non-natural chemical reactions • Feynman Prize in Nanotechnology awarded for work in molecular electronics and the synthesis of molecular motors and nanocars, and for

	theoretical contributions to nanofabrication and sensing
2009	• An improved walking DNA nanorobot • Structural DNA nanotechnology arrays devices to capture molecular building blocks • Design ‘from scratch’ of a small protein that performed the function performed by natural globin proteins • Organising functional components on addressable DNA scaffolds • Feynman Prize in Nanotechnology awarded for experimental demonstrations of mechanosynthesis using AFM to manipulate single atoms, and for computational analysis of molecular tools to build complex molecular structures
2010	• DNA-based ‘robotic’ assembly begins • Feynman Prize in Nanotechnology awarded for work in single atom manipulations and atomic switches, and for development of quantum mechanical methods for theoretical predictions of molecules and solids
2011	• First programmable nanowire circuits for nanoprocessors • DNA molecular robots learn to walk in any direction along a branched track • Mechanical manipulation of silicon dimers on a silicon surface.
2016	• Jean-Pierre Sauvage, Sir J. Fraser Stoddart and Bernard L. Feringa • (Nobel Prize in Chemistry for the design and synthesis of • molecular machines).
2017	• Nobel Prize in Physics 2017: Gravitational waves.
2018	• World’s smallest tic-tac-toe game board made with DNA. • Shrinking objects to the nano-scale.

Source: Foresight.org (2011); Richards (2016); Petersen et al. (2018); Oran et al. (2018)

2.2.2 Impact of Nanotechnology

Whacker (2008) reported that nanotechnology is no longer new and novel, where a study recently released by the National Centre for Manufacturing Sciences covering 600 executives shows the increased significance of nanotechnology to both traditional and emerging fields in the last five years. In 2000, one could identify only a handful of companies with nanotechnology programs. In 2005, 18% of the surveyed industries were already marketing products, about 80% expect to commercialise nano-products by 2010, and almost everyone expressed confidence their organisations will be involved with nanotechnology in the future. Products containing nano-particles already pass unnoticed through the supply chain of many businesses.

However, the current uses of nanotechnology are still in the first or early second of four stages as defined by the Joint Economic Committee of Congress. In a report titled, "Nanotechnology: The Future is Coming Sooner Than You Think" (Saxton, 2007), those stages were defined as 2000-2005: passive nanostructures, 2005-2010: active nanostructures; 2010-2015: systems of nano-systems (2010-2015) and 2015-2020: molecular nano-systems.

Whacker (2008) further described the impact and implications of nanotechnology, which he categorised into the "Mild, Wild, and Way-Out-There Waves". He explained that the early implementation of nanotechnology can be classed as the Mild Wave, where it is characterised by utilising nanotechnology to improve existing capabilities. For the supply chain one result will be packages and packaging that ensure the quality of products from initial packaging through transport to ultimate consumption. Some of the developments in this area include:

1) Ultra-strong materials resist tearing or even bending (carbon nano-tubes are 400 times stronger than steel)
2) Ultra-light materials reduce added weight (Aerogel are solids with the feel of Styrofoam but are nearly as light as air)
3) Ultra-efficient materials provide superior insulation and protection from chemical or UV effects (Polymer nano-composites show significant improvement over conventional materials)
4) Ultra-clean materials battle microbiological effects (25nm silver particle antibacterial and anti-fungal coatings are being used on some cell phones)
5) Designer packaging that meets specific requirements of manufacturers and transporters will have a major impact on the supply chain.

A second area of impact is the use of nanotechnology to provide protection from counterfeiting. According to Industry Week, the cost of counterfeiting and piracy to the world economy is anywhere from US$500 to $650 billion. Nano-tags built into unit products can be used to verify authenticity. NanobarcodesTM are being developed for paper, plastic, metal and textiles that allow for trillions of unique codes. Surface enhanced Raman (SERS) nano-tags give a unique fingerprint when interrogated by lasers. Pharmaceutical companies are particularly interested in these capabilities because their products are highly targeted for counterfeiting.

Next, the Wild Wave of nanotechnology moves beyond enhancements to the creation of new capabilities for the supply chain. Some of the most interesting will require active and systems of nano-systems capabilities that will emerge over the next 5-10 years. One of these capabilities is the creation of Nanoelectromechanical Systems (NEMS). NEMS devices are part electronic and part mechanical allowing for the creation of ultra-small, ultra-efficient sensors. NEMS sensors will sample the quality, temperature, and other characteristics of products throughout the supply journey and signal for action should any degradation occur. A primary difference with today's sensors, aside from their ultra-low size and cost, will be their ability to be parasitic powered by harnessing the energy in motion, ambient temperature or even radio waves in the atmosphere.

Another element of this Wild Wave will use nanotechnology to enable the economic creation of high capability robots. In other words, it will move robots from isolated usage into nearly every aspect of the supply chain. One primary difference in these robots is that they will have capabilities similar to human beings. These robots will have artificial muscles powered by chemical sources, similar to human muscles fuelled by glucose and oxygen in our blood.

They will utilise NEMS sensors mentioned above and will be controlled by computers built ultra-capable with nanotechnology as well.

Finally the Way-Out-There Wave highlights the creative limits and imaginations of nanotechnologists who strive to make their flights of fancy a reality which can benefit everyone. Clark (1961) coined as one of his three laws, "any sufficiently advanced technology is indistinguishable from magic." Indeed scientists and engineers are now seriously pursuing capabilities that we would consider magical, or at least the stuff of science fiction. If built, the Space Elevator would expand the supply chain to off-of-this-world products as materials glide up to and down from earth orbit on a 24 inch ribbon. Contemplated nano-movers, with ultra-smooth surfaces lubricated by adaptive nanites may move cargo from one location to another without friction. But the ultimate and most controversial potential application of nanotechnology is the elimination of finished goods from the supply chain. Nano-factories, facilitated by nano-assemblers, would assemble molecules of raw materials into finished products on demand.

2.3 Development of Nanotechnology in Malaysia

Closer to home, the Malaysian government had funded some pioneering work in nanotechnology during the Seventh Malaysia Plan which span the years 1996 to 2000 (National Nanotechnology Initiative – NNI, 2010). Further reinforcement was of this nanotechnology research drive was seen with the emphasis of nanotechnology being one of 14 priority research areas in the Intensification of Priority Research Areas (IRPA), which was governed by the Malaysian Ministry of Science, Technology, and Innovation (MOSTI).

Furthermore, NNI (2010) had stated the short term strategy for Malaysia was, geared towards identifying researchers in various areas of nanotechnology with specific expertise; upgrading and equipping nanotechnology laboratories with state-of-the-art facilities; and to prepare a comprehensive human resource development programme for producing nanotechnologists.

This is further reinforced by the National Science and Technology Policy II (Ministry of Science, Technology, and Innovation – MOSTI, n.d.) which, specifically with regard to nanotechnology, desires to position Malaysia as a technology provider in the key strategic areas of nanotechnology; to ensure the widespread diffusion and application of nanotechnology, leading to enhanced market-driven research and development (R&D) to adapt and improve technologies by undertaking a detailed scrutiny of the industry; and to build competence for specialisation in key emerging technologies by developing a secure knowledge base in nanotechnology to sustain technology support for the Malaysian industry (MOSTI, n.d.).

2.3.1 Inclusion in the Malaysia Plan

Prior to the 6th Malaysia Plan (1990-1995), there was no mention of nanotechnology, let alone focus being put upon nanotechnology as the direction to take. The main sectors identified for the industrial technological development during this time were automated manufacturing, advanced materials, electronic technology, biotechnology, and information technology. Focus was also given to areas of technology development that are capable of saving energy and industries that utilise energy effectively and efficiently. R&D was allocated RM225 million from the national budget and the universities were encouraged to form joint research with private bodies so that the findings will be more meaningful and usable, and eventually the output from research can be commercialised. Interestingly, it was mentioned that new emerging technology will be given priority to ensure that focus was given areas with high economic return. This was evident through the directive to enhance human capital and manpower to utilise such new technologies through early preparation in institutions of higher education and training. The main research programmes focused on were the fundamentals of science that can support emerging technologies such as engineering, electro-optics, advanced materials, telecommunications, semi-conductor technology, computer systems and software, manufacturing systems, and medical, plant, and animal biotechnology. Other key areas include environment, resource management and non-conventional energy.

Meanwhile, the 7th Malaysia Plan (1996-2000) earmarked the emergence of nanotechnology in the bigger picture with the first and sole mention in the report. It was classified under the advanced manufacturing technology as nano- and micro-fabrication, which also included flexible unified computer manufacturing, robotic and intelligent machines, and system management technology. Other areas of technological focused upon by this Plan were communications and information technology (ICT, which included high performance calculations, networking, communication, digital imaging, multimedia, high definition display, high density storage space, software, simulation, and modeilling), micro-electronics (such as sensor technology, semiconductor materials, micro-electronic circuits, opto-electronics, avionics, and advanced semiconductor equipment), biotechnology and life sciences (such as biotechnology processing and materials, diagnostic and medical equipment, and medical technology), advanced materials (such as composites, ceramics, photonics, superconductors, and high performance alloys and metals), and energy and the environment (green materials, agriculture based waste, renewable energy, mobile energy, and waste rehabilitation and management.

Next, as time progressed, the 8th Malaysia Plan (2001-2005) witnessed the fully mention of the term “nanotechnology”. The report presented evidence of support for this emerging technology by providing a number of scientists for the areas of nanotechnology, as well as biotechnology, photonics, and fuel cell technology. Since nanotechnology and other related technologies required specialised equipment and setting, the concept of high technology parks were presented in the Plan. More specifically, the Kulim High Technology Park can provide a solid base for the development of supporting technologies, such as nanotechnology, to provide advanced materials for industries such as automotive, electronic, telecommunications, aerospace, and healthcare industries. In recognition of nurturing and supporting these new and emerging technologies, the Plan has placed focus on the fortification and enhancement of support services, especially small and medium enterprises (SMEs). To ensure that research projects contribute more to the needs of the country, the IRPA funding mechanism was restructured and streamlined to give greater emphasis on innovation development and thus enhancing the commercial viability of R&D projects. Focus was given to local product development, processes, and related services for commercial purposes. More than a third of the allocation for R&D was given to research in strategic fields to ensure enhancement in competitive advantage for the nation in the future, especially in new and emerging technologies, such as optical technology, specialised fine chemical technology, software design technology, as well as nanotechnology and precision engineering.

The following Plan, the 9th Malaysia Plan (2006-2010), saw the continuation of focus on advanced manufacturing fields, thus continuing to enhance overall industrial productivity and competitiveness as well as facilitate strategic development of high-technology industries. Emphasis was given to capacity reinforcement of key technologies, particularly in biotechnology, ICT, advanced manufacturing, advanced materials, aerospace-related technology, and nanotechnology. Recognising the potential impact of nanotechnology on a wide range of industries, efforts were focused on capacity building in nanoscience and nanotechnology research. The areas of nanotechnology R&D undertaken were related to nanoparticles, micro-machining and fabrication as well as sensors for electronics, communications, automotive and chemicals industries.

Meanwhile, new sources of growth was witnessed in advanced manufacturing that included robotics, smart sensors, intelligent software, high-technology packaging, automation, and nano-processing. In the manufacturing sector, emphasis was given to strategic and high technology industries such as ICT, biotechnology, photonics, nanotechnology, advanced manufacturing, and precision engineering. To expand the range of new products and appliances in the industry, greater emphasis was placed on the utilisation and application of new and advanced materials, especially through nanotechnology. Local research as well as design capacity and capability was further expanded with a view to developing new and improved components in nanoelectronics and nanomaterials for microelectronics devices and various other industrial applications. Moreover, it was also anticipated to be an increasing demand for production engineers, mould and die engineers and metallurgists as well as skilled technical human resource in robotics and sensor technologies, advanced materials, nanotechnology, and mechatronics.

From the perspective of infrastructure during this Plan period, greater emphasis was placed on targeted R&D to build competence and specialisation in emerging technologies to generate new sources of growth. To avoid the spreading of resources too thinly across a broad range of areas, priority was given toward developing a few niche areas. In this regard, focus was directed at biotechnology, advanced materials, advanced manufacturing, ICT, and nanotechnology to generate 300 science and technology-based companies through public funded R&D and 50 companies with global partnerships. To fully harness the benefits of technology development, diffusion and application in targeted growth areas, a cluster-based approach was adopted and collaboration between the research community and industry players was enhanced through improved mechanisms and processes. During this Plan period, R&D in nanotechnology focused on areas with high potential for application in local industries. These included nanostructured catalysts for environment-friendly hydrocarbon fuels, nanostructured membranes for waste water treatment, and MEMS for medical diagnostic devices. The R&D capacity in nanotechnology was enhanced to develop a strong knowledge base among researchers to enable them to participate in international networks and leverage on the global knowledge in nanotechnology advances.

2.3.2 Nanotechnology Trends in Malaysia

Nanotechnology is globally recognised as a high-priority emerging technology that brings dramatic benefits. As such, there has been increasing funding granted by the government in order to support the nanotechnology development in Malaysia (Table 2.2).

It started when the Malaysian government had funded some pioneering work in nanotechnology during the Seventh Malaysia Plan which span the years 1996 to 2000 (National Nanotechnology Initiative - NNI, 2010). Further reinforcement was of this nanotechnology research drive was seen with the emphasis of nanotechnology being one of 14 priority research areas in the Intensification of Priority Research Areas (IRPA), which was governed by the Malaysian Ministry of Science, Technology, and Innovation (MOSTI).

Table 2.2
Allocation of Government R&D Grants

Malaysia Plan	Government Grants			
	Intensification of Research in Priority Areas (IRPA)	Industry Research and Development Grant Scheme (IGS)	Multimedia Super Corridor Research and Development Grant Scheme (MGS)	Demonstrator Application Grant Scheme (DAGS)
Fifth	RM400 million	-	-	-
Sixth	RM600 million	-	-	-
Seventh	RM708 million	RM100 million	RM65 million	RM30 million
Eighth	RM833 million	RM230 million	RM100 million	RM90 million

Source: ATIP (2006); Hashim, (2009)

Furthermore, NNI (2010) had stated the short term strategy for Malaysia was, geared toward identifying researchers in various areas of nanotechnology with specific expertise; upgrading and equipping nanotechnology laboratories with state-of-the-art facilities; and to prepare a comprehensive human resource development programme for producing nanotechnologists.

This is further reinforced by the National Science and Technology Policy II (Ministry of Science, Technology, and Innovation - MOSTI, n.d.) which, specifically with regard to nanotechnology, desires to position Malaysia as a technology provider in the key strategic areas of nanotechnology; to ensure the widespread diffusion and application of nanotechnology, leading to enhanced market-driven research and development (R&D) to adapt and improve technologies by undertaking a detailed scrutiny of the industry; and to build competence for specialisation in key emerging technologies by developing a secure knowledge base in nanotechnology to sustain technology support for the Malaysian industry (MOSTI, n.d.).

Meanwhile, Hashim, Nadia, and Salleh (2009) had provided the current outlook of the nanotechnology industry in Malaysia through their research. The study had concluded that the Malaysian scenario required much work in the management of such high technology. Some of the highlighted problems within the nanotechnology industry include lack of linkages between various projects, no central facility, there is no definitive plan to realise and develop the nanotechnology industry, there is no clear overall road-map for nanotechnology research, and lack of effort in promoting awareness of nanotechnology.

Furthermore, Hashim et al. (2009) also revealed a Strength, Weakness, Opportunity, and Threat (SWOT) analysis of the nanotechnology industry in Malaysia, as formulated by the Malaysian Industry-Government Group for High Technology (MIGHT), which is placed under the supervision of the Economic Planning Unit (EPU) of the Malaysian Prime Minister's Department. Some of the weaknesses identified were, no dedicated policy for nanotechnology, need for human resource planning, lack of private sector investment and participation, lack of facilities, and lack of world-class companies to raise the standard.

The report by the Asian Technology Information Program (ATIP) had identified the infrastructure components for supporting the nanotechnology industry, namely R&D infrastructure, human resource, industry infrastructure, and industry readiness (ATIP, 2006). From the comparison performed in 2006, it was highlighted that the Malaysian nanotechnology industry still requires more development in R&D infrastructure and human resource development, as compared to the other ANF countries; ANF being a network organisation that is supported by 13 countries, including Australia, China, Hong Kong, India, Indonesia, Korea, Japan, Malaysia, New Zealand, Singapore, Taiwan, Thailand, and Vietnam.

Thus, based on the preliminary review of material, there is a need to look into the management aspects of nanotechnology (Bürgi & Pradeep, 2006; Hipkin, 2004; Ghazinoory & Farazkish, 2010) in order to manage the development of this potentially viable industry to become more focused and successful by identifying factors which may be of influence in facilitating the growth of this industry.

Not wishing to take the wait-and-see approach, the Malaysian government has taken up the challenge of exploring the vast potentials of nanotechnology by launching its own National Nanotechnology Initiative on 4 July 2005 in Johor Bahru, Malaysia (Asia Pacific Nanotech Weekly, 2005). In order to remain competitive, Malaysia has to have its own nanotechnology policies, as well as strategic plan to manage this viable technology, as extensively stressed by the then Deputy Prime Minister, in several of his public appearances regarding the research and management of nanotechnology.

In order to enhance Malaysia's competitiveness and to be part of this nanotechnology revolution, Malaysia has developed its own technology policies and initiatives as well as strategic plan (Hashim et al., 2009) Nanotechnology R&D started by the Malaysian government in 2001 and categorised as a Strategic Research (SR) program under IRPA in the Eight Malaysia Plan (8MP) which spans from 2001 to 2005. The Malaysia's National Budget 2006 unveiled the allocation of RM868 million to be provided under MOSTI and R&D. The focus will be biotechnology, nanotechnology, advanced manufacturing, advanced materials, ICT, and alternative source of energy including solar, to encourage innovation among local companies and developing new products.

Later, the initiatives have been continued in the 9th Malaysia Plan (2006-2010) where the government first thrust is to move the economy up the value chain. The Government aims to increase the value added of existing economic sectors. In addition, the manufacturing sector is expected to shift into high technology and generate new knowledge-intensive activities with high value added content in various industries, especially involving electrical and electronics, petrochemicals, biotechnology, machinery and equipment, aerospace and maritime. The Government has prepared prepare specific incentives to attract investments, including high quality FDI for manufacturing sector activities that are being promoted.

Furthermore, small and medium enterprises (SMEs) with high innovation capabilities have been encouraged to become part of the global supply chain. Some of the projects that have been implemented to enhance the manufacturing sector include the expansion of Kulim High Technology Park, the establishment of Sarawak Technology Park and Perak Technology Park, the development of 20 industrial and SME parks throughout the country, and infrastructural improvements to existing industrial areas. To improve access to sources of finance, the Government has created several funds such as the Strategic Investment Fund, the Automotive Development Fund, the Industrial Restructuring Fund, the Automation Fund, and specific funds for biotechnology products.

In the context of steering the direction of the nanotechnology industry toward a more sustainable future, here, a roadmap is designed to guide the industry's science and research activity by highlighting a strategy that provides the broad context and high level directions from the Malaysian perspective. Roadmaps may represent the governing body's stance or position on the science of nanotechnology, emphasising on how the industry efforts should be developed in order to best meet Malaysia's future needs. This roadmap is not one filled with detailed milestones, targets, or research plan, since all of these particulars need to be decided by those with the responsibility for funding particular pieces of research in conjunction with the end-users of the research, which consequently, will build toward clarifying the overall picture that is being presented by this roadmap.

The Malaysian Government has produced a National Nanotechnology Roadmap, titled "Malaysia NNI Roadmap Report" in 2007 (MIMOS Berhad, 2008), which was based on a study that identified five industries that would benefit from the development of nanotechnology, namely, biotechnology, energy, environment, agriculture, and medicine.

After a screening process of all the potential nanotechnology-based products in the industry was performed, six target products were identified as being able to bring the most impact to the above identified industries directly, and consequently the development of the country. These products include biosensors as being on the top of this list, as follows, biosensors, biochips, molecular farming, drug delivery system, solar, and lithium-ion.

Furthermore, other countries have observed the potential of nanotechnology even earlier. For example, Thailand has established the National Nanotech Centre (NANOTEC) in 2003 by the Thai Cabinet's decree. NANOTEC's objectives among others are to set the agenda and lay out the nanotechnology roadmap for Thailand. That nation's first nanotechnology roadmap includes nano-biosensors, as well as nanopolymers, nano-composites, nano-particles, nanoclay, nanofibers, nano-tubes, nanoporous materials, nanocatalysts, and solar cells (MIMOS Berhad, 2008).

Even though currently there is no clear and detailed roadmap for nanotechnology specifically on research and development (Hashim et al., 2009), because of the importance of such a promising industry, certain bodies have attempted to produce roadmaps in line with countries from overseas. For example, relating to the nanoelectronics industry, MIMOS Berhad (2008) had developed a roadmap for the Malaysian Ministry of Science, Technology, and Innovation. In this roadmap, it was highlighted that sensors play an important role in supporting other industries, of which includes the role played by nano-biosensors in energy and environment, food and agriculture, and medical and health.

2.3.3 Current Performance of Nanotechnology in Malaysia

Nanotechnology, although well accepted by the global community, is still yet to be firmly established in this country. The report by Hashim et al. (2009) had highlighted this, even though the NNI was initiated several years earlier. This is due to the fact that setting up such an industry requires intensive capital costing in setting up the initial infrastructure to support this industry.

Firstly, after establishing the theoretical part of this study through the literature review, this research attempted to identify and source out the nanotechnology community players that are active in maintaining the growth of this industry. It was discovered that the main players of this industry is characteristically different from the other industries. This is because of the nature and stage of development of this industry. Other established industries such as in electronics and automotive manufacturing, all have established supply chains, and these industries have been researched fairly extensively. Other industries, such as the construction industry, have also started taking up the technology management concept and integrating it into their operations, but like nanotechnology, researchers have revealed the characteristics that makes that industry unique. Therefore, in order to identify the players in Malaysia, several agencies were approached for a directory listing of the players in Malaysia. It was identified that the players can be categorised into three broad categories, which are the suppliers, the research centres, and the private companies that commercialises the nanotechnology products.

However, initial attempts had proven difficult. Enquiries made to several agencies had yielded in little useful information, even though nanotechnology would be under their jurisdiction. With regard to nanotechnology suppliers, there is no listing or directory that is being maintained by any agency. These suppliers need to be obtained from the research centres and private companies themselves.

With regard the research centres, a previous study in surveying the nanotechnology industry (Elliazir, 2009) had used nine agencies involved directly in nanotechnology (Table 2.3).

Table 2.3
Identified Research Centres from Previous Research

Research Centres	Specialisation
1) Nanochem and Nanophys Lab (IIS-UTM)	• Nanocatalyst, nanoelectronics devices, carbon nano-tubes, nanostructured materials
2) Universiti Putra Malaysia (UPM):	• Nano-composites, carbon nanotube
• Advanced Material	
3) Universiti Sains Malaysia (USM)	
• Nano-materials Research	• Supramolecules, carbon nanotube, nano-composites, OLED
• Medical Biotechnology	• Drug delivery systems, sensors
4) Universiti Kebangsaan Malaysia (UKM)	• Nanoelectronics
• IMEN	
5) SIRIM (AMREC)	• Nano-materials, processes
6) Universiti Malaya (UM):	• Advanced materials and catalysis, glycolipids and photonics.
• Combicat	
• Centre for Nanotechnology, Precision and Advanced Materials	
7) Universiti Teknologi Petronas (UTP)	• Devices and Sensors

Source: Udin et al. (2011)

However, after some consultation with these centres, it was quickly discovered that this list is out-dated. Therefore, this research has to identify manually the actual agencies involved. Through some extensive Internet search, many individuals numbering in the hundred and attached to different research centres and agencies were identified. After through some cross-checking and grouping, it was discovered there were many centres that were newly identified, and that some which were identified in previous research were not listed at active. Therefore, for this research, the identified organisations are presented in Table 2.4.

Table 2.4
The Organisations and Number of Interest Groups Identified for the Research

No.	Name of Organisation	Number of Centres/Interest Groups
1.	Universiti Teknologi Malaysia (UTM)	19
2.	SIRIM	6
3.	Universiti Teknologi Mara (UiTM)	5
4.	Universiti Teknologi Petronas	4
5.	Universiti Malaya	3
6.	Universiti Kebangsaan Malaysia	2
7.	Universiti Putra Malaysia	2
8.	Universiti Sains Malaysia	2
9.	Universiti Malaysia Sarawak	2
10.	Universiti Pertahanan Nasional Malaysia	1
11.	Universiti Malaysia Perlis	1

Source: Udin et al. (2011)

Further inspection of these organisations had revealed much information. Some organisations had established research centres, which they display on their on their website. Other organisations had listing of individuals involved in nanotechnology-related research, while others had listed interested groups related to nanotechnology. From all the information that was gathered, the research team members identified the contact persons for each of the identified research centres/institutes/interest groups related to nanotechnology (Table 2.5).

Table 2.5
Identified Research Centres/Institutes/Interest groups Related to Nanotechnology

No.	Org.	Research Centre / Institute / Interest Group Name
1	UTM	IbnuSina Institute*
2		Advanced Photonic Science Institute*
3		Zeolite and Nanostructured Materials Laboratory*
4		Material Innovations and Nanoelectronics Research Group (MINE)
5		Nano & Mesoporous Materials for Biological Applications (NAMBAR)
6		Novel Materials and Process Materials (NoMPTec)
7		Separation Science and Technology (SepSTec)
8		Catalytic Science and Technology (CST)
9		Nanophotonics
10		Industrial And Scientific Computation (ISC)
11		Scientific Computational and Industrial (SCNI)
12		Applied Algebra and Analysis Group (A3G)
13		Laser
14		Phosphor RG
15		Fiber Optics
16		Quantum Nanostructures Research (QuaSR)
17		Theoretical and Computational Modeling for Complex Systems (TCM)
18		Terahertz & Optical Imaging
19		Mathematics Statistic Industrial Group (MSIG)
20	UPM	Advanced Materials and Nanotechnology Laboratory (AMNL)*
21		Institute of Advanced Technology
22	USM	School of Materials and Mineral Resources Engineering*
23		Nano-materials Initiative Group
24	UKM	Institute of Microengineering and Nanoelectronics*
25		InstitutSel Fuel (Biohydrogen Research Group)*
26	SIRIM	Advanced Materials Research Centre (Amrec) - Advanced Polymer & Composites Programme*
27		Advanced Materials Research Centre (Amrec) - Biomaterials Programme*
28		Advanced Materials Research Centre (Amrec) - Electrochemical Materials Programme*
29		Advanced Materials Research Centre (Amrec) - Industrial Nanotechnology Research Centre*
30		Advanced Materials Research Centre (Amrec) - Photonics & Electronic Materials*
31		Advanced Materials Research Centre (Amrec) - Structural Materials Programme
32	UM	Centre for Fundamental and Frontier Sciences in Nanostructure*
33		Centre for Research in Nanotechnology and Catalysis (NANOCEN)*
34		Centre For Nanotechnology, Precision And Advanced Materials (CNPAM)*
35	UTP	FAS
36		ME
37		EE
38		CHE
39	UiTM	Centre of Nanoscience & Nanotechnology*
40		Centre of Advanced Material*

41		Centre of Nano-material*
42		Centre of Research & Innovation In Sustainable Energy
43		Centre of Synthesis & Chemical Biology
44	UniMAS	Faculty of Engineering - Dept of Chemical Eng & Energy Sustainability*
45		Faculty of Resource Science and Technology - Department of Chemistry*
46	UPNM	Fakulti Kejuruteraan - Unit Penyelidikan Perlindungan dan Sustainabiliti*
47	UniMAP	Institute of Nano Electronic Engineering (INEE)*

*Centres involved in on-going research projects

Source: Udin et al. (2011)

From this field of 47 identified centres and after more confirmation, 22 companies were identified as currently involved in on-going research projects.

From the private sector side however, obtaining a list of companies that are actually involved in nanotechnology is somewhat difficult. In certain directory listings that are maintained by overseas companied only yield in one or two companies involved in nanotechnology. Meanwhile, other directory listings had returned more than 290 companies that had the term "nano" in their company name or product. In order to confirm whether each of these identified companies actually deal with nanotechnology, and not just use the term nano in order to market their product and increase sales, each company would have to be contacted. However, due to the varied numbers being returned, as well as the large number of companied that needed to be contacted, the research team members had decided that this was beyond capabilities scope of this research endeavour. Besides, the list is maintained by companies not associated with the government or government agencies, which means that these listings may not be certified and verifiable. Therefore, more reliable sources were required for this research.

As for the government agencies that are monitoring the progress of the nanotechnology industry in Malaysia, only one agency maintains a list, even though there was admission that the list is somewhat out-dated. After personal contact was made, a representative of the Malaysian Industry-Government Group for High Technology (MIGHT) had released a listing of actual nanotechnology companies, meaning that these companies were either involved in the research, development, production, and/or commercialisation of nanotechnology related products. The list, along with a brief description of each company is exhibited in Table 2.6.

Table 2.6
Listing of Private Companies Involved in Nanotechnology, as Provided by MIGHT

No.	Name of Organisation	Description
1.	Gelanggang Kencana Sdn. Bhd.	In 2007, MaerogelTM was patented in Malaysia and marked a new chapter in the history of Aerogels. The product was produced by Prof. Dr. Halimaton Hamdan, of the Department of Chemistry at Universiti Teknologi Malaysia. She had patented an innovative method to produce aerogel from rice husks at a fraction of the normal cost. The features of the Maerogel that make it unique are: lightest solid – only 3 times the density of air, consists of 96% air, space-age nano-materials, porous amorphous solid with pore diameter of 1 - 30 nm, large surface area - 600 to 900 m2 per g and have the properties of dielectric material with thermal, electrical and acoustic insulating behaviours. This invention relates to silica aerogels and to a method for their preparation from rice husk. Rice husk is very rich in silica, and its ash can contain up to 92-97% of amorphous silica. The rice husk ash is prepared by burning the rice husk on a heating plate with excess air until the white ash is obtained. Silica from rice husk ash is in a very active form and has been found to be a very potential starting material for silica aerogels. Here, a low cost process utilising low cost raw material was developed. The overall production cost was reduced by 50-75%).
2.	Unitechnologies Sdn. Bhd.	This company focuses actively in nanostructured catalysts, nanomembranes and nanoherbs. This company works with UniMAP in producing nanosized herbs extracts which are functionalised and used as drug delivery systems to treat brain cancer, brain healing, HIV, influenza H1N1, immunization improvement and bone healing.

3.	UPM Holdings Sdn. Bhd.	This company focuses on research and commercialisation activities involving nano-composites and nano-biofertilisers.
4.	Nanopac (M) Sdn. Bhd.	Malaysia's pioneer in providing nanotechnology solutions, Nanopac (M) Sdn. Bhd., has invested about RM 8 mil to set up the countries first nanotechnology Research and Development (R&D) facilities and plant. Nanopac, established in November 2003, is a joint venture between a Malaysian party and South Korea-based Nanopac (Korea). Nanopac was granted pioneer status by the Malaysian Industrial Development Authority and had successfully commercialised its nano solutions, currently adopted by several multinational companies manufacturing air-conditioners in Malaysia, Thailand, Japan and South Korea. Under the joint-venture agreement, Nanopac (Korea) will transfer their unique and advanced nanotechnologies to Nanopac Malaysia. Nanopac is establishing strong overseas network covering China, Australia, Poland, Germany, the United States, and Japan.
5.	USains Holdings	The company focuses on research and products related to carbon nano-tubes, nano-particles. Their product on biosensor kits was developed jointly with UniMAP and able to carry out halal product detection, early cancer detection (stage 1) and conduct medical diagnostics.
6.	Malaysian Biotech Corporation	The Malaysian Biotech Corporation is set to commercialise its maiden and home-grown nanotechnology-based product. The nanotechnology product is healthcare-related and is ready for commercialisation for any Malaysian biotechnology company. It is mainly for the export market. Biotech Corp bought the exclusive worldwide license of a nanotechnology platform from French biotechnology company Nanobiotix and the two rollouts are part of a minimum eight nanotechnology projects that it plans to get into the market by 2011.
7.	Nanobiotix	This company owns 14 nanotechnology applications in healthcare, environmental and agricultural applications (five) and food and cosmetic applications (four), which are obtainable from Nanobiotix's current products, meaning no further research and development is required.
8.	MIMOS Berhad	MIMOS is also taking steps in managing nanotechnology-based products, primarily towards nanoelectronics and currently exploring nanotechnology based sensor and photovoltaic cell devices. Their main focus in the nanotechnology research is the growth of nanostructures, which includes characterisation, testing and integrating these nanostructures into Nano/Micro Electronic Mechanical Systems (NEMS/MEMS).
9.	JC Nanotech Sdn. Bhd.	JC Nanotech, a subsidiary of JC International, devotes in nanotechnology development geared towards environment protection. The company provides solutions in car care, automotive and construction industries.

Source: Udin et al. (2011)

Meanwhile, to further the advancement of nanotechnology in Malaysia, NanoVerify Sdn. Bhd. (NVSB), a wholly-owned company under NanoMalaysia Berhad (NMB), was established to deal with the commercialisation of nanotechnology as well as facilitate its development. NMB is an agency under the Minister and Deputy Minister of Energy, Technology, Science, Climate Change, and Environment, who have been given the responsibility of monitoring and facilitating nanotechnology research, development, and commercialisation in Malaysia. NVSB has been appointed by NMB to fully operate Malaysia's first and only nanotechnology verification and certification programme, which is known as the NANOVerify Programme.

NVSB's core service is the NANOVerify programme. This particular programme can certify the process and product of a company with claims of nanotechnology elements in the range of 1 to 100 nm, in order to market the high-technology product more successfully and earn public trust. This programme is operated together with SIRIM QAS International. Advantages of getting nanotechnology certification include assuring sales of genuine nanotechnology products, boosting consumer confidence and trust, creating greater market acceptance in other countries, and increasing value of products. Upon the successful completion of the NANOVerify programme, the processes and products will be awarded the "Nanoverified" mark (Figure 2.1).

Meanwhile, other services include consultancy and due diligence, programme development, and training services. The consultancy and due diligence that they provide can provision front-end technology assessment and perform commercial evaluation programmes of business segmented capabilities reports, as well as carry out programme verification on the applications of nanotechnology in the industry. NVSB can also assist in programme development through program development in the various nanotechnology areas as they have the expertise to advise professionally on potentially viable nanotechnology projects, as well as perform the product certification. Last but not least, NVSB can organise training programmes/workshops that provide organisations and individuals with the technical and management skills needed to enhance future success in the industry.

Figure 2.1
"Nanoverified" Mark Given to Certified Products and Processes
Source: http://www.nanoverify.com.my/images/2018/ 08/14/nanoverified.png

Not just performing a major role at the national level, the NANOVerify programme is part of a network of six international volunteer certification programmes. These programmes are located in Thailand, Russia, Iran, Taiwan, and United Kingdom (Figure 2.2).

Figure 2.2
International Volunteer Nanotechnology Certification Programme Network
Source: http://www.nanoverify.com.my/images/2018/04/12/worldwide_xl.jpg

2.4 Challenges Facing the Nanotechnology Industry

2.4.1 Human Resource

In a report prepared by McNeil, Lowe, Mastroianni, and Cronin (2007), one of its main findings was that there is lack of employees with the specific skills needed for the research and development (R&D) of nanotechnology. The report revealed that a large company "usually has only several people working in nanotechnology R&D so it is difficult to get the attention of company management and budget funding". Because of this phenomenon, these large companies would benefit by investigating the R&D landscape of small organisations, but usually they have limited time and personnel to investigate the many universities and government laboratories to try and determine what kinds of R&D are available and the potential benefits if they invested in those R&D projects.

Previous reports (Hashim et al., 2009; ATIP, 2006) had indicated that the Malaysian public is not ready in terms of expertise and training. This is further emphasised upon during the interview, where the "manpower" is sorely lacking in Malaysia.

Since human capital is a crucial issue, the research team members started an initial probing into the education system, which had revealed an interesting phenomenon. The call for improving and enhancing the workforce from the nanotechnology standpoint has been received by the various education institutions, and a movement toward improving the future of nanotechnology workers can be observed.

An initially search had pointed the research team to a Wikipedia page containing links and listing on the various institutions of learning that provide nanotechnology education throughout the world. From various listings, the following Table 2.7 shows the number of institutions and programmes that are being offered related to nanotechnology according to the country that has been documented on Wikipedia. Even though this list is maintained by the public, is clearly illustrates the development and acceptance of this field of science by the global community.

It is interesting to note that the Wikipedia listing shows that most of the focus of nanotechnology education is more on the postgraduate level, which makes sense because most of these programmes will involve nanotechnology research, which is what drives the innovative application of materials at the nano-scale. However, certain countries recognise that without the support from education of the undergraduate levels, the postgraduate education would not be so successful and fruitful. Some countries, like Australia, go even earlier in educating its potential future workforce by teaching nanotechnology related matters at the high school level.

Table 2.7
Nanotechnology Related Courses Offered Globally

No.	Country	Number of Courses	Level of Education
1.	India	24	Undergraduate & Postgraduate
2.	United States	23	Undergraduate & Postgraduate
3.	United Kingdom	18	Undergraduate & Postgraduate
4.	Mexico	16	Undergraduate & Postgraduate
5.	Australia	13	High School, Undergraduate, & Postgraduate
6.	Germany	11	Undergraduate & Postgraduate
7.	Canada	9	Undergraduate & Postgraduate
8.	France	7	Postgraduate
9.	Turkey	6	Postgraduate
10.	Brazil	5	Undergraduate & Postgraduate
11.	Denmark	5	Undergraduate & Postgraduate
12.	Netherlands	5	Postgraduate
13.	Sweden	4	Undergraduate & Master
14.	Norway	3	Undergraduate & Master
15.	Spain	3	Undergraduate & Master
16.	Thailand	3	Undergraduate & Postgraduate
17.	Belgium	2	Master
18.	Czech Republic	2	Undergraduate
19.	Switzerland	2	Undergraduate & Postgraduate
20.	New Zealand	2	Undergraduate
21.	Malaysia	2	Undergraduate
22.	Egypt	2	Master
23.	Greece	1	Master
24.	Italy	1	Master
25.	Poland	1	Undergraduate & Postgraduate
26.	Israel	1	Postgraduate
27.	Hong Kong	1	Postgraduate
28.	Singapore	1	Undergraduate
29.	Japan	1	Postgraduate

Source: Udin et al. (2011)

Going deeper into the listing and taking one of the leading countries as an example, another search into the courses offered in the United States of America had yielded in a list provided by the National Nanotechnology Initiative website (http://www.nano.gov/education-training/centre/university-college). The website highlighted the fact that nanotechnology is gaining more and more acceptance by the general public, and they are aware of the importance of education regarding the development of this field. The website also advised potential students who are interested in nanotechnology at an early stage, not to be disappointed if their school or college does not offer a specific nanotechnology course. These potential nanotechnology scientists should choose to go into chemistry, physics, engineering, biology, IT, or other technology fields. They can, with the help of a college advisor or a trusted professor or mentor, navigate college-level science courses to learn a great deal about nanotechnology, while keeping in mind that the further they get in their education, the greater the options and choices that become available to them.

The following table provides the list of courses available in the USA from the undergraduate degree level to the doctorate degree level. The following Table 2.8 shows this comprehensive list.

Table 2.8
List of Available Nanotechnology Related Courses in the USA

Bachelor Degree Programmes	
1.	Clarion University – Minor in nanotechnology
2.	Drexel University – BSc Materials Engineering with Specialisation Nanotechnology
3.	Louisiana Tech University – B.S. in Nano-systems Engineering
4.	Michigan Technological University – Minor program in nanotechnology
5.	Northwestern University – B.S. in Physics with Nano-scale Physics Concentration
6.	University at Albany College of Nano-scale Science and Engineering (CNSE) – BS in Nano-scale Science and Nano-scale Engineering
7.	University of California, Riverside – B.S. in Chemical Engineering with Nanotechnology Concentration
8.	University of California, San Diego – B.S. Nanoengineering
9.	University of Central Florida – B.S. in Nanoscience and Nanotechnology track in Liberal Studies
10.	University of Maryland, Maryland Nanocentre – Interdisciplinary minor in nanotechnology
11.	Pennsylvania State University, Centre for Nanotechnology Education and Utilisation, Nanofabrication Manufacturing Technology (NMT) Capstone Semester

	– Minor in nanotechology
Masters Degree Programmes	
1.	Arizona State University – Professional Science Master (PSM) in Nanoscience and M.A. in Applied Ethics (Ethics and Emerging Technologies)
2.	Johns Hopkins University – M.S. in Materials Science and Engineering with Nanotechnology Option
3.	Joint School of Nanoscience and Nanoengineering (collaborative project of North Carolina A&T State Univ. and Univ. of North Carolina Greensboro) – M.S. in Nanoscience and M.S. in Nanoengineering
4.	Louisiana Tech University – M.S. in Molecular Sciences and Nanotechnology
5.	Rice University, Centre for Nano-scale Science and Technology – Professional Science Master (PSM) in Nano-scale Physics
6.	Stevens Institute of Technology – M.Eng. with Nanotechnology Concentration and M.S. with Nanotechnology Concentration
7.	University at Albany College of Nano-scale Science and Engineering (CNSE) – Nanoscience/Nanoengineering + MBA program; M.S. degrees with Nano-scale Science and Nano-scale Engineering tracks
8.	University of California, San Diego – M.S. Nanoengineering
9.	University of Pennsylvania – M.S. in Nanotechnology
10.	University of Texas at Austin – MSc Engineering Nano-materials Thrust
Ph.D. Degree Programmes	
1.	Brown University – Nano/Micromechanics Laboratory
2.	City University of New York, Chemistry Department
3.	California Institute of Technology (CalTech) – Materials and Process Simulation Centre
4.	Clemson University – The Laboratory for Nanotechnology
5.	Cornell University – The Nanobiotechnology Centre and Cornell Nanofabrication Facility Home Page
6.	Florida Institute of Technology - Division of Engineering Sciences
7.	Georgia Institute of Technology - Nanocrystal Research Laboratory and Nanostructure Optoelectronics
8.	Iowa State University - Ames Laboratory Condensed Matter Physics Group (Department of Energy)
9.	Johns Hopkins University – Institute for NanoBioTechnology
10.	Kansas State University - Visual Quantum Mechanics
11.	Kaunas University of Technology - Research Centre for Microsystems and Nanotechnology
12.	Massachusetts Institute of Technology - NanoStructures Laboratory
13.	Michigan State University - The Nanotube Site
14.	New Jersey Institute of Technology - Nonlinear Nanostructures Laboratory (NNL)
15.	New York University - Nadrian C. Seeman's Laboratory
16.	North Carolina State University – "NANO@NCState" program
17.	Northeastern University, NSF's Integrative Graduate Education and Research Traineeship (IGERT) - Ph.D. in Nanomedicine
18.	Princeton University - Nanostructure Laboratory
19.	Purdue University - Graduate Level Courses in Nano-scale Science and Engineering
20.	Rensselaer Polytechnic Institute - Nanostructured Materials
21.	Rice University - Centre for Nano-scale Science and Technology

22. Seoul National University - Centre for Science in Nanometer Scale, ISRC
23. South Dakota School of Mines and Technology – Nanoscience and Engineering program
24. Stanford University - Stanford Nanofabrication Facility and NanoNet
25. Stevens Institute of Technology
26. University at Albany College of Nano-scale Science and Engineering (CNSE)
27. University of Arizona - Nanomechanics and Mesoscopic Physics and Prof. SrinManne's AFM Lab
28. University of Chicago - University of Chicago Materials Centre
29. University of Cincinnati - Nanoelectronics Laboratory
30. University of Connecticut - Advanced Technology Centre for Precision Manufacturing
31. University of Delaware - Department of Chemical Engineering, Centre for Molecular Engineering Thermodynamics Department of Electrical and Computer Engineering, Centre for Nanomachined Surfaces
32. University of Illinois at Urbana-Champaign - Beckman Institute Home Page and Scanning Tunneling Microscopy Group
33. University of Michigan - Centre for Biologic Nanotechnology
34. University of Nebraska - Department of Electrical Engineering, Quantum Device Laboratory
35. University of New Mexico - Nanoscience and Microsystems
36. University of North Carolina at Chapel Hill - North Carolina Centre for Nano-scale Materials and The Nanomanipulator Project
37. University of North Carolina Greensboro/ North Carolina A&T University Joint School of Nanoscience and Nanoengineering
38. University of North Carolina at Charlotte - Ph.D. Program in Nano-scale Science
39. University of Notre Dame - Centre for Nano Science and Technology and Engineering Molecules for a New Technology
40. University of Southern California - Laboratory for Molecular Robotics
41. University of South Florida - Centre for Molecular Design & Recognition
42. University of Texas at Austin
43. University of Utah – Certificate in Nanotechnology while earning science field Ph.D.
44. University of Washington - Centre for Nanotechnology
45. University of Wisconsin Madison - Department of Physics: Nanowires Materials Research Science and Engineering Centre Seed Project, Magnetic Nanostructures
46. Virginia Commonwealth University
47. Washington State University - Nanotechnology Think Tank
48. Yale University - Department of Engineering, Microelectronics and Optoelectronic Materials and Structures

Source: Udin et al. (2011)

Table 2.9
Listing Provided by Trynano According to Countries

Country	Number of Courses	Level of Education
United States	32	Undergraduate & Postgraduate
United Kingdom	19	Undergraduate & Postgraduate
India	17	Undergraduate & Postgraduate
Australia	13	Undergraduate & Master
Germany	12	Undergraduate & Master
Canada	6	Undergraduate & Postgraduate
Netherlands	5	Postgraduate
Brazil	4	Postgraduate
Denmark	4	Undergraduate & Postgraduate
France	4	Postgraduate
Korea	4	Undergraduate & Postgraduate
Sweden	4	Master
Belgium	3	Master
Spain	3	Master
Czech Republic	2	Undergraduate & Master
Italy	2	Master
Mexico	2	Undergraduate & Postgraduate
Norway	2	Undergraduate & Master
Switzerland	2	Undergraduate & Postgraduate
Taiwan	2	Master
Thailand	2	Undergraduate & Master
Turkey	2	Master
Greece	1	Master
Hong Kong	1	Postgraduate
Ireland	1	Master
Israel	1	Postgraduate
Japan	1	Postgraduate
New Zealand	1	Undergraduate & Master
Russia	1	Undergraduate & Master
Singapore	1	Undergraduate

Source: Udin et al. (2011)

Therefore, from this comprehensive list, there are more and more courses being offered by the USA institutions of higher learning, (11+10+48 = 69 courses) as compared to the Wikipedia list of 23 courses.

However, after further inspection, this USA government website had suggested two other directories for further information regarding nanotechnology education, Trynano.org (http://www.trynano.org/university_listings.html) and Nanowerk.com (http://www.nanowerk.com/nanotechnology/nanotechnology_degrees.php).

The Trynano.org provided similar entries to the Wikipedia listing (with an additional entry for Korea, Taiwan, Ireland, and Russia, and omission of Egypt, Malaysia, and Poland), and this is summarised in Table 2.9.

Nanowerk had provided a matrix or cross-tabulation between country and level of education, which is presented in Table 2.10. It can be concluded here that even though the directories that are being maintained by different organisations are not consistent, the global community can be observed to be moving toward establishing nanotechnology as a proper field of study. The main players or drivers of educating the workforce are being spearheaded by the developed nations, like USA, UK, Australia, and Germany to name but a few, with some developing countries following suit, like India.

When compared to Malaysia, Wikipedia identified two courses being offered, which are shown in Table 2.11 below. It is interesting to note that both these courses are offered at the undergraduate level, and they are being offered by private institutions of higher learning. With regard the approaches taken by these institutions, MMU has approached the subject of nanotechnology from the engineering perspective, while MUST has taken the science and management route.

Table 2.10

Listing Provided by Nanowerk According to Countries and Course Levels

Country	Level of Education				TOTALS
	Bachelor	Master	Other	Ph.D.	
Australia	13	4	2	-	19
Austria	-	1	-	-	1
Belgium	-	3	-	-	3
Brazil	-	2	-	-	2
Canada	11	2	1	1	15
Czech Republic	1	-	-	-	1
Denmark	3	3	-	3	9
Egypt	-	1	-	-	1
Finland	-	1	-	-	1
France	-	9	-	1	10
Germany	11	16	1	2	30
India	2	13	3	4	22
Ireland	2	1	-	-	3
Israel	-	1	-	1	2
Italy	-	4	2	1	7
Netherlands	1	5	-	1	7
New Zealand	2	1	-	-	3
Norway	1	3	-	1	5
Poland	1	1	-	-	2
PR China	-	1	-	1	2
Singapore	-	-	1	2	3
South Korea	-	1	-	-	1
Spain	1	5	-	-	6
Sweden	-	6	-	-	6
Switzerland	1	4	-	-	5
Turkey	-	2	1	1	4
UK	6	32	1	1	40
USA	7	18	24	18	67
TOTALS	63	140	36	38	277

Source: Udin et al. (2011)

Table 2.11

Courses Offered in Malaysia as Listed by Wikipedia

Name of Institution	**Level of Education**	**Name of Degree**
Malaysia Multimedia University (MMU)	Bachelor Degree	Electronic Engineering majoring in Nanotechnology (Nano-Engineering)
Malaysia University of Science & Technology (MUST)	Bachelor Degree	Science in Nanoscience & Nanoengineering with Business Management

Source: Udin et al. (2011)

An online search directory related to education (http://www.uniguru.com), it was discovered that there are six institutions that offer courses at various levels here in Malaysia. The description of these courses is shown in Table 2.12 below.

Table 2.12
Nanotechnology Courses Offered in Malaysia

No.	Name of Institution	Level of Education	Name of Degree
1.	Malaysia Multimedia University (MMU)	Bachelor Degree	Engineering (Hons) Electronics majoring in Nanotechnology
2.	Universiti Teknologi Mara (UiTM)	Master of Science	Advance Material and Nano Technology (By Research)
3.		Doctor of Philosophy	Advanced Material and Nanotechnology (PhD)
4.	Universiti Putra Malaysia (UPM)	Master of Science	Physics - Nanosciences
5.		Master of Science	Advanced Materials Engineering Nano-Materials and Nano Technology (with thesis)
6.		Master of Science	Nanobiotechnology
7.		Doctor of Philosophy	Physics - Nanosciences (PhD)
8.		Doctor of Philosophy	Nanobiotechnology (PhD)
9.		Doctor of Philosophy	Advanced Materials Engineering Nano-Materials and Nano Technology - PhD (with thesis)
10.	Universiti Malaysia Sarawak (UNIMAS)	Master Degree	Surfaces and Nanostructures by Research
11.		Doctor of Philosophy	Surfaces and Nanostructures (PhD)
12.	Malaysia University of Science & Technology (MUST)	Bachelor of Science (Hons)	Nanoscience and Nanoengineering with Business Management
13.	Akedemi Tentera Malaysia (ATMA)	Master of Science	(Electric and Electronics Engineering) - Nanotechnology (By Research)
14.		Doctor of Philosophy	(Electric and Electronics Engineering) - Nanotechnology (By Research)

Source: Udin et al. (2011)

2.4.2 Infrastructure and Utilities

Infrastructure availability is crucial to assist businesses, especially small companies that cannot afford the cost of nanotechnology instrumentation, equipment and facilities (McNeil et al., 2007). Nanotechnology virtually demands university and industry cooperation due to basic science innovations, expensive laboratories, and need for highly trained workers.

McNeil et al. (2007) further added that researchers involved in nanotechnology R&D who are working at transforming their scientific innovations into prototypes, “do not have access to their own private workshop or other independent facilities separate and apart from the university laboratories”. In a private workshop, the researcher would be able to, “transform scientific theory into practical applications that might qualify for new patents that they would own” (McNeil, 2007).

In the assessment of developing countries technology transfer, which is an important component under the technology management practices umbrella, Khurana et al. (2013) highlighted that the lack of a well-established industrial infrastructure is the most critical problem.

In addressing this issue, the concept of technology parks have been conceived with the advent of the Silicon Valley that was established in the 1950s to facilitate the development of the computer age (Baluch, Abdullah, & Abidin, 2015). Technology Parks are physical foundations which are designed and built for the development of knowledge-based institutions. They concentrate research and information capabilities of government, private institutions and universities in one location. Technology parks also gather some of the facilities with high values work-place and high standards for corporations to carry out their R&D activities.

According to Baluch et al. (2015), the definition of technology parks differs almost as widely as the individual parks themselves. The United Kingdom Science Park Association (UKSPA) defines the park as a business support and technology transfer initiative that encourages and supports the start-up and incubation of innovation-led, high growth, knowledge-based institutions. It provides an environment where larger and international businesses can develop specific and close interactions with a particular centre of knowledge creation for their mutual benefit. Also, it has formal and operational links with centres of knowledge creation such as universities, higher education institutes and research organisations. The Department of Town and Country Planning, Peninsular Malaysia defines the technology park as an exclusive real estate development which encourages the formation and growth of the commercial and industry sectors based on knowledge, encourages the transfer of high technologies and skills to the organisations while having formal and close links to universities, institutes of higher learning and research institutes (Abdullah et al., 2013). They have formal and operational links with a university or other higher education institution or major centre of research; are designed to encourage the formation and growth of knowledge-based businesses and other organisations normally resident on site; and have a management function that is actively engaged in the transfer of technology and business skills to the organisations on site.

Baluch et al. (2015) concluded that Technology parks of East Asia are the result of investments and partnerships among national stake holders, transnational corporations, and international institutions. Technology parks have contributed to gross domestic product (GDP) growth, infrastructure development, knowledge community expansion, capacity building, and export production and distribution. Technology parks have contributed to national inclusion in global information society, while some have become resource centers for development of ICT applications to further national goals of ICT education and distribution. Considering the disproportionate performance of the three countries' technology parks by comparing the GCI 2015 index and the GDP difference one is impelled to surmise that the performance of the technology parks is playing a key role in the economic growth of the respective countries. Optimum benefits of Technology Parks accrue when they are established and managed professionally in line with the best practices and all transactions are equitable, just, and transparent; the whole process should culminate trust nationally and internationally. Therefore, technology parks, or in the case of nanotechnology, high technology parks are a viable solution to promote and facilitate the local development of nanotechnology industry in Malaysia.

2.4.3 Consumer Awareness

Any form of technology, more so for nanotechnology, public or consumer awareness is pertinent in making the technology acceptable and usable by all walks of life. This is critical for companies to ensure that their product is accepted by the public. The public needs to know all the facts and figures, so to speak, in order to come to their own conclusion in accepting the technology or otherwise.

Various researchers originating from different sectors had performed research to investigate the importance of consumer awareness in promoting a technology (Viscecchia, De Devitiis, Carlucci, Nardone, & Santeramo, 2018; Boatman & Chaplan, 2018; Yolcu & Dyehouse, 2018; Sahin & Ekli, 2013). These researchers had the same ultimate concern, which was nanotechnology awareness in their respective areas, including food, education, construction and others.

Viscecchia et al. (2018) performed a survey related to the use of nanotechnology in the food industry, with the background setting established in Italy. They highlighted that few studies have analysed the interaction between this new technology with human population and the environment. The most important factor that limits the diffusion of nanotechnology applications in the food market is the relatively limited knowledge of the potential risks for human health and environment. More precisely, while toxicology studies are providing increasing evidence that engineered nanoparticles may have adverse effects on human health and environment (He et al., 2014; León-Silva et al., 2016; McShan et al., 2014; Nikodinovska et al., 2015), the knowledge on the implications for humans and the environment due to repeated exposure to engineered nanoparticles is still limited (Pathakoti et al., 2017; Ranjan et al., 2014). In addition, because toxicity is specific for different nanoparticles, a safety and environmental assessment must be performed on a case-by-case basis (Handford et al., 2014).

Another potential barrier to the commercialisation of food nanotechnology products is related to public concerns about the use of such novel and unfamiliar technology with consequent uncertainty of consumers' acceptance. Several studies have been carried out in different countries (Bieberstein et al., 2013; Chen et al., 2013; Cook & Fairweather, 2007; Farshchi et al., 2011; Matin et al., 2012; Schnettler et al., 2013; Stampfli et al., 2010) to investigate public awareness and attitude toward food nanotechnologies. Results of these studies show that public knowledge on food nanotechnology is quite limited, and attitude varies across individuals. As expected, the attitudes towards nanotechnology food applications are influenced by the associated perceived benefits and perceived risks (Chen et al., 2013;

Siegrist et al., 2008; Stampfli et al., 2010). Consumers' perception of risks and benefits is, in turn, mainly determined by the general attitude toward new technologies (neophobia/neophilia), nanotechnology knowledge, and social trust (i.e., trust in scientists, regulatory agencies, food industry and retail) (Chen et al., 2013; Cook & Fairweather, 2007; Matin et al., 2012; Stampfli et al., 2010). Specifically, positive attitude toward new technology, deep knowledge on nanotechnologies, and higher social trust tend to increase consumers' perceived benefits and to reduce consumers' perceived risks of nanotechnology applications. Finally, consumers' acceptance of food nanotechnologies varies across different applications: it tends to be greater for "nano-outside" applications as that the lack of ingestion is perceived as a minor exposure to potential hazards (Siegrist et al., 2008; Stampfli et al., 2010).

The results from the study by Viscecchia et al. (2018) for the food industry, the more consumers trust science, the food industry, and retail, the higher they perceive the benefits and the lower they perceive the risks. These findings are in line with other studies, which also showed that perceived benefits are more important than perceived risks for the acceptance of this food technology (Sodano et al., 2016). The results also identified the "knowledge-wealth paradox", where "both knowledge and wealth indirectly increase the willingness to buy but while building knowledge allows to communicate and comprehend the benefits of innovations, increasing wealth (or targeting high income class consumers) tends to decrease the perceptions of risks favouring the willingness to buy foods with nanotechnologies applications".

Meanwhile in the construction industry, Boatman and Chapman (2018) revealed similar findings in that awareness of nanotechnology is fairly low amongst the players in the construction industry. They identified that there is a need to provide a clear and precise definition of nanotechnology, because, “perceptions of what nanotechnology is and how it is being applied in construction are all over the map; we need to get everyone on the same page and develop a clear message that can easily be brought to a diverse audience”. There is a dire need to develop a strategic plan to increase awareness and improve understanding of nanotechnology and nanomaterials in the construction industry.

Meanwhile, in engineering education, Yolcu and Dyehouse (2018) revealed that engineering students’ exposure to nanotechnology and awareness about nanotechnology is low, but their motivation to pursue nanotechnology knowledge or careers is high. This lack of exposure and awareness is problematic at a time when nanotechnology is becoming increasingly important to the field of engineering. As this study has shown, engineering students have little to no exposure to nanotechnology in a classroom setting. Educators can take advantage of students’ motivation to learn more about nanotechnology by integrating information about the field into the engineering curriculum, thereby increasing students’ exposure and awareness. More specifically, there were gender differences in the awareness of nanotechnology. Although students’ exposure to nanotechnology and awareness about nanotechnology were low, there were still significant differences found between males and females with regard to levels of nanotechnology awareness. Because females show a lower awareness of nanotechnology than males, it may be helpful for educators who integrate nanotechnology into their curriculum to emphasise the more socially relevant aspects of nanotechnology that may interest women in particular, such as how nanotechnology can improve society.

While staying on the education theme but at a different education level, Sahin and Ekli (2013) investigated awareness, factual knowledge, opinions, and risk perceptions of students from Turkish middle schools with regard to nanotechnology in a very general sense. The study wanted to determine middle school (secondary school or post-elementary) students' awareness and opinions of nanotechnology and to consider the factors influencing risk perceptions of nanotechnology. Their results showed that the majority of students (74%) had some awareness of nanotechnology even though it was not included as part of the 6th to 8th grade learning goals. This is in contrast to previous studies dealing with adult attitudes (Sahin & Ekli, 2013).

It was clearly evident that awareness of nanotechnology plays an important part in the promotion of this emerging technology and needs further investigation and research, thus it was included in this study.

2.4.4 Regulatory Framework

Recent evidence does not allow a nation to build a sound science-based regulatory framework, and thus there are currently no specific regulations on nanotechnology food applications either in EU, USA, or elsewhere (Coles & Frewer; 2013; Magnuson et al., 2013). In addition, there is a lack of universal guidelines specifically developed for the safety and environmental assessment of nanotechnology food applications, even though experts from around the globe are working in bringing an international dimension and harmonization to "nanometrology" and standardization of approaches (Magnuson et al., 2013; Schoonjans & Chaudhry, 2017). However, according to Viscecchia et al. (2018), the current lack of a clear governance framework and consequent regulatory uncertainty makes it difficult for developers and manufacturers to know what, if any, regulations should be complied with, and what risk assessments, if any, are appropriate.

According to Karim, Munir, and Yasin (2014), there is no denying of the potential promises that nanotechnology can bring to the world, as well as enhance mankind, however, "there are many concerns on the safe application of this technology". From the legal prospective, Karim et al. (2014) had stated that hundreds of papers have already been written on health and environment concerns and safety issues regarding this technology. Apart from the laboratory researches, there are many researches which are conducted on animals and the adverse effects of this technology were noticed. Furthermore, in much of the research, concerns were expressed that the people who are directly in contact with the technology i.e., the researchers and the workers are in real danger. Therefore, the law should intervene to regulate this technology.

Previously, it has been seen that genetically modified foods and nuclear energy were introduced with unlimited prospects, but was not successful due to many factors. Due to numerous prospects, it is whole heartedly desired that the nanotechnology innovation should be continuous, but within the regulatory framework.

The above discussion provides the rationale for the need for a regulatory framework for the nanotechnology industry. Thus this dissertation intended to investigate this particular area.

2.5 Critical Success Factors (CSFs)

Critical Success Factors (CSFs) are the critical factors or activities required for ensuring the success of a business. The term was initially used in the world of data analysis, and business analysis. Critical Success Factors have been used significantly to present or identify a few key factors that organisations should focus on to be successful.

In general, CSFs are those elements that are required to deliver success (Osman, 2013), which include the set of circumstances, forces, facts, or influences, levers, essential activities, and key variables. Some other researchers defined CSFs are the set of standards, level of performance, and dimensions to deliver success.

As a definition, critical success factors refer to "the limited number of areas in which satisfactory results will ensure successful competitive performance for the individual, department, or organisation" (Morrison, 2016). Identifying CSF's is important as it allows firms to focus their efforts on building their capabilities to meet the critical success factors, or even allow firms to decide if they have the capability to build the requirements necessary to meet Critical Success Factors (CSFs).

The principle of identifying critical success factors as a basis for determining the information needs of managers was proposed by Daniel (1961) as an interdisciplinary approach with a potential usefulness in the practice of evaluation within library and information units, but popularised by Rockart (1979). Over time, many academics have applied the methodology increasingly outside the educational establishment. Rockart (1982) defined CSFs as those few key areas of activity or factors that favour results which are absolutely necessary for managers to reach their goals. He further explained that these key areas are where "things must go right" for the business to flourish and for the managers' goals to be attained.

However, Saraph et al. (1989) viewed CSFs as those critical areas of managerial planning and action that must be practised in order to achieve effectiveness. Meanwhile according to Rowlinson (1999), CSFs are those fundamental issues inherent in the project that must be maintained in order for team work to take place in an effective and efficient manner. Despite the wide acknowledgement of applicability of the CSF approach in previous studies, no fixed or comprehensive rules have been developed for the identification of CSFs.

Meanwhile, Freund (1988) defined CSFs as those things that must be done if a company is to be successful and it is worthwhile exploring the CSFs as it could ensure success (Isik et al., 2009). According to Westerveld (2003), CSFs could be defined as "what to achieve" and "how to achieve".

Thus, from the above explanation, CSFs can be observed to have a close relationship to an organisation's objectives. Like other strategic planning elements that affect strategy indirectly, CSFs affect strategy through their effect on organisational achievement of the objectives and the ability to enable the success of the mission. This relationship is illustrated in Figure 2.3.

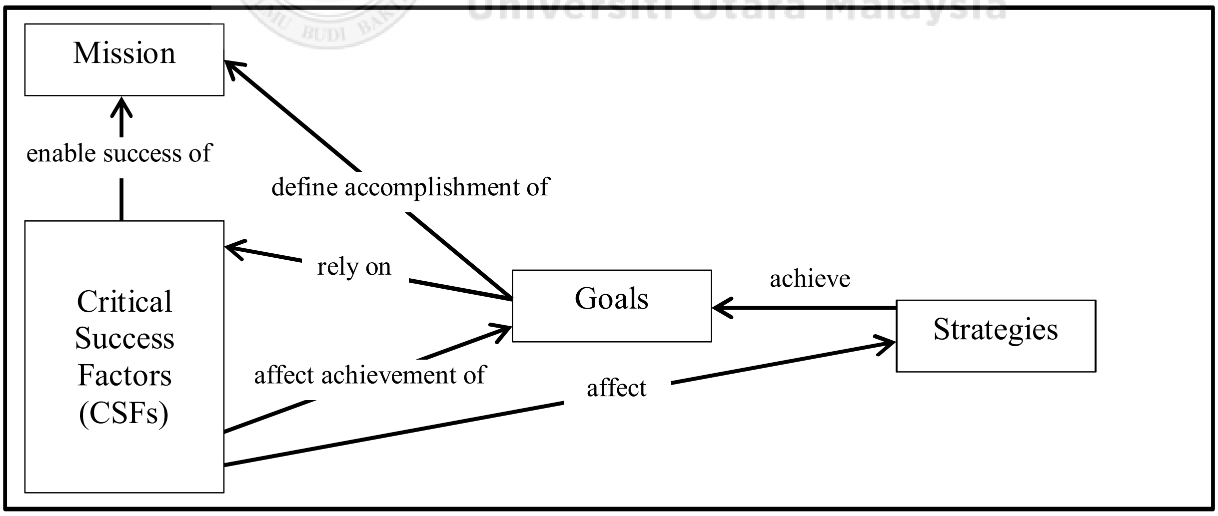

Figure 2.3
CSFs Relationship to an Organisation's Mission and Goals
Source: Osman (2013).

The idea or concept of CSFs is very simple, where “in any organisation certain factors will be critical to the success of that organisation, in the sense that, if objectives associated with the factors are not achieved, the organisation will fail – perhaps catastrophically so” (Morrison, 2016).

With a phrase like Critical Success Factors having ‘common usage’ within technical environments it is difficult to identify its true history in the context of business, management and human resources. One test for originality is the use of the three letter acronym of CSF. And one of the earliest uses of this was by Daniel (1961) and Rockart (1979). Daniel (1961) does not use the term CSF or even the phrase Critical Success Factors, but does discuss critical elements and non-critical elements of a business leading to “controlling competitive success”. He also used the term “success factors” in the context that we would understand today.

According to Morrison (2016), there are four basic types of CSFs, and they are:

1) Industry Critical Success Factors (CSF’s) resulting from specific industry characteristics;
2) Strategy Critical Success Factors (CSF’s) resulting from the chosen competitive strategy of the business;
3) Environmental Critical Success Factors (CSF’s) resulting from economic or technological changes; and
4) Temporal Critical Success Factors (CSF’s) resulting from internal organizational needs and changes.

The focus of this study is the first of the above CSFs, which is the Industry Critical Success Factors. These factors are dependent upon the specific industry characteristics. It is important that the organisation continues to monitor these factors to be able to compete in the market. For instance, a chemical company demands specific technology and a clothing producer absolutely requires cotton. These CSFs may influence all competitors within a specific industry, but could also affect individual organisations. The following sections describe nanotechnology industry related CSFs identified through previous research.

2.5.1 Lee, Lee, Jhon, and Shin's Critical Success Factors

Lee, Lee, Jhon, and Shin (2013) investigated key factors affecting the development of nanotechnologies. Identifying key factors of nanotechnology development through literature review and interview with CEOs, we collected data from 206 Korean nanotechnology-based companies, and analysed the causal relationship between key factors and financial performance. Logistic and Tobit regression models were used. Overall, companies achieving successful development hold some common characteristics including consistent exploratory R&D, governmental funding, and nano-instrument/energy/environment-related products. Also, the use of potentially toxic materials makes commercialisation difficult even if the products themselves are not toxic.

In greater detail, their results revealed that among the nanotechnology fields, the nano-instrument field is developed better than others, meaning that equipment such as nano-detecting equipment and nano-lithography equipment are easy to be developed and commercialised.

In terms of R&D strategy, one of the CSF is the proportion of R&D personnel and the in-house laboratory that are usually expected to drive commercialisation in other technologies, where higher percentage of R&D personnel is favourable to ensure successful nanotechnology development success, but given the chronic shortage of qualified manpower for nanotechnology, it could simultaneously decrease developmental success.

Another CSF is related to funding. Virtually all nanotechnology projects need funding, whether private or public. Because nanotechnology is in its infancy stage, there is a high possibility of “valley of death” phenomenon occurring similar to all other start-up technologies, so firms need sufficient R&D financing to successfully navigate this “valley”. Lee et al. (2013) highlighted that venture capital investment for nanotechnology compared to biotechnology is also insufficient. Thus, public funding, including government-initiated R&D projects, will guarantee stable long-term R&D projects which will help secure technical stability and safety and eventually increase commercialisation. The fact that a firm even receives government R&D support had a greater and more significant influence on development success than the amount of support, likely because the technological achievements made with government financing differ among firms.

Another highlighted CSF by Lee at al. (2013) is public awareness levels. One notable result of their study was the verification of public acceptance of nanotechnologies. Their empirical analyses have shown that nanotechnology firms mainly related with nanosilver, CNT, or TiO2, have difficulties in developing their products. Public acceptance of nanotechnology products could change if toxicity concerns continue. Therefore, there is the need for communication of nanotechnology risk, toxicities (under certain conditions) should be investigated and clarified, clearly and promptly, and the results should be communicated.

Government funding injected into nanotechnology R&D activities also positively influenced nanotechnology development. Thus, government can play an enormous role. Government support for nanotechnology R&D in the energy and environment field together with clarifying toxicity issues will achieve two goals: stable long-term accumulation of technology and securing of public acceptance of nanotechnology.

2.5.2 Yassaei and Tari's Critical Success Factors

In a research performed by Yassaei and Tari (2015), they investigated procedures employed for conducting R&D in nanotechnology in a developing country, and the factors governing its success and its failures. To accomplish this task, they performed a thorough literature review and the related critical factors were identified. Next they conducted an extensive survey to gather the perception of the specialists in this field via a questionnaire that was designed and distributed to the R&D managers and academicians in the field of nanotechnology. To obtain more accurate reply, the answers were gathered by the means of the face to face interview. A total of 27 factors were identified and categorised in seven classes. Then by the use of the Fuzzy mapping the most critical factors of the success and failure of nanotechnology were analysed.

Their results indicated that the most important CSF is the enhancement of the general awareness of nanotechnology in the society. In greater detail, the ranked CSFs that could lead to failure in development from their study are as follows:

1) interaction between researchers and engineers,
2) proposing the strategy of research and development to government,
3) relationship between industry and university,

4) encouraging manufacturers for increasing competitiveness by more understanding of potentials, ability and risks of nanotechnology,
5) supervision the intellectual property and patent in the field of nanotechnology,
6) releasing information among entrepreneurs, researchers and investors,
7) venture capital fund,
8) establish appropriate nanotechnology legal basis by the government,
9) quality control reference lab,
10) investment insurance in nanotechnology, and
11) exchanging new technical information.

2.6 Overview of the Research Process for this Study

According to Remenyi et al. (2004), "the nature of the research process is often relatively unstructured and frequently unpredictable along its journey", however in order to reduce the risk of uncertainty and mistakes, having a sound understanding of the philosophical stance of a particular research would at least keep the researcher on the straight path (Remenyi et al., 1998; Abdullah & Raman, 2000/2001). Therefore, it is not only vital to fully comprehend the issue that needs to be researched, the researcher also needs to know how to acquire knowledge derived from the issue being studied (Abdullah & Raman, 2000/2001; Tobi, 2010). The researcher's view point literally assists in describing whether they are characteristically a quantitative or qualitative researcher. Table 2.13 presents detailed features of the two types of research methodologies.

Since this research attempts to uncover in greater detail about the surrounding issues and challenges associated with the proper management of nanotechnology, therefore, the nature of this research will be more geared towards employing a qualitative approach. A qualitative study's research objectives are generally governed by the qualitative inquiry of "what" and "how" questions in order to achieve success.

Table 2.13
Differences of Quantitative and Qualitative Research Methodologies

Feature	Quantitative methodology	Qualitative methodology
Nature of reality	Objective; simple; single; tangible sense impressions	Subjective; problematic; holistic; a social construct
Causes and effects	Nomo logical thinking; cause-effect Linkages	Non-deterministic; mutual shaping; no cause-effect linkages
The role of values	Value neutral; value-free inquiry	Normativism; value-bound inquiry
Natural and social Sciences	Deductive; model of natural sciences; nomothetic; based on strict rules	Inductive; rejection of the natural sciences model; ideographic; no strict rules; interpretation
Methods	Quantitative, mathematical; extensive use of statistics	Qualitative, with less emphasis on statistics; verbal and qualitative analysis
Research role	Passive; distant from the subject; Dualism	Active; equal; both parties are interactive and inseparable
Generalisations	Inductive generalisations; nomo-thetic statements	Analytic or conceptual generalisations; time-and-context specific

Source: Nawi (2012)

The proceeding sections will further elaborate on the research methodology adopted for this study. This entails an in depth description of the research philosophies, approaches, strategies, and techniques for data collection and analysis, as well as the appropriate justifications to support this study.

The term of "research" is defined as the process of, "finding out something you do not know, and is a systematic and methodical process that increases knowledge" (Philips & Pugh, 2005;

Philips & Pugh, 2010; Amaratunga et al., 2002), whereas the word "methodology" is a system of organising the principles underlying an area of study. On the other hand, research methodology is a "systematic and orderly approach" taken towards achieving a logical development of the research process (Collis & Hussy, 2003).

Generally, there is a total of six distinct stages of this research that covers the literature review (establishing the field), exploration (finding out data sources), data collection (collecting the data), framework development (organising the data), validation (justifying the data and findings), and last but not least the recommendations (putting the data and results into use). In order to give a sense of sequence and provide a guideline to the researcher, several authors (Kagioglou et al., 1998; Saunders et al., 2015; Keraminiyage, 2009; Tobi, 2016) outlined that the stages or layers within the research process. This enables the researcher to monitor the research progress to ensure that the process is more or less on the right track.

In order to select the most appropriate research methodology, the researcher should choose based on a particular research philosophy. This philosophy would then assist in describing the process of the research, employed style, different methods used, extent of control, degree of focus, and nature of the enquiry (Yin, 2009). In order to achieve the aims of this research, the research process has to be systematic, both from the aspects of what to do and in what order, and thus follows the methodology of the "onion" research model (Figure 2.4) that was introduced by Saunders et al. (2009). Saunders et al. (2009) described a research methodology as having six main layers, similar to that of an onion, which are research philosophies, approaches, strategies, choices, time horizons, and techniques and procedures. Each of these elements is discussed in greater detail in the following sections.

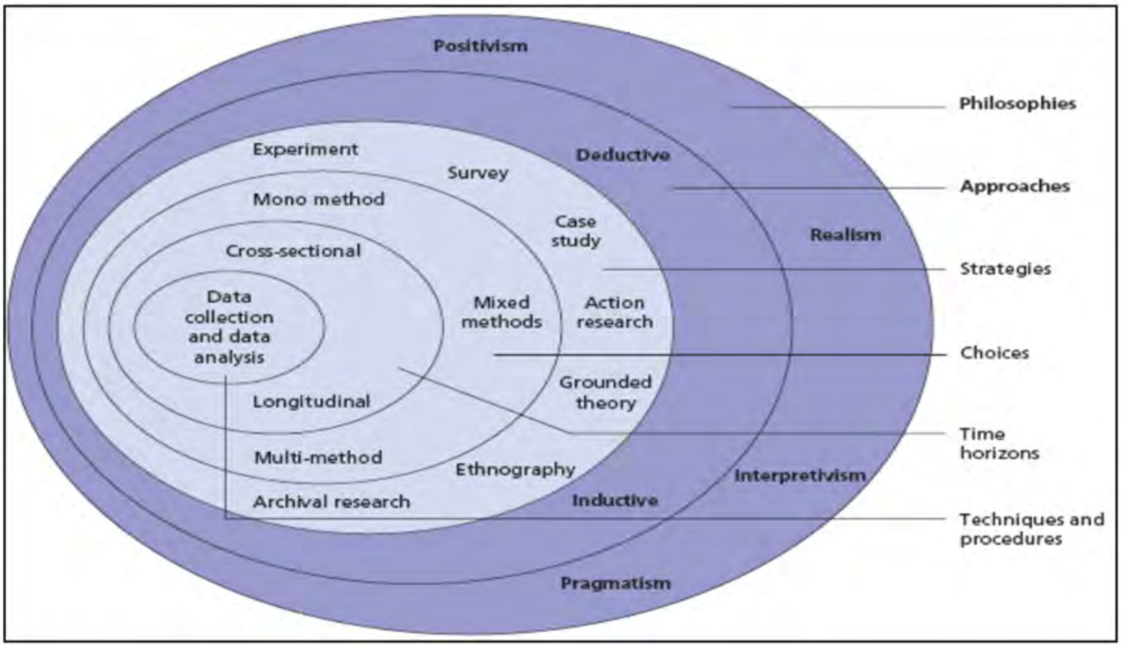

Figure 2.4
The Original Onion Research Model Adapted for this Research
Source: Saunders et al. (2009)

2.6.1 Research Philosophy

The research philosophy is the underlying belief that the researcher has to form the overall guideline to follow in order to fulfil the objectives of the study. However, without having a clear picture on all the available research philosophies, a researcher would have a difficult time in choosing the most appropriate one (Mkansi & Achaempong, 2012). Therefore, the following subsections will describe in greater detail the research philosophies that have been established by previous esteemed scholars along with the strengths and weaknesses of each. Finally, the research philosophy for this research is selected and stated, along with the justification and rationale behind the selection.

The researcher’s thinking, understanding, and assumptions about the progress of knowledge will have a direct bearing on the research philosophy which, in turn, shall affect the way the research is performed (Saunders et al., 2015). The research strategy and methods chosen as part of a research strategy will be guided by the underpinning research philosophy that contains important assumptions. Thus, the quality of the research will be affected if the researcher fails to mind the philosophical issues (Easterby-Smith et al., 2006). This is because the basis for effective research design is the proper selection of a research philosophy. There are at least three reasons why an understanding of philosophical issues is pertinent (Easterby-Smith et al., 2006):

1) helps in clarifying research design (more than simply the methods by which data is collected and analysed),
2) assists in recognising which research designs will and will not work under the given circumstances of the research concerned, and
3) helps in identifying and creating research designs that may be outside his or her past experience.

The context of this research involves a study that focused on practices and barriers in the nanotechnology industry. Accordingly, this research is from the social perspective in trying to uncover the issues and challenges in implementing successful nanotechnology development support in order to assist in furthering the development of the nanotechnology industry. Based on this context, it is argued that this study leans more toward the social science standpoint. As stated by Yin and Davis (2007), this kind of research (social science research) comes under the umbrella of applied.

In social science research, there are two main research philosophies, namely, positivism and interpretivism (Easterby-Smith et al., 2018). Easterby-Smith et al. (2008) described positivism as “the social world exists externally, and that its properties should be measured through objective methods rather than being inferred subjectively through sensation, reflection or intuition".

Furthermore, Tobi (2010) defined positivism as "a behaviourism and cognitivism based learning and instructional theories are grounded in positivist philosophy because they suggest that learning can be acquired and that reality as well as knowledge is discovered, rather than created". The philosophy is usually attached to the ontological assumption of reality being external and objective (Tobi, 2017; Tobi, 2010; Keraminiyage, 2009).

On the other hand, Easterby-Smith et al. (2008) described interpretivism (constructionism) as something which "focuses on the way that people make sense of the world, especially through sharing their experiences with others via the medium of language". In addition, Tobi (2010) defined interpretivism as "social learning based theories are more closely aligned with constructivist philosophy because they suggest that knowledge is constructed based on experience of the world and people, so that reality is constructed".

Previous researchers (Collis & Hussey, 2014; Creswell, 2014; Amaratunga et al., 2002) who have supported this definition asserted that interpretivist philosophy refers to the subjective aspects of human activity. These aspects focus on the meaning rather than the measurement of social phenomena. In conclusion, the key idea of positivism is observed as knowledge that is based on the learning theories that can be discovered, instead of created, and should be measured through objectivism instead of being inferred subjectively through sensation or intuition. Meanwhile, interpretivism is characterised by reality as constructed, based on the knowledge gained from the experiences through subjective measures of the world and people. The details of positivism and interpretivism philosophy will be explained further in later sections. Table 2.14 shows the differences between the characteristics of positivism and interpretivism research philosophies.

Table 2.14
Contrasting Implications of Positivism and Intrepretivism

Element	Positivism	Interpretivism
The observer	Must be independent	Is part of what is being observed
Human interest	Should be irrelevant	Is the main driver of the science
Explanations	Must demonstrate causation	Aim to increase general understanding of the situation
Research progress	Hypotheses and deduction	Gathering rich data from which ideas are induced
Concepts	Need to be operationalised so that they can be measured	Should incorporate stakeholder perspectives
Units of analysis	Should be reduced to the simplest terms	May include the complexity of the "whole" situation
Generalisation Through	Statistical probability	Theoretical abstraction
Sampling requires	Large numbers selected randomly	Small number of cases chosen for specific reasons

Source: Easterby-Smith et al. (2002)

Based on the above discussion, there are two extreme ends of a continuum, either positivism or interpretivism, where any research can be placed. There are three main fundamental assumptions of the research philosophy that would determine where a research can be placed at;

1) Ontological assumptions: deals with the nature of reality (e.g., what does research focus on? What is out there to know?)
2) Epistemological assumptions: deals with the nature of knowledge (e.g., what kind of knowledge is the research investigating? What and how can researcher find out about it?)

3) Axiological assumptions: deals with nature of the value the researcher places on the study (e.g., what researcher values go into it?)

Often, these ontological, epistemological, and axiological assumptions within a research project are interconnected, and often described as the research philosophy characteristics (Keraminiyage, 2009). This area of study influences social research from the perspective of the structure and process, which is known as the philosophy of science (Sarantakos, 2005). What really is important is that the philosophy of science assumption leads to the underpinning of the chosen research strategy and method, as part of that strategy (Saunders et al., 2015). This process will probably assist the researcher in gaining information and knowledge, based on an empirical study, and eventually contribute toward the body of knowledge in an appropriate manner (Tobi, 2010).

Ontological assumption, according to virtually all past researchers, is classified as a study of conceptions of reality and the nature of being. As defined by Sexton (2007), ontology is the assumption that the researcher makes about the nature of reality. In Sexton's model of a continuum research approach, it shows that ontology could either fall under the realism or idealism aspect of research knowledge.

Initially, Sexton (2007) defined realism as representation in literature or art of objects, actions, or social conditions as they actually are, without idealisation or presentation in abstract form. Meanwhile, idealism refers to the practice or act of pursuit of one's ideals or envisioning things in an ideal form. Then, Aouad (2009) further described idealism is an unknowable reality perceived in different ways by individuals, while realism is a commonly experienced external reality with a predetermined nature and structure. These definitions illustrate that the two are opposites of one another.

Meanwhile, Bryman and Bell (2007), and Sutrisna (2009) divided research ontology into two opposing poles, namely constructivism (or subjectivism) and objectivism (idealism). Constructivism (subjectivism) in this aspect is an ontological position which asserts that phenomena and their meanings are continually being accomplished by the actors (Sutrisna, 2009). In contrast, objectivism refers to an alternate ontological position which asserts that phenomena and their meanings have an existence that is independent from actors (Bryman & Bell, 2007). This means that, constructivists believe that reality is constructed by every one of us differently, while objectivists view that there is only one reality experienced the same way by all.

In conclusion, there are two main philosophies for research ontology, namely idealism (subjectivism) and realism (objectivism) (Aouad, 2009; Sutrisna, 2009; Sexton, 2007; Bryman & Bell, 2007). In terms of ontological assumption, idealism refers to reality being constructive (subjective) and multiple as seen by different participants (in other words, viewing things as being the way one wants them, e.g., opinion/plan based), while realism refers to reality being singularly objective, as seen by different participants (in other words, viewing things as they actually are, e.g., practice/experience based) in a study.

Epistemological undertaking was described by Aouad (2009) as a general set of assumptions about "how we know what we know". This branch of philosophy is concerned with what one accepts as valid knowledge (Collis & Hussey, 2009). Furthermore, Sutrisna (2009) elaborated that "epistemology looks at the theory of knowledge, especially with regard to its methods, validation, and possible ways of gaining knowledge in the assumed reality". The most commonly used examples of epistemological positions are positivism and constructivism.

This would indicate that an epistemological assumption is knowledge that can only come from observation (discovering) rather than created of this external reality. Creating knowledge involves an affirmation of theories through strict scientific method, such as those provided through quantitative approach (Easterby-Smith et al., 2018). In addition, a positivist develops a hypothesis by using existing theory to establish an epistemological position that is tested and confirmed, in whole or part, which leads to further theory development (Saunders et al., 2015). The positivist believes that the use of the deductive approach for research will need no further discussion to explain why the qualitative research is equal to positivist research (Sarantakos, 2013; Easterby-Smith et al., 2018; and Remenyi et al., 2004).

Meanwhile from the ontological assumption stance on the other hand, interpretivists would argue that reality is not objective and exterior, because the world is socially constructed and given meaning by people (Keraminiyage, 2009; Easterby-Smith et al., 2002). According to Neill (2006), interpretivism "is a way to gain insights through discovering meanings by improving our comprehension of the whole", especially through the sharing of experiences with others through the medium of language.

Furthermore, from the interpretivism stance, qualitative and naturalistic approaches can be utilised to inductively and holistically understand human experience in context-specific settings (Thanh & Thanh, 2015).

Axiology is explained as philosophical areas that depend crucially on notions of value and are sometimes held to lay the groundwork for these fields (Tobi, 2010; Tobi 2017). Axiological assumption is about the nature of values and the foundation of value judgments (Sexton, 2007). It means how one "thinks" about the world and how one "acts" in the world (Kasim et al., 2008; Nawi, 2012). The processes will reflect and influence how one "thinks" about and consequently "sees" the world that helps one to "act" in inquiry and practice within the ontological and epistemological orientations (Nawi, 2012). As illustrated in Figure 2.5, axiology urges congruence between ontological and epistemological assumptions in order to put the standards and requirements of an acceptable research approach and research technique. Nawi (2012), through his review, surmised that the nature of value could be determined either as value-free and unbiased, or as value-laden and biased (Tobi, 2017; Sexton, 2007; Kasim et al., 2008; Sarantakos, 2013; Remenyi et al., 2004; Easterby-Smith et al., 2018). Positivists always believe that science and the process of research is value free (Collis & Hussey, 2003). This is in contrast to the social constructionist who considers that researchers have values, and these values help to determine what are recognised as facts and the interpretations which are drawn from them.

The phenomenon in this study was interpreted within a context through direct interactions with individual members who are representatives from industry. The research objectives that have been initiated in this study are not only exploratory but also explanatory in approach. In terms of an axiological view, this research favours the more value-laden and subjective nature of research.

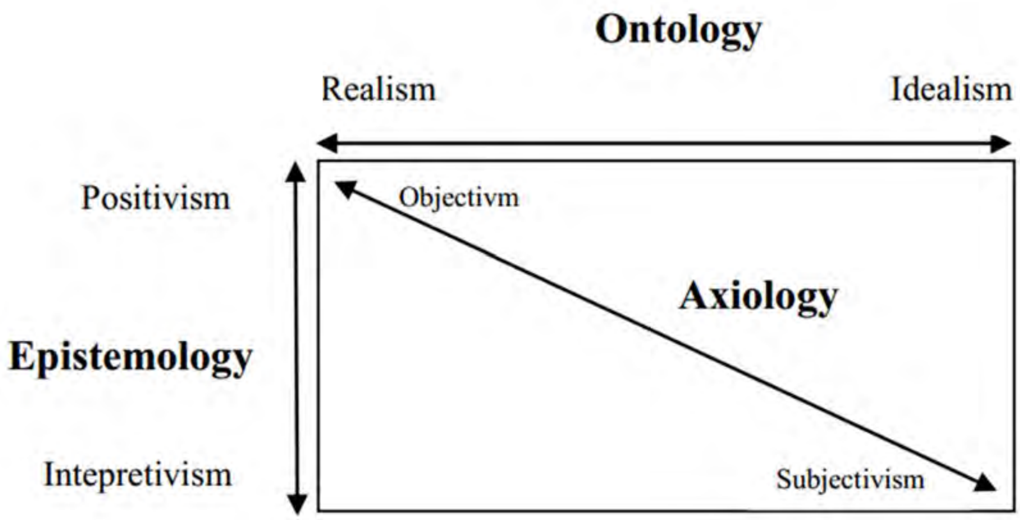

Figure 2.5
Philosophical Orientation
Source: Sexton, (2003a)

2.6.1.1 Philosophical Position of this Study

In view of the characteristics of both research philosophies as discussed earlier, the research positioning of interpretivism has been identified as the most appropriate research philosophy for this study. Previous literature recognised that the approach relating to technology management existed but specifically, there are no guidelines to be followed by practitioners on how to achieve success in the nanotechnology industry. As the main aim of this research is to develop a framework of critical success factors (CSFs) for effective nanotechnology industry development in the nanotechnology industry, therefore, this study is generated to seek answers from nanotechnology practitioners with regard to the factors inhibiting their attitude and practice (experience based) for the enhancement of the nanotechnology industry development. In this regard, information such as current practice, problems/challenges and appropriate solutions that are related to the problems need to be investigated. Therefore, this study requires the researcher to understand, explore, and elicit opinions and perceptions from Malaysian nanotechnology practitioners which places this research within the interpretivism paradigm. In contrast, the positivism paradigm is concerned with establishing a strictly cause-effect relationship instead of understanding the issue and thus, is inappropriate for this study in that it will not assist this researcher to achieve the established aim and objectives.

After considering all the factors in the above discussion in developing a framework, the information and data required for this study needs to originate from the respondent's view based on the reality of their actual real experience and practice (realism) instead of the ideal and unrealistic view (idealism), more specifically relating to the Malaysian nanotechnology industry. Therefore, this study is more of an attempt at theory building, rather than an attempt at theory testing. Additionally, the research environment was not expected to be controlled. It is rather simplified with assumptions and hypotheses, as in the deductive research approach used in positivist studies. Conversely, an inductive research approach is used with the intention of generating rich data to build up theories.

As discussed earlier, the nature of this study leans more towards interpretivism, as opposed to positivism. Therefore, the nature of this study is rooted in the notion of lived-world experiences that involve social construction, instead of actual reality among multiple stakeholders, in order to discover the information required for developing a framework of critical success factors for effective nanotechnology industry development in the Malaysian nanotechnology industry. Thus, the research environment cannot be controlled as ideas are constructed and determined by human beliefs and interests, whereas knowledge is gained from participation. Accordingly, the constructivism assumption has been identified as the most appropriate research epistemological approach for this study based on the knowledge gathered, and not created.

This research also intended to develop and validate a framework of CSFs for effective nanotechnology industry development in the Malaysian nanotechnology industry. The phenomenon under study is interpreted within a context of direct interaction and co-operation with nanotechnology stakeholders and experts as discussed earlier, through a series on face-to-face interviews. In view of that, this study leaned more toward the value-laden research choices.

In conclusion of the research philosophy, this research leans more towards interpretivism with the ontology stance of realism, followed by the epistemological territory of social constructionism and the axiological view of being value laden and therefore possibly biased, as it is determined by the experience and interpretation of the researcher. This philosophical stance of the research influences the selection and decision-making process of an appropriate research approach.

2.6.2 Research Approach

Previous researchers defined the term "research approach" in different ways. Easterby-smith et al. (2002) clarified research approach as being about organising and managing research activities that consists of data collection methods for achieving research aim and objectives. Creswell (2014) highlighted that knowledge claims, strategies, and method contribute toward the study. Meanwhile, Tobi (2017) views research approach as the strategy used for data collection and analysis.

Sutrisna (2009), as well as Gill and Johnson (2002), claimed, in different ways, that research approach can be differentiated and placed along the philosophical continuum, depending on the emphasis of deductive or inductive research, degree of structure, and the type of data they generate. Sutrisna (2009) emphasised that there are two methods of undertaking research in the acquisition of new knowledge, namely deductive and inductive research.

Simply put, Hyde (2000) describes deductive research as referring to a theory testing process that begins with an established theory, then formulates a hypothesis, and observes whether the theory applies to specific instances. Similarly, it is a strategy in which theory informs the research at the outset and the hypotheses dictate what evidence the researcher looks for (Grix, 2010), and data is then collected to accept or reject the formulated hypotheses.

Meanwhile according to Yin (1994), inductive theory is an inquiry into understanding a social or human problem from multiple perspectives. Researchers in inductive research seek to gain richer and more comprehensive information by keeping their minds open for any possible and sometimes unexpected results, while proposing a further set of steps for data collection in an attempt to answer the phenomena in question (Sutrisna, 2009). The development of a theory is based on the conclusions from the empirical evidence and data analysis (Saunders et al., 2003; Landman, 2000).

According to previous research (Grix, 2010; Sarantakos, 2005; Bryman, 2004), this type of research is not hypotheses-driven. Instead, theory is generated and built through the interaction with and analysis of empirical data. The researcher looks for patterns in the data and in particular, relationships between variables. Additionally, Hart (2003) also described the difference between deductive and inductive research procedures. Figure 2.15 shows the differentiation based on research procedures.

Table 2.15
Comparison of Deductive and Inductive Procedures for Research

Deductive procedure for research	Inductive procedure for research
The researcher tests a theory	The researcher gathers information and data
↓	↓
Hypothesis or research questions are derived from theory	Questions are asked about the phenomenon
↓	↓
Concepts and variables are operationalised	Data is classified and placed into categories
↓	↓
An instrument is used to measure variables in the theory	Patterns are looked for in the data and potential theories are proposed
↓	↓
Verification of the hypothesis	Theories are tested and developed and patterns compared with other patterns and theories

Source: Hart (2003)

It can be concluded that inductive reasoning goes from the specific to the general and is characteristically theory building, while deductive reasoning goes from the general to the specific and is characteristically theory testing. Deductive research is often associated with positivist philosophy while inductive research is often associated with interpretivist philosophy (Sutrisna, 2009; Saunders et al., 2003).

2.6.3 Research Strategy

According to research philosophy and the nature of this current study that is not theory testing—it is theory building— the researcher had on the onset intended to gather deep and rich information from the field study. Therefore, the inductive research approach was selected as the reasoning for this research. However, in order to validate the gathering of all the information and data, this researcher needs to clarify the process of data collection in a suitable manner.

According to Saunders et al. (2009), the research strategy is really important because it will enable the researcher to answer the research questions and meet objectives. The implementation of a research strategy is guided by the research objectives and questions, philosophy underpinning the research, the existing knowledge, as well as the amount of available time and other resources. Three conditions can be used to select the appropriate strategy for the research (Yin, 2009), which are:

1. the type of research question;
2. the control of the researcher over behavioural events; and
3. the degree of focus on contemporary issues as opposed to historical events.

Robson (2007) recommended research strategy in social science research should typically comprise the selection of one from three established methodologies, namely an experiment, a survey, or a case study. Furthermore, Blismas (2001) added another category of methodology, which is action research, thus making it four research strategies as viable options to address questions posed in social science research. Additionally, Sexton (2003) categorised research design into five main research strategies, namely ethnography, surveys, experiments, action research, and case studies.

The terms of research strategies defined under the "onion" model (Saunders et al., 2009; Tobi, 2017; Nawi, 2012) adopted for this research, seven main strategies to indicate ways of conducting research were established, namely survey, experiment, action research, case study, ethnography, grounded theory, and archival research. Yin (2009) also listed five different types of research strategies such as survey, experiments, archival analysis, case study, and historical.

Based on the literature review (Yin, 2009; Saunders et al., 2008; Sexton, 2003; and Blismas, 2001; Nawi, 2012; Tobi, 2017), eight main strategies were identified, namely experiment, case study, survey, action research, grounded theory, archival research, history, and ethnography, as guidelines to be considered in this research.

2.6.3.1 Strategy Adopted for this Research

As discussed earlier, the research concerned is built around a "what" type of research problem, which is related to processes within nanotechnology organisations. This study investigated relationships among stakeholders involved in the nanotechnology industry. Therefore, it does not intend to observe behavioural patterns or the psychology of participants, or to test relationships between the research variable and the dependent variables through manipulation, where an ethnographic and experimental approach would have been beneficial. For instance, an experiment deliberately divorces a phenomenon from its context; attending to only a few variables which are typical in experiments, where the context is "controlled" by the laboratory environment. A historical study by comparison does deal with the entangled situation between phenomenon and context, but usually with "non-contemporary" events.

Furthermore, since the process of this study requires information from different participant viewpoints, based on the reality of actual experience and practice (realism ontological stance), this research will not deal with any historical data as described in the history strategy section of this dissertation. Although this research is positioned toward an inductive approach, the theory to be developed is based on direct interaction and corporate views (knowledge gained from current of practices and experiences) among the multiple stakeholders and experts, but it is not based on prediction or explanation of observed behaviour as implied in grounded theory. This research approach is also in contrast with the characteristics of action research which requires the involvement of practitioners who specifically collaborate with the researcher or become part of the study. It can, therefore, be assumed that experiment, grounded theory, action research, ethnographic, and historical method are all inappropriate strategies to be applied in this research, if the aim and objectives are to be met.

In addition, this research also concentrates on contemporary events, but does not demand control of variables of the environment, but rather favours an uncontrolled environment. All these criteria are associated with survey, archival research, and case study strategies. As highlighted earlier, the purpose of this research focused more on an explanatory approach which is limited to identifying the problems that exist in the nanotechnology industry but at the same time, to recommend a generated solution for the problems in order to enhance the Malaysian nanotechnology industry. In addition, the case study was used to answer questions of "why" as well as "how" based on explanatory and exploratory research. This strategy involves an empirical investigation of that particular issue to gain a rich understanding and insight into the context of the research and the processes being enacted (Saunders et al., 2009; Creswell, 2007; Yin, 2009).

In addition, archival research focuses on secondary data which is very often used in combination with other strategies during the data collection process. This strategy also applies a quantitative method in order to analyse all archival data, either in quantitative or qualitative research.

Since the aim of this study is to gather qualitative data by answering the questions of "what" (to explore and understand the context of a number of variables—the problems of nanotechnology industry and CSFs for effective nanotechnology industry development) and "how" (to investigate and acquire in depth information and explanation for which data is collected about problems and CSFs descriptions), therefore, this research requires a thorough review of literature to be used as secondary data and combined with primary data (explanative data) derived from investigations into the industry (via an industry interviews).

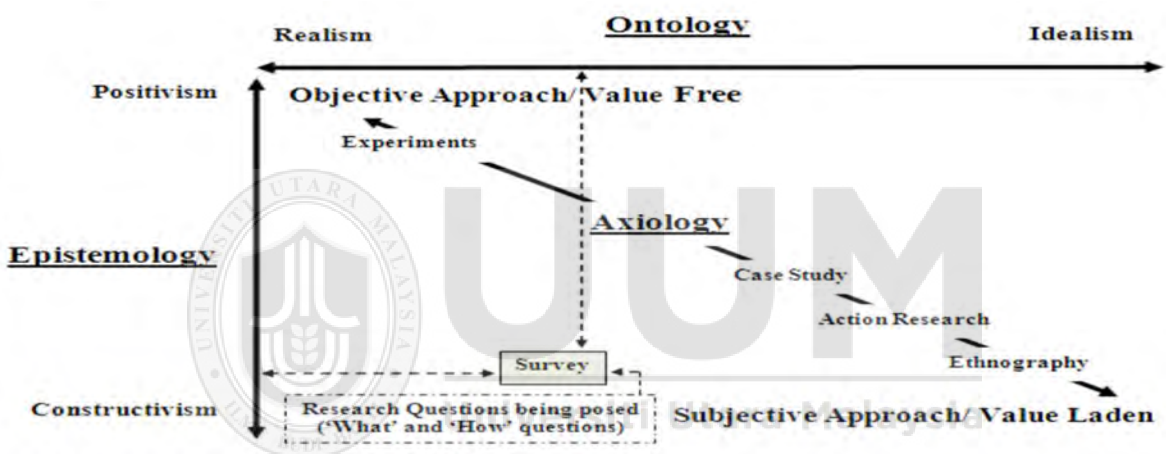

Figure 2.6
Position of Research Paradigm for this Research
Source: Sexton (2007); Yin (2003)

In this regard, the survey method (interview based) is considered as the most appropriate strategy for this study rather than the case study method or archival research (Figure 2.6). Detailed explanations of the data collection process based on the survey research strategy will be discussed further.

2.6.4 Research Choices

Saunders et al. (2009) claimed that the choice of research topic guides the researcher into the selection of appropriate research techniques and analysis procedures. There are three types of research choices in social and business management research, namely mono-method, multi-method, and mixed-method. All the methods can be used by the researcher either as a single data collection technique and corresponding analysis procedure (mono-method), or to use more than one data collection technique and analysis procedures (multiple-methods), or use both quantitative and qualitative data collection techniques and analysis procedures to answer the research questions or meet the research objectives (mixed-methods) (Saunders et al., 2009).

Previous research (Grix, 2010; Yin, 2009; Saunders et al., 2009; Creswell, 2009; Sarantakos, 2005; Bryman, 2001) maintained that the terms of quantitative and qualitative data have been used widely in social and management research in order to distinguish both data collection techniques (such as workshops, questionnaires, or observation) and data analysis procedures (such as discourse analysis; narrative analysis data). The terms of quantitative data, for example, it is used to describe the type of information that can be counted or expressed numerically (Creswell, 2009). This type of data is often collected in experiments, manipulated, and statistically analysed to focus on numbers and frequencies rather than on meaning and experience. Typically, it describes patterns and trends in size and quantity through the visualisation of graphs, histograms, tables, and charts. In contrast, qualitative data relies on text and images of the data which are concerned with describing the meaning, rather than with drawing statistical inferences (Creswell, 2009). Qualitative data provides deep and rich descriptions of people's knowledge, attitudes, or behaviour (Saunders et al., 2009).

Both of them have their own techniques or methods of data collection. In quantitative research for example, the researcher can use techniques, such as, questionnaires, archival records, and experiments in the data collection process (Bryman, 2004; Sarantakos, 2005; Saunders et al., 2015).

Table 2.16
Strengths and Weaknesses of Data Sources

Data source	Strengths	Weaknesses
Documentation	• stable - can be reviewed repeatedly • unobtrusive - not created as a result of the case study • exact - contains exact names and reference and event details • broad coverage - long time span, many events and settings	• irretrievability - can be high biased selectivity from incomplete collection • reporting bias - reflecting unknown author bias • access- can be restricted
Archival records	• same strengths as documentation • precise and quantitative	• Same weaknesses as documentation accessibility due to privacy reasons
Interviews	• targeted - directly focussed on case study • insightful - provides perceived causal inference	• biased if question are poorly constructed • biased response likely • inaccuracies when recollection is poor • reflexivity - interviewee gives what interviewer wants to hear
Direct/Non-time participant observation	• reality - covers events in real time • contextual - covers the context of the event	• Expensive and time-consuming • can be selected unless broad coverage • reflexivity - events may proceed differently from what is being observed
Participant observation	• same as for direct observation • insight into interpersonal behaviour and motives	• same as for direct observation • bias due to investigator's manipulation of events
Physical artefacts	• insightful into cultural features • insightful into technical operation	• Selectivity • Availability

Source: Yin (2009)

Yin (2009) listed a further six types of qualitative data which includes; documentation, archival records, interviews, direct observation, participative observation, and physical artefacts. According to him, these sources have strengths and weaknesses and no single source has complete advantage over the other (refer Table 2.16).

2.6.4.1 Justification of the Adopted Research Choice

As highlighted previously, this study is descriptive with the focus on exploring and structuring existing practices in order to develop a framework of CSFs for effective nanotechnology industry development in Malaysian nanotechnology industry. Accordingly, this study investigated the related pertinent issues in order to appreciate and understand its practice. Therefore, the data for this study leans more towards qualitative (subjective) not a quantitative (objective) approach. This means that this research is associated with qualitative research that is based on theory building (inductive) and will not be involved in any creation and subsequent testing of a theory or hypothesis, which is related to quantitative research (Amaratunga et al., 2002).

Since the aim of this study is to answer the questions of "what" and "how" (where the investigation requires in-depth information and explanation of the current problems and the finding of a solution), therefore, this research employed the survey technique as the main strategy for the qualitative primary data collection process and used the literature review as the main source of secondary data. This study, therefore, gathered soft, descriptive, and less structured data (qualitative data), as the researcher intended to gather deep and rich information from multiple views of Malaysian nanotechnology stakeholders (knowledge based experience) through interviews. Accordingly, all the secondary sources of data relating to historical data or which focuses on non-contemporary events (e.g., archival records) will not be relevant and therefore, will not be used in this study. The strategy of this research however, does not focus on investigation or exploration of interpersonal behaviour, attitude, and motive, and thus disqualifies any sources related to observations for being used in this study.

Furthermore, the nature and duration of the study does not allow involvement in confidentiality issues and physical artefacts are not used as a data source either. Since the philosophical stance of this research is interpretivism, a combination of research methods (literature review and verbal surveys), which align with the interpretive research philosophy was used to meet the aim and objectives of this study.

Therefore, following the above discussion the research approach will follow a qualitative multi data collection technique using a corresponding analysis procedure (multi-method qualitative studies) and appropriate research time horizons which are discussed in the following.

Previous researchers (Easterby-Smith et al., 2008; Robson, 2002) highlighted that cross-sectional studies are often employed when using a survey strategy. This research sought to describe the incidence of a phenomenon or to explain how factors are related in different organisations. For example, many survey studies have been conducted based on group interviews over a short period of time such as Delphi studies and workshops. Therefore, it could be used in either quantitative or qualitative methods.

On the other hand, longitudinal research is based on a long term period of study. According to Nawi (2012), the main strength of this research (longitudinal study) is the capacity it has to study change and development. The best example of this research comes from outside the world of business. It is based on the study of several years duration aimed at gaining rich sources of data for the development a new theory. Following the above descriptions of time horizons, a cross-sectional study is a more relevant time horizon for adoption, based on the researcher's time and resource constraints.

Based on the "onion" research methodology model adopted for this research, the research techniques occupy the inner most ring (layer) of the model and are influenced by the other five layers including the research approach and philosophy. Research techniques and procedures in this context refer to the method used for data collection and analysis.

2.6.4.2 Modified Delphi Technique

The Delphi method or Delphi technique, also known as Estimate-Talk-Estimate or ETE) is a structured communication technique or method, originally developed as a systematic, interactive forecasting method which relies on a panel of experts (Brown, 1968; Dalkey & Helmer, 1963; Linstone & Turoff, 1975; Sackman, 1974). The technique can also be adapted for use in face-to-face meetings, and is then called mini-Delphi or Estimate-Talk-Estimate (ETE) method. Delphi has been widely used for business forecasting and has certain advantages over another structured forecasting approach, prediction markets (Green Armstrong, & Graefe, 2007).

This technique is an iterative process, and first aims to get a broad range of opinions from the group of experts. The results of the first round of questions, when summarised, provide the basis for the second round of questions. Results from the second round of questions feed into the third or more rounds. The aim is to clarify and expand on issues, identify areas of agreement or disagreement and begin to find consensus.

More specifically, the Delphi technique is based on the principle that forecasts (or decisions) from a structured group of individuals are more accurate than those from unstructured groups (Rowe & Wright, 2001). The experts answer questionnaires in two or more rounds. After each round, a facilitator or change agent (McLaughlin, 1990) provides an "anonymised" summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the "correct" answer. Finally, the process is stopped after a predefined stop criterion (e.g., number of rounds, achievement of consensus, stability of results), and the mean or median scores of the final rounds determine the results (Rowe & Wright, 1999).

For this research, the Modified Delphi Technique was employed as the tool to systematically gather the required data to achieve the research objectives as well as address the research questions that were formulated for this study. According to Haughey (n.d.), the steps in original Delphi Technique include, 1) choosing a facilitator, 2) identify experts, 3) define the problem, 4) round one questions, 5) round two questions, 6) round three questions, and 7) act on findings.

However, for the Modified Delphi Technique employed in this study had the following steps, 1) choosing a facilitator: this researcher, 2) identify experts: list of nanotechnology certified companies as provided by NanoVerify Sdn. Bhd., the sole company responsible for certifying nanotechnology companies in Malaysia, 3) define the problem: why is nanotechnology development slow compared to other countries?, 4) round one questions: main data collection interviews with companies, 5) round two questions: verification interviews with research institutions and government agencies, and 6) act on findings: this report.

2.7 Underpinning Theories

Underpinning theories are referred to, by Gregor (2002) as theories for understanding social context in studies. The theories are intended to explain "how" and "why" things happen in the way that they do. The theory which underpins a study is often viewed as a lens. In Orlikowski (2000), the word "lens" is used in the sense of assessment, where certain features are focused upon and emerge, and where the rest of the picture falls into the background. Lenses are used as an analytical tool to aid interpretation and analysis of data in research. The analysis of the data determines and shapes the results of the study. The analysis of data is fundamental to any study. Hence, the tool (theory) used in the analysis is deemed critical. How data is collected and analysed is within the frame of the theory which underpin the study (Mkhomazi & Iyamu, 2013).

One of the significance factors of underpinning theories is that they encompass both technical and social contexts within phenomena under study. A theory which underpins a study is characteristically relied upon for rationales such as:

1. To help exhume the dependence and relationships which exist among actors within an environment.
2. Provides guidance in the interpretation of empirical data which was gathered over time and within a context.

3. Creates awareness of social events, processes and activities which takes place in the development, implementation and practice of information technology and systems.
4. Reduces the gap of assumptions and prediction of actions within a context.

The use of socio-technical theory to underpin a study could be viewed as the heart (core) of a research. The theory helps to shape the result of the research, through its understanding of the socio-technical contexts that are involved. In this research, the underpinning theories that were identified to explain the phenomenon under study included the Resource Based View and Diffusion Theories, both of which are described in greater detail in the following sections.

2.7.1 Resource Based View (RBV) Theory

Resource Based View (RBV) is an essential part of strategic management. It lays emphasis on the fact that the internal capabilities of a firm make it competitive, mainly entailing the firm's capabilities and different resources. Indeed, it is the utilisation of these resources that adds value to the firm. Barney's 1991 article "Firm Resources and Sustained Competitive Advantage" (Barney, 1991) is widely cited as a pivotal work in the emergence of the RBV. However, some scholars argue that there was evidence for a fragmentary resource-based theory from the 1930s. RBV proposes that firms are heterogeneous because they possess heterogeneous resources, meaning firms can have different strategies because they have different resource mixes.

During the 1990s, the RBV (also known as the resource-advantage theory) of the firm became the dominant paradigm in strategic planning. RBV can be seen as a reaction against the positioning school and its somewhat prescriptive approach which focused managerial attention on external considerations, notably industry structure. The so-called positioning school had dominated the discipline throughout the 1980s. In contrast, the RBV argued that sustainable competitive advantage derives from developing superior capabilities and resources.

RBV is an interdisciplinary approach that represents a substantial shift in thinking (Fahy & Smithee, 1990). The resource-based view is interdisciplinary in that it was developed within the disciplines of economics, ethics, law, management, marketing, supply chain management and general business (Hunt, 2013).

RBV focuses attention on an organisation's internal resources as a means of organising processes and obtaining a competitive advantage. Barney (1991) stated that for resources to hold potential as sources of sustainable competitive advantage, they should be valuable, rare, imperfectly imitable and not substitutable (now generally known as VRIN criteria) (Barney, 1991). RBV suggests that organisations must develop unique, firm-specific core competencies that will allow them to outperform competitors by doing things differently (Prahalad & Hamel, 1990).

Although the literature presents many different ideas around the concept of the resource-advantage perspective, at its heart, the common theme is that the firm's resources are financial, legal, human, organisational, informational and relational; resources are heterogeneous and imperfectly mobile and that management's key task is to understand and organise resources for sustainable competitive advantage.

However, despite its appealing nature, the Resource Based Approach has faced a lot of criticism from diverse scholars globally. The resource-based view is founded on various concepts. First, inputs into the production process are determined by resources, which form the fundamental units of analysis (Royer, 2005, p. 95; Jones & Tilley, 2003, p. 124). The most common categories in which resources are grouped include the human resource, fiscal resources, technology related resources, reputation based resources, and organisational/industrial ones.

However, most resources offer very weak competitive value when applied on their own. Thus, both collaboration and coordination of resources from different categories are required to obtain a competitive and productive activity. Furthermore, strategic capabilities can result from bundles of resources. What an organisation can do effectively and better compared to its competitors is what constitutes its capabilities (Lengnick-Hall, 2003, p. 168).

Moreover, capabilities are embedded in cumulative skills and knowledge that are practised through organisational process to enable a firm not only to coordinate its functions, but also to utilise its assets. The capabilities of a firm are based on its resources. A firm’s main competitive advantage is founded on its resources (Remenyi, 2008, p. 80; Birkinshaw, 2000, p.103). To attain long-term success, most firms are supposed to be excellent in several aspects of value creation such as having developing insight in the dynamic client needs, responding promptly to advancement in technology, designing products with an innovative touch, being efficient and responding to problems quickly.

The resource based view focuses on organisational internal abilities that enable it to it achieve a sustainable competitive advantage in its markets and industries through formulation of a suitable strategy. Based on the ability to see an organisation as one that is endowed with resources and capabilities that can be configured to enable it have a competitive advantage, then an inside-out perspective is enhanced (IvyPanda, 2019). Put in different words, the way it competes in its external environment is determined by its internal capabilities. In some cases, both the creation of new markets and addition of value to the consumer may be the direct results of the organisation's capabilities.

Resources refer to inputs, without which, an organisation will not be able to carry out its operations. Cases of organisations in the same industry having varied levels of performance may be attributed in the varying ways in which they utilise their resources. Organisations do not receive any added value from resources that lie idle within them. Value only comes after putting the resources to some productive use. Resources can be classified as either as either tangible or intangible (Henry, 2008, p. 127; Karami, 2007, p. 160). An organisation's physical assets such as its physical, fiscal and human resources are what constitute its tangible resources. Intangible resources comprises of an organisation's intellectual, technological, cultural resources, brands and reputation (IvyPanda, 2019).

For this research, the Resource Based View (RBV) has been identified as the underpinning theory, which can explain the phenomena that is being oberved occurring in the nanotechnology industry. This industry, although having seen as having a great potential of contributing toward the economy and society at large, is seen to be lagging behind its counterparts in the more developed nations.

2.7.2 Diffusion of Innovation (DOI) Theory

Diffusion of Innovation (DOI) is the process by which an innovation is communicated through certain channels over time among the members of a social system (Rogers, 1995). The theory seeks to explain how innovations are undertaken by population within a context. DOI is aimed at making voluntary decisions to accept or reject an innovation which is based on the benefits that they expect to accrue from their own independent use of technology.

Rogers proposes that four main elements influence the spread of a new idea: the innovation itself, communication channels, time, and a social system. This process relies heavily on human capital. The innovation must be widely adopted in order to self-sustain. Within the rate of adoption, there is a point at which an innovation reaches critical mass.

In 1962, Everett Rogers, a professor of rural sociology, published his seminal work: Diffusion of Innovations. Rogers synthesized research from over 508 diffusion studies across the fields that initially influenced the theory: anthropology, early sociology, rural sociology, education, industrial sociology and medical sociology. Using his synthesis, Rogers produced a theory of the adoption of innovations among individuals and organisations.

DOI and Rogers' later books are among the most often cited in diffusion research. His methodologies are closely followed in recent diffusion research, even as the field has expanded into, and been influenced by, other methodological disciplines such as social network analysis and communication (Rogers & Shoemaker, 1971; Easley & Kleinberg, 2010).

The key elements in DOI research are:

1. Innovation – This is a broad category, relative to the current knowledge of the analysed unit. Any idea, practice, or object that is perceived as new by an individual or other unit of adoption could be considered an innovation available for study.
2. Adopters – These are the minimal unit of analysis. In most studies, adopters are individuals, but can also be organisations (businesses, schools, hospitals, etc.), clusters within social networks, or countries (Meyer, 2004).
3. Communication channels – Diffusion, by definition, takes place among people or organisations. Communication channels allow the transfer of information from one unit to the other. Communication patterns or capabilities must be established between parties as a minimum for diffusion to occur (Ghoshal & Bartlett, 1988).
4. Time – The passage of time is necessary for innovations to be adopted; they are rarely adopted instantaneously. In fact, in the Ryan and Gross (1943) study on hybrid corn adoption, adoption occurred over more than ten years, and most farmers only dedicated a fraction on their fields to the new corn in the first years after adoption.
5. Social system – This is the combination of external influences (mass media, surfactants, organizational or governmental mandates) and internal influences (strong and weak social relationships, distance from opinion leaders) (Strang & Soule, 1998). There are many roles in a social system, and their combination represents the total influences on a potential adopter.

Peres, Muller, and Mahajan (2010) suggested that diffusion is "the process of the market penetration of new products and services that is driven by social influences, which include all interdependencies among consumers that affect various market players with or without their explicit knowledge".

Meanwhile, Eveland (1986) evaluated diffusion from a phenomenological view, stating that, "technology is information, and exists only to the degree that people can put it into practice and use it to achieve values".

Diffusion of existing technologies has been measured using "S curves". These technologies include radio, television, VCR, cable, flush toilet, clothes washer, refrigerator, home ownership, air conditioning, dishwasher, electrified households, telephone, cordless phone, cellular phone, per capita airline miles, personal computer, and the Internet. These data can act as a predictor for future innovations (Moore & Simon, 1999). Diffusion curves for infrastructure reveal contrasts in the diffusion process of personal technologies versus infrastructure.

2.8 Chapter Conclusion

This chapter has set the backdrop for this research through a brief description of the setting in the nanotechnology industry in Malaysia and its development towards the realisation of the national goals as a developed and industrialised country by year 2020. However, based on its current levels of quality, productivity, safety and slow uptake by the consumers, the nanotechnology industry is not in line with the future development of Malaysia. As a result, the Malaysian government has taken the initiative to promote the premium nanotechnology products as a long term advantageous alternative to the traditional products. Despite the well-documented benefits in other countries and strong support from the Malaysian government, the take-up for nanotechnology products in not as high or as rapid as anticipated. In an attempt to understand this slow-uptake, some researchers have investigated the barriers to effective nanotechnology industry development implementation in the industry. One of the main barriers facing the Malaysian nanotechnology industry is related to poor awareness amongst consumers, as well as the "silo" and non-collaborative approach by industry players to develop their own technology. The next chapter will discuss all the research design and methodology to investigate the issues related to the nanotechnology industry.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Introduction

In order to meet the established objectives of this research, this chapter presents the narrative in the search for an appropriate research design and methodology. There is a plethora of available research strategies and methods, each with its own strengths and weaknesses, and the challenge is to select the most appropriate for this study (as described in the previous Chapter 2). All the decisions that were made had to be based on the information gathered through a review of the available research strategies and methods. These decisions were made to tailor the best research design to this research.

3.2 Methodological Framework

A qualitative study is appropriate when the goal of research is to explain a phenomenon by relying on the perception of a person's experience in a given situation. As outlined by Creswell (2014), a quantitative approach is appropriate when a researcher seeks to understand relationships between variables. Because the purpose of this study was to examine the perceptions of nanotechnology practitioners and developers regarding the development of the nanotechnology industry, the qualitative approach was deemed most appropriate. As such, a strategic approach was required to attempt to answer the research questions developed for this study by achieving the established objectives. The methodological framework that was devised for this study is illustrated in Figure 3.1, which consists of the literature review stage, exploratory stage, data collections stage, framework development stage, validation stage, and last but not least, recommendation state.

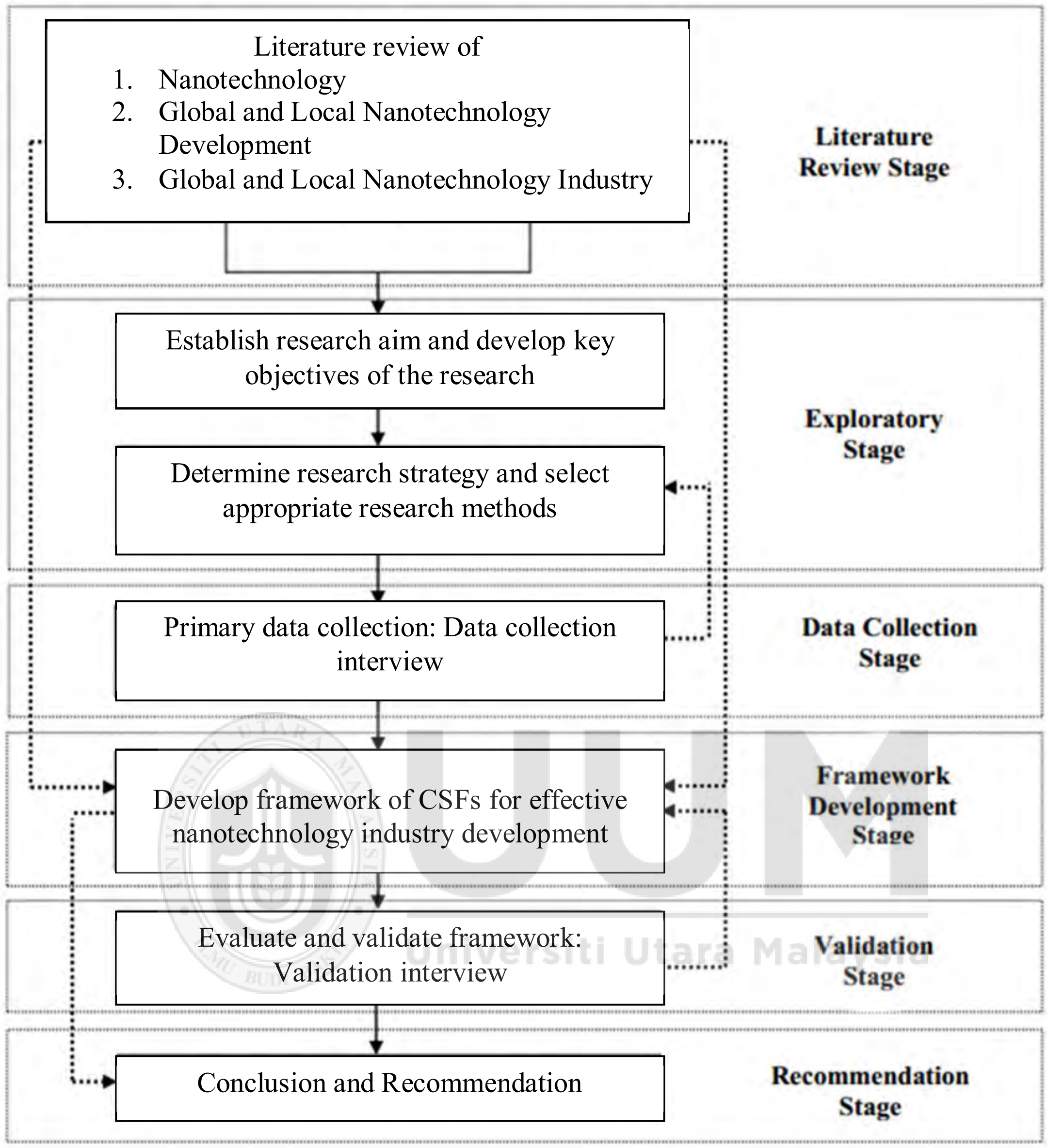

Figure 3.1
Research Methodological Framework Process Flow for this Research
Source: Nawi (2012)

3.3 Method of Data Resources Adopted for this Research

Many scholars like Ghauri and Gronhaug (2005), and Churchill (1999) recommend that all research should start with secondary data sources. This secondary data refers to any information or literature that has been collected and recently published. Saunders et al. (2009)

categorised the data into three main groups; documentary, multiple source, and survey (refer Figure 3.2).

According to them, documentary secondary data is often used in research projects as a primary data collection method. These methods can also be used either on their own or with other sources of secondary data. The examples of documentary secondary data are written material or documents such as notices, correspondence (including email), minutes of meetings, books, journals, magazine articles, newspapers and dairies (Saunders et al., 2009).

On the other hand, primary data is refers to newly collected data (raw data) that has been generated from multiple research techniques of data collection including observations, questionnaires, and interviews (Saunders et al., 2009; Sarantakos, 2005; Bryman & Bell, 2007).

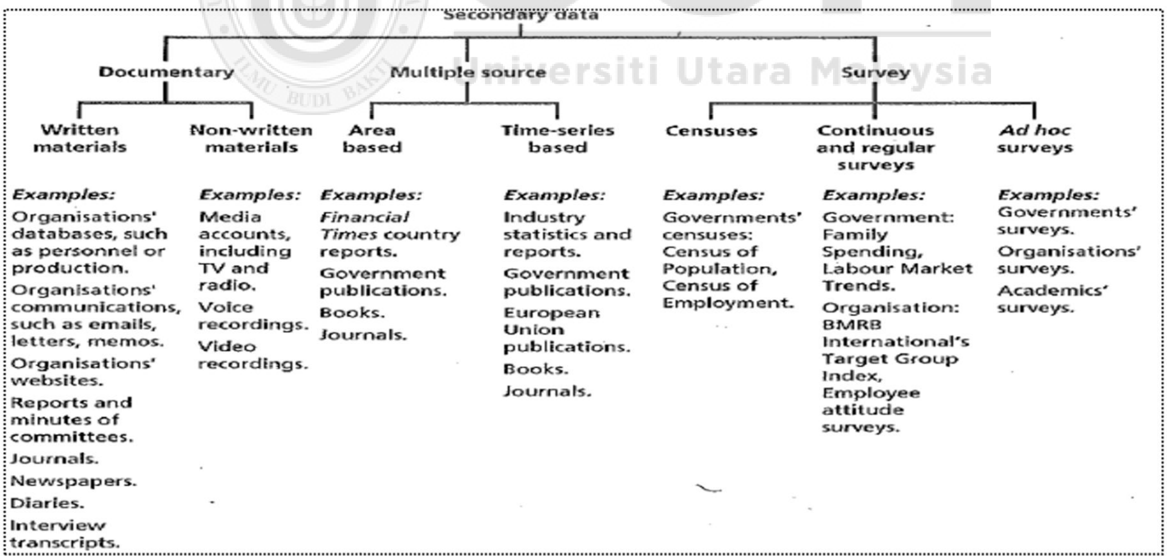

Figure 3.2
Types of Secondary Data
Source: Saunders et al. (2009)

As discussed in the literature review, this research used qualitative multi data collection techniques as the main source for primary and secondary data. Based on its strengths and weaknesses, interview was identified as the main method to be used for the primary data collection process while the literature review has been used as a main source for the secondary data in this research. The next section will discuss both of these methods in detail.

3.3.1 Data Source 1 – Literature Review

There are two objectives in conducting the literature review for this study; to identify a research gap and to gather secondary data for the research (Chapter 2). In identifying a research gap, the literature review was conducted to gain a comprehensive understanding of the research topic. The literature review explored published information and data (reports, statistics, websites, journals, books, etc.), including the process of its implementation, design, and barriers. The information found that the main barriers to the nanotechnology industry are related to the lack of top management support, lack of awareness, lack of communication, cultural barriers, investment cost, excessive government intervention and regulation, lack of infrastructure, lack of technical professionals, lack of in-house technological capabilities, organisational resistance, and consumer/market forces (Kapoor & Abid, 2014; Khurana, Khan, & Mannan, 2013). The discussion of these issues than facilitated an initial background understanding of the topic and concept, from which recommendations can be made to formulate an appropriate strategic framework to overcome the problem.

Further literature review was performed to gather more information on the viable recommendations to overcome these problems. The process involved a comprehensive literature review of secondary source of data including reports, concepts, principles and guidelines. All the documentation has been thoroughly reviewed in order to identify the critical success factors (CSFs) for developing a framework for effective nanotechnology industry development implementation in the Malaysian nanotechnology industry.

Unfortunately, the findings from the literature review, which explored frameworks, concepts, principles or strategies, identified varying advantages and disadvantages, and this has obviously caused some confusion for industry practitioners, especially for Malaysian nanotechnology industry players and stakeholders when choosing the best or most appropriate approach for improving development, management, and practices.

In addition, Bell (1991) warned that secondary data has the disadvantage of becoming out-of-date, as well as not being appropriate for the precise needs of a particular research problem. Furthermore, Mohammad (1999) also claimed that secondary data by itself cannot meet the specific needs of particular situations, problems or settings, and it is essential to obtain primary data to overcome this shortcoming. Therefore, this research needs to generate a study of the industry in order to gather primary data to be combined with secondary data from the literature review.

3.3.2 Data Source 2 – Data Collection Interview

The secondary data from the literature review needs to be combined with primary data in order to be comprehensive, up-to-date, and appropriate for the precise needs of particular situations in this study. Accordingly, interviews were conducted to gather primary data (to support the existing current secondary data) for the development of a framework for effective nanotechnology industry development practices in Malaysian nanotechnology industry.

There are several researchers (Holter, Johansen, Ness, Brinkmann, Hoybye, & Brendryen, 2019; Alshenqeeti, 2014; Edwards & Holland, 2013; Esch & Esch, 2013; Maxwell, 2009) who recognise interviews as a highly effective and experiential method of data collection and validation process in the qualitative research. However, the literature and information source of this technique, such as definition, criteria and guideline for implementation are varying. Kvale (1996, p.174) defined an interview as “a conversation, whose purpose is to gather descriptions of the [world] of the interviewee”, in relation to the interpretation of the meanings of a phenomena that is being investigated. Similarly, Barbour and Schostak (2005) added that an interview is “an extendable conversation between partners that aims at having ‘in-depth information’ about a certain topic or subject” (Alshenqeeti, 2014), by which a phenomenon under review can be interpreted in terms of the meanings interviewees bring to it. Meanwhile, Nawi (2012) stated that an interview is defined as a purposeful discussion between two or more people to gather valid and reliable data that is relevant to the research objective. Using interviews can help a researcher to gather valid and reliable data relevant to the research questions and objectives. The interview technique has two main categories (Figure 3.3) known as standardised (structured) and non-standardised (semi-structured and unstructured/in-depth) (Fellows & Liu, 2015; Alshenqeeti, 2014; Nawi, 2012; Saunders et al., 2009). So, the interview is a valid and flexible qualitative research technique involving the participant to share his/her experiences, perceptions, opinions, beliefs, and attitudes based on topics that are determined by the researcher or interviewer.

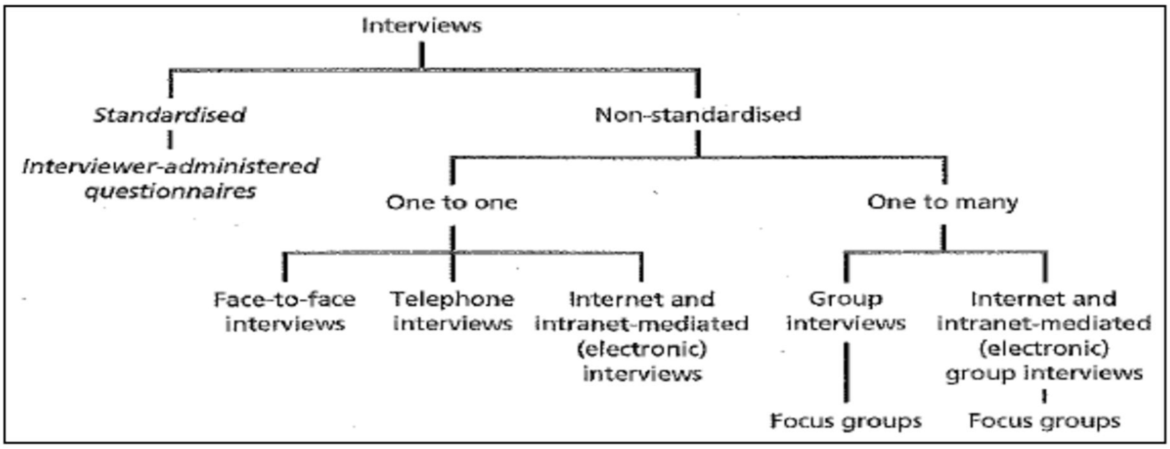

Figure 3.3
Forms of Interviews
Source: Nawi (2012)

Structured interviews (standardised) are based on a specific predetermined set of techniques, and often the questions are asked in a specific sequence (Keraminiyage, 2009). In this type of interview, a standardised set of questions are used with little scope for probing an interviewee's responses by asking supplementary questions to obtain more details about some interesting aspects. Conversely, unstructured interviews (non-standardised) are often conducted within an informal setting with the aim of exploring a general area (broad topic) in depth, without a predetermined list of questions or guidelines, and allowing the interviewee to freely communicate their ideas on the subject (Nawi, 2012; Saunders et al., 2009; Fellows & Liu, 2015). Marshall and Rossman (1989) stated that structured interviews are more suited to be used where there is a particular phenomenon with many generalisations, whereas unstructured interviews provide the facility to investigate a problem in more depth.

On the other hand, semi-structured interviews (non-standardised) fill the spectrum between the two approaches (Fellows & Liu, 2015; Nawi, 2012). Within semi-structured interviews, the researcher would have a list of themes and questions to be covered (Saunders et al., 2009; Nawi, 2012), and the area being researched would be more specific than in unstructured interviews. Furthermore, the questions are predetermined and formal interview guidelines are present but the order and wording can be modified when appropriate (Keraminiyage, 2009). The interviews are used to clarify and provide more detail on issues that were observed. Other major advantages of semi-structured interviews are their adaptability, as a skilful interviewer can follow up ideas, probe responses, and investigate motives and feelings, which is not possible using a questionnaire (Bell, 1991). The high degree of interaction in semi-structured interviews further allows and makes it possible for the interviewer to know "how" as well as "why" a particular process occurred as it did.

In addition, the types of interview can also be differentiated on the nature of interaction between the researcher and participant involved in the session. Some interviews are "one-to-one" where a single participant is interviewed face to face, by telephone or electronic means. However, "one-to-many" refers to sessions where a researcher conducts non-standardised interviews with several respondents at one time or namely as group interview (Nawi, 2012; Saunders et al., 2009; Sarantakos, 2005).

For the purpose of this study, based on those criteria, it clearly shows that interview is appropriately categorised under the research interview technique which is a subcategory of individual interview. Another reason is that the candidates for interview were not open to focus group or group interviews due to their conflicting schedules, as well as obvious stated reluctance to share information with possible rivals in the nanotechnology industry.

During the data collection stage in this research, the industry interviews involved organised discussions within selected company representatives from the upper management so that they are able to give a birds' eye view of the industry from their position as well as to gain in depth information about their views and reactions to the topic. To minimise the impact of bias or prejudice in terms of information and data gathering during the interviews, it was decided that the interviews were to be held at the interviewees' workplace at their convenience.

In an attempt to obtain the most effective environment, at the beginning of the interview session, the participant was briefed about the objectives of the interview as well as the ethical procedures which would protect the participants' confidentially and anonymity. Moreover, the interviewer tried to manage and maintain the situation by ensuring that all contributions to the interview were treated equally and also encouraged the interviewees to become share their views of each points raised. According to Gibbs (1997), one way that an interviewer can convey respect and encourage participation is through the use of an effective introductory statement. The introduction should communicate the purpose for which the interviewee had been called, why the participant was selected, the ground rules for the interview, and the opening question. Most importantly, the introduction should make the interviewee feel comfortable and welcome.

Accordingly, an interviewer needs to conduct a properly managed interview session that can provide a unique perspective and can produce ideas that lead to innovative solutions as well as possible improvements. The interviewer need to also keep the session focused and may sometimes have to steer the conversation back on course. At the same time, the interviewer is encouraged not to show too much approval (Edwards & Holland, 2013), so as to avoid favouring particular statements. The interviewer must avoid giving personal opinions so as not to influence the interviewee toward any particular position or opinion (Nawi, 2012).

For example, throughout all the interview sessions, sometimes there were several occasions when the discussion was veering off topic, thus perhaps not focusing more on the issues on hand. Concerned about this trend, the experienced interviewer tried to address this situation by controlling the focus of discussion and not allowing it to drift in order to ensure that the interviewee had every chance to speak more on the topic. On occasions, the interviewer used the "probe technique" or moved things forward when the conversation drifted or became difficult. The probe is simply a question or statement which encourages the interviewee to add to or elaborate on something which was said. According to Gibbs (1997), this technique is a common and effective method used by most interviewers to elicit responses from interviewees who may be reluctant to contribute more information to the discussion.

Additionally, the interviewer may employ the “pause technique” in order to prepare the environment for effective conversation and to manage the conversation so that the delicate balance between outcome and genuine dialogue is maintained. The pause is simply a period of silence after the question is asked (Nawi, 2012). Although a five-second pause may seem awkward to the inexperienced interviewer, it is usually successful in encouraging a response from the interviewee who would be willing to break the silence. All the techniques highlighted above are important in order to ensure that the interviewees have the competency, particularly in the work discipline, to discuss every issue throughout the entire interview session.

The primary data from data collection Interviews has been combined with secondary data based on the literature review in order to develop a framework of CSFs for effective nanotechnology industry development practice implementation in the Malaysian nanotechnology industry. Furthermore, the same technique (using some of the same respondents from data collection interviews) was used during the validation stage to evaluate and validate the framework in the Malaysian nanotechnology industry.

Several questions were asked in each section of the interview sessions to check for common views and to explore differences between each interviewee.

3.3.2.1 Interview Aim and Objectives

The aim of the interviews was to enhance the current literature review of the CSFs. Therefore, the main objective of these interviews was to provide insight into the perceptions (experience-based) gained from various nanotechnology practitioners in the Malaysian nanotechnology industry. It focused on the barriers to successful nanotechnology industry development and discusses its potential use to improve current practice in Malaysian nanotechnology industry. In addition, these interviews served as a platform for the researcher to examine the acceptance of this approach among nanotechnology practitioners in order to solve the current problems and barriers in the Malaysian nanotechnology industry.

To achieve the objectives stipulated above, the interviews adopted a semi-structured discussion approach among participants which centred on the drivers, benefits, barriers, and solutions to the Malaysian nanotechnology industry. As highlighted by Abukhzam (2011), this method of data collection assists in the revision and refinement of the current literature review identified from various sources such as internet websites, academic books, research journals and other documented reports. Finally, the analysis of the data from these interviews will be combined with the information that was identified from the literature in order to develop a framework of critical success factors (CSFs) for effective nanotechnology industry development in Malaysian nanotechnology industry. The development of the framework will be discussed in the next chapter.

3.3.2.2 Selection of Interview Participants

The interview appointments were made by the researcher himself based on the list of certified nanotechnology companies provided by NanoVerify Sdn. Bhd. The appointments were confirmed with nanotechnology practitioners from the list via their respective contact persons. Several criteria were used for the selection of the participants for interviews. Firstly, the participants should have at least five years working experience involving the local nanotechnology industry. This criterion is to exclude inexperienced individuals involved in Malaysian nanotechnology industry, as they perhaps would not be able to identify the appropriate CSFs. In addition, the participants must possess the required qualifications, knowledge, and skills relevant to the field.

This selection criterion is important in order to ensure that the participants have the competency, particularly in the work discipline, to discuss every issue in the entire interview session.

Table 3.1
List of Participants and Background Information for the Data Collection Interviews

ID	Position	Experience	Sector	Product	Gender
R1	Senior Staff Researcher	17	Electronics	Carbon nanotubes	Female
R2	Senior Executive	9	Agriculture	Fertiliser	Male
R3	Senior General Manager R&D	10	Cosmetics	Gold serum	Male
R4	Chief Operating Officer	13	Textiles	Nano-hybrid socks	Male
R5	Managing Director	15	Home Appliances	Gold coating	Male
R6	President	7	Agriculture	Compound fertiliser	Male
R7	Senior R&D Engineer	7	Cosmetics	Gold moisturiser	Male
R8	Senior General Manager R&D	11	Home Appliances	Nano glass filter media	Male
R9	Chief Technology Officer	8	Textiles	Nano silver fabric	Male
R10	Managing Director	9	Home Appliances	Nano selenium filter	Male
R11	Assistant Managing Director	6	Automotive	Nano quartz coating	Female
R12	Managing Director	10	Home Appliances	Nanogel	Male
R13	Managing Director	8	Automotive	Engine lubricants	Male
R14	Managing Director	14	Textiles	Nano-hepa face mask	Male
R15	Managing Director	12	Textiles	Nano-shirt	Male

Source: This Research

Based on the selection criteria discussed above, 15 respondents were identified as suitable and invitation letters were sent to them two weeks prior to the date of the interview. Due to time availability and other circumstances, 15 respondents agreed for an interview, but all these interviews had spanned over a period of almost a month (27 days). Due to issues of confidentiality and anonymity, it was decided that the names of the participants in this study would not be disclosed, and the use of generic codes (e.g., R1 represents the first respondent, R2 represents the second respondent, and so on) were employed to identify the participants. The list of the interview respondents is shown in Table 3.1.

3.2.2.3 The Interview Process

With the permission of the respective participating companies the interviews were conducted on site at the respective companies from 16th August 2018 to 12th September 2018. The interview locations were mainly in meeting rooms or in the respondents' office. After introducing himself to the participants, the researcher gave a briefing on the objectives of the interview as well as the ethical procedures which would protect participant confidentiality and anonymity. Following this, the questions were forwarded to the participants by the researcher, highlighting the importance and purpose of the study. The researcher performed the role of the interviewer and note taker simultaneously to record vital information which transpired in the interview discussions. The details of the interview questions, in terms of the terminology, were verified and approved by NANOVerify prior to the interviews. The process used for gathering the data from the interviews has been discussed previously earlier in Chapter 3. The next section will discuss the analysis of the findings from the interviews.

3.3.3 Data Source 3 – Validation Interview

The validation interviews were conducted, successfully, on 11 January 2019 to 29 January 2019 at the various locations where the respondents were situated. The selection process of interview respondents followed the same criteria as employed in data collection interview sessions; participants should have at least five years of work experience, have been actively involved in the nanotechnology industry, as well as being knowledgeable and familiar with nanotechnology. The criteria for selection of the participants were the same as to provide continuity of discussion to the research. It was envisaged that this event would augment the findings from the previous interviews.

Accordingly, 60 respondents were identified that matched the selection criteria from academia and research centres as well as government agencies, and invitation letters were sent to them by using the same process and procedures as the data collection interviews. However, compared to the previous interviews, these validation interviews received 23 respondents who agreed to be interviewed.

From these 23 positive responses, only 17 respondents were successfully interviewed, as five respondents had changed their minds, or agreeable meeting times were not able to be made. The 17 interviews were performed on various individuals ranging from managing directors, to senior researchers who were from research institutes, certification bodies, administrative bodies, and other organisational representatives who are actively involved with nanotechnology development in the industry. Due to issues of confidentiality and anonymity, their identities shall not be disclosed and they were assigned a code for easy reference. The list of the interview respondents and background profile is shown in Table 3.2.

During the interviews, this author performed the role of a note taker to record vital the information that transpired from each group. A recording was also made, when consent was given, whenever possible.

Each validation interview began with an introduction by the researcher about himself to the respondent, followed by a briefing on the objectives of the interview as well as the ethical and anonymity procedures of the research. Subsequently, the aims of the validation interview were achieved by asking each respondent to discuss three main topics; the challenges or problems faced during nanotechnology industry development; the approach towards improving the nanotechnology industry; and the need of a framework of critical success factors in enhancing and facilitating the Malaysian nanotechnology industry. The validation interviews involved 17 sessions, all of which were captured by the researcher either by note-taking and/or recording with prior respondent consent. The discussion with the respondents is part of the validation process of the framework.

Table 3.2
List of Participants and Background Information for the Validation Interviews

ID	Position	Experience	Organisation	Gender
V1	Managing Director	12	Certification	Male
V2	Director	11	Research Institute	Male
V3	R&D Coordinator	7	Research Institute	Male
V4	Research Officer	9	Government Agency	Male
V5	Senior Research Fellow	12	Government Agency	Female
V6	Director	9	Research Institute	Male
V7	Professor	15	University	Female
V8	Senior Lecturer	8	University	Male
V9	Deputy Director	10	Research Centre	Male
V10	Managing Director	19	Government Agency	Male
V11	Manager	8	Certification	Male
V12	Research Officer	8	Research Centre	Male
V13	Researcher	7	Research Centre	Female
V14	Researcher	11	University	Male
V15	Managing Director	17	Research Institute	Male
V16	Associate Professor	12	University	Male
V17	Chief Technology Officer	10	Research Centre	Female

Source: This Research

All feedbacks, debates, and discussion points during the interviews were audio and manual recorded by the researcher. Recordings were transcribed verbatim for analysis. The same technique as data collection interviews (Thematic/ Coding Analysis) was used to analyse the data to form descriptive information and also to ascertain a pattern of responses from the respondents throughout the duration of interviews. These patterns were cross-checked with the framework, and any differences or similarities were then used to refine the reliability of the final framework and conclusion. The next section will discuss the analysis of the findings from the interviews.

3.4 Objectives of the Study Addressed through Data Collection

Table 3.3 shows how the objectives are addressed through the data collection methods. After a thorough discussion on the data collection techniques, the following section tackles the techniques of data analysis.

Table 3.3
Objectives of the Study and the Mode of Investigation

Objectives	Method of Investigation		
	Literature Review	Data Collection Interviews	Validation Interviews
a) to investigate the existing scenario of the nanotechnology industry, particularly in current and future outlook as well as its barriers to implementation in the Malaysian industry;	✔		
b) to identify the critical success factors associated with nanotechnology industry development;	✔	✔	
c) to develop a framework of critical success factors (CSFs) for nanotechnology industry development in Malaysian nanotechnology industry; and	✔	✔	
d) to validate the critical success factors of nanotechnology industry development in Malaysian nanotechnology industry.			✔

Source: This Research

3.5 Data Analysis

Burns (2000) indicated that the purpose of analysing data is to find meaning, and this is done by systematically arranging and presenting the information. Easterby-Smith et al. (2002) however, deduced that, in making the data collected to become meaningful to the study, a clear explanation of how the analysis is done and a demonstration of how the raw data is transformed into a meaningful conclusion is required. Although there is no standardised procedure for analysing qualitative data, according to Nawi (2012) and Saunders et al. (2009), it is still possible to group data into three main processes: summarising (condensation) of meanings; categorisation (grouping) of meanings; and structuring (ordering) of meanings using narrative.

Summarising a qualitative study involves condensing the meaning of large amounts of text into fewer words. On the other hand, categorising involves two activities; developing categories and, subsequently, attaching these categories to meaningful chunks of data; whilst structuring commonly involves the reduction in the amount of interview text and it may also be expanded as the narrative of what happened is developed (Nawi, 2012; Saunders et al., 2009). As aim of this study was to identify the CSFs for effective nanotechnology industry development practice implementation, therefore, categorisation (grouping) of meanings is significantly appropriate to be applied in this research. This approach deals with data that involves the creation and application of "codes" or "theme" (Castleberry & Nolen, 2018; Maguire & Delahunt, 2017; Nawi, 2012). "Coding" refers to the creation of categories in relation to data from all kinds of "places" (e.g., theory, literature, research experience, the data itself); the grouping together of different instances of datum under an umbrella term that can enable them to be regarded as "of the same type" (Miles & Hurberman, 1994). In practice, the coding process of qualitative data can be analysed using inductively and deductively based analytical procedures (Nawi, 2012; Saunders et al., 2009). Since this research adopts an inductive approach, therefore the discussions of qualitative data collection in this study will focus on inductively based analytical procedures, such as data display and analytic approach; grounded theory; discourse analysis; narrative analysis; and template analysis.

According to Miles and Huberman (1994), data display and analytic approaches consists of three concurrent sub-processes; data reduction, data display drawing, and verifying conclusions. This approach involves organising and assembling data into summary diagrammatic or visual displays such as matrices and networks (Nawi, 2012). Miles and Huberman (1994) argued that these forms of display are relatively easy to generate and allow the researcher to make comparisons between the elements of the data and to identify any relationships, key themes, patterns and trends that may be evident.

The term grounded theory strategy refers, in particular, to "theory building" which is helpful for the researcher to predict and explain behaviour, the emphasis being upon developing and building theory through an induction approach (Goulding, 2002). According to Charmaz (2006), in developing theory, this strategy applies simultaneous processes for data collection and analysis. Saunders et al. (2009) explained that the process of data collection starts without the formation of an initial theoretical framework, whereas theory is developed from data generated by a series of observations. Charmaz (2006) further identified a two-step coding process for analysing data using grounded theory; line-by-line open coding (substantive); and theoretical coding. Corbin and Strauss (2008) also elaborated that the disaggregation of data into units is called open coding, whereas the process of recognising relationships between categories is referred to as axial coding, and the integration of categories to produce a theory is labelled selective coding.

Alba-Juez (2009) refers to discourse analysis as the linguistic analysis of naturally occurring connected speech or written discourse. Discourse analysis is a general term that covers an extremely wide variety of approaches to the analysis of language in its own right and is concerned with how and why language is used by individuals in specific social contexts

(Nawi, 2012; Saunders et al., 2009). In particular, it explores how language (discourse) in the form of talk and text both constructs and simultaneously reproduces and/or changes the social world rather than using it as a means to reveal the social world as a phenomenon (Nawi, 2012). Based on the above discussions, discourse analysis, therefore, focuses on understanding how language is used to construct and change aspects of the world.

According to Saunders et al. (2009), the implementation of narrative analysis depends on the research questions and objectives, the data collection methods used and the data that is produced, either as the principal means to analyse qualitative data, or as complementary means. From the human science perspective, narrative analysis refers to a family of approaches to diverse kinds of texts, which have in common a storied form (Allen, 2017). This technique mainly focuses on written or oral texts, but can also be used to analyse photographs, films, or even dance performances (Riessman, 2008). Research that focuses on the role of narrative usually involves life story research or oral history such as the sequence of events (Griffin, 1997). The structural elements that are present in narratives may also help the researcher to analyse each narrative account and perhaps to compare the course of events in different narratives where there is likely to be some analytical benefit in their comparison (Saunders et al., 2009). Most narrative studies limit the number of narratives analysed, and presents the findings in the form of case studies (Allen, 2017).

In addition, one of the common approaches to analysing qualitative data is called "template analysis" originated by King (2004). Template analysis refers to the process of organising and analysing textual data according to "codebook analysis" or "thematic coding" (Crabtree & Miller, 1999). It is a form of thematically organising and analysing textual data that focuses on using the textual content to describe a phenomenon (King, 2006). Saunders et al.

(2009) further described that the essence of the approach is that the researcher produces a list of codes or categories ("template") that represent the themes or issues revealed from the data that has been collected. This code is very important to the researcher for the interpretive process. As discussed by King (2004), some of the codes will usually be defined a priori, but they will be modified and added to, as the researcher reads and interprets the texts. In contrast to other techniques, template analysis is a flexible technique with less specified procedures that permits researchers to tailor it to match their requirements. It works particularly well when the research aim is to compare the perspectives of different interviewees within a specific context (King, 2006).

The aim of the interviews however, does not focus on understanding how language is used to construct and change the world or seek to identify relationship between themes or to compare aspects of the findings. This research is not involved with life story research, oral history, or case study such as the sequence of events by constructing and testing a set of causal links between events, actions, etc. in one case, and the iterative extension of this to further cases.

At the same time, this research does not deal with diagrammatic or visual displays such as matrices and networks during the organising and assembling of data. This research has, however, been particularly focused on identifying the barriers to nanotechnology industry development and has attempted to gain detailed explanation to obtain a deeper understanding of the problem.

Furthermore, the researcher intended to gather and update information from the background setting of the Malaysian nanotechnology stakeholders in order to fill the gap which exists in the current literature on CSFs for effective nanotechnology industry development. This clearly justifies that "template analysis" is a significant and most appropriate technique for use in analysing the qualitative data from this research. As highlighted by King (2006), the term "template analysis" refers to a particular way of thematically analysing qualitative data. The detailed steps of analysing qualitative data by using template analysis in this research are highlighted in the next section.

3.5.1 Analysis Process of this Research

This section elaborates on the development of the analytical template and illustrates how it aligns with this research. King (2006) developed three analytical stages (Figure 3.4) for analysing interviewees transcripts in a research study; creating the initial template; revising the template; finalising the template. According to the same author, the starting point for creating the initial template is the interview agenda that includes the set of question areas, probes, and prompts used by the researcher. The topic guide is drawn from multiple sources that particularly relate to the study, such as academic literature, the researcher's own personal experience, anecdotal and informal evidence, and exploratory research. Once the initial template is constructed, it must then be revised by the researcher in order to reveal any inadequacies that arise within the template.

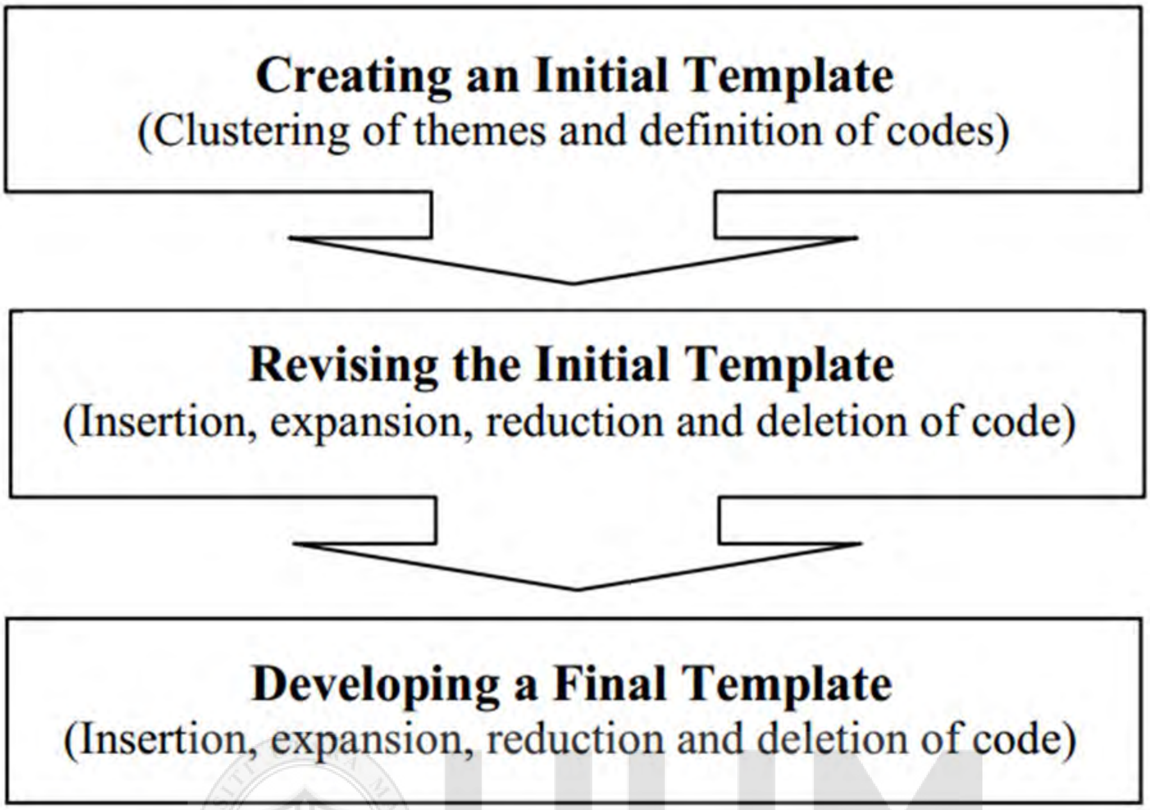

Figure 3.4
The Steps of Template Analysis
Source: King (2006)

Modifications to the template usually take one or more of the following forms; insertion, deletion, expansion, or changing the scope, and changing high-order classification (King, 2006; King 1998). The most difficult decision during the process of developing the template is the final stage, also known as "developing the final template". This is because the researcher has limited time in which to produce the "ideal" template (King, 2006). Commonly, the template could be considered final when most or all of the data (transcripts) has been read through at least three or four times, and when the researcher is confident that the template is accurate.

Details of processes are necessary for creating the initial template, revising the initial template, and creating the final template analysis for this research, which are explained in the following.

Preliminary coding is related to defining “themes” and “codes”, which are the two main processes in the development of an initial template analysis. According to King (2018), themes are “features of participants’ accounts characterising particular perceptions and/or experiences that the researcher sees as relevant to the research question” while coding refers to the “process of identifying themes in accounts and attaching labels (codes) to index them”. In this research, the data analysis process began by translating the interview transcripts from recordings (the interviews were mostly conducted using the Malay language with some use of English) from Malay to English. The transcripts were read manually and data was coded by hand (using colour coding) to help ease the cumbersome process of conventional coding. This kind of collaborative strategy could increase the efficiency of the analysis since the development of the template occurs simultaneously to the coding process (King, 1998). However, according to King (2004), there is a danger during this process of neglecting some aspects of the data. Therefore, all the transcripts were re-read several times to ensure that all the themes relating to this investigation were highlighted and that nothing was omitted.

The next step involves the grouping or clustering of themes and definition of codes. Template analysis normally starts with some predefined codes or use of priori themes as a guide for the analysis process. King (2004) however, suggested that the use of priori themes should be restricted as far as possible so that as little as possible of the data is neglected. This is because a large number of priori themes might restrict the effect and prevent the exploration of more pertinent issues during the analysis process (King, 2018; Nawi, 2012).

On the other hand, too many codes may lead to an overwhelming mass of rich and complex data (Nawi, 2012). Taking this into account, the researcher defined key themes based on the questions and the initial review of the interview transcripts.

However, some of the themes had been identified earlier based on the literature review that focused on critical success factors (CSFs) for the success of nanotechnology industry development. The process of identifying some themes in advance is common in template analysis and is usually referred to as "priori" themes (King, 2018). It creates an advantage in terms of accelerating the initial coding phase of the analysis, which is normally very time-consuming (Nawi, 2012). The researcher, however, must always be aware that the purpose of developing predefined codes is for use as a guideline and not aimed at influencing the researcher to make a decision (the process should be transparent and not biased toward specific themes or codes) during the analysis of the primary data findings. As a result, the initial template was developed as shown in Figure 3.5.

In revising the initial template, King (1998) described that once the initial template is completed, it needs to be developed further until the researcher feels that it gives as good as a representation as possible of the themes identified in the data. This iterative process involves insertion, deletion, changing the scope and changing the higher-order classification of a theme.

In creating the final template, King (2006) noted that there is no stage where the researcher can say with absolute certainty that the template is "finished." It is because there are always others ways of interpreting any set of qualitative data (King, 2011).

INITIAL TEMPLATE FOR TECHNOLOGY MANAGEMENT IMPLEMENTATION IN NANOTECHNOLOGY INDUSTRY

- HUMAN RESOURCE
  - LOCAL SKILL LEVEL VERSUS OVERSEAS
  - HUMAN CAPITAL DEVELOPMENT
    - SCHOOLING EDUCATION
    - TERTIARY EDUCATION
  - TECHNICAL EXPERTISE AND KNOW-HOW TRANSFER
- INFRASTRUCTURE AND UTILITIES
  - HIGH TECHNOLOGY PARK
  - RELIABLE AND GUARANTEED UTILITIES
  - COLLABORATIVE RESEARCH FACILITIES
- CONSUMER AWARENESS
  - PUBLIC AWARENESS CAMPAIGNS
  - FOCUSING ON BENEFITS INSTEAD OF TECHNOLOGY
  - LONG TERM BENEFITS VERSUS CHEAPER TRADITIONAL ALTERNATIVES
- REGULATORY FRAMEWORK
  - PRODUCT VERIFICATION/CERTIFICATION
  - PARLIAMENTARY ACT
  - GOVERNMENT SUPPORT
  - FINANCIAL INCENTIVES

Figure 3.5
Initial Template from Preliminary Coding
Source: This Research

Abukhzam (2011) stated that one of the most difficult decisions faced by the researcher is when to stop the analysis. Although it very difficult to finalise the completed template it easier to make a decision when the research was conducted by a group. The researcher must make a pragmatic decision about when to stop the development process otherwise the writing up process cannot be started. On the other hand, the template could be considered final when most or all of the data (transcript) has been read thoroughly.

According to King (2006), the researcher needs re-read at the template at least three or four times to look for material that was not successfully encompassed in the initial template and change the template, where necessary, and to know when to stop the development of the template. The final template is presented in Figure 3.6.

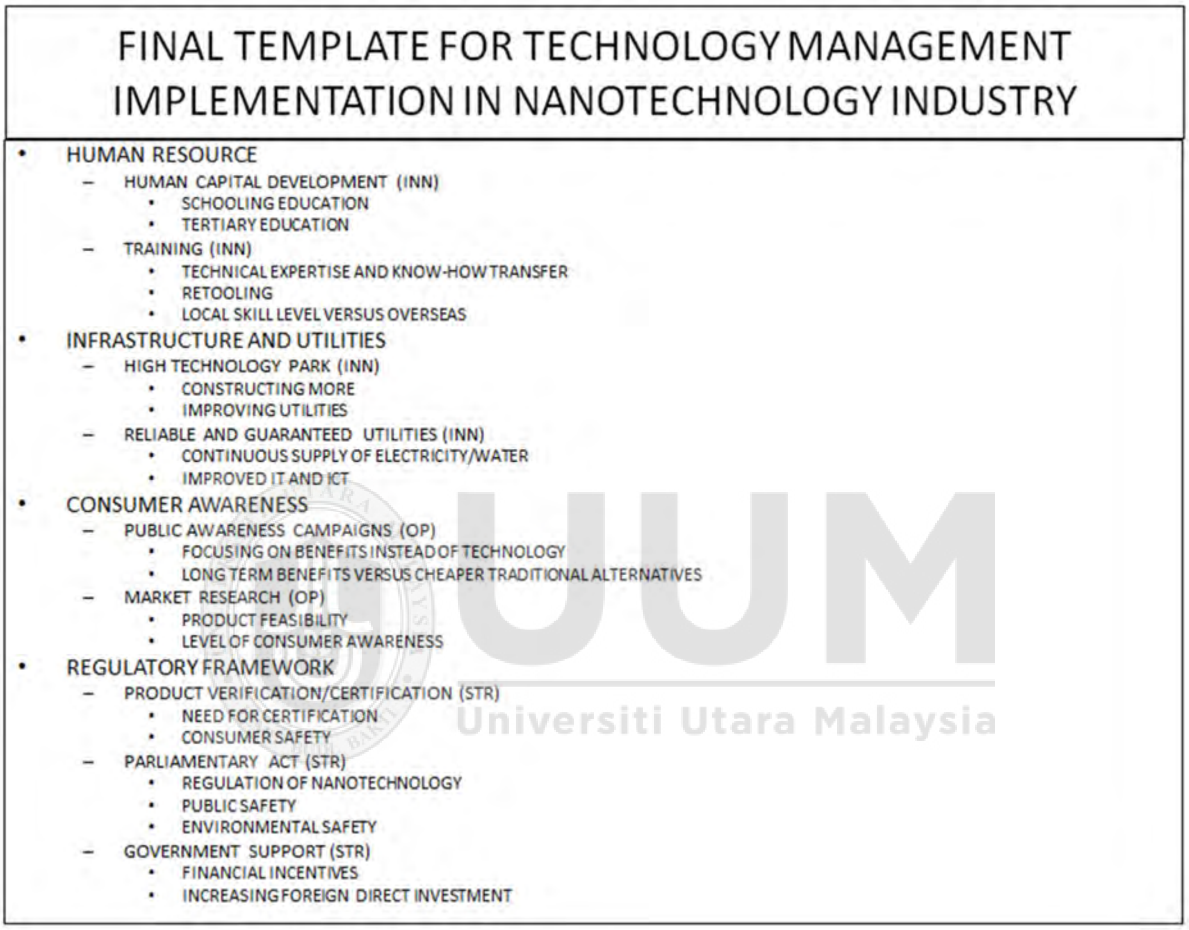

Figure 3.6
Final Template of CSFs for Nanotechnology Industry Development
Source: This Research

The themes highlighted in Figure 3.6 emerged from the researcher's interpretation of the interview transcripts and were constantly revised until all the relevant sections of the transcript had been scrutinised in the coding process and were deemed to be satisfactorily represented in the analysis.

It is important, nonetheless, to give a brief explanation as to how the themes were created during the analytical process. The following quotation transcribed from participant R8 is an example of the analysis and the coding process using a portion of the interview transcript.

"*Make sure everything, when the graduate enters the industry, retooling is not required. Retooling is very expensive.*" – Respondent R8

The text contained a number of factors (themes) related to this study, in this case, in relation to the factors of tertiary education and retooling. From the researcher's observation of the transcript, participant R8 highlighted the issues of ensuring that the education system is sufficient enough and capable of producing graduates that can fit the industry. This also is linked to the retooling factor, an issue that needs to be addressed and can be alleviated by the human capital development element. The researcher vigilantly read the extract and highlighted the themes that were related to the categories that were identified in Figure 3.10 and then assigned each theme to the appropriate category. Themes that were not related to the initial categories were given another category name.

Throughout this section, it shows that template analysis resides in the fact that it is a highly flexible approach that can be modified for the needs of any study in a particular area. It also produces the template and forces the researcher to take a well-structured approach to handling the data, which can be a great help in producing a clear, organised, final account of study (King, 2006).

3.5.2 Coding Process of this Research

Previous researchers (Abukhzam, 2011; Kvale, 1996) described coding as a process of breaking down, examining, conceptualising, contextualising and categorising data to yield new concepts, categories and theories from the phenomenon investigated. This process can be conducted either manually (by hand) or with the use of the qualitative research software such as NUD*IST (Non-numerical Unstructured Data: Indexing Searching Theorizing) and NVivo. As highlighted by Buchanan and Jones (2010), NVivo is a powerful tool to aid the researcher in examining possible relationships amongst themes.

Smith and Hesse-Biber (1996) pointed out that software is used mainly as an organising tool and to decide whether to code the data either manually or mechanically. Basit (2003) however believed that since qualitative research involves a smaller sample and does not deal with large datasets, NVivo is less useful and does not require a great deal of time for analysis like quantitative research. Even though most of the computer-assisted data analysis software that is used to organise data in a systematic way is capable of perceiving a links between theory and data; it still requires the researcher's analytical skills, vision and integrity to produce an analytical and theoretical explanation (Catterall & Maclaran, 1997; Buchanan & Jones, 2010).

As the number of questions and data sets were mangeable, the researcher decided there was no inherent need for NVivo. Therefore, all the data from this research was managed manually by using manual coding techniques in respect of the transcript from the interviews. This involved the manual identification of key research themes and topics that emerged from the interview transcripts as being potentially significant to the phenomena being studied.

3.6 Framework Definition

Prior to proceeding with the definition of the proposed framework, it is important to illustrate the different meanings of the term framework as it is used within the scientific world. The term framework is used in a variety of situations that are often sufficiently different to necessitate a clear understanding of what is meant by this term. According to Paim and Flexa (2011), "framework" can be defined as a set of concepts used to solve a problem in a specific domain. The same author further defines a framework as a conceptual structure that enables different business objects to be framed and treated homogeneously. Meanwhile, Sekaran (2000) defined the term "framework" as a conceptual model of how one theory makes logical sense of the relationships amongst the several factors that have been identified as important to the problem.

Within the management sector, Wiig et al. (1997) defined a framework as a set of guiding principles and a methodology that can be thought of as a specific, detailed description of how to carry out the ideas and objectives. In this dissertation, a framework provides a view of how to improve the nanotechnology industry by bringing out explicitly the critical success factors (CSFs) for effective nanotechnology industry development implementation in the Malaysian nanotechnology industry. The framework was developed based on a critical appraisal of the literature with regard to the key factors in this respect, and on a comprehensive analysis of the findings of data collection interviews conducted by the researcher. Therefore, the proposed framework can be defined as a set of factors that are critical for the Malaysian nanotechnology industry towards effective nanotechnology industry development implementation.

The literature review identified several main barriers to enhance the nanotechnology industry. In a report prepared by McNeil, Lowe, Mastroianni, and Cronin (2007), one of its main findings was that there is lack of employees with the specific skills needed for the research and development (R&D) of nanotechnology. The report revealed that a large company "usually has only several people working in nanotechnology R&D so it is difficult to get the attention of company management and budget funding". Because of this phenomenon, these large companies would benefit by investigating the R&D landscape of small organisations, but usually they have limited time and personnel to investigate the many universities and government laboratories to try and determine what kinds of R&D are available and the potential benefits if they invested in those R&D projects.

Previous reports (Hashim et al., 2009; ATIP, 2006) had indicated that the Malaysian public is not ready in terms of expertise and training. This is further emphasised upon during the interview, where the "manpower" is sorely lacking in Malaysia.

Since human capital is a crucial issue, the research team members started an initial probing into the education system, which had revealed an interesting phenomenon. The call for improving and enhancing the workforce from the nanotechnology standpoint has been received by the various education institutions, and a movement toward improving the future of nanotechnology workers can be observed.

Meanwhile, infrastructure availability is crucial to assist businesses, especially small companies that cannot afford the cost of nanotechnology instrumentation, equipment and facilities (McNeil et al., 2007). Nanotechnology virtually demands university and industry cooperation due to basic science innovations, expensive laboratories, and need for highly trained workers.

McNeil et al. (2007) further added that researchers involved in nanotechnology R&D who are working at transforming their scientific innovations into prototypes, "do not have access to their own private workshop or other independent facilities separate and apart from the university laboratories". In a private workshop, the researcher would be able to, "transform scientific theory into practical applications that might qualify for new patents that they would own" (McNeil, 2007).

Any form of technology, more so for nanotechnology, public or consumer awareness is pertinent in making the technology acceptable and usable by all walks of life. This is critical for companies to ensure that their product is accepted by the public. The public needs to know all the facts and figures, so to speak, in order to come to their own conclusion in accepting the technology or otherwise.

Various researchers originating from different sectors had performed research to investigate the importance of consumer awareness in promoting a technology (Viscecchia, De Devitiis, Carlucci, Nardone, & Santeramo, 2018; Boatman & Chaplan, 2018; Yolcu & Dyehouse, 2018; Sahin & Ekli, 2013). These researchers had the same ultimate concern, which was nanotechnology awareness in their respective areas, including food, education, construction and others.

Recent evidence shows that nations find it difficult to build a sound science-based regulatory framework, and thus there are currently no specific regulations on nanotechnology food applications either in EU, USA, or elsewhere (Coles & Frewer; 2013; Magnuson et al., 2013). In addition, there is a lack of universal guidelines specifically developed for the safety and environmental assessment of nanotechnology food applications, even though experts from around the globe are working in bringing an international dimension and harmonization to "nanometrology" and standardization of approaches (Magnuson et al., 2013; Schoonjans & Chaudhry, 2017). However, according to Viscecchia et al. (2018), the current lack of a clear governance framework and consequent regulatory uncertainty makes it difficult for developers and manufacturers to know what, if any, regulations should be complied with, and what risk assessments, if any, are appropriate.

According to Karim, Munir, and Yasin (2014), there is no denying of the potential promises that nanotechnology can bring to the world, as well as enhance mankind, however, "there are many concerns on the safe application of this technology". From the legal prospective, Karim et al. (2014) had stated that hundreds of papers have already been written on health and environment concerns and safety issues regarding this technology. Apart from the laboratory researches, there are many researches which are conducted on animals and the adverse effects of this technology were noticed. Furthermore, in much of the research, concerns were expressed that the people who are directly in contact with the technology i.e., the researchers and the workers are in real danger. Therefore, the law should intervene to regulate this technology.

3.7 Chapter Conclusion

The chapter discussed the philosophy that underpins the research and the choices made in the research approach, strategy, and technique. The approaches and strategies available to the researcher were highlighted and clarification of the reasons why those choices were made for the research was discussed. Philosophically, this research adopts the interpretivism epistemological paradigm and the constructivism ontological position. The main differences between the inductive and deductive research approaches were highlighted and the reasons for choosing an appropriate research strategy were also justified.

A qualitative verbal survey design in the form of interviews was selected due to the need for an in-depth explanation necessary to generate data and validate the developed framework in this research. Finally, the execution of the interview technique for collecting primary data and the use of "template analysis" for analysing the data was also documented.

Fundamentally, the research proceeded in three stages. At the first stage (exploratory stage), an in-depth literature review of the issues in nanotechnology industry development (details are presented in Chapter 2). The second stage of the research involves the development of a framework to improve nanotechnology industry development. The framework for the nanotechnology industry development was developed based on the data collected from the in-depth literature review and data collection interviews. The third stage was to validate the developed framework. A second round of validation interviews was used to validate the draft framework of CSFs for effective nanotechnology industry development in the Malaysian nanotechnology industry.

Semi-structured interviews were used as data collection techniques. Furthermore, this qualitative data collected was analysed using an inductively based analytical procedure called "template analysis". Details of the processes for developing and validation the draft framework are presented in Chapter 4. Figure 3.7 below summarises the research methodology implemented in this research.

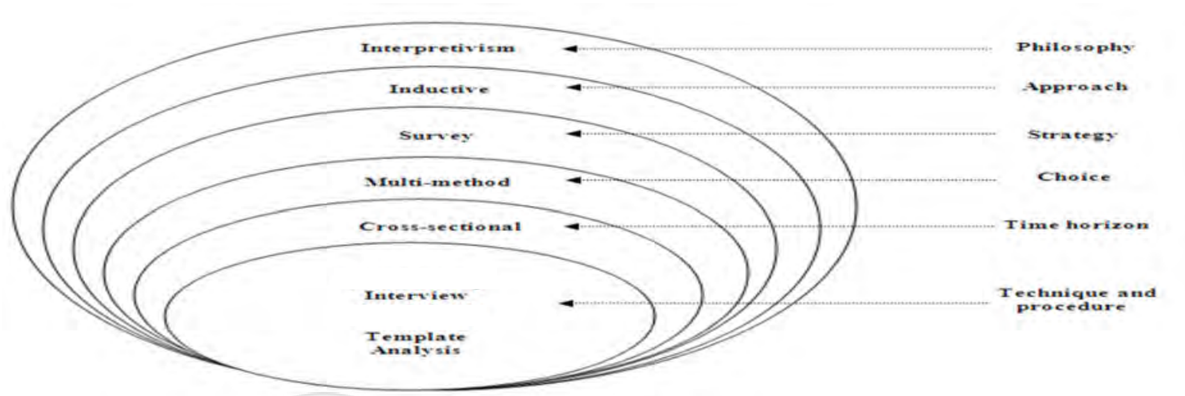

Figure 3.7
Summary of Research Methodology for this Study
Source: This Research

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

Chapter 2 presented the literature which identified the critical success factors (CSFs) for effective nanotechnology industry development integration in the nanotechnology industry. This chapter focuses on the analysis of the findings (primary data) gained from the first round of interviews among the players in the nanotechnology industry. The structure of this chapter is as follows: section 4.2 discusses the results of the data collection interview, whilst section 4.3 provides the framework development, and finally the validation interview results (section 4.4) are presented to support the developed framework.

4.2 Analysis and Discussion of Findings from the Data Collection Interviews

The aims of the interviews were to aid and improve the current literature review relating to the critical success factors (CSFs) of nanotechnology industry development. All the findings will be used in the development of a framework of critical success factors (CSFs) for effective nanotechnology industry development in the Malaysian nanotechnology industry. The findings of the interview analysis are discussed below.

4.2.1 Findings for Question 1 – The Challenges of Nanotechnology Industry

In terms of the challenges or problems faced by the nanotechnology industry, the question: "What are the challenges or problems that you face in the Malaysian nanotechnology industry?" was asked in order to gain an understanding of the issues that exist from the perspective of nanotechnology practitioners.

4.2.1.1 Human Resource Issues

Overall, all of the respondents were in full agreement that there is a shortage of skilled workers in the nanotechnology industry in Malaysia.

Respondent R1 has held the position of senior staff researcher for 17 years and is well versed in nanotechnology, especially in his specialised field of electronics. Respondent R1 gave examples of large projects that wanted to come into the country, which did not eventuate because of the problem of lack of expertise in the human capital at that time. Even though the approval was given by the Minister of International Trade and Industry at that time for bringing in all the required expertise from overseas to Malaysia, the company had opted to open up its expansion in Singapore, our neighbouring country instead. The respondent had expressed disappointment because the fabrication facilities (also known as "fabs") are large businesses which can churn out profit in a short time, even though the start-up costs is phenomenal when compared to industries of a similar size.

> "*So at that time, there was one of the biggest player in the microelectronic industry in the world, that is TSMC [Taiwan Semiconductor Manufacturing Company Limited] from Taiwan, they are the biggest. In microelectronic fabrication and microelectronic chip producer, they are the biggest…what they need from us, besides the infrastructure, utilities support, and all this, it was manpower. At that time we were not prepared to provide the required manpower. So because of the lack of manpower, they changed their minds and moved to Singapore*" – from R1 interview.

Respondent R1 had given a reason for this, where the bottom-line is different when comparing Malaysia to other countries, such as Singapore, when it comes to technology. Respondent R1 said that, "*Singapore different… they focus on the technology. We [Malaysia] still more toward the FDI… for the survival of Malaysia*".

The issue of manpower is especially a critical one, because, in one example that respondent R1 gave, a foreign company was understandably reluctant to bring the company to Malaysia because of the lack of skilled manpower. Even with the offer of allowing the foreign company to bring in an unlimited number of skilled workers through a deal with the government, but the company declined and took its FDI elsewhere, with the main reason being too expensive.

> "*I still remember, the minister offered by saying they can bring as many engineers as they want from their home country, no limitation, but they declined as they would have to pay double*" – from interview with R1.

Another example that been highlighted by respondent R14 was the scenario in China, where they have 400,000 trained nanotechnology workers, which is why the USA find it viable to invest in and open up their business in that country. Furthermore, the key to capable human capital in servicing the nanotechnology industry is that it needs to be based on a stable and solid education. Other examples given were Russia, Iran, and several other settings. Respondent R1 had recommended the following:

> "*We have to prepare our manpower. If you look at China, they have nanotechnology… if I am not mistaken, they have about 400,000 [strong workforce], that is why America is very happy to move to China, because they do not have this problem… because manpower is a crucial*" – from R1 interview.

Meanwhile, respondent R10 highlighted that that the nanotechnology industry requires first class students. This is because due to the nature of the industry, the human capital for the nanotechnology industry needs to have good problem-solving skills. Respondent R10 further described a typical production line in Malaysia, where it starts with the operators having SPM level qualification, and then we have the line supervisors, which are followed by the engineers (maintenance and process). Line supervisor plays a critical role in ensuring what should be done is normal and emergency conditions, which means that when there is a problem with the line, he or she will know to contact either the maintenance engineer or the process engineer. This is because one second of down time can cost millions, which is why problem solving skills is very important. These days, operators in high technology industries need to be Diploma holders.

> "*In the old industry system, the system always changes with the technology. We use operator… all [have] SPM and SRP [qualifications]… after the operator we have line supervisor… and then we have engineer… back then we have maintenance engineer, process engineer, etc. This system, anything down in the production line… the first person in charge, will not do anything… anything to the top. He will only push the on and off switch… that is the Japanese style. He will call the line supervisor, who will look to see whether he can resolve the problem. He will decide who can do the problem solving… which then involves the engineer… by this time the production line will stop… However in the new industry system, everyone is first class… now, the minimum [qualification] for an operator is diploma*" – from interview with R10.

After the line supervisors stand the engineers, as mentioned above. These engineers need to be first class, due to the same reasons for first class line supervisors. Thus, again the respondent stressed that man power is very important. At the government level, for high technology industries, the Key Performance Indicator (KPI) is manpower. There is still a need for engineers, even though hundreds of thousands are being produced. This is because these engineers are more of general engineers that are perhaps not suitable for the nanotechnology industry.

> "*Manpower is very important. That is why at the government level for high technology park, one of the KPI elements is manpower. Numbers of manpower produced in each field… from biotechnology to nanotechnology… that is why in the government they are still looking for [skilled graduates] … they are still having shortage of engineers… 200,000 … they are still unclear why hundreds of thousands of graduates yet still insufficient… [the issue is] respective area … we lack [in nanotechnology], the ones produced are in general areas*" – from interview with R5.

Furthermore, respondent R15 emphasised that, "*that is why this kind of industry, this high technology industry in particular, they need first class student. They do not want the average student… workers with brains will know how to manage how to solve problem*".

Meanwhile, Respondent R8 strongly emphasised that "retooling" (retraining) is extremely expensive, therefore basic or starting education is pertinent.

> "*Make sure everything, when the graduate enters the industry, retooling is not required. Retooling is very expensive. The old system is like that, when he first reports for duty, he undergoes training. Nowadays, no more… start work, do work. No time wasted, no money wasted [on training]… unnecessary*" – from interview with R8.

Furthermore, respondent R1 gave an example of a US-based company in Malaysia that sent its first batch of workers to Santa Clara in the USA for training, "*they sent to NSI, near Santa Clara… they send some of them for one year, six months, three months… according to their [job specifics] … they spent RM200 million… just for training/retooling their staff*".

Respondent R3 also added that the MIDA had allocated RM30 million for training to foreign companies that are interested in coming to Malaysia, "*that is why now, if you contact MIDA, most of the foreign company if they come to Malaysia, if I am not mistaken, MIDA will allocate RM30 million or something like that just for training the Malaysian [workforce]… expertise… that is in MIDA … incentive*". The respondent concluded that there needs to be a stepping stone for outside companies to come into the Malaysian nanotechnology industry, and human resource is a potential stone.

In addition, respondent R10 put forth the concern by the government regarding human capital to service the nanotechnology industry. There are two institutes being set up for this reason, one in Kulim and one in Kuala Lumpur (Beranang), one under MARA and the other under Ministry of Human Resource. However, these two institutes have not been finalised yet, and is still at the discussion stage. The respondent speculated that the agencies are not brave enough to proceed, perhaps due to lack of qualified manpower to train these potential nanotechnology workforce.

> "*the institutes ... one in Kulim, one in Kuala Lumpur in Beranang, one under MARA, one under Human Resource Ministry… but still unconfirmed. They do not have the expertise. They are not brave to take a chance… we want to help but they [delay]… this is the government style*" – from interview with R10.

There are many more views relating to manpower and human capital issues, all of which fall under human resource. One of which is at which level of education nanotechnology is introduced to learners and students. Respondent R12 made quite a good remark in that in order to successfully market their products, the consumers need to be aware and learned about nanotechnology, i.e., consumers know the benefits of nanotechnology, before they would choose nanotechnology based products over the traditional products in order to reap the benefits in the long run. Other more developed countries take an even earlier step in educating their workforce by introducing nanotechnology in primary schools.

> "*We are going from the industry and consumer demand side… so creating the big demand in order to pull the human capital… whereas, when you look at developed nations, they start at K12, they start at schools… they already have nanotechnology curriculum*" – from interview with R12.

However, the question where to start focusing on assisting and facilitating the nanotechnology industry is a vicious cycle according to respondent R4. In order to establish a profitable and well-oiled nanotechnology industry, the appropriate human capital is required, however, in order for students to delve into nanotechnology, the industry needs to be already well established in order to attract potential individuals to start studying nanotechnology in preparation to enter the nanotechnology industry workforce.

> "*Your question about human capital… but to me, the bottom-line is, if the industry is not there… so… there is no demand [for manpower], there is no tools for the human capital, so… it is a vicious cycle*" – from interview with R4.

Therefore, there needs to be an initiative of tackling this problem from two points, both in developing a capable workforce, and establishing a solid nanotechnology industry. Respondent R13 illustrated this point in the following.

"*I was in aviation for some time… it was difficult for you to get a trained aircraft engineers… simply because there was not any demand… when the industry starts…you suddenly realised there is a vacuum… same with nanotechnology… in Malaysia it is fairly new… so when there is no demand… you will not have the resources available… [we need] to build human capital in tandem… with the industry… with the demand… it is not an easy task*" – from interview with R13.

To make things worse, not just having to deal with the domestic lack of skilled workforce, the nanotechnology industry is also faced with competing countries that can offer a much cheaper workforce for foreign companies to operate in. An example was given by respondent R11, where it was clearly stated that compared to Malaysia, the same worker wage rates are comparatively cheaper overseas.

"*At my workplace there were about 14 thousand staff workers. I only took in 800 and let the rest go. Their wages is about USD25 a month… Very cheap… The Chief Engineer I gave USD150 only [per month]. Even with that he could survive*" – from interview with R11.

Meanwhile, according to respondent R3, the education system changes too often at different levels, which had caused the education system to become slightly unstable. Respondent R3 stated that,

"*if the education system is correct… if we have the right education system, the people of the nation will be [great] <respondent shows two thumbs up gesture>. Our education system always changes, never stable*" – from interview with R3.

The primary and secondary education system has, in recent years, undergone medium of instruction changes from *Bahasa Melayu* to English and reverting back. At one stage it was bilingual. This not only had an effect of the students who were trying to learn, but also the teachers who had traditionally taught in *Bahasa Melayu* having to switch to English, which is not an easy task when you consider that all the Mathematical and Scientific terms that were taught in *Bahasa Melayu* needed to be learned all over again for the equivalent in English.

Not only the language used as a medium of instruction became a problem for the education system, but the focus of certain institutional bodies also contributed to this phenomenon. Respondent R8 mentioned that switching focus is a problem, with the supporting statement,

> "*our problem has been this [switching focus] for a long time… we change from this to that so quickly… first it was technical, then switch to vocational… now we are back at technical schools*" – from interview with R8.

Meanwhile other respondents mentioned that compared to other countries, Malaysia is not at par. Respondent R1 talked about Iranian education,

> "*when we look at the Iranian education system, it is quite impressive. They start teaching science and technology at an early age, which include nanotechnology. We have not come close to Iranian education system*" – from interview with R1.

Respondent R6 also described education in another country and elaborated on the German education system. He described that education system as taking the strategy of specialising their students at an early age. This would mean that there are focused schools and institutions that would cater to the demands of the industry according to the job types. Respondent R6 stated that,

> "*look at the German education system… in Germany they try to specialise their student from as early as primary school. They look at what the student in interested in. If agriculture, then you go to agriculture school very early on. If you like engineering, then you go to engineering school very early*" – from interview with R6.

Respondent R13 explained the way of doing things are perhaps different in the education system overseas. Respondent R13 described the method of filing system as being taught at an early age so that students are familiar with the system even before going into tertiary education. This was evident in the statement,

> "*the students over there [Europe] that I see… filing system, even school children are familiar with the concept of filing system. They know how to handle. They do not use the school book system like we do over here, they just use a filing system. So their topics can be in module form… once you finish one topic, you can file it and move onto another topic… so their [school children] bags are lighter. They*

> *do not have to carry around large textbooks all the time… and just focus on the current topic*" – from interview with R13.

This above interview excerpt shows one approach of familiarising the students at an early age with concepts that are useful later on in their lives, especially applicable in their future jobs. It also highlighted a possible solution of heavy bags that our students are currently facing in schools. Respondent R13 also added rather negatively, "*even we now at work, the banking companies do not know how to do proper filing system*".

From all the interviews, there were many points uncovered related to the issue of human resource development. All 15 respondents had much to say about this issue. When verifying the nanotechnology industry development aspect in relation to this human resource issue, it can be revealed that this would fall under the innovation category. Talent management is the key to sustain the nanotechnology industry.

The next section highlights the next important issue that needs to be addressed in the nanotechnology industry.

4.2.1.2 Infrastructure and Utilities Issue

Meanwhile, regarding the infrastructure and utilities of nanotechnology in Malaysia, all respondents were in agreement that there were many issues that they encounter in relation to this. Nanotechnology is wholly dependent on specialised equipment, which makes it also a limitation. An individual who is experienced in nanotechnology would be able to tell whether an equipment is nanotechnology capable or otherwise. Respondent R2 stated that,

> "*during my auditor days, nano[technology] is basically equipment dependent. Actually, if I visit their labs, when I inspect their labs, I know whether they are nano[technology] or not. Sometimes they claim to have nano[technology] labs,*

> *but by looking at the equipment, they are not working with nanotechnology*" – from interview with R2.

This is especially so in the electronics industry. Respondent R1 was pragmatic in that the current nanotechnology in the electronics industry is not ready with the available equipment.

> "*in terms of facility, they [wafer chip fabricators] cannot move toward nano[technology]… their current facilities can only cater to micro. They cannot move to nano[technology] because of their limitations… they have to have a separate set of equipment. Totally separate set. Existing equipment is simply not capable*" – from interview with R1.

Respondent R1 had shared the experience of setting up a wafer fabrication facility during the interview. She stated that,

> "*so before we start anything, the first thing before we decide on the facility of the setup, first thing we have to understand the actual technology. So they [the fabricators] have to declare the technology, what kind of technology they want to produce. Based on this technology, we set the specification toward this technology*" – from interview with R1.

When considering setting up a nanotechnology capable facility, the main issue is the cost. Respondent R9 had given an illustration or rough picture of the start-up costs for a nanotechnology capable facility.

> "*So different family [sizes], the prices are different… huge difference. One equipment, say for pattern transfer, is for 1 micron to 0.5… [setup costs] RM20 million… 0.3 micron is approximately RM50 million. So a difference of RM30 million, but if you want nano[technology], it is currently more than RM100 million. So, this means that when we set up facilities, we cannot simply just buy, because of this price. It has to be controlled… it needs to be decided from the very beginning*" – from interview with R9.

Not only are the start-up costs expensive, the maintenance, as well as the unforeseen and unexpected breakdowns can amount to millions as well, even though production only stops for a second. This is because working with nanotechnology is not similar to the traditional manufacturing process, where sterility and security is a critical issue. Respondent R3 and respondent R7 highlighted experiences with their respective cosmetics companies during a breakdown.

> "*the electricity supply is crucial… even a small trip, downtime to the industry takes about two weeks… calibration is one thing… faulty electronics cards need to be replaced… clean-up after a trip… because after a trip, bacteria will generate… takes two weeks to clean… then need to certify again the enclosure*" – from interview with R3.

> "*when there is electricity shortage, bacteria will generate… when bacteria generates, cleaning takes two weeks. After that certification is needed… so this is the issue*" – from interview with R7.

Therefore, utilities are another critical factor for the nanotechnology industry. Respondent R6 from a company that produces nano-enriched fertilisers described that,

> "*in high technology industry, first thing is utility. You are talking about utility, the water supply, they must be very consistent, the second is electricity that must be very consistent, almost zero downtime, and then all the gases all the nitrogen, oxygen… argon, all those are underground. They just plug in and then and use*" – from interview with R6.

Meanwhile, with regards the equipment, they are very specialised to each research group in that each equipment serves a specific purpose or task to perform. Because of this, the equipment is very expensive and difficult to acquire and access. However, due to the secrecy and the confidentiality of nanotechnology, since each idea of a company gives them a leading competitive advantage over their rivals, work is done in secrecy and silo-like manner. Collaboration between all parties involved is not readily available. This was highlighted by respondent R7.

> "*What I find [when] engaging the government, engaging with academia, engaging the industry, is that they all like to work in their own silos… industry forever… I mean …not to say that [it] is wrong… but [ultimately] they are serving the customer, right? … and also nanotechnology… very secretive*" – from interview with R7.

Moreover when dealing with international trade of equipment and research. Due to his previous work with SIRIM and the government, respondent R1 had much experience when dealing with overseas counterparts, as well as experiencing first-hand what occurs when transporting nanotechnology equipment. During the interview, respondent R1 recalled his experience when dealing with Russia, which involved a lot of security and also transacting with the KGB (Russian intelligence agency).

> "*I had two to three bodyguards. KGB we also used [when in Russia]. At that time we bought equipment… I brought from Norway [to Russia], we paid KGB to bring it in. We simply cannot [do it ourselves]. At every border of communist countries, all have military [stationed]. Not easy to go through. To enter a country by train, it would take weeks… but when he [KGB] deals… everything signed as KGB [business]. Along with my business card in my pocket, I bring along a KGB card… a Colonel in the KGB. If the police detained me, I would show that card, he has authority…he is something, he is a special person…his power*" – from interview with R1.

As a summary, infrastructure and utilities factor is critical to ensure that the nanotechnology industry thrives. High technology parks can form a solid foundation for the R&D to be established. Through technology transfer and the latest technological advancements, these high technology parks can serve as local hubs for the facilitation of R&D. Next is the consumer awareness issue.

4.2.1.3 Consumer Awareness Issue

Next are the findings regarding the consumer awareness issue. All respondents agree that generally speaking, the public has low awareness of nanotechnology, its uses, and advantageous. The general consumer is more concerned with dollars and cents, where the cheaper product will be selected over the premium priced nanotechnology enhanced product. Respondent R3 mentioned that, "*so really the challenge is to get across the message… the application of nanotechnology actually benefits you in more ways than one… hammering the point over until they are curious to try*". This indirectly describes the method companies are trying to market their product, by repetitively 'hammering' home the advantages of nanotechnology enhanced products.

In order to assist these companies in marketing the nanotechnology goods, awareness campaigns also needs to be run by government agencies in order to facilitate the nanotechnology industry. Respondent R12 mentioned that in the USA,

> "*before introducing to the public, to the society, they do some kind of awareness program ... the first thing, before they start launching their initiatives, ... they spend about USD400 million in the US*" – from interview with R12.

This notion was further supported by respondent R8, who had stated that,

> "*as with anything that is new, we need to do an awareness programme, so that people are aware about this thing ... the beauty, the goodness of this thing, then only they can penetrate market*"

Because of being unaware of nanotechnology, even more so the advantageous and benefits of nanotechnology, consumers are perhaps resistant to accept nanotechnology and as something they should embrace, since it will change the way they live their lives. Respondent R2 mentioned that,

> "*main issues are consumer acceptance where most are unaware of what nanotechnology entails, and are hesitant to fork out the extra RM for such products*" – from interview with R2.

Being unaware is partly the problem, but respondent R15 gave an issue for the slow nanotechnology product up-take, which is public mentality. The locals generally focus more on cost rather than real benefits, which is a different approach or outlook taken by people of developed nations. Respondent R15 stated that,

> "*as opposed to developed nation… look, this is better… and the mentality of the people… of those developed countries… they see the benefit in the long run… and they are willing to make that move [to nanotechnology products]… it is that sort of thinking… mentality*" – from interview with R4.

This further impacts the type of products that are being marketed, which is quite natural, since demand will create a successful market. Respondent R9 had highlighted that the general public wants relatively cheap products, and that the industry is not capable of forcing consumers to take up new products.

> "*our industry [nanotechnology], like I was telling you… it only caters what the consumers want… but …they [industry players] do not really get to educate them [consumers]… so what they [consumers] want, that is what they [industry players] give… you want cheap, ok, I give cheap*" – from interview with R9

Due to this phenomenon, the types of nanotechnology products that thrive in the Malaysian market are governed by the relatively cheaper product types when compared to the developed countries. The Malaysian nanotechnology market is dominated by textile, cleaning, cosmetics, and other relatively inexpensive per unit products, whereas in the more developed nations, the focus of consumer purchase is more toward products with higher end applications of nanotechnology, like electronics, which has a higher per unit price. This was highlighted by respondent R12, who mentioned the following,

> "*when you look at the sort of industries affected by nanotechnology in Malaysia and compare it to more developed nations… almost the total opposite… developed nations are more toward electronics… more on the higher end of the application… while we [Malaysia], cosmetics… car care, lubricants… filtration…so it is still very very low level activities*" – from interview with R12.

This is further supported by the statement offered by respondent R7, who stated that "*cosmetics, automotive care… these are how should I say…areas where nanotechnology is mostly applied in Malaysia*". Further support was given by respondent R2, who mentioned that,

> "*Automotive with lubricants, agriculture with fertilisers, air and water filtration, and multipurpose cleaners for household use…the sectors i mentioned are quite matured in their nanotechnology application*" – from interview with R2.

Respondent R10 also observed the same phenomenon in Malaysia, where

> "*in Malaysia, if I am not mistaken, there are 11 or 12 nanotechnology-based companies. Most of them are nanotechnology material. The simplest one that I remember is the shoes, they swab it with silver particles… powder, this silver particle, so the shoes are shining and does not dull… keeps on shining… all the easy types… just particle-based material*" – from interview with R10.

Even with all the products available in the market, the general public is still not aware of nanotechnology as well as its advantages. Meanwhile on the industry-side, there is a mismatch in the focus of R&D, where respondent R13 stated that,

> "*when we look at the research that is going on, a lot on electronics… so you see, there's a mismatch in development…these sort of technologies, but not commercialised in Malaysia… so realising that, we also try to bridge the gap internationally… we work closely with the likes of MATRADE, MITI*" – from interview with R13.

This issue can be assisted by the operational process category, which includes market research. This aspect can be considered critical due to the fact that awareness can have a positive pull effect in the other categories. For example, when the public is aware of nanotechnology benefits, a shift in purchasing decisions can be influenced so that the public will purchase nanotechnology-based products. The increase in demand for nanotechnology products will only promote the nanotechnology industry and it will continue to expand. This would create a vacuum of talent amongst the graduates and increase demand. When the tertiary institutions are aware of the importance of nanotechnology, then graduates can be geared toward being prepared to enter the nanotechnology industry. When the government is aware of the nanotechnology benefits and the great potential to contribute toward the GDP, then a regulatory framework can be established to regulate the nanotechnology industry. As part of the regulation and a strategic move toward facilitating this potentially profitable industry, high technology parks can be constructed more frequently and of better quality. Therefore, awareness is a pertinent factor of nanotechnology industry improvement.

As a summary, the public awareness level needs to be increased in order promote nanotechnology, so as to create a demand to enhance the industry. This in turn would create job opportunities and enhance the education system to gear the potential school leavers to target the employment in the nanotechnology industry.

4.2.1.4 Regulatory Framework Issue

Meanwhile from the perspective of regulatory framework, it was a general consensus that the government has started the nanotechnology initiative, but the uptake of products is not as fast as the more developed nations. One of the reasons highlighted by all respondents was that there is a resistance to change. Respondent R3 stated that,

> "*just follow this standard… need nothing else… because the level of maturity is there… Our maturity is not the same… and of course at the same time we are trying to cultivate that [nanotechnology] technological ecosystem… but always the question that I asked is whether or not we are ready for that… shift… in paradigm you know… it is not something that you can force upon the people*" – from interview with R3.

One common theme that occurred during the interviews was political problems and barriers when dealing with other governments or government agencies. Respondent R1 recalled during his time with SIRIM,

> "*for example, like Intel last time… its industry chain is not completely 100% in Malaysia… if we look, the processor design is in Malaysia, ok, but fabrication occurs in US, which then gets forwarded to Israel or Ireland. After that repackaging in Malaysia… actually, their initial intent in the 1990s was to setup fabrication in Malaysia… they already trained 60 Malaysian engineers but because of political reason… George Bush at that time… he made a decision, at that time to move to Israel. This is political. They move to Israel, that particular fab. So in Israel there are four fabricators, in Ireland also four fabricators. Then the latest fabricator for nanotechnology capabilities, 22 nanometre transistor, they do in Oregon now. So, they did not come to Malaysia*".

Not just other governments, our own Malaysian government sometimes pose problems for nanotechnology practitioners as well. This was emphasised by several respondents, including respondent R5 who stated that,

> "*you realise there is this huge commercial potential… for your knowhow… yet you [the government] do not want to tap on that… put it very simply… there is this department called NNC… National Nanotechnology Committee… which they were tasked to come out with a guideline…oh sorry… the Parliament Act on Nanotechnology… so it has been over 10 years… still nothing*" – from interview with R5.

What more, respondent R14 observed that the "*parliamentary act [was] in the making for 10 years… the Minister [responsible] has been changed three times*".

And when the government does act, it seems that certain activities have an opposite to the desired effect, with respondent R8 mentioning that, "*we have too much political intervention. It influences too much in our decision making*".

Moreover, respondent R11 was disappointed that there are no clear regulations for nanotechnology products already available in the market, with the statement,

> "*what I am really disappointed with is the government… it [nanotechnology] is something that is required in the new economy, knowledge economy, differentiating the products… it is all about the services and knowhow… but yet, there is no push… regulating the product for example… you know it is already being sold in the market locally*" – from interview with R11.

Meanwhile, there seems to be lack of or very little support from the government. Respondent R13 mentioned that "*well not to say no [support from the government] but very minimal*", while respondent R2 stated that "*one more very glaring thing was that [the Ministry] didn't give any KPIs for us… you do advocacy but what are you looking for*".

Overall, domestic and international politics can play a large part in deciding the success of a nanotechnology endeavour, or otherwise. Respondent R1 shared an experience when her company tried to bring in a foreign partners into the country, "*last time we had five fabricators promising to come to Malaysia, almost all did not come*". The company attempted to persuade those who did not want to come, and "*if they still do not come, then actually, that is a political reason*".

As for the safety of consumers, NANOVerify performs similar duties as SIRIM does in protecting consumer safety by verifying and certifying products before they are brought into the market. Any product with a SIRIM certification can be considered safe for public consumption and these products can be purchased without worrying that they would fail unexpectedly. However, there is neither rule nor regulation to enforce certification for nanotechnology-based products. Respondent R5, who has some previous experience in nanotechnology product certification, mentioned that,

> "*the challenge like I was mentioning…KPDNHEP [Ministry of Domestic Trade and Consumer Affairs] they do not want to make it [certification] mandatory… so that is the challenge… they do not see the importance of it [certification]*" – from interview with R5.

This particular issue of regulatory framework can be addressed by the strategy component of technology management. By strategically establishing a regulatory framework, this would enable the nanotechnology industry to proceed and advance at a greater rate, as they are guided and supported by this framework. Too often, new companies enter the market without being fully aware of the governmental benefits and incentives that are made available to assist in the development and expansion of the nanotechnology industry.

As a summary, the supporting government structure for the nanotechnology industry needs to be improved in order to facilitate the nanotechnology industry in driving the national economy by establishing a regulatory framework that would ultimately speed up the advancement process. Through this framework, it would present a stable platform for the development of the nanotechnology industry and signal to companies overseas that Malaysia is ready to receive FDI from the more developed nations.

4.2.1.5 Other Issues

The findings from the first interview question identified many other problems and challenges faced by the nanotechnology practitioners in the industry as well. Other problems that have been highlighted are summarised below:

Foreign investor sincerity – Respondent R1 had previous experience being the senior technical consultant to the Malaysian government. He was sent on a preliminary fact-finding mission to verify the foreign company. He stated that,

> "*I recommended to the Prime Minister and government… we stop this project. The government wanted to give… release USD200 million… in relation to the satellite industry… but there were many lies on their end, so I spent about two years… we wanted to see how sincere they are… but they were not, so I returned home*" – from interview with R1.

Equipment reliability – Respondent R1 noted that nanotechnology related equipment and products have a reliability issue. When equipment gets tested and passes a certain benchmarked standard, it gets more expensive. Certain partners/vendors have the tendency for shortcuts in cost, and would utilise less tested products. He summarised this by having said,

> "*actually the microchip, the problem is the reliability… it gets hot. Rule of thumb, [for] microchip… [the standard] shelf life is a hundred years. You buy any microchip component… transistor… any component… its shelf life is 100 years…*

> *less than that unacceptable. That is why we buy from Taiwan, China, they do not consider this… the difference between cloned and branded*" – from interview with R1.

Difficulties in establishing certification – Based on an observation by respondent R2, stated that "*the certification itself…which is slowly gaining traction on the ground in Malaysia itself because as you know, technology and Malaysia is…Malaysia is not the ideal place to roll out*". This shows how difficult it is to introduce new technologies to the public, especially when it is of extra cost. This notion was also supported by a statement made by respondent R9,

> "*we are press sensitive…even though it is beneficial for you to perform better, saving money in the long run, but if have to spend more in the beginning [expensive], then automatically it is out… it is not considered*" – from interview with R9.

Decision made at the top – Respondent R13 had highlighted that high technology in Malaysia relies on top level decision making in order to survive. This is because the top level management will bring in the huge projects to ensure the sustainability of that technology. In the case of nanotechnology, it faced a small setback when the focus was shifted to another technology during the time of the previous Prime Minister. He summarised the affair as,

> "*the previous Prime Minister made a wrong move, trying to highlight biotechnology, that is why at that time the FDI was very low, at one time, it was only RM4 billion. That is why at that time our economy was very bad. Malaysia still relies on FDI to survive*" – from interview with R13.

False claims – Respondent R8 mentioned that nanotechnology is being used as a buzzword these days and can confuse the general public,

> "*most of them claim nano, but if they do not work within 100 to 1 nanometre, they are not nano. They are just talking about nano, but from the practical sense they are not nano. We already set the nano definition, they have to follow this*" – from interview with R8.

4.2.2 Findings for Question 2 – How to Overcome Problems?

In terms of the initiatives or method to be taken to overcome the issues identified in question 1, the question: "What is the solution to resolving the problem of nanotechnology issues of human resource, infrastructure and utilities, consumer awareness, and regulatory framework?" was asked to identify the type of solutions from different perspectives of nanotechnology practitioners from various sectors for overcoming the problems that were identified in question 1.

In this respect, all the participants agreed that the solutions to resolving the above summarised problems are more related to soft issues in organisations and not hard issues (technical aspects of nanotechnology). They agreed that enhancing the nanotechnology industry requires a fundamental a multi-faceted approach facilitate success.

Based on the findings identified from the interviews, some improvements in the current practice needs to be undertaken in order to solve the issue of lack of nanotechnology industry success. Some efforts towards this approach were highlighted by the respondents during interview. These recommendations were then mapped to the technology management practices that were highlighted in the literature review, and they are described in the following passages.

Technology commercialisation and marketing (getting the public involved through social media, getting other public and private bodies involved) is one important factor. According to respondent R2, a good method of reaching out to the public is through social media. This is because of the disruptive nature of information and communication technologies (ICTs) that has changed our daily lives, which similar to what nanotechnology is capable of achieving some day in the future. Thus, traditional media such as newspapers, television, and radio, can be less focused upon when attempting to raise the awareness of the public regarding the importance of nanotechnology. Respondent explained,

> "*because [nanotechnology is] fairly new… people do not know about it… people do not know the importance of it… so… use key opinion leaders… social media and whatnot… because traditionally what… Nano Malaysia group has been doing was via printed media…who reads newspapers right?*" – from interview with R2.

This notion is also supported by R4, who declared that,

> "*who listens to radio talk shows…TV talk shows… very very few people… and when you go in and you talk about hard core technology, you know... going into the fundamentals… people do not really appreciate… they really prefer the results… they watch the video, they see the effects, that is it… it goes viral*" – from interview with R4.

This statement depicts the current trend of the public that tends to shy away from technical jargon and would much prefer to watch videos that are attractive and eye-catching. So, respondent R4 highlighted the potential benefits of going viral can do for nanotechnology.

Respondent R9 further added that information that is shared on a more personal level would have a better effect on conveying information to the audience rather than sharing technical information that would simply bore the audience. This was described in an effort to promote their product by focusing on the

> "*experience of using the [nanotechnology] product… that is why… we prefer Instagram, Facebook, experiential sort of sharing… rather than… hard-core science*" – from interview with R9.

Meanwhile, respondent R7 viewed social media in a different way, more related to work. Respondent R7 is of the view that social media can quickly and successfully get the message across, so that all involved parties would gather the same understanding of a topic of conversation or subject. This respondent finds, "*[social media] very useful… in team environment… like working… so… everyone is on the same page… literally… we need to innovate our approach*" – from interview with R7.

Additionally, respondent R3 added that getting other agencies and bodies involved, and not just the general public, would assist in promoting and enhancing the awareness of the nanotechnology industry. Respondent R3's company continuously attempts to,

"*hook up with other…regulatory bodies like Halal, National Pharmaceutical Regulatory agencies… we found out that there is actually quite a lot of… like I said, nanotechnology in cosmetics… in the National Pharmaceutical Regulatory database, a lot of cosmetics… so there is significant amount of overlap there… and there is also overlap in terms of Halal database*" – from interview with R3.

Technology protection, license/patent acquisition (local and international accreditation/certification) is another significant factor. From the perspective of protecting the consumer, the Malaysian government has set up a government linked company, NANOVerify Sdn. Bhd. that performs tasks and assignments similar to SIRIM. NANOVerify certifies nanotechnology based products. Respondent R10 highlighted the benefits of getting accredited by a certification company. He mentioned that once their product has been verified and certified,

"*so now what we are looking to do is to further boost sales… because now more confident because… they are being accredited by a… government-affiliated body… so the story is about growing the business… within and also outside Malaysia through certification*" – from interview with R10.

Technology acquisition, transfer, dissemination (local development-international market matching, international branding, local partnering, high technology park development and design) is also another significant factor. Respondent R12 described the dire mismatch between the locally developed products with the domestic market. Because of the slow uptake of nanotechnology based products by consumers in the local market, local companies need to push their products onto the international market in order to survive. This means that nanotechnology based companies in Malaysia have the opportunity to sell their products world-wide, although actually doing it is another set of problems entirely. Respondent R12 stated that,

> "*the canvas is a lot bigger than what it appears to be… initially the idea is to help grow the industry in Malaysia, but then again, looking at what other activities going on here, and the market uptake over here… we cannot escape…we cannot survive and we cannot escape pushing our products out*" – from interview with R12.

Since local products are being forced to look elsewhere to be sold, international branding needs to be done. Respondent R1 is involved with her company in the electronics sector, which is a sector that has underappreciated nanotechnology based products. However, this does not stop the company from pursuing nanotechnology R&D to cater for the electronics industry, because

> "*when we look at the research that is going on, a lot on electronics… so you see, there's a mismatch in development…these sort of technologies, but not commercialised in Malaysia… so realising that, we also try to bridge the gap internationally… we work closely with the likes of MATRADE, MITI and … so we try to hook them up, we do business matching and whatnot*" – from interview with R1.

However, when dealing with the international market, the local nanotechnology company needs to have a partner in that particular market. Respondent R15 recalled that through his

> "*experience doing business in China… is you need to have very strong local partner … more so than any other country in the world… even if you speak the language, there are challenges along the way … so you need a very strong local partner to look out for you*" – from interview with R15.

Other than expanding market boundaries, respondent R14 focused more on the infrastructure side of nanotechnology industry development. He recommended that high technology parks are a viable solution. This is because nanotechnology inherently requires reliable and continual utilities. Respondent R14 stated that, "*in high technology industry, first thing is utility. You are talking about utility, the water supply, they must be very consistent, the second is electricity that must be very consistent, almost zero downtime, and then all the gases all the nitrogen, oxygen… argon, all those are underground. They just plug in and then and use*" – from interview with R14.

Meanwhile, respondent R7 further added that the design of the high technology park is critical. His company was involved in the setting up of nanotechnology abled facilities, and

"*how we design, just like that [Kulim] hi-tech park, is that there is two [electrical] line… one from Perai and one from Bukit Mertajam, for example… so there are two commercial line, so when one trips, the other covers. But there is some down-time… even though it is just a fraction of a second, some of the more sensitive machines can be damaged*" – from interview with R7.

Since electrical supply is a pertinent and critical issue, respondent R13 added that,

"*actually right now at that tech park, besides commercial lines, they have a generator and gas turbine backup… at the back*" – from interview with R13.

Since the high technology park is being run by a separate body, companies that invest in setting up their business in high technology parks would not have to worry about their operations being interrupted by downtime due to utilities failure. This is because the high technology park will provide some sort of guarantee with some confidence. Otherwise, appropriate compensation would have to be rendered in cases of utilities failure. Respondent R11 said in order to bring in,

"*this kind of industry, this is the thing they ask, so Kulim Hitech you have to give the guarantee, 100% guarantee on the power. Later if any failure, they will pay, whatever you request*" – from interview with R11.

Respondent R1 shared an experience she had when she,

"*assisted in the construction of a fab in Kuala Lumpur ... TNB will pay RM200,000 from every electrical trip. Even in Kuala Lumpur it always happens. It is just like that, so have to pay*" – from interview with R1.

Technology utilisation and integration (strengthening education, curriculum alignment, manpower development) is yet another important factor. Since nanotechnology is such a specialised industry, the manpower needs to be shaped in order to sustain the nanotechnology industry. The education system needs to be updated. Other countries have started early in educating their people about nanotechnology early. Respondent R15 stated that he,

> "*once… went to a nanotechnology meeting… a committee one… country representatives meeting in Taiwan. When we looked at the Iran presentation… impressive… in terms of their education. Iran has a great education system. If the education is spot-on, if we have the right education system, the people of the country would excel*" – from interview with R15.

In order to sustain the nanotechnology industry, the education system needs to be revised to include nanotechnology concepts in the student's learning material and curriculum. Respondent R1 highlighted that,

> "*micro-electronics and the like, they are very popular... because they are very specialised. The industry is very happy with graduates from [OMIT]… the ones produced. If you go to Silterra Infineon… majority of the junior engineers are [from there]... the developed curriculum is more or less tailored to the industry*" – from interview with R1.

The name of the local university was removed at the request of the respondent, but the statement was included in the analysis since it was appropriate and supported the notion of better developing human capital to sufficiently cater to the workforce demands in the Malaysian nanotechnology industry. It is very important that the human capital is educated early about the concepts in nanotechnology, so as to be able to enter the job market of the nanotechnology industry without having to cost the employing company from the aspect of having to train and retool newly recruited employees. Respondent R5 had highlighted this fact because the education should,

> "*make sure [of] everything, when the graduate enters the industry, retooling is not required. Retooling is very expensive. The old system is like that, when he first reports for duty, he undergoes training. Nowadays, no more… start work, do*

work. No time wasted, no money wasted [on training]… unnecessary" – from interview with R5.

Not just focusing on the earlier part of the education system, the issue of manpower shortage needs to be addressed holistically, i.e., at all levels of education and training. Respondent R2 has observed that Nano Malaysia has taken the overall approach to developing the appropriate human capital for the nanotechnology industry in Malaysia. Respondent R2 said during the interview that,

> "*what Nano Malaysia… is trying to address is to build human capital in tandem… with the industry… with the demand… it is not an easy task*" – from interview with R2.

Meanwhile, respondent R1 mentioned that before joining the private company, she was involved directly in the development of human capital and said that,

> "*UKM was the first university to introduce nanotechnology under the microelectronic subject pioneered by Prof. Rohan… when I came to UniMAP, I submitted a proposal to open up an institute [for nanotechnology]*" – from interview with R2.

Knowledge management and organisation of technological activities (political partnerships) is another important factor. Since nanotechnology involved huge amounts of capital, the decision to bring in foreign entities as well as to form strategic partnerships would involve participation at the governmental level. Respondent R1 stated that,

> "*if we buy from the US, everyone will know. We buy a little from Russia, a little from Britain, a little from South Africa, a little from France… like that… That is all strategy. We sacrifice the millions or billions of the government's money, just to maintain political relations… that is all strategy*" – from interview with R1.

Respondent R1 further emphasised the importance of maintaining political relations in dealing with foreign partners. When attempting to secure governmental projects and grants, politics plays an important part in determining the outcome of a proposal. Respondent R1 said during interview that, "*last time, we were close with the middle east, the Prime Minister formed good relations… everything is political … That is why at the very start when I want to write a proposal, the first thing… the justification must have military reason… when you go to the strategic, this is it*" – from interview with R1.

Technology Strategy (do first/pioneers, financial initiatives, increasing FDI) is another pertinent factor. With regards to technology strategy, companies in the nanotechnology industry need to be pioneers in their respective field of focus in order to gain strategic competitive advantage. It is with this attitude that certain companies can lead the industry in their field of expertise, only then they can forage forward in exploring new ventures and forging new alliances and partnerships with their counterparts abroad. Respondent R5 highlighted this point by saying,

"*like in Malaysia right now with respect to nanotechnology, like how we used to do [for electronics] there needs to be a stepping stone. Stepping stone… let us say we want to start a new industry in Malaysia, so we have to start first. If they [possible foreign partners] see we do activities related to them, they would be brave to come in*" – from interview with R5.

So the pioneering spirit is one characteristic that needs to be instilled, although it is easier said than done. Malaysia, in this respect, was fortunate during the 1980s when the highest level of administration had this pioneering spirit and put forth into motion the development of various industries. Respondent R1 recalled that the then Prime Minister took steps in order to forge ahead, even though at that time the expertise was not apparently at hand. Respondent R1, having had decades of experience in the electronics industry, reminisced the time when MIMOS was formed in order to spearhead the electronics industry and establish a body that is capable of dealing with potential foreign investors and companies that want to form strategic alliances and partnerships. Respondent R1 said that,

"*I still remember in the 1980s, at that time Tun Dr. Mahathir was the Prime Minister… when a foreign company or industry wants to come to Malaysia, when they want to talk on this particular [electronics] area … nobody can represent Malaysia. That is why he immediately formed MIMOS*" – from interview with R1.

Meanwhile, respondent R10 had mentioned the strategy of providing financial incentives in order to promote activities in the industry. Of the many industries, one such industry that promotes environmental stability is renewable energy. This industry can be seen to be a key industry to provide sustainable energy that is virtually clean and pollution free. Respondent R10 recorded that,

> "*[one focus is] the field of solar [energy] if I am not mistaken … so we are trying to launch this one and gather all the researchers. If you research in this area… [the government] will provide the grants…[they] will financially sponsor*" – from interview with R10.

Further financial incentives are also provided by several governmental agencies, in relation to human capital development, and to some degree, technology transfer. Respondent R3 mentioned that there is support given financially to train the Malaysian workforce,

> "*that is why now, if you contact MIDA, most of the foreign company if they come to Malaysia, if I am not mistaken, MIDA will allocate RM30 million or something like that just for training the Malaysian [workforce]… expertise… that is in MIDA … incentive*" – from interview with R3.

The strategy of providing financial incentive is in actual fact, a strategy of bringing in larger amounts of funding from overseas. Foreign direct investment is one of the key areas that has the potential of driving the nanotechnology industry, as well as the other industries. This is not a new strategy, as respondent R12 has mentioned during interview, since it has been the focus in the 1980s and 1990s, during the then Prime Minister Mahathir Mohamed. He said that,

> "*during Mahathir's time, his emphasis was more toward the semiconductor industry. That is why Samsung gained entry into Malaysia, along with other foreign companies bringing in the FDI*" – from interview with R12.

All industries can be geared towards bringing in the FDI, but to varying degrees. Some industries can at most bring in around RM2-3 million, while other like nanotechnology can bring in billions. Respondent R6 lamented the government's focus on biotechnology previously was perhaps a little bit short-sighted, as the developing countries at that time were already initiating moves toward developing the nanotechnology industry. Respondent R6 stated that,

> "*at that time, we wanted to help the villagers with emphasis on biotechnology, which is very much related. The biotechnology industry requires the most is RM2-3 million only, and many countries would be interested, like Australia and Finland… they would bring in relatively small companies. That is not what we want. If we really want to survive, we need to go to nanotechnology, which is our current direction*" – from interview with R6.

Respondent R1 also was also of the similar disposition, when he provided another example of FDI,

> "*if we attract foreign petro-chemical companies, it will not be that high… maybe around RM40-50 million… but, if we go to this one [nanotechnology], ha… billions. Infineon was like that. [OMIT] when they first entered [Malaysia], they brought RM600 million, now they have expanded beyond that*" – from interview with R1.

R&D Management (product specialisation) is an important factor. With regards to the product selection, nanotechnology companies need to be specialised in order to maintain a competitive advantage. This was highlighted by respondent R11, who mentioned that,

> "*they have to specialise their product… unlike [OMIT], they are now making microchips in many products like watches, toys, … anything the customer wants, they can produce. They are not specific… whereas [OMIT] is very specific for automotive… actually 100% for automotive… they do not do anything else. However, their design processes are different… so this is on micro, basically for nanotechnology, the same thing also will happen*" – from interview with R11.

Technology planning and forecasting (mandatory Acts, implementing awareness programmes, roadmap formulation) is a relevant factor. Like for information and communication technology, which is a disruptive technology that has integrated itself into our daily lives, nanotechnology also required rules and regulations to ensure that all parties are protected, both consumers and producers alike. According to respondent R8, "*for as long as there is technology to be developed in industry… technology to be commercialised… these acts that make it mandatory then… it will be easier*" – from interview with R8.

This is because nanotechnology has the potential to impact lives similar to other disruptive technologies. Due to this characteristic, respondent R3 had mentioned that his company was requested to run a campaign to promote their products, "*[the Ministry] requested for us to run the advocacy programme*".

Like all good and potentially disruptive technologies, its development requires a roadmap prior to fully launching the research and development of those technologies. This is to ensure that the appropriate technologies will be focused upon in order to facilitate its development faster and drive all parties toward the correct direction. A concentrated effort will ensure the technology will be properly and fully developed in a matter of time. Respondent R7 mentioned that,

"*so at the moment the activities that we do is to try and gather as many researchers as possible in this field of nanotechnology, and then we try to focus on the Malaysian roadmap. We already decided on [following] our national roadmap*" – from interview with R7.

Based on the findings identified from the interviews, some improvements in the nanotechnology industry need to be undertaken in order to resolve the issue of the relatively slow up-take of nanotechnology products by the public. Some efforts towards this approach include:

1) Requirement of a more comprehensive and holistic approach to infrastructure developments, such as;

    i) Soft infrastructure – human resource development needs to take place at all levels, ranging from primary schooling, secondary schooling, and tertiary education. Currently, the development is taking place at the tertiary education (both undergraduate and postgraduate levels). Enhanced education will lead to a more informed and capable workforce, which in turn will assist in driving the nanotechnology industry forward.

ii) Hard infrastructure – more technology parks needs to be constructed, with more specific attention paid to the requirements of nanotechnology. Since nanotechnology has far reaching consequences and impacts across industries, perhaps these new technology parks can focus on different aspects or industries of nanotechnology, such as materials, electronics, cosmetics, and others. These facilities can promote the clustering of companies which can then foster collaborative efforts and also speed up the process of research and development, as well as eventual commercialisation. These technology parks can also provide opportunities to utilities companies major contracts in supplying guaranteed continual supply of electricity, water, and other required materials specific to an industrial type.

2) Requirement of a more comprehensive and holistic approach to making the public more aware through;

i) Awareness campaigns – the government needs to work with the private sector in order to promote awareness of nanotechnology-based products and highlight all the benefits in the long run. This will assist in not only increasing profit for the nanotechnology industry in order to assist in contributing to the national GDP, but also in facilitating industrial growth which in turn will create more job opportunities and open up avenues for the education sector to fulfil the demand for nanotechnology graduates and workers.

ii) Regulatory Act – an Act needs to be put into place in order to regulate and control the nanotechnology industry so as to protect the consumers and producers alike. Protection for the consumers from the aspects of product security and safety, and from the point of view of producers is the safety of the manufacturing process to ensure that there is no toxic waste and that the environment is preserved and maintained. If and when this Act is in place, it will secure nanotechnology as a technology that will change public perception and acceptance, thus widening the opportunities for further industrial growth.

Following these findings, the industry and the government is recommended to collaborate and work together to enhance the nanotechnology industry. The following section will focus on this strategy in more detail in order to identify the critical success factors (CSFs) for effective nanotechnology industry development implementation in the nanotechnology industry.

4.2.3 Findings for Question 3 – Identifying the CSFs

In terms of the critical success factors, the question: "What are the critical success factors for effective nanotechnology development in Malaysia?" was asked in order to identify the critical success factors necessary for effective nanotechnology industry development implementation, from the perspective (either experience or knowledge based) of nanotechnology practitioners from various sectors.

The analysis has been categorised under four main elements identified by the respondents in all interviews, as well as the through literature search, which are namely human resource, infrastructure and utilities, consumer awareness, and regulatory framework.

4.2.3.1 Human Resource

It was apparent from the interviews that human resource development to support the nanotechnology industry is a major issue. The current education system still supports the traditional jobs, and it is not catering for the nanotechnology industry. Statements were made by respondents during their respective interviews that support this critical success factor, which are the following:

> Respondent 1: "*I believe that human resource is a critical issue when it comes to the sustainability of the nanotechnology industry. We surely need more and more capable graduates to maintain the industry*".

> Respondent 2: "*One major issue that will decide the survival of the nanotechnology industry is the manpower… more local graduates in nanotechnology*".

> Respondent 3: "*Our human capital simply is not sufficient. Because nanotechnology spans all industries, we need more workers that are competent in nanotechnology in all industries*".

> Respondent 4: "*Nanotechnology cannot maintain without proper human resource development… I believe this is a critical success factor*".

> Respondent 5: "*We can get nanotechnology expertise from overseas, but with limited capital, we cannot afford to do so. Therefore, the local education sector needs to produce capable graduates to sustain the nanotechnology industry*".

> Respondent 6: "*One major critical success factor that cannot be ignored is the labour force. In order for the nanotechnology industry to be successful, we need more skilled workers*".

> Respondent 7: "*No doubt. More nanotechnology graduates is needed. This is a critical factor*".

> Respondent 8: "*Graduate numbers are simply not enough… we have to import skilled employees…. very costly… cannot survive in the long run. So, local education needs to supply the suitable manpower*".

> Respondent 9: "*A critical success factor is human resource. We simply need more*".

> Respondent 10: "*As nanotechnology advances, workers need more skills. To circumvent the time to train workers, new recruitment need to be well versed in nanotechnology… education needs to supply that*".

Respondent 11: "*Nanotechnology is disruptive. It needs to 'disrupt' the education sector to produce more nanotechnology abled workers*".

Respondent 12: "*A drastic change needs to be done to help the nanotechnology industry. More workers needed, so we need them trained early*".

Respondent 13: "*Although retooling workers is not the ideal, we still do it. The education system can help us reduce this problem by producing more engineers in nanotechnology. This is a critical issue*".
Respondent 14: "*What I don't understand is… nanotechnology has the potential to drive the GDP… yet we are not preparing ourselves enough for it… more graduates needed for the nanotechnology industry*".

Respondent 15: "*Bottom line is no workers, no industry. Definitely, human resource is a critical success factor of the nanotechnology industry*".

All the above statements support the human resource development as being a critical success factor for the nanotechnology industry. From question 2, identified recommendations were revealed during the interviews. Based on those findings two technology management categories were identified to address this human resource issue, namely technology utilisation and integration, and technology strategy. All this information will be used in formulating the framework to be evaluated during the follow-up interviews.

4.2.3.2 Physical Infrastructure and Utilities

The next critical success factor to support the nanotechnology industry that was identified during the interviews was related to the physical infrastructure and utilities. Starting nanotechnology from nothing would be next to impossible unless there is an unlimited supply of money that can fund such endeavour. Therefore, there needs to be a starting platform to launch nanotechnology efforts in research and development, as well as commercialisation, one of which can fall on the government. Since providing a platform can involve a huge amount start-up capital, undoubtedly government-level decision making will be involved in determining the establishment and success of the nanotechnology industry.

From all 15 interviews, it was revealed that infrastructure and utilities are an important factor in determining the success of the nanotechnology industry. This billion ringgit industry needs the maintained support from the utilities industry as well as the government to provide the required infrastructure.

As with the human resource critical success factor, the infrastructure and utilities critical success factor also have supporting statements made during all 15 interviews that support this, which are:

> Respondent 1: "*Infrastructure needs to be provided to help the nanotechnology industry. Without infrastructure, this industry simply cannot survive. Since infrastructure cannot be constructed solely by individual firms, a larger body like the government, needs to provide this*".

> Respondent 2: "*When a potential foreign partner knocks on the door wanting to come to Malaysia, they will ask about the manpower and also infrastructure. How much infrastructure is available, and is it reliable. This is a strong determining factor for them to come in or not*".

> Respondent 3: "*Another critical success factor is the infrastructure, which goes beyond the physical structure to house nanotechnology development. It also covers the utilities… electricity, water, waste disposal… without proper infrastructure, the industry cannot stand up*".

> Respondent 4: "*I remember one time there was power shortage in our plant. We were without power for 10 minutes, and that cost us millions of ringgit worth of production loss. So, utilities are a critical factor for the nanotechnology industry*".

> Respondent 5: "*Frankly speaking, the nanotechnology industry relies heavily on the utilities industry. Reliable electricity, water, gas, waste disposal, sewage works, and others… very important. When a nanotechnology facility is constructed, all these utilities need to be in place, 24 seven. There needs to be a guarantee*".

> Respondent 6: "*The government can attract FDI by building infrastructure… like high technology parks to make Malaysia an attractive place to set up their business. This coupled with manpower, I think, is a critical success factor for the nanotechnology industry*".

Respondent 7: "*Good infrastructure, continuous electricity supply… a must for the nanotechnology industry to thrive. This is especially critical when dealing with premium products, where power outage can cost millions to the company in production loss*".

Respondent 8: "*High technology parks are a good option for the government to pursue. It can put Malaysia on the map and attract foreign investment. Local companies can also benefit by moving into these parks… they can get all sorts of benefits… uninterrupted power supply, high speed Internet… all needed for the nanotechnology industry*".

Respondent 9: "*The then Prime Minister Tun Mahathir had great vision. Infrastructure development was rapid during his time. Who would have thought that the Internet would play a major role in the development of the country… he foresaw it… the MSC (Multimedia Super Corridor) was a testament to this… if only nanotechnology was in his radar at that time. I am sure that more high technology parks would have been created to enhance the rate we develop nanotechnology… infrastructure must be established before nanotechnology can flourish*".

Respondent 10: "*Having a stable political environment means that the development of infrastructure continues at a good rate. However, more awareness is needed about nanotechnology so that the top level decision makers can focus on developing the infrastructure for this potentially profitable industry… also utilities are very important… cannot survive without it*".

Respondent 11: "*Something that our production cannot proceed without is power… electricity ensures the safety of our production lines by maintaining a sterile environment. The air filtration system requires a large amount of non-stop electricity. So, utilities play a valuable role for the nanotechnology industry… as well as a stable and solid infrastructure*".

Respondent 12: "*Like most industries, nanotechnology needs a physical place to settle and grow. In order to do that, it needs enough support to make it flourish. For our nanogel to be produced, we require uninterrupted power supply, as well as elemental gasses that need to be restocked often, in case we run out. Our link with the vendors requires real time information that needs to be shared, so that we are not short on supply. This means that our Internet connection needs to be on all the time. Electricity cannot stop, meaning the infrastructure needs to be world class*".

Respondent 13: "*Nanotechnology needs specialised equipment, usually custom made, and they require great care. Due to the nature of the science, which deals with really minute scaled objects, sensitivity is an issue. Therefore, the infrastructure and utilities must be at par with the technology. This is vital for the longevity of the [nanotechnology] industry*".

Respondent 14: "*Downtime is a killer. That is why we need stable and reliable supply [of electricity]. The infrastructure needs to be tip-top… this is a critical* *issue… for the nanotechnology industry to [become a] success… government support definitely needed*".

Respondent 15: "*Of course we can build our own infrastructure [laughs]… yeah, and we can have a nanotech[nology] suit like Iron Man… if we have unlimited money like Tony Stark, sure we can. But in reality… the nanotechnology industry relies on the government to provide this. No infra[structure], no industry*".

4.2.3.3 Consumer Awareness

As with the human resource, and infrastructure and utilities critical success factors, the consumer awareness critical success factor also has supporting statements made during all 15 interviews that support this, which are:

Respondent 1: "*There needs to be a push and pull effect for the nanotechnology to succeed. Push from the industry and pull from the public… the public consumer will not create the pull for products if they are not aware of nanotechnology… this is where the government should play a role in addressing this critical factor… to improve the nanotechnology industry*".

Respondent 2: "*Awareness needs to be increased… like overseas, they do introduction and awareness campaigns first before introducing a new product to the market. They also do market research, and initial consumer surveys to see whether the product would be well received by the public or not… but to find out whether the public will accept or reject a new product, consumers must know the product… awareness programmes are vital for this*".

Respondent 3: "*the ministry wanted us to run advocacy programmes… awareness programmes… we need support. We cannot do it on our own… we can do local campaigns, but nationally, we cannot afford it. Awareness is vital… how can consumers buy our product when they do not know about it… [they] don't know, [they] don't buy*".

Respondent 4: "*the public is comfortable… at ease with using the current products. Nanotechnology products are at a premium price, meaning they are more expensive than the traditional products. Consumers are not aware of nanotechnology products… don't know benefits… don't know advantages in the long run… so they don't buy. So I would say that awareness is critical for the nanotechnology industry to survive long term*".

Respondent 5: "*We need to inform the public… persuade buyers… make the aware about nanotechnology products and benefits. They need to see nanotechnology products in action. It is no longer effective to explain the technology… the public wants to see result. A demonstration video is enough to engage an audience… if it goes viral, then the public will soon know about it. The* *movies are a good platform, and have been doing advertising for nanotechnology for years… but they illustrate the potential future of nanotechnology, not what we have right not… if the public knows, it will buy*".

Respondent 6: "*There is a difference between the general public in Malaysia and the people abroad, especially developed countries. We can see by their general attitude, and preference in nanotechnology products. The money makers are in the higher end products, like electronics and medical fields, which is the direction developed countries are pursuing rapidly. Over here, we still focus on cosmetics, fertilisers, and textiles. Don't get me wrong, there is nothing wrong in that, it is just it takes longer to achieve similar profit to the developed countries when the focus is on lower end nanotechnology. The public must be aware to increase acceptance*".

Respondent 7: "*Nanotechnology is a buzzword. It is used in marketing, even though the products may not necessarily contain any nanotechnology. In the movies, nanotechnology is represented by wildly imagined applications, probably based on Feynman's idea of bottom-up construction… creating matter atom by atom or molecule by molecule… so the public has many views on nanotechnology, most probably not accurate. This is why it is vital to do awareness programmes, not just for promoting products, but also to educate the consumers on selecting better products for their use*".

Respondent 8: "*in the US for anything, before introducing to the public, to the society, they do some kind of awareness programme first. I once attended a meeting on this, in Santa Clara, under NSTI [Nano Science Tech Institute]. The first thing, before they start launching their initiatives… national nanotechnology initiate yes, they spend about USD400 million in the US…because this thing is new… we need to do awareness, so that people are aware about this thing… the beauty… the goodness of this thing, then only they can penetrate market*".

Respondent 9: "*If nobody is aware or has no knowledge on nanotechnology, then this has dire implications on all levels. The public doesn't know, so they don't demand it… no demand, no development… no focus given by the government, no infrastructure development… so you can see, consumer awareness if a critical success factor of nanotechnology industry… definitely*".

Respondent 10: "*consumer awareness is not just important, it is vital. The public needs to be informed. Once informed, they can make the choice. They can decide… to buy or not. Anyone can see that nanotechnology has many benefits. So if the public knows about it, then most probably they will buy it. If students know about it in schools, then they may develop an interest in it, and further their education in the direction of nanotechnology. Consumer awareness can indirectly affect the job market this way*".

Respondent 11: "*teach the students. Let them know about the real nanotechnology… not the ones shown in movies. The movies show fantastical ideas… not reality. Once they grow up, they are more informed, so when buying stuff, they can decide to take the nanotechnology-based product over the traditional product. Consumer awareness is key*".

> Respondent 12: "*If nanotechnology is to succeed, then people need to know about it. No longer having to wait for traditional media… social media nowadays… the platform to disseminate knowledge. Nanotechnology can utilise this platform in order to increase consumer awareness, which plays a critical role in enhancing the nanotechnology industry*".

> Respondent 13: "*These days, wherever you look, you see technology in action… key word is 'in action'… nanotechnology cam be demonstrated… public can be convinced… but there needs to be a shift in focus made by the highest administration. This is because the nanotechnology industry is a billion dollar industry. The government can provide support in many ways… consumer awareness campaigns to increase awareness… more buying*".

> Respondent 14: "*Consumer awareness can be done in many ways. Formal education can help by shaping the future generation to be well versed in nanotechnology. The current general public also needs to be educated. Traditional media, such as the radio, television, newspapers, billboards, etc. all can be used, but the current social media is more effective. The government needs to get the word out… nanotechnology, it is real, and it is here today*".

> Respondent 15: "*The general public tend to buy their normal things every day. Most of the time, they just stick to the same brands, not wanting to try and experiment with other brands. This is because they are already at ease with the traditionally selected products. Sufficient awareness needs to be instilled in people so that the benefits of nanotechnology can influence them to buy nanotechnology-based products, even though they cost slightly more*".

4.2.3.4 Regulatory Framework

As with the human resource, infrastructure and utilities, and consumer awareness critical success factors, the regulatory framework critical success factor also has supporting statements made during all 15 interviews that support this, which are:

> Respondent 1: "*There is no parliamentary Act to support the nanotechnology industry, so we are not protected… the consumer is not protected. We have to move on our own*".

> Respondent 2: "*getting certification for nanotechnology products is something we want to do. This is to validate our product. It is good product… encourage people to buy… but right now it is not compulsory. There is no regulation that we know of… no watchdog… to ensure safety… that is why we need a regulatory framework*".

Respondent 3: "*We have a national roadmap [for nanotechnology]… now we need to follow it. There needs to be better regulation of nanotechnology… not to say to keep everyone in check, but rather to speed up the process of discovery and drive nanotechnology to become more advance and cheaper… always bottom line… cheapest*".

Respondent 4: "*for me… for as long as there is technology to be developed in industry… technology to be commercialised…we will do it …of course the bonus is if we have these acts that make it mandatory then… easier to do work. You can say that a regulatory framework will play a key role in facilitating the nanotechnology industry… definite critical factor*".

Respondent 5: "*we have been waiting for such a long time… still no laws, no act. This act has been 10 years in the making… three heads… three times we changed ministers to spearhead this effort… twice the minister had to be briefed and brought on board about the importance of a regulatory framework for nanotechnology industry… until now, no act*".

Respondent 6: "*it is good to have a monitoring body keeps the industry in check… have a place of reference… when we have problems, we can contact somebody. Also an act would definitely help the industry to move at a faster rate… also the roadmap plays an important role. All of these add up together to become a regulatory framework... important to be established since nanotechnology is a potentially disruptive technology... like ICT*".

Respondent 7: "*Of course the research and development is done in isolation… secret… security very tight… if we have rules and regulations to protect us, maybe we can be more open… more collaboration, less silo approach… and act can help for sure*".

Respondent 8: "*Why do we need a regulatory framework? Well, we have nanotechnology agencies and bodies, we have industry players, we have research and development, we have a roadmap, we have some government assistance… all of this need to be coordinated. If not coordinated how to move forward together… no cohesion… this is where a regulatory framework comes in… puts everyone on the same page… on the map*".

Respondent 9: "*For years the nanotechnology industry in Malaysia is moving at a slow pace, when compared to what is happening in more developed countries. There are many things that we need to improve… one this is regulation. For electrical we have SIRIM, for halal aspect we have JAKIM… ICT we have SKMM AND [strong emphasis] an Act… nanotechnology needs that kind of framework for it to move forward and become a significant contributor to GDP*".

Respondent 10: "*For technology to evolve properly, it needs a framework to help facilitate the development, while putting into place features that will help it along… I believe this… a regulatory framework needs to be established to protect the consumers and also the industry players. Since this technology is far-reaching, regulation will help to control it and also move it forward. There is obvious potential in investing in nanotechnology, but the start-up is quite costly*".

Respondent 11: "*Technology regulation in this sense means the basic minimum or requirement for that particular technology… including nanotechnology. We need properly formed regulations to ensure that nanotechnology is developed accordingly. Regulations can also inform all parties… industry players and the public… and thus put everyone on the same page. If the public is aware of the regulations, then the industry players will strive to meet these requirements, thus creating better more advanced products. As you can see, regulation is a critical success factor for the nanotechnology industry*".

Respondent 12: "*Laws, legislations, and regulations… very important… they shape the industry. Without them… chaos. The development would not be done properly, and this can lead to waste of time, money, and effort. Project failure is always a risk when it comes to technology development… a regulatory framework is needed*".

Respondent 13: "*in Malaysia, they have laws, rules, and regulations when it comes to communication technology. We can see now that communication technology is disruptive technology and has large consequences… changes the way we do things… no longer static communication, but dynamic. Nanotechnology is also disruptive. One nanotechnology-based material can be applied across industrial sectors… nano-silver can be used in cosmetics, lubricants, textiles, and many more… so nano-products needs to be developed and regulated*".

Respondent 14: "*regulatory framework is definitely a critical success factor. This includes procedures, guidelines, codes of conduct… regulations. This framework can provide a path for the industry to follow. It can help drive the industry* ".

Respondent 15: "*If we look at overseas… the developed nations, they have established a framework to assist their leading industries. Currently, nanotechnology is their focus… a gold mine of opportunities… and they are successful in doing it. Their regulations have been formulated to grow the [nanotechnology] industry because they are aware that it is the next big money maker*".

4.2.4 Findings for Question 4 – Strategic Approach/Framework Implementation

In terms of the process flow or method of implementation, the question: "What is your strategy and how was it implemented into your nanotechnology company?" was asked to understand the process of implementation that has been used among the different nanotechnology practitioners from various sectors. The findings from the interviews identified that several strategies had been implemented in order to improve the level development in the nanotechnology companies.

With regard the human development, respondents R1, R2, R6, and R13 stated that they implemented strategies to assist the company resolve some manpower issues. They take active roles in forming close ties and relationships with tertiary institutions so that the graduates can be better tailor made to fit into the industry. This was evident by their statements that were recorded during their respective interviews, which are as follows:

> "*our company actively seeks out graduates from higher education. One strategy we employ is to get involve with universities and communicate to them the kind of graduates we are looking for… our senior management often go to these universities to participate in discussions and consultations to help better shape the graduates*" – from interview with R1.

Respondent R1 reveals that tertiary education needs to be kept well-informed or the current needs in the industry. The strategy they can employ is to form links and good communication channels to provide information on what skills and knowledge is required by students to enable them to be successful in joining the nanotechnology industry. This is also supported by respondent R2 with the following statement:

> "*careers fairs, talks… many activities in these universities are channels for us hunt for talent. I believe that we have the talent… but we need to hunt for them. One strategy is to actively look for them… not just waiting for them to send their CVs*" – from interview with R2.

Respondent R2 highlights an interesting point. Where most companies wait for potential workers to apply for job positions, their approach is to actively seek out potential employees by getting actively involved in recruitment programmes run by universities. Respondent 13 also mentioned this method of recruitment:

> "*if we don't actively find workers, then we will be left behind. The best way to do this… go out and find them… that is the strategy we use. Since talent is scarce, we cannot afford to wait for them to find us…we find them*" – from interview with R13.

Implementing strategies to attract new recruitment seems to be critical in sustaining the nanotechnology industry, but respondent R6 also highlighted the importance of maintaining the current worker skill and knowledge levels in order for the company to remain competitive. Respondent R6 described the following:

> "*we strategise all levels… to improve current manpower and future workers as well. The current employees are sent for training and short courses to equipment with new skills and knowledge… future recruitment is sourced out in universities… we have MOUs with several universities. We even take practicum students*" – from interview with R6.

Where most companies take the stance of having formal boundaries and maintaining external relationships with tertiary institutions, respondent R6 works for a company that perhaps form open and tighter relationships with education institutions. Here, memorandums of understanding (MOUs) and memorandums of agreement (MOAs) are potential avenues that can be explored by nanotechnology companies in order to achieve a win-win situation for all parties involved.

The next issue that have been addressed by the respondents in this study is the infrastructure and utilities. Perhaps these companies do not have the capacity to create their own infrastructure and utilities, but they are actively seeking out new providers and vendors to better improve their respective companies' performance. Respondents R5 and R15 had revealed during interview that,

> "*we have been in this industry for a long time… we look for opportunities to further expand our company. Physically, we try to look for the best facilities… open up new branches or divisions… depends on location… and utilities. We take note of high tech[nology] parks and new government initiative to build more… so if feasible we move. So far, we have moved once in our company history, and opened up three divisions*" – from interview with R15.

Respondent R15 had illustrated the success the company is experiencing by highlighting the expansion of the company that has successfully moved to better premises and also the opening of the divisions. This would neither have been possible nor feasible if the company is not doing well.

Meanwhile respondent R5 described how the company attempts to better improve its position by upgrading its physical buildings. Respondent R5 stated that:

> "*we renovate our plant every three to five years to improve the layout and increase size where we can. We still have the land to accommodate this… recently we changed Internet providers… much cheaper now. We have better communication channels with our partners overseas*" – from interview with R5.

Here, respondent R5 also added that they take the strategy of selecting and changing service providers to improve the company's performance. Nanotechnology companies may not be able to create infrastructure, but they can perhaps improve their performance by investing in providers that offer better and less expensive services, more suited to their needs.

The issue of consumer awareness in perhaps different from infrastructure and utilities issue; from the aspect of control and how to address it by nanotechnology companies. While infrastructure is difficult to implement by just a single company, consumer awareness can be controlled by the company to a certain degree. All respondents agreed that consumer awareness is a critical issue, and they have mentioned that they improve this by carrying out advertising and marketing in one form or another. From the interviews, respondents R3, R7, R9, R10, R12, and R13 highlighted some interesting facts. Respondent R3 highlighted an important fact by saying:

> "*more money, more results. That is advertising… our last marketing campaign was the most expensive to date, and we saw that it was the most successful. We employ a combination of both traditional and social media to promote our product. Social media is the cheapest… but we cannot ignore the power of television and radio… newspapers not so, but magazines does have a positive impact on our sales… if you have a better strategy let us know*" – from interview with R5.

By taking a mixed approach, respondent R5's company is able to strategically address the issue of consumer awareness. However, it is an expensive strategy. Respondent R5 stated that for a marketing strategy to be effective in addressing consumer awareness, more capital is required to channel information through traditional means, like television and radio, and to a certain extent magazines. Since respondent R5's company produces cosmetics products, their marketing campaigns in magazines would be featured highly in women's magazines.

Meanwhile, respondent R7 stated that social media is key nowadays to successful marketing. This is,

> "*because it [nanotechnology] is fairly new… people do not know about it… people do not know the importance of it… so… use key opinion leaders… social media and whatnot… because traditionally what… some [companies] have been doing was via printed media…who reads newspapers right?*" – from interview with R7.

Respondent R7 also pointed another interesting fact, which is using key opinion leaders. Key opinion leaders can come in all shapes and forms. They can range from famous celebrities, charismatic politicians, and even over-night sensations that go viral in the social media. These social media "influencers" can have a positive, or negative, effect on a marketing campaign. Social media influencers can be found in Instagram, Facebook, Twitter, Tik Tok, and many more platforms. So, selecting a champion for nanotechnology in advertising and marketing is one potentially viable strategy to promote consumers awareness. Respondent R13 further emphasised the use of key opinion leaders by saying,

> "*we also use…key opinion leaders…for example known figures in automotive care…because these are how should I say…areas where nanotechnology is mostly applied in Malaysia*" – from interview with R13.

This is further supported by respondent R9, who stated that,

> "*Who listens to radio talk shows…TV talk shows… very very few people… and when you go in and you talk about hard core technology, you know... going into*

the fundamentals… people do not really appreciate… they really prefer the results… they watch the video, they see the effects, that is it… it goes viral" – from interview with R7.

This statement illustrated the mentality and public attitude when it comes to hard facts. Previously, before information can be communicated seamlessly like we have today, the general public is perhaps eager to learn new facts and discoveries when information is released via traditional media like newspapers and television. Every new discovery would be highlighted in the media and become a topic of daily discussion. These days, however, daily conversations would revolve around the latest viral sensations that are happening on social media, like Instagram and Youtube. It seems that the public is more attracted to entertainment news rather than informative news, which has given rise to the concept of edutainment, which is perhaps ones avenue nanotechnology can explore further, more specifically in relation to the company products. Respondent R10 described some of the success in social media marketing,

"*I have not only been doing facilitation, we also go the extra mile to actually promote the technology via social media, so we have quite established Instagram… Facebook… LinkedIn… LinkedIn just started… but our website is getting about 13000 hits a month*" – from interview with R10.

Meanwhile, respondent R12 further emphasised this point of using social media by saying,

"*so that is what we are focusing [on] right now… on experience of using the [nanotechnology] product… that is why… we prefer Instagram, Facebook, experiential sort of sharing… rather than… hardcore science*" – from interview with R12.

Evident from the statement above, respondent R12's company has employed the strategy of using testimonies by customers and experience of using nanotechnology products to educate the public through social media. This can influence potential customers to buy the product as they are influenced by previous success stories by actual customers.

Aside, social media also has added benefits to the nanotechnology company. Respondent R13 stated that,

> "*I also find it [social media] very useful… in team environment… like working… so… everyone is on the same page… literally… we need to innovate our approach*" – from interview with R13.

This illustrates the power of social media to unify the audience and promote uniform understanding about certain issues and products. This statement also calls for the innovation of consumer awareness approach.

With regard to the regulatory framework issue, respondents R2 and R8 summarised some strategies taken by their respective companies. Respondent R2 recorded that his company,

> "*tries to hook up with… regulatory bodies like Halal, National Pharmaceutical Regulatory agencies… we found out that there is actually quite a lot of… like I said, nanotechnology in cosmetics… in the National Pharmaceutical Regulatory database, a lot of cosmetics… so there is significant amount of overlap there… and there is also overlap in terms of Halal database*" – from interview with R2.

The above statement reflects the collaboration strategy, where the company forms beneficial relationships with certain bodies that have information the company can use. These established bodies also have guidelines that companies can employ to help facilitate their products and company performance.

Meanwhile, respondent R8 highlighted a strategy of getting certification and validation of their products in order to enhance company performance. This was evident in the following statement,

> "*so now what we are looking to do is to further boost sales… because now more confident because… they are being accredited by a… government affiliated body… so the story is about growing the business… within and also outside Malaysia through certification*" – from interview with R8.

When a product is certified by a recognised body, then consumers would be more confident in and would be more trusting of the product. When consumer trust is achieved, sales can be increased.

It can be summarised that all the interview participants agreed and confirmed that poor human resource planning, insufficient infrastructure, lack or very little consumer awareness, and poor regulatory framework significantly adversely affects successful Malaysian nanotechnology industry development. The findings from the interviews, therefore, identified the improvements that were needed in terms human resource development and enhancement, high technology parks, awareness campaigns, and the establishment of a Nanotechnology Act to strengthen the regulatory framework.

In addition, the involvement of all nanotechnology players such as manufacturers, researchers, and government agencies are required in order to avoid duplication of effort and especially to convince and educate the Malaysian government or private clients about nanotechnology industry development practices. The participants conceded, with no opposition, the benefits of this approach for the nanotechnology industry. The interviews revealed that 1) human resource, 2) infrastructure and utilities, 3) consumer awareness, and 4) regulatory framework are the key or critical success factors. The next chapter will discuss the development of a framework of critical success factors (CSFs) for effective nanotechnology industry development implementation in the Malaysian nanotechnology industry based on the triangulation of the factors that were identified from the literature review and data collection interviews. Next section elaborates on the framework developed for this study.

4.3 Framework Development

The nanotechnology industry development framework is proposed to improve Malaysian nanotechnology industry development. There are four elements in this framework that work together by supporting technology management practice. These elements are human resource, infrastructure and utilities, consumer awareness, and regulatory framework (refer Figure 4.1).

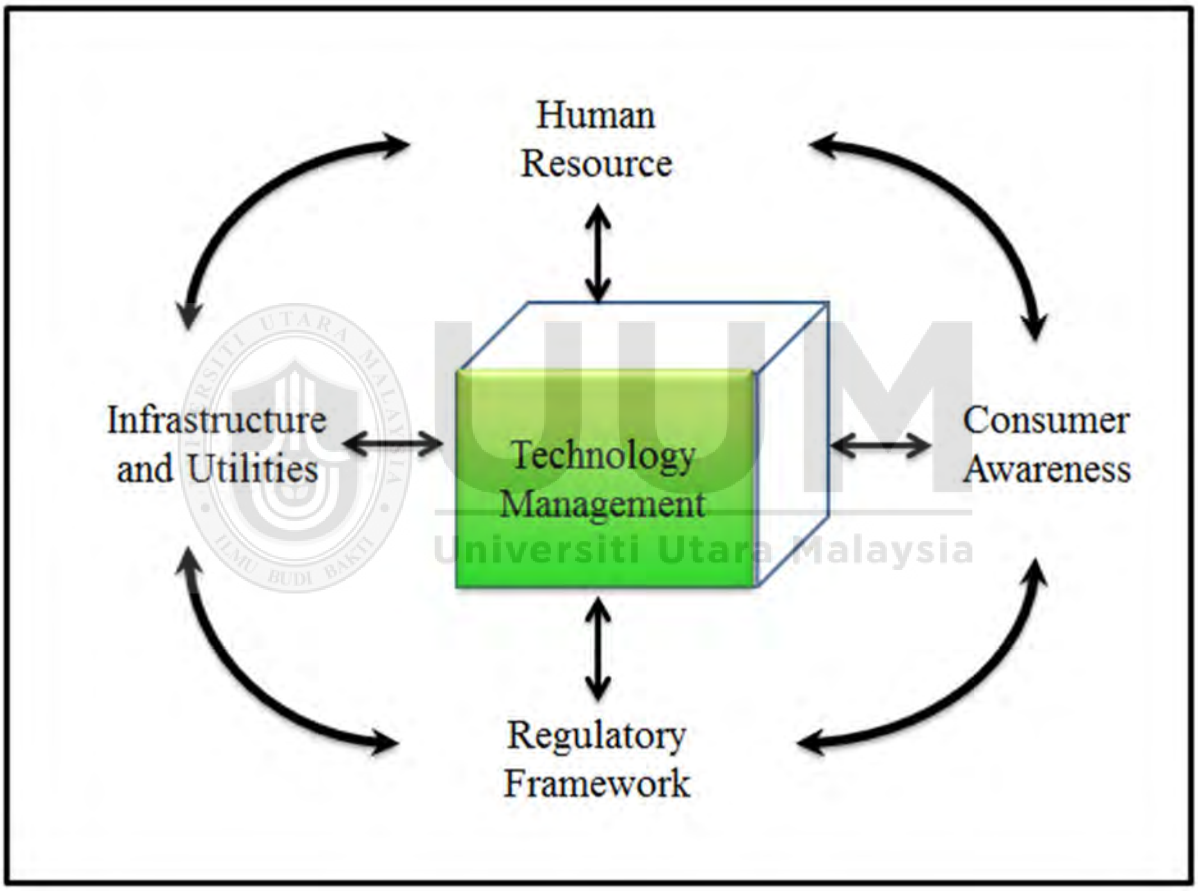

Figure 4.1
Nanotechnology Industry Development Framework for the Malaysian Nanotechnology Industry
Source: This Research

The development of this framework was based on the work by Nawi (2012), where the researcher adapted the main issues revealed during interviews as well as uncovered during the literature review. The difference between this thesis and the one by Nawi (2012) is the setting for the research (nanotechnology industry development, as opposed to construction industry focusing on integrated design team), as well as the data collection method (interview session, as opposed to focus group workshops).

The framework developed for this research is different from the one formulated by Nawi (2012), but it shares a similar characteristic, in that it needs all the elements to be implemented successfully in order to achieve the objectives of the framework, as was supported by the following statement, “one has to be clear that the failure of any one of the pillars among people, process and technology will lead to failure for achieving fully integrated team practice”. In the context of this research, failure of any one of the pillars among human resource development, infrastructure and facilities development, consumer awareness, and regulatory framework will lead to failure in achieving successful nanotechnology industry development.

Therefore, the framework developed for this study (Figure 4.1) clearly illustrates a holistic approach whereby the problem of enhancing the nanotechnology industry requires co-development of the four pillars illustrated in the framework. This means that there needs to be development occurring in human resource at all levels of education, development of good infrastructure such as high technology parks, running of awareness campaigns to increase the level of awareness amongst consumers, and establishment of a parliamentary Act to form the basis for a regulatory framework, as was discussed in the literature review and revealed during the interviews. Since these four pillars need to be developed co-jointly, there is no discerning or clear starting point to assist in the enhancement of the nanotechnology industry.

However, for the sake of discussion, let us begin with the human resource factor. Formal education needs to be implemented at primary or secondary schools, where the focus is more toward the benefits of the technology, rather than the hard core science of it. This is because, in the interviews, it was revealed that the general public in Malaysia would be more interested in the benefits of nanotechnology products rather than the science behind it. The facilitation of knowledge and also promoting awareness of nanotechnology amongst the impressionable young minds can help in creating awareness in future generations. This means that starting at an early age will have a continuing effect later on in their lives. This would lead to established awareness when these young students mature and start to enter the tertiary education system. This education system needs to be fine-tuned for preparing students to enter the nanotechnology industry workforce. This in turn would help promote the industry and develop it even further. With the further development, better and more products can be released into the market.

As the industry prospers, the infrastructure can be upgraded. More high technology parks can be implemented in order to attract more foreign direct investment (FDI) into the country. This would help enhance the industry even more. As more and more companies populate these high technology parks, there will be an increase in research and development of new products that can be potentially released into the consumer market. This in turn will have a positive effect on the other elements in the framework developed for this study. More products can assist in increasing the level of awareness of the public about nanotechnology products and their benefits.

By having more products in the market, this will indirectly increase the awareness of the consumers. However, this would not be a profitable method of increasing awareness, so awareness campaigns need to be executed and put into place in order to increase public awareness of nanotechnology products. Awareness campaigns can be done individually, by the manufacturing company, but this method would not have far reaching effects, as they are limited financially. Therefore the larger bodies, such as government institutions and agencies related to the nanotechnology industry needs to assist the companies to increase awareness of the available nanotechnology products. As more demand for these products occur, more and more development of the nanotechnology industry would ultimately drive the other elements or pillars in the framework developed by this study. As awareness increase, more high technology parks will be required as the industry expands, and more capable and nanotechnology-skilled human capital is needed to support the growing industry.

Not just waiting for this industry to grow in size and contribution to the GDP, the government as well and their respective agencies need to push forward for the establishment of a parliamentary Act so that a regulatory framework can be formulated to protect both the producers and consumers alike.

All these elements cannot be examined in isolation; they must all come together and cannot stand alone to realise the value of the framework to overcome the problems identified in this study (Figure 4.2). So, if one of the elements is taken out, the objectives of enhancing the nanotechnology industry will fail to be achieved.

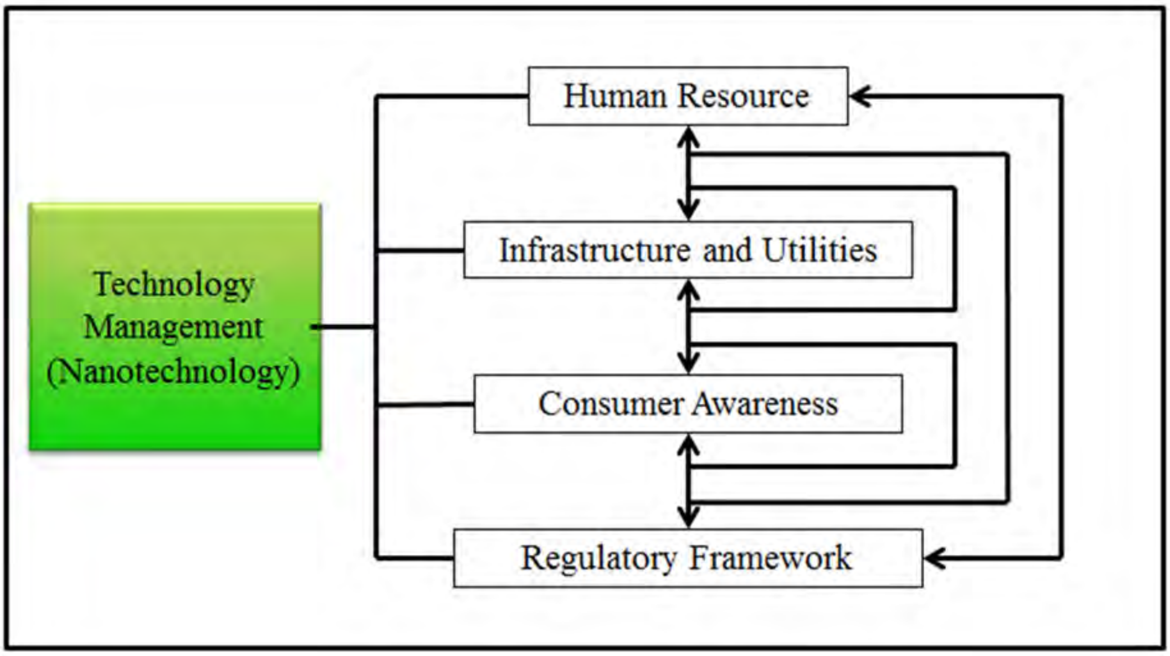

Figure 4.2
Interaction of Technology Management with Nanotechnology Industry Development Framework Elements
Source: This Research

The development of the framework is based on the discussion and triangulation of the results from the literature review as well as the results from the industry interviews. The literature review in Chapter 2 identified a list of critical success factors affecting the nanotechnology industry. As explained in Chapter 3, secondary data from the literature review needs to be combined with primary data in order to ensure that it is comprehensive, up-to-date and appropriate for the precise needs of this study. Accordingly, an industry interviews (data collection interviews) comprising of confirmed Malaysian nanotechnology producers had been conducted to gather qualitative primary data to be combined with the secondary data from the literature review to develop a framework for effective nanotechnology industry development in the nanotechnology industry.

4.3.1 Framework Structure

According to the findings from the literature review and the industry interviews (data collection interviews), 9 factors and 20 sub-factors were identified as critical to the Malaysian nanotechnology industry development. The list of the critical success factors identified from the literature and data collection interviews are depicted in Table 4.1.

All the critical success factors have been combined in order to develop a draft framework of CSFs for effective nanotechnology industry development in Malaysian nanotechnology industry (Figure 4.3). The framework can be seen as a guideline for Malaysian nanotechnology stakeholders to improve the nanotechnology industry. It can be used by anyone involved in the development of nanotechnology products, including the manufacturers. There are, however, some uncertainties as to what extent such a framework will contribute to the implementation of integrated approach in Malaysian nanotechnology industry context; this will be described in detail in the next section related to framework validation. The following paragraph will discuss the structure of the framework in more detail.

Table 4.1
CSFs for Effective Nanotechnology Industry Development in Malaysia

Elements	Factors	Sub-Factors
Human Resource	• Human Capital Development • Training	• Schooling Education • Tertiary Education • Technical Expertise And Know-How Transfer • Retooling • Local Skill Level Versus Overseas
Infrastructure And Utilities	• High Technology Park • Reliable And Guaranteed Utilities	• Constructing More • Improving Utilities • Continuous Supply of Electricity/Water • Improved IT and ICT
Consumer Awareness	• Public Awareness Campaigns • Market Research	• Focusing on Benefits Instead of Technology • Long Term Benefits Versus Cheaper Traditional Alternatives • Product Feasibility • Level of Consumer Awareness
Regulatory Framework	• Product Verification/ Certification • Parliamentary Act • Government Support	• Need for Certification • Consumer Safety • Regulation of Nanotechnology • Public Safety • Environmental Safety • Financial Incentives • Increasing Foreign Direct Investment

Source: This Research

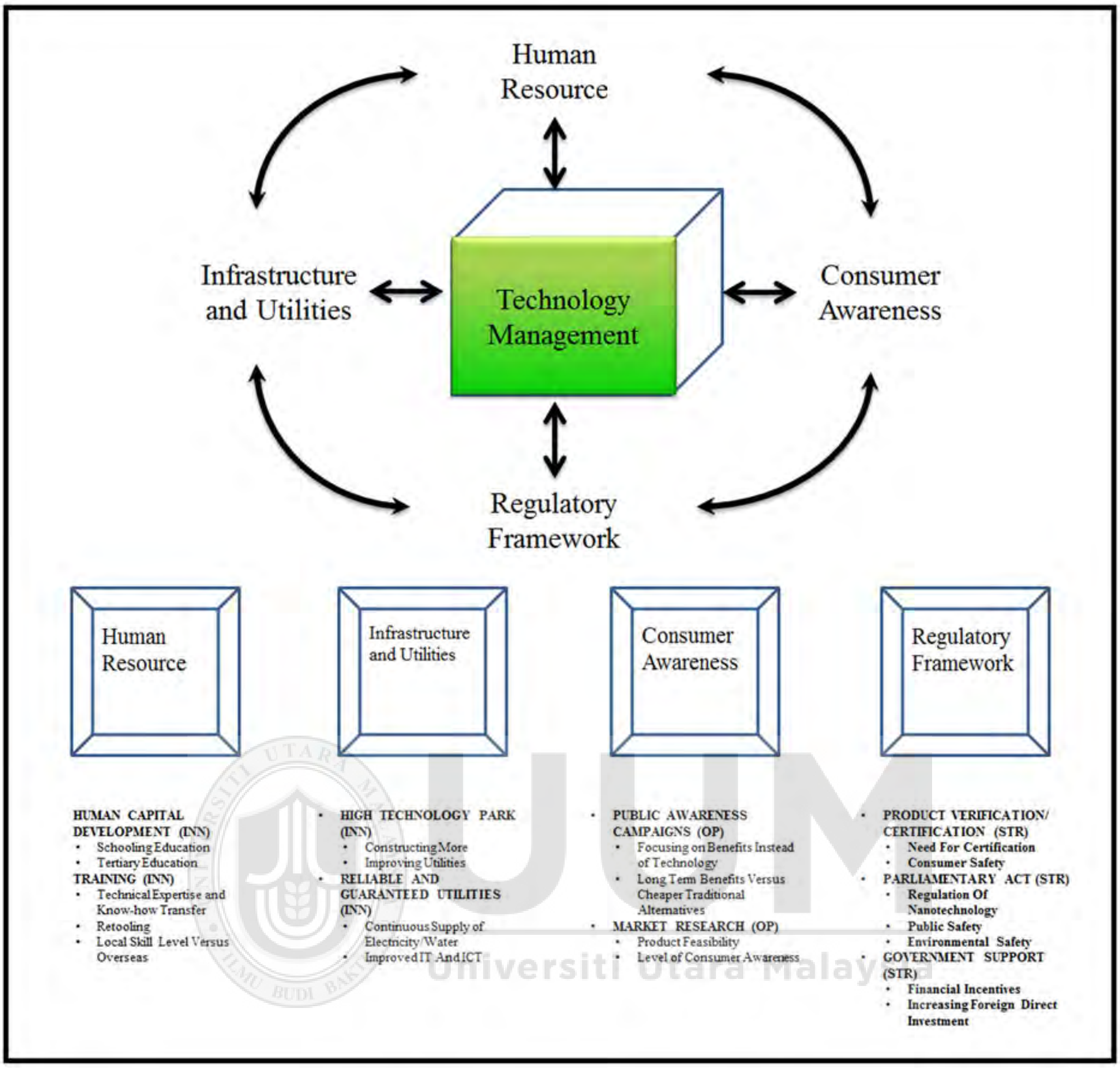

Figure 4.3
Draft Framework of CSFs for Nanotechnology Industry Development in Malaysian Nanotechnology Industry
Source: This Research

The "human resource" element in the framework refers to human resource factors, such as primary and secondary education, tertiary education, training, and retooling. This implies that for the nanotechnology industry to thrive, the industry needs to develop workforce capabilities in order to achieve an effective nanotechnology industry. Secondly, in terms of "infrastructure and utilities", the existing approach which is based on the traditional "silo" approach needs to be changed and geared more towards an integrative and collaborative process. This element should include improvements to high technology park development, effective utilities management, back-up and contingency plans, IT and communication infrastructure, and efficient logistics. Next is the "consumer awareness" element, which can help facilitate both directly and indirectly all the other elements, as it acts as a pulling factor. This element needs awareness campaigns, marketing campaigns, and market research. Finally, nanotechnology industry development has to be supported by the "regulatory framework". Regulatory framework in this research has been described as an appropriate medium or tool for improving the development of the nanotechnology industry as a whole.

The following sub-sections will discuss the triangulation process of the findings from both the literature review and data collection interviews and their respective contributions to the development of the framework.

4.3.3.1 Human Resource Factors

As highlighted in the previous sections, findings from both the literature review and the interviews showed that the "human resource" element had a significant impact on the nanotechnology industry. The CSFs for effective nanotechnology industry development are highlighted below.

According to Abicht, Freikamp, and Schumann (2006), demand for qualified nanotechnology personnel is increasing in R&D. The development of new products and services also demands more well-trained staff in manufacturing, quality assurance, marketing and distribution. For instance, in 2004 the European network Nanoforum conducted an online survey to assess responses to the European Commission's proposed document Towards a European strategy for nanotechnology. Altogether 749 persons were questioned across Europe. In this context it is especially noticeable, that there is an urgent need to develop nanotechnology education and training, with 90% of participants indicating that inter-disciplinary is considered to be crucial (Malsch & Oud, 2004).

Meanwhile, Abicht et al. (2006) had presented the findings of a review of existing education and training opportunities in Europe, the US, and Asia, and presented the results of qualitative research in Germany regarding the identification of trend-setting skills in nanotechnology. New skill requirements in companies were categorised within qualification profiles for R&D, manufacturing, quality assurance, documentation of analyses, research and production processes, marketing, and distribution. Referring to the overall analysis of skill development in nanotechnology, Abicht et al. (2006) proposed a six-step method to implementing and verifying innovative training measures in Europe. Following analysis of nanotechnology and its institutions in Europe and worldwide, a survey of scientific-technological development, identification of innovative demands for qualification and the development of qualification profiles, new training measures throughout Europe have to be developed and tested. This is more so in Malaysia in order for the Malaysian nanotechnology industry to be able to thrive. The next step is the generalisation and broad implementation of new education and training measures. It was concluded that on the basis of international comparison, that there is extensive public promotion of sciences and technological research. Unfortunately few activities can be found regarding identification and development of the required human resources. As far as these activities are promoted, they are usually a component of science and technology research and lead to individual solutions without involving the neighbouring areas. In the medium-term this could cause a shortage of qualified employees, which could be a limiting factor for the successful transfer from nanotechnology research to nanotechnology production and commercialisation.

In this context, Abicht et al. (2006) demonstrated that there are new demands for qualification in nanotechnology and the need to improve training and higher education. Introducing nanotechnology qualification contents into professional and vocational training will be decisive in maximising nanotechnology's potential. Companies with nanotechnology business activities need an increasing number of qualified staff. So, new recruitment needs to be equipped with the basic knowledge that can be swiftly applied into the work place. With the ever advancing nanotechnology discoveries being made, the current work force needs to be up to date, so training and further education is required to support this industry.

Even though the economic significance of nanotechnology is increasing, many applications are currently at the level of research or applied R&D, with numerous trends and development tendencies having growth potential but not being seen as sufficiently concrete. Due to nanotechnology's enormous innovation potential, R&D jobs are mainly carried out by higher education at present indicating an increasing need for graduates. In addition, further achievements in intermediate skill needs are necessary, i.e. vocational training, to process research results in nanotechnology production. To be able to fill the demand for adequately qualified staff in the relevant nanotechnology fields of work, exploration into innovative job and qualification requirements is necessary.

The framework of CSFs was supported by the interviews which recognised that all the sub-factors in the CSF framework were significantly associated with successful nanotechnology industry development supported by technology management in Malaysia (Table 4.2).
Although Table 4.2 shows that the interview respondents confirmed all the factors previously identified in the literature review, discussions during interviews were far more detailed compared to the literature reviews. This is because the respondents perhaps had personal

experience and are very aware of the current scenario for the industry. Meanwhile, the literature review basically presented the general overview that can be explained based of secondary data. The findings from data collection Interviews identified that there is a need for the education industry to produce more capable and knowledgeable graduates to support the nanotechnology industry development.

Table 4.2
Cross-referencing of Human Capital Development Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Schooling education is required to promote nanotechnology awareness.	✔	✔
2. Tertiary education is required to equip labour force with necessary knowledge.	✔	✔

Source: This Research

With the focus on nanotechnology research comes an increasing demand for qualified staff. With the development of new products and services, the demand for well trained staff in industrial fields of work, such as production, quality assurance and in marketing and distribution will also increase. Companies in nanotechnology, irrespective of their size, indicate roughly an equally strong demand for natural scientists, engineers and intermediate qualified workers. Employees are required on a short-term and medium-term basis as much as graduates but, semi-skilled and unskilled personnel are little needed, so employers first ask for well-qualified personnel with advanced and intermediate qualifications.

The findings from the interviews confirmed that training was a key factor to the success of nanotechnology industry development in Malaysia. The interviews concentrated on understanding the concepts of upgrading new recruits as well as current employees through re-tooling (workers, new and old are sent overseas to learn new knowledge and techniques to be applied in the company when they return home). These technical expertise needs to be transferred as they are developed on foreign soil. Through joint ventures and bringing in foreign companies to carry out their research in Malaysian high technology parks, indirectly foreign expertise can be transferred locally without having to send workers overseas. It was also evident during the interviews that there was a different level of skills when comparing the workforce of nanotechnology industries. So based on this literature review and the outcome from interview sessions, training factor has been identified (Table 4.3).

Table 4.3
Cross-referencing of Training Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Technical expertise needs to be transferred.	✔	✔
2. Retooling needs to be minimised.	✔	✔
3. Local skill level of graduates and workers need to catch up with overseas counterparts.	✔	✔

Source: This Research

4.3.3.2 Infrastructure and Utilities Factors

Infrastructure and utilities factor refers to a physical location where nanotechnology companies, both domestic and foreign, can establish their company within a supportive infrastructure that has uninterrupted utility service.

Success in nanotechnology research, development, and commercialisation requires a skilled workforce—from the shop floor to the laboratory—and world-class physical and computational tools. In the USA, they continue to promote the development of new experimental and computational tools to support advances in nanotechnology (NSTCCT, 2016). A key accomplishment was the development of unique, high-value nanofabrication and characterisation facilities that are open for use by researchers from industry, academia, and government. They pursue an “evergreen” approach to physical infrastructure that continually supports workhorse tools in addition to providing support for the development of new tools and techniques and for workforce training to maintain these facilities. This physical infrastructure must be complemented by a robust cyber infrastructure, including modelling and simulation tools, databases, and advanced data analytics. This cyber toolbox has been and will be increasingly critical to the understanding and development of nanotechnology. The USA also has a rich legacy in education and outreach through programs such as the NSF sponsored Nano-scale Informal Science Education Network (NISE Net), a network of museums and other institutions that had more than 30 million people participating in its programmes, events, and exhibitions from 2008 to 2015. Recently their National Nanotechnology Initiative (NNI) agencies, in collaboration with NNCO, have significantly expanded outreach and student engagement in nanotechnology-related topics through activities such as contests and challenges and through the development of networks to encourage students and provide support for educators. NNI agencies will build on these mechanisms and explore other approaches to education and engagement that will inform students and the public about nanotechnology and will also inspire the next generation of scientists and engineers, including those from underrepresented groups.

Progress in R&D will require the availability of a skilled workforce, infrastructure, and tools and will produce the discoveries that will enable the responsible incorporation of nanotechnology into commercial products.

As highlighted in the literature review and through the data collection interviews, the sub-factors include high technology park, and reliable and guaranteed utilities.

It is clear from the interviews and literature that high technology parks can have a positive effect on the growth of a technology based industry, especially the nanotechnology industry (Baluch, Abdullah, & Abidin, 2015; Abdullah et al., 2013). This factor refers to the number of high technology parks that have been constructed with the need for a push to build more and improving the utilities services provided by companies. This is because high technology parks can have many benefits provided that they are constructed and implemented properly. A high number of high technology parks can signal foreign investors that Malaysia is ready and capable of catering to their business and technological needs.

During the interviews, the topic of infrastructure and utilities cropped up many times, with the main issue being the loss of time and money during downtime. Because of this, the utilities services need to provide a certain degree of guarantee in the form of a contract and compensation scheme whereby the utility company is required to pay compensation to the nanotechnology company that has had they supply interrupted.

According to Baluch et al. (2015), high technology parks are physical foundations which are designed and built for the development of knowledge-based institutions. They concentrate research and information capabilities of government, private institutions and universities in one location. These parks also gather some of the facilities with high values work-place and high standards for corporations interested in participation at technology parks. Most literature on technology parks agree that science and technological parks are originally derived from the ideas of Stanford University which later on grew as successful Silicon Valley which was establishes in USA during1950s. They also agree that Silicon Valley is the first successful model for science and technological parks (Lai & Yap, 2004).

The clustering of high-technology firms and the synergies it creates among various institutions in the cluster is a defining characteristic of Silicon Valley and Route 128 in the USA. Observers have noted that such concentration of innovative firms and individuals in a region helps to create an entrepreneurial and innovative culture that breeds a continuous stream of innovations in an environment of information sharing and knowledge spill-over, both across firms and between firms and academic institutions, often via informal channels (Saxenian, 1996).

According to Baluch et al. (2015), the role of the parks is to create and fuse the necessary links amongst persons getting together for the purpose of exploiting idea's potential. There are three functional components in the technology parks which are; park, incubator, and higher education institute. "Park" refers to development of the property that enables new technology based firms to engage in R&D that enables R&D-related facilities to be located in the vicinity and "incubator" refers to the provision of business services for those who aim to start or have established new technology based firms; however, it does not refer to physical arrangements such as shared offices. High education institute refers to the site location of research facilities or liaison offices of high education institutes or the presence of a partnership with higher education institutes (Abdullah et al., 2013).

Abdullah et al. (2013) found that from the perspective of the industrial tenants, clustering and geographic proximity is highly important because being located at the high-tech park provides the companies with proximity to a good pool of readily available skilled and semi-skilled human resource for their operations. This really means that the work force around this location is accustomed to working in, as well as having sufficient knowledge and skills in, the technology industry. Besides, a study by Abidin et al. (2014) found that the services provided by the technology park are essential in supporting and enhancing the development of the companies' social capital which is an important resource gained by social relationships with other human beings and organisations. The central intention of social capital is network of relationships which are valuable resource for the individual or organisation. So based on this literature review and the outcome from interview sessions, high technology part factor has been identified (Table 4.4).

Table 4.4
Cross-referencing of High Technology Park Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Benefits of constructing more high technology parks.	✔	✔
2. Improving utilities through enhancement of services.	x	✔

Source: This Research

The interviews identified reliable utilities and guaranteed utilities to be an important factor for the development of the nanotechnology industry. However, the literature focuses more on the positive benefits of nanotechnology has on the utilities industry (Yunus et al., 2012; Bhattacharya et al., 2013), rather than vice versa which was revealed during the interviews.

According to NSTCCT (2016), a good physical infrastructure that supports nanotechnology must be accompanied by a robust cyber infrastructure, including modelling and simulation tools, databases, and advanced data analytics, while networking, wi-fi and Internet connections are the bare minimum. This cyber toolbox has been and will be increasingly critical to the understanding and development of nanotechnology.

This finding is supported by the outcome from the interviews, which confirmed that current high technology parks need to upgrade their utilities to provide a more stable and conducive environment to attract foreign investors and companies to establish their plants for R&D in Malaysia. So based on this literature review and the outcome from interview sessions, reliable and guaranteed factor has been identified (Table 4.5).

Table 4.5
Cross-referencing of Reliable and Guaranteed Utilities Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Continuous uninterrupted supply of electricity/water	x	✔
2. Improving utilities through enhancement of IT and ICT services.	✔	✔

Source: This Research

4.3.3.3 Consumer Awareness Factors

Consumer awareness factors in this study were revealed through the interviews and literature review and they consists of public awareness campaigns and market research sub-factors. These two sub-factors are discussed further in the following sections.

According to George, Kaptan, Lee, and Frewer (2014), societal acceptance of emerging technologies is shaped by many factors, including individual differences in acceptance or rejection of products linked to socio-demographic factors, people's level of knowledge about technology in general, and people's perceptions associated with the risks and benefits of the technology and its applications, inter alia (Gupta et al., 2012). Whilst there is evidence to suggest that nanotechnology is positively perceived by the public (Kahan et al., 2009; Siegrist et al., 2008), the provision of balanced risk–benefit information may differentially influence the attitudes held by individuals (Fischer et al., 2013).

Research addressing the attitudes of the public has frequently considered nanotechnology generically, without differentiating perceptions and attitudes focused on specific applications or application sectors (Pidgeon et al. 2009). As more and more products are becoming commercially available, one might predict more contextualised and differentiated attitudes to be observed across application domains, as it has been the case for other areas of scientific endeavours (Frewer et al., 2011; Frewer et al., 2013). Thus, it is necessary to consider attitudes towards different types of application at the current translational growth stage as acceptability of nanotechnology may vary across different application domains. Currently, however, the results of research focused on Asia-Pacific consumer responses to different areas of application of nanotechnology are limited (Frewer et al., 2013).

A recent study has estimated that Asia will dominate the global use and release of nanomaterials to environment because of the size of the population (52 %) and rising Inequality-adjusted Human Development Index (IHDI) values (Keller & Lazareva, 2013). In the Southeast Asia region, Singapore is an example of an economy that is fuelled by technological innovation, including that associated with nanotechnology and its applications (Gupta et al., 2012). However, there is a lack of information regarding the attributes of people with different levels of risk and benefit perceptions associated with nanotechnology (Pidgeon et al., 2009).

Similar views had surfaced during the interviews where respondents indicated that awareness of nanotechnology products, its use, its benefits, the risks, and everything else associated with nanotechnology is relatively slow on the up-take. “Nano” has become a buzzword among the public, and many products on the market use the term as a selling point, without having actual nanotechnology embedded in the product. As such, the general public is at risk when purchasing nanotechnology products that have no nanotechnology. This is a viable reason for pushing for awareness campaigns in order to keep the public well informed to make sound decisions. So based on this literature review and the outcome from interview sessions, public awareness campaign factor has been identified (Table 4.6).

Table 4.6
Cross-referencing of Public Awareness Campaign Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Focusing on benefits of nanotechnology	✔	✔
2. Benefits of nanotechnology versus cheaper traditional alternatives.	✔	✔

Source: This Research

Market research in this study refers to product feasibility and level of consumer awareness. This sub-factor involves the marketing aspect of nanotechnology whereby companies need to carry out the various aspects of marketing, such as the original four “P”s of product, price, promotion, and placement, or any of the current variants (now there are seven originating from the original four) that have evolved over time. The product market needs to be investigated in order to find out the feasibility of starting such a project of selling that particular product. The pricing needs to be researched to find out what the market wants to pay and whether that is enough to make profit. The promotional part is more than just the obvious formal advertising, as nowadays it can be done virally. The placement of the product can be traditional in the physical sense, but it also has to be made available on line in order to improve sales and profits.

The term business is commonly referred as doing anything with profit motivation. Organisations involved in business always develop their objective on sustainable profit for long term through formulating proper strategy. The term strategy in business management is viewed as long term or shortcut systematic plan to ensure winning in the process of reaching the objectives of the organisation. The organisations which are involved in business of both products and services have similar objectives of earning profit for sustainable growth and expansion. According to Aithal and Aithal (2016), the various strategies followed by organisations for sustainability and growth in their business model can include competitive/red ocean strategy (Porter, 1998), monopoly/blue ocean strategy (Kim & Mauborgne, 2004), environmental care/Green ocean strategy (Hou, 2007), unethical/black ocean strategy (Aithal & Kumar, 2015), or mixed /white ocean strategy (Aithal & Aithal, 2016). Business organisations can sustain in their business based on using these strategies until there is a drastic change in features of products/services or in the business model. For example, due to advents in technology, the classical business model called brick and mortar model is changed to click and mortar model. Similarly it is anticipated that the breakthrough of nanotechnology is going to change the features of products and services in almost all areas in the society. The nanotechnology is expected to be the general purpose technology and is going to affect both basic needs and the aspirations of human life. The applications of nanotechnology in different identified areas provide lots of business opportunities. It includes food, medicine, cleaner water, better quality air, electronics, fuel cells, solar cells, batteries, space travels, chemical sensors, sporting goods, fabrics, cleaning products, energy, environment, health, and life span increase (Aithal & Aithal, 2016). These applications of nanotechnology in the society is expected to change the definition of civilisation in the future generations and going to change the features and various products and the services so that business organisations may have to worry on developing new strategies for continuing in the business.

As part of these strategies, the marketing aspect is crucial for the business to thrive. Product feasibility is one element that is critical to be addressed, and also level of consumer awareness. Consumers need to be knowledgeable and aware of the nanotechnology product before they would decide to make a purchase. Therefore it is pertinent for nanotechnology-based products to be marketing through a solid marketing campaign that needs to be implemented using a more holistic approach. This would have to involve all stakeholders of the nanotechnology industry, which includes the government, governmental agencies, nanotechnology companies, etc. So based on this literature review and the outcome from interview sessions, marketing campaign factor has been identified (Table 4.7).

Table 4.7
Cross-referencing of Marketing Campaign Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Product feasibility.	✔	✔
2. Level of consumer awareness.	✔	✔

Source: This Research

4.3.3.4 Regulatory Framework Factors

For this study, it was revealed that regulatory framework factors play a major role in facilitating the nanotechnology industry. This was observed through the literature review of the initiatives taken by the developed countries, such USA, UK, Japan, and Germany to name but a few, and also the highlighted need by the interview respondents. According to Amenta et al. (2015), some Asian countries are quite active in the production and regulation of nano-materials (NMs). Beside national regulations, several countries have established standards and certification systems for nano-enabled products and Japan and Korea are actively participating to the OECD Working Party on Manufactured Nanomaterials (WPMN). In Japan, the safety of food products is regulated by the Food Sanitation Law. No NMs-specific legislation is available to date in Japan but various research activities are on-going in the nanotechnology field. Meanwhile, for the Republic of South Korea the main piece of legislation for foods, food additives, and food packaging is the Food Sanitation Act. No specifications for NMs are available to date (Amenta et al., 2015). In India the key piece of regulation for food safety is the Food Safety and Standards Act (2006). The Indian government had launched in October 2001 a programme called the Nano Science and Technology Initiative (NSTI), followed by the programme "Nano Mission" in 2007. A series of research activities have been undertaken under this programme and only recently some initiatives have started to address risk issues. Standardisation remains an area of concern, as India has only taken initial steps in addressing standardisation issues. As reported in some publications specifically addressing the topic of nanotechnology risk management in India, the nation does not have a legislation that takes in consideration nanoparticles as a hazard (Chugh, 2009), has a loose framework of legislation where nanotechnology risks can be addressed (Jayanthi et al., 2012), and lacks resources and expertise to handle nanotechnology risks (Barpujari, 2011).

Meanwhile in China, food safety is regulated under the Food Safety Law, which does not include any NM specifications. The National Centre for Nanoscience and Technology (NCNST) and the Commission on Nanotechnology Standardisation are responsible for developing national standards in the nanotechnology area. One of these standards contains a definition for nano-materials (GB/T 19619-2004) (Park, 2012; ISO, 2013). Applications of nanominerals or NMs to be used as food ingredients have been rejected so far by the Chinese regulatory authorities (FAO/WHO, 2013).

Closer to home, in Malaysia a National Nanotechnology Regulatory and Safety Committee, placed under the National Nanotechnology Directorate, was established to monitor and review issues related to health, safety and environment. Regulations to ensure health, safety and environmental aspects of nanotechnology include "The Nanotechnology Industry Development Act" and "The Nanotechnology Safety-Related Act". Revisions of "The Food Regulations 1985" and "The Food Act 1983" are expected to include among others specifications relating to nanotechnology (NanoMalaysia, 2013). However, as revealed during the interviews, the nanotechnology Act has not seen any development with the change in ministerial leadership three times over the past few years.

For this study, regulatory framework sub-factor includes product verification/certification, parliamentary act, and government support. All of these will be explained in the next sections.

Product verification/certification involves an organisation managing the certification and verification process of the applying company. In Malaysia, a company has been appointed by NanoMalaysia, namely NanoVerify Sdn. Bhd., to perform duties of verifying and certifying nanotechnology-based products. NanoVerify has good working relations with SIRIM and other related bodies to carry out their tasks. During the interviews of this study, it was revealed that there is a need for certification in order to preserve consumer safety. This is because nanotechnology-based products may have risk effects associated with them, just like any other products. Due to its potential benefits, as well as risks, steps have to be taken in order to ensure the safety of the consumer. The literature review also revealed the need to protect consumers from the risks associated with nanotechnology (Sudarenkov, 2013;

Maynard, 2006). So based on this literature review and the outcome from interview sessions, product verification/certification factor has been identified (Table 4.8).

Table 4.8
Cross-referencing of Product Verification/Certification Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Need for Certification.	✔	✔
2. Consumer Safety.	✔	✔

Source: This Research

In this study, parliamentary act factors include regulation of nanotechnology, public safety, and environmental safety. It was revealed in the interviews that these issues need to be addressed. The more developed countries have established acts, regulatory frameworks, administrative bodies, and other initiatives to support and facilitate the growth of the nanotechnology industry. So based on this literature review and the outcome from interview sessions, parliamentary act factor has been identified (Table 4.9).

Table 4.9
Cross-referencing of Parliamentary Act Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Regulation of Nanotechnology	✔	✔
2. Public Safety	✔	✔
3. Environmental Safety	✔	✔

Source: This Research

Government support factors in this study were revealed to be financial incentives and increasing FDI into Malaysia. It was clearly highlighted during interviews and also in the literature that increasing FDI is a viable option to facilitate the growth of the nanotechnology industry (Ho, Li, & Zhou, 2017; Meek et al., 2013), which in turn would contribute to the national GDP. The top level management in the government has the final say in accepting or declining foreign investors and companies to come into Malaysia, as was discussed during the interviews. This means that the government plays a pivotal role in ensuring the success and sustainability of the nanotechnology industry.

The government can also provide financial support in the form of subsidies or rebates in order to attract FDI into Malaysia, as was discussed during the interviews, and highlighted in the literature (Ouellette, 2015). According to Lauterwasser (n.d.), the electronics industry is producing the vital components known as MOSFETs (metal oxide semiconductor field effect transistors) with critical dimensions of just under 100 nm, with half that size projected by 2009 and 22 nm by 2016. However, the industry will then encounter technological barriers and fundamental physical limitations to size reduction. At the same time, there are strong financial incentives to continue the process of scaling, which has been central in the effort to increase the performance of computing systems in the past. This illustrates the importance of financial incentives by the government in facilitating the growth of the nanotechnology industry. So based on this literature review and the outcome from interview sessions, government support factor has been identified (Table 4.10).

Table 4.10
Cross-referencing of Government Support Factors Based on Triangulation of Findings

Critical Success Factors (sub-factors)	Literature	Data Collection Interviews
1. Financial Incentives	✔	✔
2. Increasing Foreign Direct Investment	✔	✔

Source: This Research

4.4 Analysis and Discussion of the Findings from the Validation Interviews

The following sub-sections will describe the key points and findings of the follow-up validation interviews. The results of this are used for the validation of the framework developed for this study.

4.4.1 Requirement Verification to Improve Nanotechnology Industry

After completing the interview's introduction and ethical procedure briefing, the researcher then opened the topic of discussion to the current nanotechnology industry scenario. The researcher highlighted that according to the latest publications, the take-up of nanotechnology products by the Malaysian public is still below expectation. The barriers to nanotechnology development stemmed from the issues related to human resource, infrastructure and utilities, consumer awareness, and regulatory framework. Therefore, the question of "What do you think about current nanotechnology industry? Do you face any challenges or problems of in nanotechnology industry development? How would the industry overcome the issue of the slow development and up-take of nanotechnology in Malaysia?" was asked in order to cross check and evaluate the findings that have been gained from the literature and data collection interviews.

The key findings from all the interviews are summarised and presented in Table 4.11 and proceeding sections. Generally, all the interviews were in agreement with the key findings from the data collection interviews.

Table 4.11

Summary of Points Captured from Validation Interviews

Key Issue	Points Put Forward During Validation Interview
Education system	Education system cannot meet the demand of the job market Curriculum needs to be updated Graduates lack the soft-skills Communication is a key issue
Added cost of re-tooling/upgrading	Fresh graduates need to be sent for re-tooling which incurs cost Current employees need to be upgraded by sending to courses abroad
Mismatch in curriculum	Fresh graduates who studied the appropriate course may not have the correct knowledge required by the industry Industry-Academia curriculum mismatch
Government needs to take charge	The government needs to take control and drive the industry More facilities need to be constructed and current ones upgraded Financial incentives need to attractive enough to draw in FDI
General public awareness	General public mostly unaware of the potential impact of nanotechnology General public need to be made aware through campaigns
Purchasing preference	No preference by the consumer when given a choice of a nanotechnology product or its normal counterpart Cost still a decision making factor, as opposed to quality and benefits due to nanotechnology
More specialised physical infrastructure required	Foreign companies wanting to come to Malaysia need to be attracted to available infrastructure High technology parks need to be more specialised "Smart" parks need to be developed to include industrial revolution 4.0 elements
Parliamentary act needs to be expedited	Long process of establishing nanotechnology act needs to be fast tracked The long it takes, the more potential FDI is loss
Safety of the general public needs to be preserved	Nanotechnology is viewed to have associated risks Risks need to be managed Public safety needs to be put first Rules and regulations to control nanotechnology needs to be established
Going global	Malaysian researched products have the potential to break into the international market More focus should be given on globalisation
Enablers of nanotechnology	Developments in other industries can help nanotechnology development The advent of industrial revolution 4.0 (IR4.0)

Source: This Research

These findings indirectly acknowledged the validity of the data that has been gained from the literature review and previous data collection interviews for the need of nanotechnology industry development in Malaysian nanotechnology industry. The above summary is supported by the following statements by the respondents during the validation interviews.

The national issue of human resource development is even more critical in the nanotechnology industry. This was evident during the validation interviews. Some of the points that were uncovered included the gap in the supply and demand of nanotechnology-enabled graduates. One respondent (V9) stated that,

> "*our education system is still relying on the traditional job areas… nanotechnology requires new skills and knowledge… a gap in the supply and demand, so you can see that the education simply cannot meet the demand of the job market*" – from interview with respondent V9.

Meanwhile, Respondent V17 added that the current graduates that the education system is supplying the industry,

> "*lack the technical skills. This is understandable since nanotechnology is not being driven by the system, unlike the traditional engineering fields and medicine… the curriculum needs to be updated so that Malaysia is not left behind… this is a critical issue in the national agenda, and should be given priority*" – from interview with respondent V17.

The above statement by respondent V17 reflects the technical aspects of nanotechnology that can be integrated into the curriculum, perhaps in the tertiary education stage. This is because the primary and secondary education level would be the introduction stage for the nanotechnology curriculum, so it should focus more on the awareness of nanotechnology among students, rather than imbuing technical skills in them.

Also, respondent V4 during the validation interview had highlighted the industry-academia mismatch in curriculum. This means that fresh graduates may study the courses needed by the industry, but they may not have the correct knowledge required by the industry. Respondent V4 surmised this by saying during interview,

> "*mismatch, it is about the mismatch. Nanotechnology is a very wide field, it can span across fields of knowledge. In Malaysia, there is a focus on electronics being established in the roadmap, but the products that are dominating the market are more towards cosmetics and lubricants… so a mismatch. The education system of*

course would use the roadmap… but the industry needs other things" – from interview with respondent V4.

Interestingly enough, it is not just about the technical skills that graduates are lacking, as respondent V2 also highlighted during the validation interview that,

> "*I get many graduates who come in for interview, and they just cannot convey ideas… they lack soft skills… they don't keep up with the general knowledge, what more with nanotechnology… they also seems to struggle to communicate, even though they go through many many many years of schooling and tertiary education*" – from interview with respondent V2.

Meanwhile, respondent V13 added during interview that fresh graduates that enter the company and the job market in the nanotechnology industry needs to be sent away for "re-tooling", or a shift of focus. However, this would incur a great cost to the company, in terms of finance and time, as the new recruits would have to be sent for retooling. This was reflected in the following statement,

> "*you just cannot imagine the real cost we have to bear to send graduates to be re-trained. Of course, you can just look at the fees of the courses that we send them to, but you also need to calculate the time factor… more time in re-tooling means no output for the company. We have to bear the other costs as well, like transports and accommodation, not to mention the pay that continues even though they are away*" – from interview with respondent V13.

To address the above problem that has been highlighted regarding the human resource factor, respondent V6 suggested that,

> "*maybe the education system can help us earlier on… the curriculum needs to be updated from time to time. Maybe the government can take a more overall or holistic approach. Maybe at the primary education level, students are introduced to the concept and shown the wonders and benefits of nanotechnology… more to attract their attention rather that instilling technical knowledge… more deeper knowledge for the secondary level of education. The tertiary education then fine tunes this progression by making introducing specific nanotechnology topics in the current courses*" – from interview with respondent V6.

Meanwhile, the government role in supporting the development of nanotechnology, was also highlighted as a main issue, which was similar during the data collection interviews. Since the industry is characteristically a billion Ringgit industry, individual companies cannot proceed with rapid development without assistance from larger bodies that have the capacity and resources to facilitate the development progress, like the government. Therefore, nanotechnology development can be advanced by innovative approaches implemented by the government, which needs to take control to drive the industry. This was previously witnessed through the previous governments that focused on various aspects through the many progressive Malaysia Plans, such as the shift of focus from agriculture to industrialisation, the focus on developing advance ICT infrastructure through the development of the Multimedia Super Corridor (MSC) was officially inaugurated by the then fourth Malaysian Prime Minister Mahathir Mohamad on 12 February 1996 (Yigitcanlar & Sarimin, 2015), the focus on developing a local automotive industry with the launch of the Proton Saga in July 1985 (Jawi, Kassim, Isa, Hamzah, & Ghani, 2016), and many other examples. From these examples of taking charge, the current government perhaps needs to take a more active role in taking control and driving the industry, similar to what is being done in the construction industry through the various government agencies, including the Construction Industry Development Board (CIDB). This was supported by the statement made by respondent V16,

> "*the government needs to play a more actively role through its agencies… more awareness campaigns… more marketing… more financial incentives… make it more attractive for players to develop their products at a rapid rate to ultimately contribute toward the GDP*" – from interview with respondent V16.

Respondent V17 added that,

> "*more facilities need to be in development. Like in the Field of Dreams… 'build it and they will come'… just like in that movie… we need a solid platform… a base… physical base to attract foreign investment as well as develop the local talent pool… provide an outlet for the nanotechnology trained local graduates venture into the nanotechnology industry… facilities like high technology parks… and they need to be properly maintained and upgraded frequently*" – from interview with respondent V17.

The above statement ended with “upgraded frequently” which supports the recommendation that the government needs to continually upgrade the current facilities, in tandem with establishing new high technology facilities. The high technology parks of today perhaps can be developed to be more specialised according to the related fields of the nanotechnology product. Facilities specialised in enhancing the development of various fields, such as cosmetics, lubricants, electronics, fertilisers, and many more can be established in their separate clusters to that it can facilitate product development and collaboration between the players and stakeholders in the nanotechnology industry.

Meanwhile, respondent V3 had highlighted that the new and advancing era of industrial revolution 4.0 (IR4.0) can potentially affect the development of the nanotechnology industry, as well as across all the manufacturing sectors. This is because it is anticipated that IR4.0 will have a wide-ranging effect on the industry. This was highlighted through the statement made by respondent V3 during interview,

> “*we need more ‘smart’ parks… parks that are IR4.0 enabled… this would really speed up the process of nanotechnology development… shortened time-to-market times are one of the benefits*” from interview with respondent V3.

While respondent V17 focused on the physical infrastructure development and maintenance/upgrading for attracting FDI into the country, respondent V3 also highlighted the importance of attracting FDI, but from a different perspective. In conjunction with developing the necessary physical infrastructure, the government also needs to provide attractive financial incentives and tax relief through tax exemptions and tax breaks (Ślusarczyk, 2018). This was supported by respondent V10 who had vast experience in the nanotechnology industry from the government agency perspective, with his statement,

> “*[one focus is] the field of solar [energy] if I am not mistaken … so we are trying to launch this one and gather all the researchers. If you research in this area, we*

will provide the grants. We will financially sponsor" – from interview with respondent V10.

Again, during the Validation interviews, it was evident that the general public still has low awareness on nanotechnology and its benefits. Respondent V13 stated that,

> "*on the street level, nobody really knows about nanotechnology… I mean… if you ask anyone in the street about nanotechnology, they will give you a blank stare. Even in department stores that sell nanotechnology-based products… [when] consumers are asked whether they buy nanotechnology products, they say no… but then they admit to buying and using certain branded cosmetic products, which are nanotechnology-based products. In the end, they do not care how the product provides the results… nanotechnology or otherwise… just as long as it delivers… they need to be made aware through campaigns*" – from interview with respondent V13.

From the statement above, respondent V13 highlighted the need to run marketing campaigns to promote and enhance the awareness of the general public about nanotechnology and its benefits. The above statement also supports the notion that the general public is not too concern whether the product is or otherwise nanotechnology enabled. If the normal counterpart provides the same results and is at a cheaper price, then virtually all of the time consumers would pick and choose the cheapest alternative. This emphasises that cost can be a significant decision making factor made by consumers when deciding to purchase a product.

However, any technology is not without its associated risk, and nanotechnology is no different. This is even more so pertinent when dealing with nanotechnology because of its wide-ranging effect across industries. Therefore these risks need to be managed well, to avoid from slowing down rapid development. Public safety needs to be prioritised first, as was supported by respondent V5, who mentioned that,

> "*we need to protect the consumers, number one… number two, we have been mandated to somehow steer the industry and facilitate… so our work has to continue whether or not the [Nanotechnology] Act is there… ultimately we want it [nanotechnology] to be self-regulating without the government having to step in*" – from interview with respondent V5.

Meanwhile, respondent V9 highlighted globalisation from a different perspective. This respondent highlighted the need for our local nanotechnology companies to go global, i.e., going out with nanotechnology products and know-how, instead of bringing in nanotechnology through FDI. The following statement supports this,

> "*yes of course! I am sure that we are quite capable of breaking into the international market. I believe we have already done so… the maerogel or Malaysian aerogel… Malaysian invented, marketed worldwide… there is also a professor… one of the northern universities, he has developed lab on chips that he makes for overseas projects*" – from interview with respondent V9.

Nanotechnology may have an impact across industries, but let us also not ignore the fact that other industries that undergo rapid development can easily have an impact on the nanotechnology industry as well, i.e., it works both ways. Especially with the advent of the IR4.0 and Internet of Things (IoT), the nanotechnology industry can certainly benefit these new developments. As big data plays a bigger role in providing better decision making related information, simulations can run faster and more efficiently in the development of the nanotechnology product.

The respondents were all in agreement to some degree ranging from very strongly to strongly that strengthening the principle pillars of the framework is required towards achieving an effective nanotechnology industry development. Therefore, it can be surmised that any initiative or effort in developing a framework for improving nanotechnology industry development in the Malaysian nanotechnology industry is paramount.

The findings from these questions during the validation interviews confirmed that all the respondents agreed to the need for improvement in the current process towards achieving effective and efficient nanotechnology development. Although the current delivery of technology management concerns nanotechnology industry development, such as initiating the effort to establish nanotechnology as a focus area for development, creating infrastructure through the construction of several high technology parks, establishing a national roadmap for the nanotechnology industry stakeholders and players (tertiary education institutions, research centres, government agencies, manufacturers, etc.) to follow, providing a change agent through the creation of a national certification company, forging links for international certification bodies to establish the Malaysian presence overseas, and many more, however the establishment of technology management in the nanotechnology industry is still not successful when compared to the preparation and execution done for previously disruptive technologies, such as ICT. The respondents suggested that this approach needs to be clarified and directed in more detail for successful nanotechnology development.

Therefore, an appropriate framework for achieving effective nanotechnology industry development Malaysian nanotechnology industry needs to be developed to detail how nanotechnology practitioners (including tertiary education institutions, research centres, government agencies, manufacturers, etc.) can become involved in a collaborative manner and to share their skill, knowledge, and experience within a conducive work environment.

4.4.2 Verification of the Need for Framework of Critical Success Factors

Based on the findings from the previous question, it was clearly illustrated that improved technology management is required to increase nanotechnology development in the Malaysian nanotechnology industry. Accordingly, this researcher continued to introduce the draft framework of critical success factors (CSFs) for effective nanotechnology industry development in the Malaysian nanotechnology industry for validation.

The aim of presenting the framework to the respondents during their respective interviews was to give an overview of the framework by giving some explanation regarding the definitions of all key factors identified from the literature review and data collection interviews.

After the presentation of framework, each respondent was given 15 minutes to review the framework, and give their opinion of any improvements that could be made to further develop the framework. Based on their experience and knowledge, the interview respondents were asked to evaluate whether the CSFs, including the factors and sub-factors of the framework, were appropriate, having the correct terminology, structure, and arrangement for the Malaysian nanotechnology industry context. Any constructive opinions from the participants, in terms of improvement of the CSFs were also welcomed during the sessions.

The general view from all respondents regarding several aspects of the framework was summarised in Table 4.12. The general response by the respondents was that the framework was acceptable and easy to understand.

Following the presentation, all the respondents during their respective interview sessions agreed that the framework was easy to understand enough, rational, and has great potential to improve the Malaysian nanotechnology industry. According to respondent V3, this framework can create an effective platform for the development of the nanotechnology industry to achieve optimum value for the amount of effort put in. This view was formalised in the statement,

> "*a framework such as this has the potential to improve value and facilitate quality commercialisation projects in nanotechnology through effective use of resources in implementing a more holistic approach*" – from interview with respondent V3.

Table 4.12

General Respondent Opinion Regarding the Drafted Framework from this Study

Subject	Points Raised by Respondent
Terminology	The factors and sub-factors were too short, they needed to be expanded to become more meaningful to the reader. Most of the factors are easy to understand but a few of them need to be redefined. The terminology used to classify the factors is familiar.
Arrangement	The factors in the framework are clearly understood and related with each other. Factors look interdependent with each other. Some re-arrangement was needed to make the framework more comprehensible.
Structure	Generally, the framework looks practical and easy to be understood without any excessive training needed by Malaysian nanotechnology practitioners. The framework is vigorous and appropriate to be implemented in nanotechnology industry.
Relevancy	The elements of the framework is relevant to the nanotechnology industry as they highlight the key issues. Initiatives in managing nanotechnology can be based on the framework.

Source: This Research

Even though the illustrated framework looked fairly straight forward and easy to understand, since it was in English, the respondents required some explanation and time to fully comprehend the framework. This is because the respondents had various levels of command of English, ranging from the very basic to fluent. This was evident by the following statement made by respondent V8,

> "*the framework is easy to understand. The way to tackle this problem is clear, but maybe implementing it fully can be difficult... cannot be covered by just a single company. Needs the collaborative effort of all... especially the government*" - from interview with respondent V8.

In a previous study by Nawi (2012) that this study was based upon, it was revealed that the initial framework was difficult to understand as "some of the terms in the framework appeared to be 'jargon'…a few components that appeared superfluous," and the researcher had to provide further description and explanation of the elements in the framework. Once the explanation had taken place, confusion over the terminology used in the framework was dispelled. It was with this in mind that the framework developed for this research relied on less jargon and more direct to the point statements to furnish the framework. It was worded in lay-man's terms and easy to understand.

Additionally, according to the above statement, respondent V8 had indicated that the framework required commitment from all parties involved in the nanotechnology industry, more so the government. The government may set the underlying structure to support the nanotechnology industry, such as by establishing a regulatory framework in order to facilitate development while ensuring the safety of the public, setting the focus for human capital development on nanotechnology enabled graduates, channelling more funding into infrastructure development to better improve facilities (like high technology parks) and utilities (like electricity, water, IT/ICT), and launching nationwide awareness campaigns via its many government agencies. The government may set the platform for nanotechnology development to accelerate, but the key players in the nanotechnology industry also need to participate and give full commitment to the elements in the framework. This means that, even an individual company, no matter where they are located on the nanotechnology supply chain, can assist in the development of the nanotechnology industry by contributing toward different elements in the framework. For example, a manufacturing company may market and promote its products as being nanotechnology-based products by getting certification from NanoVerify and launching campaigns to market their products. Research centres can contribute not just in the R&D arena of the nanotechnology industry, as they can form links with the ministry of education and tertiary education institutions and voice out their need for more nanotechnology capable graduates.

Meanwhile, respondent V15 had made a statement that supports the actions of top level management to facilitate the development of nanotechnology in Malaysia, with the statement

> "*based on the 17 years of work experience in both private and government sectors, I realised that a clear directive from top level management is a vital factor to achieving an effective framework for development in any industry… more so for the nanotechnology industry*" – from interview with respondent V15.

The findings from above discussions show that all the participants agreed that the framework is easy to understand and will improve the level of nanotechnology development in the Malaysian nanotechnology industry. They found the framework useful, and although it does not introduce any new technique, it identifies familiar practices that can be geared towards effective nanotechnology development. Based on the evaluation process and constructive comments by the interview respondents, some amendments have been made to the CSFs in the draft framework in order to make it clearer. The following sections then will focus on the validity of the CSFs in more detail.

4.4.3 Verification of the Critical Success Factors Framework Applicability

The interview respondents were also asked to evaluate every single CSF in the framework in terms of appropriateness and applicability to be implemented in Malaysian nanotechnology industry. This evaluation process aims to validate from different perspectives of nanotechnology practitioners through their experiences and knowledge involved in the Malaysian nanotechnology industry. The detailed analyses of discussions in the interviews are highlighted below.

4.4.3.1 Human Resource Factors

The element of human resource factors were agreed upon as an element that is required in this CSF framework developed for this study. From the supporting statement from the interviews (both data collection and validation) and the revealed facts in the literature review, this researcher had decided to include this critical success factor in the final framework. The human resource factor element is made up of human capital development and training, both of which are described in the following sections.

All the respondents in interviews agreed that human capital development is an essential element for successful nanotechnology industry development in Malaysian nanotechnology industry. This overall sentiment is in agreement with the researcher's statement "human capital development needs to start at the earliest possible level, even from the earliest year of formal education, and this needs to be reinforced throughout the years of primary and secondary school education so as to prepare them for the tertiary education, where more emphasis and specialisation is given on the different sectors that utilise nanotechnology".

It was clear through the interviews in the data collection and validation rounds that human capital development is a critical issue, and a critical success factor the needs to be addressed in order to advance the nanotechnology development in Malaysia to be at par with the best nanotechnology producing nations in the world. For the Malaysian nanotechnology industry to be able to achieve this, the human capital development issue needs to be approached in a more holistic and integrated manner, where the different levels of education need to be incorporated the nanotechnology topics, suited to the level of education. For example, during the early years, the focus of exposing the young minds to nanotechnology is basically to promote awareness that the technology exists with the benefits that is potentially capable of improving the quality of life of the people in the long run. Then, during middle school education, perhaps the curriculum can include some practical aspects, and introduction to the materials of nanotechnology, which can be built upon further for development in the tertiary education stage. At this level, the learners can proceed to specialise their study to focus on the industry of their choosing, and the curriculum content would include both theoretical foundations as well as practical applications in order to equip the workforce with more capable and skilled human capital.

Even though the main focus of the issues surrounding human capital development is regarding the technical knowledge and skills of the fresh graduates that enter the job market in the nanotechnology industry, the soft skills aspect of graduates must not be ignored. Efforts into enhancing the soft skills of graduates need to be increased so that it would not only benefit the nanotechnology industry, but also all industries across the board.

In respect of training the current workforce to enhance the skills and knowledge of the currently employed workers, during all the interviews, it was wholly asserted that life-long learning and training is something that needs to be instilled in workers, with the guidance of the upper management. This is a vital factor in assisting the nanotechnology development in the Malaysian nanotechnology industry. This overall sentiment is in agreement with the researcher's statement "human capital development of the current workers in the nanotechnology industry needs to be enhanced from time to time, through training and short courses, in order to equip them with the latest skills and knowledge, thus aiding the firm to become more competitive and keep abreast with the main players of the nanotechnology industry".

With the first part of human capital development focusing on the early education years, the second part involves the current workers and potential workers entering the nanotechnology industry. Training, re-tooling, and further enhancement of the nanotechnology workforce is something that is unavoidable for the nanotechnology companies operating in a relatively turbulent environment, where each competitor is looking for new ways to achieve competitive advantages. So, training and re-tooling is inevitable and needs to be planned out beforehand. In order to assist in alleviating the costs of training staff overseas, perhaps the government can look into developing and pooling the local talent pool in nanotechnology research to provide the required training to enhance the currently employed workforce. This would mean that there needs to be active collaboration and sharing of knowledge amongst the players and stakeholders in the nanotechnology industry. Therefore, the 'silo' mentality of old needs to be changed for the Malaysian nanotechnology industry to evolve into a more efficient contributor to the national GDP. A summary of comparison between all these factors and sub-factors is given in Table 4.13.

Table 4.13
Comparison of Findings Related to Human Resource Factors between Literature Review, Data Collection Interviews, and Validation Interviews

Factor	Sub Factor		Requires Amendment?
	From Data Collection Interviews and Literature Review	From Validation Interviews	
Human Capital Development	• Schooling education needs to start early	• Schooling education needs to start early	No
	• Tertiary education curriculum development	• Tertiary education curriculum development	No
Training	• Technical expertise and know-how transfer is required	• Technical expertise and know-how transfer is required	No
	• Retooling issue needs to be addressed	• Retooling issue needs to be addressed	No
	• Local and overseas skill gap needs to be reduced	• Local and overseas skill gap needs to be reduced	No

Source: This Research

4.4.3.2 Infrastructure and Utilities Factors

The element of infrastructure and utilities factors were agreed upon as an element that is required in this CSF framework developed for this study. From the supporting statement from the interviews (both data collection and validation) and the revealed facts in the literature review, this researcher had decided to include this critical success factor in the final framework. The human resource factor element is made up of high technology park and reliable and guaranteed utilities, both of which are described in the following sections.

In this regard, all respondents during their respective interviews had no objections to the need for infrastructure development regarding "high technology parks" for the successful development of Malaysian nanotechnology industry. All the respondents had the same view that this physical infrastructure is paramount for effective nanotechnology development. This overall sentiment is in agreement with the researcher's statement "the infrastructure of the nanotechnology industry needs to be increased both in numbers and quality; the numbers needs to be increased so that more foreign companies can bring in more FDI, and the quality of high technology parks need to be incorporated with new technologies, such as those highlighted in the IR4.0, so that the development of nanotechnology can be further accelerated".

It was evident during the data collection and validation interview rounds that the respondents lamented about the need for physical infrastructure to be increased, both from the aspects of numbers and quality. From the national roadmap, the key core focus areas of nanotechnology can be a guided by this roadmap to build high technology parks that cater for these focus areas. For example, high technology parks for electronics, biomedical, and food and agriculture. Each of these focused high technology parks can house the companies with similar focus areas and benefit from the specialised infrastructure that is in-built into the high technology park itself. Due to the close proximity, perhaps this can promote communications and eventually collaborations in order to facilitate the growth and development of the nanotechnology industry.

In terms of reliable and guaranteed utilities, all the respondents in all the data collection and validation interview sessions had highlighted the critical importance of this issue. Many examples of production loss were given which has emphasised the importance of this issue even more.

Table 4.14
Comparison of Findings Related to Infrastructure and Utilities Factors between Literature Review, Data Collection Interviews, and Validation Interviews

Factor	Sub Factor		Requires Amendment?
	From Data Collection Interviews and Literature Review	From Validation Interviews	
High Technology Park	• More high technology parks need to be constructed	• More high technology parks need to be constructed	No
	• Current high technology parks need to be upgraded	• Current high technology parks need to be upgraded	No
Reliable and Guaranteed Utilities	• Continuous supply of electricity and water need to be guaranteed	• Continuous supply of electricity and water need to be guaranteed	No
	• IT and ICT infrastructure need to be upgraded	• IT and ICT infrastructure need to be upgraded	No

Source: This Research

However, the literature seems to focus more on the application of nanotechnology on energy and utility areas, such as the use of nanotechnology in enhancing renewable energy efficiency in solar cells, and nanotechnology additives to assist in water treatment. Perhaps this is the difference which separates Malaysia from the more developed nations where utilities such as electricity and water supply advanced enough that it would not become an issue in support of the nanotechnology industry. It was clear during the interviews from both the data collection and validation rounds that the issue of reliable and continual utilities is an issue in the Malaysian nanotechnology industry context. So much so, that it reliability comes into question when nanotechnology firms insist on having contingency plans and also assurance contracts with the utilities vendors, as well as insurance, to cover for any losses in the event of shortage. This sentiment is in support of this researcher's encompassing statement, "in the Malaysian context, the nanotechnology industry relies heavily on the utilities provided by vendors, but the quality of service is perhaps not at par with the more developed countries. Therefore, the utilities industry needs to upgrade or provide some sort of guarantee in the event of shortage or interrupted services, so that these effects can be alleviated somewhat, in order to facilitate the development of the nanotechnology industry". A summary of comparison between all these factors and sub-factors is given in Table 4.14.

4.4.3.3 Consumer Awareness Factors

The element of consumer awareness factors were agreed upon as an element that is required in this CSF framework developed for this study. From the supporting statement from the interviews (both data collection and validation) and the revealed facts in the literature review, this researcher had decided to include this critical success factor in the final framework. The human resource factor element is made up of public awareness campaigns and market research, both of which are described in the following sections.

From the first data collection interview to the last validation interview, all respondents were unanimous in emphasising the critical importance of public awareness. Since the nanotechnology products are classed as premium products, the cost per unit is relatively more expensive than the available alternatives in the market. This is because the alternatives to not have nanotechnology embedded in them, and that the R&D and production, as well as the commercialisation of said products are much cheaper when compared to nanotechnology-enabled products. The added cost should be made justifiable in the eyes of the public through promoting the benefits of nanotechnology-enabled products, especially products that can only perform innovative applications that the cheaper alternatives cannot. The benefits of nanotechnology products, such as water-proofing sprays that can be applied on virtually any surface, heat dissipating automotive lubricants, age-defying cosmetics, and etc., all can be demonstrated and attract the attention of consumers, and eventually persuade them to make purchase. If the general public is not aware of such products, then they would definitely not purchase them. Therefore, public awareness in general, and consumer awareness in specific, needs to be raised through awareness campaigns, promotional road shows, and other methods to advertise the benefits of nanotechnology products. In summary, findings support the researcher's statement, "public awareness campaigns are critical in enhancing nanotechnology development, as it can provide a pull factor for nanotechnology products to be fast-tracked into the market by creating a demand of nanotechnology products' innovative applications. A holistic approach needs to be taken by all parties involved in the nanotechnology industry, with the government playing the lead role through its various agencies, to promote nanotechnology products and thus facilitate the development of the nanotechnology industry".

Like with all products, nanotechnology products also require market research, like feasibility studies, in order to potentially identify product demand that can be fulfilled by nanotechnology products. This was revealed through the data collection and validation interviews, where the respondents were generally in agreement of this fact. It is obvious that feasibility studies of nanotechnology products have been done overseas, especially in the more developed countries, however, the products that are in demand there perhaps is not similar to the demand for nanotechnology products here in Malaysia. This was evident in the Validation interviews, where most of the researchers pointed out that the nanotechnology product demand was very different from developed countries. Overseas, the application of nanotechnology products is more toward the high-end market, where nanotechnology is embedded in products generated by the electronics, automotive, medical equipment, and other high-end industries, whereas in Malaysia, the demand for nanotechnology products is more toward cosmetics, agriculture, automotive lubricants, and textiles.

Consumer adoption is the ultimate goal of the market research and any awareness programmes that are implemented. Thus, surveys need to be carried out in order to gauge the consumer awareness of nanotechnology products, and to see if consumers can accept nanotechnology products, even though they are priced at a premium. These surveys can be undertaken by all parties, especially the individual companies themselves, as well as social science (in marketing, business, and etc.) researchers, in order to gather invaluable knowledge in relation to consumer adoption and equip the nanotechnology industry players with the necessary information to plan and proceed to the next level of nanotechnology development.

Therefore, overall, the respondents were in support of the researcher's summary statement, "market research (including consumer awareness, acceptance, and adoption) is vital to uncover the market demand for nanotechnology products, and thus enhance the nanotechnology industry". A summary of comparison between all these factors and sub-factors is given in Table 4.15.

Table 4.15
Comparison of Findings Related to Consumer Awareness Factors between Literature Review, Data Collection Interviews, and Validation Interviews

Factor	Sub Factor: From Data Collection Interviews and Literature Review	Sub Factor: From Validation Interviews	Requires Amendment?
Public Awareness Campaigns	• Campaigns to focus more on benefits than technology	• Campaigns to focus more on benefits than technology	No
	• Long term benefits need to be highlighted to overcome cheaper alternatives	• Long term benefits need to be highlighted to overcome cheaper alternatives	No
Market Research	• Product feasibility needs to be performed on test markets	• Product feasibility needs to be performed on test markets	No
	• Consumer awareness, acceptance, and adoption levels need to be investigated	• Consumer awareness, acceptance, and adoption levels need to be investigated	No

Source: This Research

4.4.3.4 Regulatory Framework Factors

The element of infrastructure and utilities factors were agreed upon as an element that is required in this CSF framework developed for this study. From the supporting statement from the interviews (both data collection and validation) and the revealed facts in the literature review, this researcher had decided to include this critical success factor in the final framework. The human resource factor element is made up of product verification/certification, parliamentary act, and government support, all of which are described in the following sections.

With the establishment of NanoVerify Sdn. Bhd., the government through one of its agencies namely NanoMalaysia Berhad (whose current motto is "energising industries through nanotechnology commercialisation"), has taken the necessary steps to assist in enhancing the nanotechnology industry, as well as to maintain public safety. Nanotechnology, like with any technology, will undoubtedly have its own risks associated with the technology. In the case of nanotechnology, much of the risk is due to the nano-particles themselves, which can leak into the environment, unintentionally or otherwise, and can cause a variety of side-effects, such causing lung damage (Oxford University Press, 2009). Also, these risks can affect a number of groups, such as the consumer of nanotechnology products through product usage, the workers making the nanotechnology products through exposure, and in general the surrounding environment through contamination risks (e.g., nanotoxicity) (Institute of Medicine, 2011).

Due to the inherent risks of nanotechnology (Lauterwasser, n.d.), steps need to be taken to lessen the risks, such as with the establishment of NanoVerify programme. This particular programme can certify the process and product of a company with claims of nanotechnology elements in the range of 1 to 100 nm, in order to market the high-technology product more successfully and earn public trust. This programme is operated together with SIRIM QAS International. Advantages of getting nanotechnology certification include assuring sales of genuine nanotechnology products, boosting consumer confidence and trust, creating greater market acceptance in other countries, and increasing value of products. Upon the successful completion of the NANOVerify programme, the processes and products will be awarded the "Nanoverified" mark. Thus, it can be observed that NanoVerify functions similarly to the certification duties of SIRIM that deals with products manufactured according to the Malaysian Standard (MS), British Standard (BS), or Regional standards such as European Norm (EN) or International Standards (ISO), or well-known association specifications/standards which are publicly available such as JKR Specification, AWWA, ASTM etc. Not just performing a major role at the national level, the NANOVerify programme is part of a network of six international volunteer certification programmes. These programmes are located in Thailand, Russia, Iran, Taiwan, and United Kingdom.

With this certification and verification programme, the main aim is for protecting the consumer, as well as to maintain product integrity. This programme can protect the consumer by ensuring that the products are in fact nanotechnology products, and that the products actually perform as advertised. It maintains product integrity by assuring consumers that the product contains nanotechnology elements and that it is safe for use. These aims also protect the consumer by ensuring that the consumer is paying the extra for actual nanotechnology products. This is similar to the Halal logo function as produced by JAKIM to assure consumers that the product is wholly Halal, and also the SIRIM sticker affixed to electrical products which assures consumers that the product has been tested for functional and safety integrity, thus it is safe for general use.

Therefore, overall, the respondents were in support of the researcher's summary statement, "through a certification/verification programme provided by NanoVerify, the risks of nanotechnology can be alleviated, and the safety of consumers can be maintained, thus facilitating nanotechnology products into the market, thus further enhancing the nanotechnology industry".

With regard to a parliamentary Act, all respondents had highlighted that it has the potential to provide a stable platform for the development and regulation of the nanotechnology industry. This is evident in other industries, such as for the ICT industry, sustainable energy industry, and the construction industry to name but a few. The ICT industry is governed by the act number 588, which is the Communications and Multimedia Act 1998 that is a Malaysian law which enacted to provide for and to regulate the converging communications and multimedia industries, and for incidental matters. The sustainable or renewable energy industry is governed through act 726, which is the Sustainable Energy Development Authority Act 2011 that contains the guideline for the government agency to provide for and regulate this industry. Meanwhile, the construction industry has act 746, which is the Construction Industry Payment and Adjudication Act 2012 that provides guideline to resolve the main issues faced by that industry. Since the construction industry has been well established, it has several acts pertaining to it, such as act 133, which is the Street, Drainage and Building Act 1974 and Building and Common Property (Maintenance and Management) Act 2007, with the latter having been repealed with act 757, Strata Management Act 2013.

As observed in the discussion above, there is a need for a parliamentary act to support and regulate the nanotechnology industry due its potential of having a great impact on the economy, as well as the potential risks it poses if the industry is allowed to proceed unchecked. Through the data collection and validation interviews, some respondents who had direct involvement or were privy to the knowledge of the establishment of a nanotechnology act had described that the move towards formalising this act had been in the works for over a decade. From their personal opinion, the issue of this act not having been established include the changing of ministers who need to champion the nanotechnology cause at the highest level of administration and management of the nanotechnology industry. This had meant that from the first initiative to implement such an act, the first minister to champion this initiative had perhaps stronger commitment and a clearer vision than the predecessors. Another issue is perhaps due to the slow development of the nanotechnology industry, even in the face of such great potential, both from the aspects of its impact on society as well as the profitable contribution it can have on the GDP, that this act has not proceeded to become a reality.

Even though this act has not been established for such a promising industry, the main players of this industry have proceeded by taking action in other areas. NanoMalaysia for example, has is spearheading the nanotechnology industry by establishing several programmes to enhance and facilitate this industry. Programmes, such as, the promotion of intellectual property rights, which the protection of any tangible asset that is created from an original thought, such as an idea, name, content, design, invention or digital media. Intellectual property is protected in law by, for example through the establishment of 1) patents / utility, innovations, 2) copyright, 3) trademarks, 4) trade secrets. This protection enables people and companies to earn recognition or financial benefit from what they invent or create by striking the right balance between interests of innovators and the wider public interest.

Meanwhile, the trademarked iNanovation is a commercialisation initiative designed for companies to establish market share, introduce new process/material, and switch from current conventional to being nanotechnology-enabled. This programme is focused on small and medium enterprises (SMEs) and start-up companies through the iNanovation platform that consists of 1) "iNanovation Push" that "pushes" nanotechology products into the market by assisting local start-ups and SMEs in setting foothold in current markets, 2) "iNanovation Pull" that assists in product development and prototyping in joint-venture initiatives for industry-RI-academia collaborations through monetisation via licensing or outright sales and the improving products, increasing market share, and venturing into new markets, and 3) "iNanovation Switch" that is designed for large companies, SMEs, and start-ups to enhance its current production process from conventional manufacturing to nanotechnology-enabled process by improving products, increasing market share, and venturing into new markets.

Another programme is the National Graphene Action Plan (NGAP), which is also a commercialisation programme focusing on Graphene applications and a high value-add manufacturing enabled by Graphene with IP in five application areas. These areas include

Lithium-ion battery anodes / ultracapacitors, conductive inks, rubber additives, plastics additives, and nanofluids. This programme's aim is to enhance downstream applications relevant to Malaysia and eventually enabling a local Graphene eco-system to accelerate downstream adoption.

Meanwhile, the Advanced Materials Industrialisation Programme by NanoMalaysia provides exclusive services through technology adoption of industrialisation of advance materials products. The programme also provides governance, avoids consumer confusion, and imbues market advantage to local manufacturers through verification and certification in terms of nanotechnology adoption and advancement, while enabling technology migration in processes, intermediaries and finished products. Some of the services under Advanced Materials Industrialisation Programme include scale-up, productivity improvement, and capacity building; technology platform and product development with industry; and up-scaling of existing shared industrial labs.

Through these endeavours, the nanotechnology industry can be regulated and developed more efficiently and expediently. Also, such an act can also function to ensure public and environmental safety as well, similar to other acts that have been established in other industries.

Therefore, overall, the respondents were in support of the researcher's summary statement, "a parliamentary act is capable of providing a solid platform for the regulation, development, and management of the nanotechnology industry".

Other than establishing a parliamentary act to assist the nanotechnology industry, other support can be provided by the government through its various agencies in the form of financial incentives and tax breaks. Financial incentives can be in the form of tax exemptions when the nanotechnology company performs certain thing in accordance to the regulations. For example, duties and taxes can partially returned in the form of tax refunds if the company achieves certain tax thresholds set by the government.

Using the high technology parks can also be an incentive for foreign direct investment by attracting foreign companies, through local partnerships, to physically establish their operations in Malaysia, thus bringing in financial flow. Another incentive that can be implemented here can be from the aspect of the labour force. Foreign companies need skilled and experienced workers that perhaps the local workforce is unable to meet, so these companies need to fulfil this gap by bringing in their own employees. Although during interviews it was highlighted that this manoeuvre is perhaps too expensive for foreign companies to do, perhaps shift of focus in training and retooling of workers is required. Instead of sending local employees overseas for training and experience to enhance their abilities and enrich their experience, perhaps foreign trainers and experts can be imported for a certain period of time to train the local employees. This would facilitate technology transfer from overseas into Malaysia, and thus perhaps lessen the skill gap between the local and international workforce.

Therefore, overall, the respondents were in support of the researcher's summary statement, "incentives by the government is capable of attractive more activities in the nanotechnology industry, especially involving foreign direct investments through collaborative partnerships with local counterparts for the development and management of the nanotechnology industry".

Table 4.16
Comparison of Findings Related to Regulatory Framework Factors between Literature Review, Data Collection Interviews, and Validation Interviews

Factor	Sub Factor: From Data Collection Interviews and Literature Review	Sub Factor: From Validation Interviews	Requires Amendment?
Product Verification / Certification	• Product verification and certification is required for regulation of industry	• Product verification and certification is required for regulation of industry	No
	• Product verification is required to maintain consumer safety and product integrity	• Product verification is required to maintain consumer safety and product integrity	No
Parliamentary Act	• Parliamentary act is required to regulate and develop the industry more efficiently	• Parliamentary act is required to regulate and develop the industry more efficiently	No
	• Parliamentary act can assist in maintaining public safety	• Parliamentary act can assist in maintaining public safety	No
	• Parliamentary act can assist in maintaining environmental safety	• Parliamentary act can assist in maintaining environmental safety	No
Governmental Support	• Financial incentives, such as subsidies and tax incentives to promote industry development	• Financial incentives, such as subsidies and tax incentives to promote industry development	No
	• Implement incentives for increasing foreign direct investment	• Implement incentives for increasing foreign direct investment	No

Source: This Research

The findings of the validation interviews revealed that all the respondents confirmed and agreed that a new approach needs to be implemented in nanotechnology development of the Malaysian nanotechnology industry. The participants recognised that this approach is part of the effort to overcome the issue of lack of collaboration and fragmentation among stakeholders involved in nanotechnology development. A summary of comparison between all these factors and sub-factors is given in Table 4.16.

All the participants concurred, with no exceptions, that the implementation of the CSF framework in Malaysian nanotechnology was a good measure. The participants recognised that all the CSFs are relevant to application in nanotechnology industry development. The participants also suggested a few improvements for the draft framework, such as, the renaming of some CSFs, as well as reorganisation of the framework. This was done with the intention of giving a clear definition, and thus makes it easy to understand for someone new to the subject. The triangulation of findings from the literature review, first round of interviews (data collection interviews) and the validation interviews are illustrated in Table 4.17 below.

According to the above findings, the draft framework of CSFs for effective nanotechnology industry development is considered to be valid to be implemented in the Malaysian nanotechnology industry. Although there have been some constructive comments and suggestion for some of the CSFs within the framework, they do not involve any major changes or corrections to the draft framework. The overall findings from this validation interviews confirmed that all the four CSF elements (nine factors and 20 sub-factors) are easy to understand and have a robust applicability to achieve effective nanotechnology industry development in the Malaysian nanotechnology industry. The final framework following the refinement process is illustrated in Figure 6.1.

Table 4.17
Summary of Findings from Literature Review (LR), Data Collection Interviews (DCI) and Validation Interviews (VI)

Element	Factor	Sub-Factor	LR	DCI	VI
Human Resource	Human Capital Development	• Schooling education needs to start early with initial exposure at the earliest level	✔	✔	✔
		• Tertiary education curriculum development	✔	✔	✔
	Training	• Technical expertise and know-how transfer is required	✔	✔	✔
		• Retooling issue needs to be addressed	✔	✔	✔
		• Local and overseas skill gap needs to be reduced	✔	✔	✔
Infrastructure and Utilities	High Technology Park	• More high technology parks need to be constructed	✔	✔	✔
		• Current high technology parks need to be upgraded	✔	✔	✔
	Reliable and Guaranteed Utilities	• Continuous supply of electricity and water need to be guaranteed	✔	✔	✔
		• IT and ICT infrastructure need to be upgraded	✔	✔	✔
Consumer Awareness	Public Awareness Campaigns	• Campaigns to focus more on benefits than technology	✔	✔	✔
		• Long term benefits need to be highlighted to overcome cheaper alternatives	✔	✔	✔
	Market Research	• Product feasibility needs to be performed on test markets	✔	✔	✔
		• Consumer awareness, acceptance, and adoption levels need to be investigated	✔	✔	✔
Regulatory Framework	Product Verification / Certification	• Product verification and certification is required for regulation of industry	✔	✔	✔
		• Product verification is required to maintain consumer safety and product integrity	✔	✔	✔
	Parliamentary Act	• Parliamentary act is required to regulate and develop the industry more efficiently	✔	✔	✔
		• Parliamentary act can assist in maintaining public safety	✔	✔	✔
		• Parliamentary act can assist in maintaining environmental safety	✔	✔	✔
	Governmental Support	• Financial incentives, such as subsidies and tax incentives to promote industry development	✔	✔	✔
		• Implement incentives for increasing foreign direct investment	✔	✔	✔

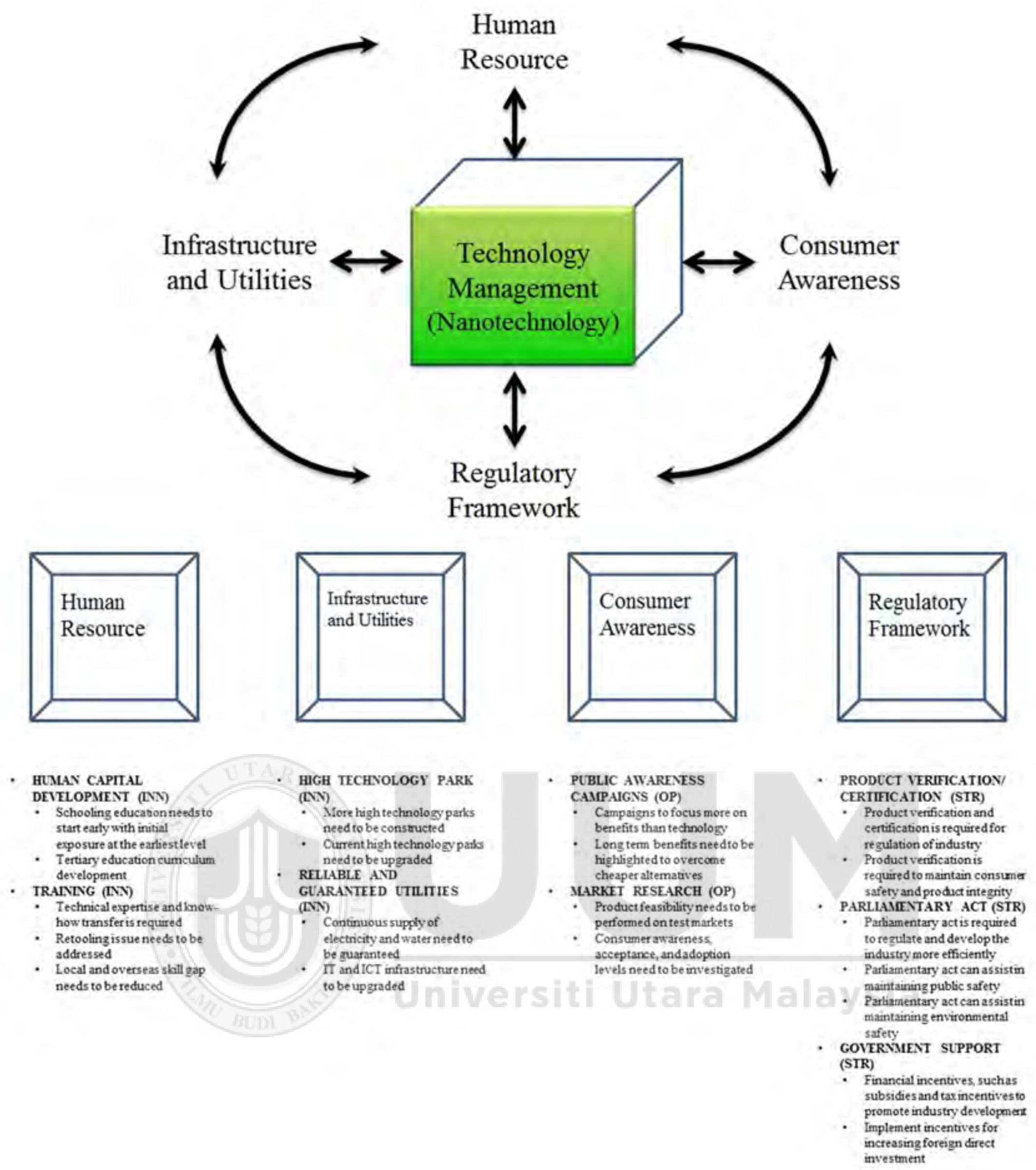

Figure 4.4
Final Framework of CSFs for Nanotechnology Industry Development in Malaysian Nanotechnology Industry
Source: This Research

4.5 Chapter Conclusion

This chapter presented the findings from the data collection interviews, framework development, and validation of the draft framework of critical success factors for effective nanotechnology industry management in the Malaysian nanotechnology industry. The validation process assessed the terminology, structural, and arrangement of the CSFs in the draft framework as well as its applicability to the Malaysian industrial context. The process involved validation interviews which were attended by experienced Malaysian nanotechnology practitioners. The findings of the interviews verified that current Malaysian nanotechnology development needs an effective integrated framework in order for it to greatly improve, thus, indirectly it will help overcome the issue of lack of integration among stakeholders involved in nanotechnology development in the Malaysian nanotechnology industry. Furthermore, these validation interviews also endorsed that all the CSFs in the draft framework are suitable and have robust applicability to be implemented in the Malaysian nanotechnology industry.

Based on the above constructive comments and suggestions, the final framework has been presented as a guideline for the Malaysian nanotechnology practitioners in order to achieve effective nanotechnology development. There are, however, some limitations in terms of the detail guideline for each CSF to be applied. Therefore, the following chapter is offered to discuss a summary of the entire research, including the main findings of the study, its limitations, recommendations, implications, and opportunities for future research.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 Summary of Research

This thesis aimed to develop a:

"Framework of critical success factors (CSFs) for effective nanotechnology industry development in the Malaysian nanotechnology industry".

This final chapter summarised the research findings from the literature review and the investigations conducted by the researcher as they were presented in this dissertation. In doing so, the research limitations and contributions to knowledge are presented in the chapter concluding with recommendations for future work. This chapter highlights how the research aims and objectives of this study were investigated and addressed:

a) to investigate the existing scenario of the nanotechnology industry, particularly in current and future outlook as well as its barriers to implementation in the Malaysian industry (Chapter 2);
b) to identify the critical success factors associated with nanotechnology industry (Chapter 4);
c) to develop a framework of critical success factors (CSFs) in Malaysian nanotechnology industry (Chapter 4); and
d) to validate the critical success factors in Malaysian nanotechnology industry (Chapter 4).

5.2 Main Findings of Literature Review

In order to develop a framework of critical success factors for effective nanotechnology industry development in the Malaysian nanotechnology industry, this thesis began by reviewing literature that related to the nanotechnology industry. In summary, the research investigated the development of the nanotechnology industry, both internationally and domestically, and highlighted the current challenges facing the industry and the emergence of governmental action groups before recommending the need for a more holistic approach as a method for enhancing the Malaysian nanotechnology industry.

The literature review began with a broad coverage of the definition and history of nanotechnology. The definition is quite varied, however, previous research efforts was in agreement that the study of nanotechnology was basically in relation to the size at which the research is performed. From the various definitions, the definition that stated nanotechnology to be "the creation of USEFUL/FUNCTIONAL materials, devices and systems through control of matter on the nanometer length scale and exploitation of novel phenomena and properties (physical, chemical, biological) at that length scale" (Tilstra et al., 2008), was the most universally accepted definition, and the one used in this study.

It is at this nano-scale that matter will behave differently in many aspects, such as physically, chemically, and biologically. Due to this, new products can be generated with novel and innovative applications. Also, due to the size of nano-enabled products, certain technologies can be enhanced significantly, such in renewable energy with regard the efficiency of solar cell batteries that are shrinking in size without sacrificing the power.

The historical aspect began with the conception of the idea of nanotechnology, the advancement of equipment, and eventually the actual work done at the nanometre level. The idea of nanotechnology was described by Feynman (1960) and basically referred to molecular machines that work at the atomic level to build molecular constructions, even though actual work at the nano-scale was perhaps science fiction at that time as the equipment and materials are not quite advanced enough to support that type of research.

With the advancement of scanning and detection technologies, actual nanotechnology level work was accomplished through the construction of a machine with nanotechnology embedded in its construction (Binnig & Rohrer, 1986). It was from then onwards that the development of nanotechnology in the developed nations began to take root. With the new discoveries, more innovative applications of nanotechnology was achievable, and thus raising its potential to have a disruptive impact across industries, and our daily lives.

It is because of this potential disruptive technology, as well as the potential benefits and profits that this technology has been touted to bring, proper management and development is required to facilitate its growth and integrate it into society while lessening the resistance and risks for the general public and consumers.

It was then illustrated that the more developed nations were taking action using a more holistic approach in developing nanotechnology, with the governments spearheading the development by establishing nanotechnology initiatives and roadmaps, as well as providing the budgetary finance to enhance greater development. The USA, Japan, Germany, and South Korea all have brought nanotechnology products from the R&D stages to the market. Although the Russian and Chinese investment in nanotechnology has shown slow progress, they are starting to pick up the pace. Other countries like India, Brazil, South Africa, Thailand, Philippines, Chile, Argentina, and Mexico are also actively pursuing nanotechnology (Court et al., 2004).

With the development and advancement being achieved overseas, Malaysia was determined not to be left behind. It started when the Malaysian government had funded some pioneering work in nanotechnology during the Seventh Malaysia Plan which spanned the years 1996 to 2000 (National Nanotechnology Initiative – NNI, 2010). Further reinforcement was of this nanotechnology research drive was seen with the emphasis of nanotechnology being one of 14 priority research areas in the Intensification of Priority Research Areas (IRPA), which was governed by the Malaysian Ministry of Science, Technology, and Innovation (MOSTI).

Furthermore, NNI (2010) had stated the short term strategy for Malaysia was, geared toward identifying researchers in various areas of nanotechnology with specific expertise; upgrading and equipping nanotechnology laboratories with state-of-the-art facilities; and to prepare a comprehensive human resource development programme for producing nanotechnologists.

This is further reinforced by the National Science and Technology Policy II (Ministry of Science, Technology, and Innovation - MOSTI, n.d.) which, specifically with regard to nanotechnology, desires to position Malaysia as a technology provider in the key strategic areas of nanotechnology; to ensure the widespread diffusion and application of nanotechnology, leading to enhanced market-driven research and development (R&D) to adapt and improve technologies by undertaking a detailed scrutiny of the industry; and to build competence for specialisation in key emerging technologies by developing a secure knowledge base in nanotechnology to sustain technology support for the Malaysian industry

(MOSTI, n.d.). Previous research had concluded that the Malaysian scenario required much work in the management of such high technology (Hashim et al., 2009). Some of the highlighted problems within the nanotechnology industry include lack of linkages between various projects, no central facility, there is no definitive plan to realise and develop the nanotechnology industry, there is no clear overall road-map for nanotechnology research, and lack of effort in promoting awareness of nanotechnology.

Furthermore, Hashim et al. (2009) also revealed a Strength, Weakness, Opportunity, and Threat (SWOT) analysis of the nanotechnology industry in Malaysia, as formulated by the Malaysian Industry-Government Group for High Technology (MIGHT), which is placed under the supervision of the Economic Planning Unit (EPU) of the Malaysian Prime Minister's Department. Some of the weaknesses identified were, no dedicated policy for nanotechnology, need for human resource planning, lack of private sector investment and participation, lack of facilities, and lack of world-class companies to raise the standard.

The report by the Asian Technology Information Program (ATIP) had identified the infrastructure components for supporting the nanotechnology industry, namely R&D infrastructure, human resource, industry infrastructure, and industry readiness (ATIP, 2006). From the comparison performed in 2006, it was highlighted that the Malaysian nanotechnology industry still requires more development in R&D infrastructure and human resource development, as compared to the other ANF countries; ANF being a network organisation that is supported by 13 countries, including Australia, China, Hong Kong, India, Indonesia, Korea, Japan, Malaysia, New Zealand, Singapore, Taiwan, Thailand, and Vietnam.

Thus, based on the preliminary review of material, there is a need to look into the improvement and barrier aspects of nanotechnology (Bürgi & Pradeep, 2006; Hipkin, 2004; Ghazinoory & Farazkish, 2010) in order to manage the development of this potentially viable industry to become more focused and successful by identifying the factors which may be of influence in facilitating the growth of this industry. As a result, the researcher undertook to address this gap using the following methodology.

Through the literature, it was highlighted that the usual problems encountered when wanting to adopt a more holistic approach in developing and managing nanotechnology, the issues that arise revolve around the human resource, infrastructure, awareness, and regulation aspects. In order to investigate these aspects, this researcher had formulated and plan and method to systematically gather and analyse the data from players in the nanotechnology industry, and present the finding in this dissertation. Naturally, the next section will cover the methodology and key findings of this research.

5.3 Methodology Analysis and Key Findings

The main aim of this research was to develop a framework of critical success factors (CSFs) for effective nanotechnology industry development in Malaysian nanotechnology industry, therefore this study required the researcher to understand, explore, and elicit opinions and perceptions based on those experienced by Malaysian nanotechnology practitioners which was governed by the qualitative inquiry of “what” (to explore the context of a number of variables associated with effective nanotechnology industry development in the Malaysian nanotechnology industry) and “how” questions (to investigate in depth information and explanation of the data to be collected—problems and CSFs) thus, this research fell within the interpretivist paradigm. Accordingly, a series of industry interviews was chosen as the mode of data collection because of the capability to obtain data based on Malaysian nanotechnology stakeholders' perspectives (experienced based) for developing and validating the framework of CSFs for effective nanotechnology industry development in the Malaysian nanotechnology industry.

The data collection process began with data collection interviews with the aim of enhancing the current literature review of CSFs for nanotechnology industry development in the Malaysian context.

The key findings of this research can be summarised that all interview respondents agreed and confirmed that the slow development of nanotechnology industry and up-take of nanotechnology products by the general public is because of several issues. The findings from the interviews further identified that these issues were related to various factors, the main ones being the human resource factors, the infrastructure and utilities factors, the consumer awareness factors, and regulatory framework factors. It was highlighted that these factors were not stand alone issues, as one factor's success would have bearing on other factors as well. Therefore, there is a need to develop and address all the issues from a more holistic approach.

In doing so, the respondents strongly agreed that an appropriate framework for achieving effective nanotechnology industry development Malaysian nanotechnology industry needs to be developed to detail how nanotechnology practitioners (including the government, agencies, and manufacturers) can become involved integratively and to share their skill, knowledge, and experience within a conducive work environment. Several of the critical success factors for effective nanotechnology industry development were identified from the discussions in the interviews are summarised below;

1) Awareness of nanotechnology needs to be raised earlier in the education system as some developed countries had integrated nanotechnology in their primary school curriculum;
2) Nanotechnology skills and knowledge needs to be inculcated at the tertiary education level in order to produce capable graduates to address the shortage of manpower in the nanotechnology industry;
3) Technical expertise and know-how needs to be transferred from external parties, normally from foreign partners, to the local work force in order to sustain the nanotechnology industry;
4) Companies need to send employees for further upgrading and re-tooling by enrolling them in training and short courses, as well as formal education, but this can be costly and the effects of which can be lessened by earlier nanotechnology education;
5) The local skill and foreign skill levels of the work force is variably different, which is why workers are sent overseas for upgrading their skills and knowledge;
6) Infrastructure is a major issue, and high technology parks are a viable solution but needs the support from the government;
7) Utilities now include more than just water and electricity, as nanotechnology requires different types of resources specific to the manufacturing sector—resources that may include different types of gasses that may be piped into the laboratories;
8) The issue of reliability and dependability of the utilities often became the topic of discussion thus utility vendors need to upgrade their services to meet the demands of the nanotechnology industry;

9) The IT and ICT infrastructure also needs to be in place and working seamlessly as many applications are needed that depend on this networked system, which can also promote collaborative activities;
10) Public and consumer awareness is pertinent in that they need to be informed and perhaps become persuaded by nanotechnology products when the marketing focuses more on the demonstration of the benefits rather than the actual science;
11) Consumers are in a comfort zone when using products, so marketing campaigns need to focus of the long term benefits and wrest away the domination of cheaper traditional alternatives;
12) Product feasibility depends on the level consumer awareness, which needs to be addressed in order to increase sales and profits.
13) Certification by NanoVerify is certainly necessary to protect consumers so that their safety is ensured;
14) Parliamentary act would assist in regulating nanotechnology while maintaining public safety and preserve the environment;
15) Financial incentive and tax breaks can help facilitate the growth of the nanotechnology industry; and
16) More foreign direct investment is needed to help develop the nanotechnology industry at a faster pace.

The respondents believed that a lot of benefits will be gained from the implementation of this approach such as; increasing awareness to create a pull factor to enhance human resource to address the manpower shortage in the nanotechnology industry, to promote more collaboration between the stakeholders instead of working individually from the construction of more high technology parks and improved infrastructure, better regulate the industry with the establishment of a regulatory framework that has an Act as its stable foundation. This stability is evident when looking at IT and ICT development with the establishment of laws, rules, and regulations. The most comprehensive laws governing telecommunications and digital services providers in Malaysia are the Malaysian Communications and Multimedia Act 1998 and the Malaysian Communications and Multimedia Commission Act 1998 (Hanis, Yahya, & Wan Ghani, 2009). The latter Act creates the Malaysian Communications and Multimedia Commission ("Commission"), a regulatory body that is granted jurisdiction over communications and multimedia activities in Malaysia, including the authority to enforce laws and to supervise the conduct of providers of communications and multimedia services. Other laws pertaining to ICT include the Digital Signature Act 1997 and the Computer Crime Act 1997. Laws giving particular incentives to ICT businesses were enacted to facilitate the MSC Malaysia program. This article provides an overview of those laws and others governing communications and related technology in Malaysia. All of these provide a stable platform and as a guide for players in the ICT industry to follow, thus the technology development process can be facilitated. Thus, it is anticipated that this is what an Act can do for nanotechnology.

The analysis of data from the interviews then was combined with the information identified from the literature review in order to develop a framework of critical success factors for effective nanotechnology industry development in the Malaysian nanotechnology industry.

Following the similar procedures and processes of data collection interviews, the interview technique (Validation interviews) was, again, used to evaluate the drafted framework. The aim of the Validation interviews was to validate the drafted framework and to further investigate the importance of the critical success factors to the framework among the

Malaysian nanotechnology stakeholders/practitioners. The findings of the Validation interviews verified that current Malaysian nanotechnology industry needs an effective nanotechnology industry development framework in order to improve the nanotechnology industry performance that would, indirectly, solve the issue of slow development and up-take of nanotechnology products by the Malaysian consumers. Although there were some constructive comments and suggestion for some of the CSFs within the framework, they did not involve any major changes or corrections to the drafted framework, except to modify one of the original factors. The overall findings from the Validation interview confirmed that all the CSFs (9 main factors and 20 sub-factors) are suitable, easy to understand, and have a robust applicability to achieve effective nanotechnology industry development in the Malaysian nanotechnology industry. The final framework (refer Figure 6.1) then can be presented to government agencies responsible or are actively involved in the development of the nanotechnology industry, such as NanoMalaysia and NanoVerify, as a guideline to achieve an effective nanotechnology development progression .

5.4 Research Limitations

In the course of conducting this research, the following obstacles were encountered:

1) Having a limited number of respondents for data collection and validation of the framework.
2) Participants were located in various locations which took time to get to them.
3) Participants agreed to meet at different times, so the actual process of data gathering took quite a long time.
4) Difficulties in obtaining and accessing information directly from the participants because of the researcher’s weaknesses in interviewing techniques.

5) The discussions during interviews had the tendency of veering off course and the respondent would supply information outside the boundaries of this research.
6) The number of respondents for the data collection interviews was limited to what NanoVerify could supply the researcher.
7) Some senior practitioners (e.g. General Manager, and Senior Project Manager) tried to lead the discussions thus required intervention on the part of the researcher.
8) The issue of translation (*Bahasa Melayu* being the main language, but most interviews were a mixture of both English and *Bahasa Melayu* with many colloquial words being thrown into the mix) emerged and proved to be a challenge for the researcher. This was handled by the researcher who is fluent in both languages.

5.5 Contribution to Knowledge

Despite the above limitations, the contribution of knowledge of this research comes from both practical and academic perspectives. From the practical perspective, previous discussion on Malaysian nanotechnology industry development implementation guides are none existent, so each stakeholder and player moves in their own manner, with some guidance provided by the government through the NNI and national nanotechnology roadmap. According to previous researchers, there has been a lack of attention paid to a more integrated approach toward managing nanotechnology, which is why this study was performed. However, previous attempts at assisting the nanotechnology industry development have not fully addressed the problem from a more holistic perspective and thus achieved less than the expected success. Therefore, this research was generated to develop a framework of critical success factors (CSFs) as a tangible example for the Malaysian industry to improve nanotechnology industry development in the Malaysian nanotechnology industry.

This researcher believes that this framework will be used as a term of reference for both Malaysian nanotechnology practitioners and academicians for achieving a more holistic approach toward developing and enhancing the potentially profitable nanotechnology industry. For example, identifying the CSFs characterising effective nanotechnology development will guide nanotechnology stakeholders and players (especially government agencies, policy makers, and private clients) in developing more systematic and comprehensive guidelines and policies for improving nanotechnology industry development in the Malaysian nanotechnology industry. In addition, highlighting the CSFs that underpin the framework will help nanotechnology stakeholders and players to manage their own projects in an integrated and efficient way without having to learn painful lessons the hard way.

Although the use of this framework would not necessarily instantly transform nanotechnology industry into a fully integrated and high performing GDP contributor, however, nanotechnology stakeholders should acknowledge these characteristics is required for a more developed and efficient nanotechnology industry in Malaysia.

Accordingly, this researcher endorsed this framework as providing a significant step toward improving the performance of nanotechnology development if it is followed carefully. It sets out to gradually, but systematically, unearth potential development practices within the nanotechnology industry so that they can be structured towards a more effective application. Notably, one CSF does not necessarily lead to effective development, but instead, a whole range of integrally linked CSFs could achieve this aim. More importantly, nanotechnology stakeholders and players need to ensure that the framework is properly structured for effective implementation and monitoring so as to avoid introducing too many new techniques at any one time and to identify familiar practices that can be geared toward effective nanotechnology development. Moreover, this framework does not imply that each and every CSF is required to be implemented for optimal performance of the nanotechnology industry, but it merely identifies the factors that are critical and should be addressed. It is up to each individual company, agency, research centre, education institution, and other organisations or firms related to nanotechnology to decide which factors to implement and focus upon, and in which order, as this research has not prioritised the CSFs. This study, is merely the first step, in the process of many steps, geared toward uncovering the viable solutions toward enhancing the nanotechnology industry in order to ultimately contribute toward the accelerated prosperous growth of this nation.

Moreover, from the perspective of academic research, many studies on nanotechnology in the Malaysian nanotechnology industry have focused on technical issues (hard issues) such as the actual research and development of nano-materials, nano-structures, and nano-applications across the various industries, such as cosmetics, electronics, pesticides, food, sensors, automotive, lubricants, and more. Although recently there has been some improvement in research into commercialisation and management issues (soft issues), most of the research is still based on promoting just the benefits of nanotechnology instead of investigating actual relevant issues, such as, fragmentation or lack of integration in more detail, as well as developing some initiative frameworks, guidelines, or principles of how to overcome and improve these issues effectively. For example, in identifying a list of CSFs for Malaysian nanotechnology industry development, it has contributed significantly to the current body of knowledge by reducing the existing gap in terms of limitation of tangible examples of an holistic approach, especially in the Malaysian nanotechnology industry.

This research has compiled definitions, chronology (history), drivers and barriers for future reference. The compilation was one of the strategies to improve the perceptions of nanotechnology industry development . It further discussed the issue of lack of holistic approach in more detail. The research then compiled CSFs and issues for effective nanotechnology industry development. The CSFs were evaluated and confirmed as reflecting the development of a framework for effective nanotechnology industry development to be applied in Malaysian nanotechnology industry.

The result of this research has been established for either the academician or practitioner. This framework however, is not only applicable in the Malaysian context, but may also be used in other developing Asian countries (such as Thailand, Indonesia, Brunei, etc.) where the circumstances and culture are similar to those in Malaysia. Thus, the achievement of this framework makes significant contributions across all areas of nanotechnology industry development research and practice.

Last but not least, the outcomes of this study could also be used for appropriate education and training either for academic programmes or professional hands-on practical purposes. This would improve students' and practitioners' understanding of nanotechnology industry development and strategies for implementing a more holistic approach. Once academia and industry have gained an in-depth knowledge and understanding of this matter, it will indirectly help in the up-take nanotechnology products in the future of Malaysian nanotechnology industry.

5.6 Recommendations for Future Work

This section suggests related areas of research where additional investigations may be valuable or would further enhance this study. In the entire process of this research, there were various issues that were uncovered and highlighted. Therefore, the following are some recommendations for the further improvement of nanotechnology industry development in Malaysian nanotechnology industry:

1) Further research on nanotechnology industry development in other developing Asian countries that have similar practices and the same cultural background would be helpful to validate the framework. Additionally, it might be useful to consider a comparative study with other Asian countries that are at a different stage of development (developed countries) to Malaysia in order to see whether this framework is applicable for implementation.
2) Further study can be performed in order to investigate and produce more detailed guidelines or procedures that are specific to each industrial player type (for example, government agency, education institution, research centre, manufacturer, retailer, etc.) for successful implementation of the factors in the Malaysian nanotechnology industry.
3) Further study is required in terms of investigation and validation processes among non-Malaysian nanotechnology stakeholder to generalise and enhance the applicability and validity of the CSFs in Malaysian nanotechnology industry.
4) Since improving the performance of the nanotechnology industry involves so many parties such as various government agencies, third party organisations, education institutions, research centres, manufacturers, and retailers, there needs to be research into whether there should be an encompassing governing body to act as mediator to

gather together all the parties involved, as well as to be in charge of the nanotechnology development for the Malaysian nanotechnology industry.

5) Future studies should also focus on the readiness aspect. It is really important to know whether the current local nanotechnology industry as well as its players and stakeholders are well prepared or have enough capability in terms of knowledge, skills, and resources to consistently maintain the nanotechnology industry development.

5.7 Conclusion

This chapter presented a summary of this research's key findings, contributions, limitations, and the recommendations for possible future research. In spite of some of the limitations highlighted, the researcher remains confident in the results, which have successfully developed a framework of critical success factors (CSFs) for effective nanotechnology industry development in Malaysian nanotechnology industry. The value of this framework was confirmed and considered to be valid for implementation into the Malaysian nanotechnology industry by the industry interviews that were participated by experienced and knowledgeable nanotechnology experts and practitioners. Although there have been some constructive comments and suggestions for some of the CSFs within the framework, they do not involve any major changes or corrections to the framework. The overall findings from this research confirmed that all the CSFs (9 factors and 20 sub-factors) are easy to understand and have robust applicability to achieve effective nanotechnology industry development implementation in Malaysian nanotechnology industry.

Despite the difficulties and limitations faced throughout this study in gaining access to the research subject, the fact that this study engaged with different data collection techniques should be indicative of the worth of the results. However, although the interpretation of the data for the purpose of this thesis has concluded, the significance of the findings should be refined in the future for dissemination purposes.

Further invitations, publications, and presentations at academic and industry (practitioners) programmes have already been planned and accepted. It is believed that the output of this research will meet the current academic (trainer, facilitator, researcher, policy maker and lecturer) and practitioner (e.g., government body, manufacturer, retailer, and consumer) needs for those who have an interest in achieving the success of nanotechnology industry development in the Malaysian nanotechnology industry. Finally, a framework of CSFs for effective nanotechnology industry development has been presented as a guideline for the Malaysian nanotechnology practitioners and stakeholders in order to enhance nanotechnology development in the Malaysian nanotechnology industry.

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