Innovation within the UAE’s Space Sector – past, present and future

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ABSTRACT

This research builds on three projects that aim to investigate and explore innovation patterns adopted by the United Arab Emirates (UAE) over the past 15 years. The research proposes solutions to overcome observed issues, challenges and barriers facing emerging space countries, such as the UAE, in the development of its space sector and in particular its high technology manufacturing satellite sector. The proposed solution is articulated within the context of an integrated management system called Space Management Innovation System (SMIS) for the UAE. The SMIS was built by integrating the results and outcomes obtained from the three research projects here and aims to propose solutions for building indigenous capabilities in the high manufacturing technological satellite sector and research & development (R&D) capabilities in science, technology and innovation (ST&I) areas related to space at local universities, research centres and related manufacturing firms.

The results from the first project reveal the past and present innovation patterns and developments adopted by the UAE in the expansion of its capabilities in the space sector. It reveals the shortfall in engaging local universities and research centres in the transfer of technology and know-how on design and manufacturing, assembly, integration and testing (MAIT) of satellites, and more importantly in the development of local R&D capabilities on space related ST&I areas, which is a critical requirement to sustain future development of the UAE's space sector. The analysis reveals the importance of having a national ST&I roadmap for the purpose of aligning relevant actors and stakeholders on common visions and objectives, and prioritising and directing R&D activities towards upscaling existing capabilities and development of space related key and critical ST&I areas.

In the second project, a country space-specific ST&I roadmap is proposed. An initial proposal is aimed to develop a conceptual model framework that integrates foresight methodology and technology roadmapping to scan and identify future technologies and opportunities, and to prioritise ST&I areas. In addition, it aims to guide the space sector on which R&D activities the main stakeholders, i.e. satellite operators, universities and relevant space or aerospace manufacturing firms in the UAE, need to focus their efforts on for the short and long term.

An initial technology transfer model framework is proposed in the third project that can be applied in a future space technology transfer programme. It is aimed to provide a framework that can be utilised to sustain the development of indigenous capabilities on areas that an

emerging space country such as the UAE desires to achieve over the short and the long term to meet national requirements and other strategic objectives. It capitalises and aligns existing and future satellite programmes with the capability development of R&D on prioritised ST&I areas, across local institutions, inclusive of universities, research centres and related manufacturing firms.

The thesis consists of literature reviews, multiple case studies on a single country, i.e. the UAE, and a research synthesis of data sources, including secondary data from journals, market reports, technology roadmaps from various sources, and/or strategies of space agencies and the UAE's strategies and policies, as well as primary data from surveys and workshops.

This research attempts to provide solutions, methods and techniques that have not yet been sufficiently exploited within a geographical area and in an emerging space country such as the UAE. It is a novel and valuable contribution to academia and has considerable implications on management practices.

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DECLARATION

No portion of the work referred to in the thesis has been submitted in support of an application for another degree or qualification of this or any other university or other institute of learning.

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LIST OF ABBREVIATIONS

AIT	Assembly, Integration and Testing
AlYahsat	Al Yah Satellite Communications
CDR	Critical Design Review
CEOS	Committee on Earth Observation Satellite
CSA	Canadian Space Agency
DBA	Doctorate in Business Administration
DSI	Deep Space Industry
DTF	Distance-To-the Frontier
EIAST	Emirates Institute for Advanced Science and Technology
EMIRS	Emirates Infrared Spectrometer
EMM	Emirates Mars Mission
EMUS	Emirates Mars Ultraviolet Spectrometer
EO	Earth observation
ESA	European Space Agency
EXI	Emirates eXploration Imager
GEO	Geostationary Earth Orbit
GER	Global Exploration Roadmap
GES	Global Exploration Strategy
ICT	Information and Communication Technology
ISECG	International Space Exploration Coordination Group
ISRO	Indian Space Research Organization
ITAR	International Traffic in Arms Regulations
JAXA	Japan Aerospace Exploration Agency
KARI	Korea Aerospace Research Institute
LASP	Laboratory for Atmospheric and Space Physics
LEO	low Earth orbit
MAIT	Manufacturing, Assembly, Integration and Testing
MBRSC	Mohamed Ben Rashid Space Center
MEPAG	Mars Exploration Programme Analysis Group
MMS	Mobile Satellite Services
NASA	National Aeronautical Space Administration
NIS	National Innovation Strategy
NSSTC	National Space Science and Technology Center
NSTIP	National Science, Technology and Innovation Policy
NSTP	National Space Technology Programme
PMAD	Power management and distribution
R&D	Research and Development
SI	Satrec Initiative
SIS	Sectoral Innovation System
SMIS	Space Innovation Management System
STEM	Science, Technology, Engineering and Mathematics
ST&I	Science, Technology and Innovation
STDP	Space Technology Development Programme

LIST OF ABBREVIATIONS

TF	Technology Foresight
Thuraya	Thuraya Telecommunication Company
TRL	Technology Readiness Level
TRM	Technology Roadmapping
TT	Technology Transfer
UAE	United Arab Emirates
UAESA	United Arab Emirates Space Agency
UKSA	United Kingdom Space Agency

LIST OF NOTATIONS

Capability (Productivity Knowledge)	The prerequisite or accumulated embedded knowledge required to produce a particular product (Hausmann et al., 2012)
Capability (Space)	The launch vehicle 'rockets' required for deep space exploration missions
Complex Product	A high level of embedded knowledge or prerequisite capabilities required to produce a product (Hausmann et al., 2012)
Convergence	Shifting from investment- to innovation-based strategy (Acemoglu et al., 2006)
Convergence Trap	A country that cannot shift from initial investment- to innovation-based strategy becomes trapped by continuing funding without realising the benefit and being able to produce complex products (Acemoglu et al., 2006)
Diffusion	The degree to which knowledge has been communicated
Embedded Knowledge	The tact knowledge available within the mind of individuals and explicit knowledge available within organisations (Hausmann et al., 2012).
Explicit Knowledge	Knowledge that is codified and in a transferable format and language that can be communicated between individuals and organisations
Face-to-Face	A type of communication that takes place physically between individuals (Brown and Duguid, 1991, Dougherty, 1992, Nonaka and Takeuchi, 1995)
Heritage	A technological product or components that was designed, built and flown in a previous spacecraft/satellite
Performance Gap	The difference between existing and future desired capabilities
Productivity Knowledge	The knowledge embedded in the mind of individuals and organisations to produce a product (Hausmann et al., 2012)
Shared Knowledge	Both Face-to-Face and Shoulder-to-Shoulder type of communication to share and exchange knowledge between individuals (Nonaka and Takeuchi, 1995)
Shoulder-to-Shoulder	A type of communication method to transfer knowledge and that takes place between individuals when working together in a particular activity such as design of a technological product (Brown and Duguid, 1991, Dougherty, 1992, Nonaka and Takeuchi, 1995)
Space Technology Ladder	Capability development steps i.e. a ladder that country goes through from procuring to building partially at partner site and then building complete satellites locally at their own facilities with limited support from external partners (Wood and Weigel, 2011).
Spin-In	A dissemination from Earth activity – an application or product developed for Earth and used for space activity
Spin-Off	A dissemination from space activity – an application or product developed for space and used for Earth applications

Tacit Knowledge	Knowledge that is un-codified and in an abstract form which require articulation to generate new knowledge in a codified format.

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Why this research is important?

In April 2014, the leaders of the United Arab Emirates (UAE) government announced a historical flagship programme called Emirates Mars Mission (EMM) to build a spacecraft called 'The Hope' or 'Al Amal' in Arabic to orbit Mars in 2021, and announced the establishment of the UAE Space Agency (UAESA) (Khalifa, 2015). The UAESA was mandated with a very challenging goal, to be "focused on developing and guiding a world-class Space sector that contributes to a diversified national economy and supports sustainable development" (Khalifa, 2015).

The goal needs to be articulated around developing a national space programme, research and development in science, technology and innovation topics related to space similar to other international space agencies. However, it needs to be within a context suitable to the UAE's needs that meets the vision set by the leadership of the government. The national space programme needs to upscale existing and develop new space-related capabilities. However, the goal can be achieved if there is innovation established within the country to support the development of the space sector. As argued by Carlsson et al. (2002), an innovation system is needed that grows capabilities among actors to generate, diffuse and utilise technologies that have economic value.

The national space programmes adopted by pioneering spacefaring nations such as the USA and some countries in Europe are justified based on the return on investment by encouraging the commercial use of advanced technologies (Venturini et al., 2013). In these countries, the government plays a pivotal role in funding space programmes, creating the environments to support the related industries, purchasing space products and services, and introducing necessary regulations to support the industry. However, within a different context, governments in countries that are emerging space countries initially adopt an investment strategy. Developing countries invest in technology developed elsewhere and use it where it can innovate and eventually lead them to produce their own products (Collins, 2015). Developing countries then attempt to move from investment to innovation-based strategies where it shifts gradually from only procuring to manufacturing technological and innovation products. However, only a few developing countries have emerged as spacefaring countries and are able to make this gradual shift towards innovation-based strategy in the space sector. It seems the UAE is one of these countries.

Over the past 15 years, the UAE invested AED 20 billion on space-related activities including satellite data and TV broadcasting communications satellites, Earth mapping and observations satellites in addition to other programmes (Khalifa, 2015). These investments were scattered among several actors and without a consolidated national space programme. It is now the duty of the UAESA to lead and guide the country on space exploration and non-exploration programmes, prioritise research & development (R&D) and engage the local institutions on the development of science, technology and innovation topics related to space. However, there are ambiguities on existing capabilities available in the UAE, and the UAESA faces several challenges, some of these are identified as follows:

1. There is no known study that explores and addresses innovation patterns adopted by the UAE over the last 15 years. A study is needed which may explain how the past decisions and efforts indicate and explain how the space sector evolved in the past and may provide insight on how it will evolve in the future.
2. There is a national innovation strategy (NIS) and a national science, technology & innovation (ST&I) policy, but there is no ST&I policy or strategy developed specifically for the UAE space sector.
3. The UAE has only one deep space exploration project, which on one hand opens up a new window of opportunities on science and technology activities that did not exist before in the UAE; on the other hand, it limits the scope and size of future developments of ST&I activities.
4. It is not clear what and how effective technology and know-how were transferred from the previous commercial and scientific satellite projects and how that impacted on the development of indigenous space sector capabilities in the UAE.
5. It is not clear what are the existing indigenous capabilities in satellite manufacturing, assembly, integration and testing (MAIT) and in R&D on ST&I topics related to space in the UAE.
6. It is not clear how to identify which ST&I topics the UAE needs to prioritise, fund and support in a sustainable approach over the short and long term.

I was interested to get more insight and learn about the space exploration programmes, the upcoming technological development and technology roadmaps that are or will be pursued by international space agencies and how these are aligned or mapped together. I was interested to learn what methods or approaches from academic literature, industry-specific publications and management practices can be used to develop similar methods and approaches for the UAE space sector and to resolve some of the shortfalls and counteract the challenges listed above.

The industry and management publications tend to address results on technology roadmaps as an example, and not the techniques, methods or approaches used to build the roadmaps. On the other hand, the academic research scholars were interested to extend current theories, techniques or methods such as the work of Hertzfeld (2002b), Goehlich et al. (2005), Thirsk et al. (2009) and Venturini et al. (2013) on space technology transfer; the work of Petroni and Santini (2012) and Ricard et al. (2015) on space innovation; and Dede and Akçay (2014) on space technology foresight. Some scholars attempted to integrate innovation and foresight such as the work of Andersen et al. (2014), Andersen and Andersen (2014) and Keller et al. (2015) and some scholars attempted to integrate roadmaps, innovation and foresight, such as the work of Vishnevskiy et al. (2015).

The ability of firms to assimilate knowledge from their environment increases the 'absorptive capacity' of firms and accordingly their ability to innovate, as argued by Madu (1990). Transfers of know-how play an important role to develop local indigenous technological capabilities. I wanted to understand how academic literature addressed the international transfer of know-how to developing countries in design and MAIT of satellites.

CHAPTER 1 Innovation within the UAE'S Satellite Sector – past, present and future

1.1 Introduction

Nations go through a unique approach for development and this development signals the capability for process innovation (Porter, 1990). The decisions taken by nations in the past on which development paths to pursue may explain how technologies will evolve in these nations in the future. The innovation and development path of the UAE's satellite sector is the focus of this research. The approach of this research was based on learning and drawing on relevant theories, methods, techniques and previous research studies to investigate and explain practical phenomena related to the past and present development of the UAE's space sector. It then attempts to propose solutions to develop and sustain the technological capabilities related to space, over the short and long term. A Space Innovation Management System (SIMS) is proposed to articulate the success factors needed to overcome issues, challenges and barriers that were faced over the past 15 years, especially on technology transfer (TT) programmes.

This thesis builds on three interlinked research projects conducted as part of the DBA programme (see Table 1.1). Project 1 is an exploratory research study that draws on both the Sectoral Innovation System (SIS) and Distance-to-Frontier (DTF) to explore and explain the innovation patterns of the UAE's high technology satellite sector over the past years. In Project 1, the UAE's innovation pattern on development of the satellite manufacturing, assembly, integration and testing (MAIT) sector is explained and complies to some extent with the SIS theoretical assumptions. The SIS assumes the possibilities of countries to converge innovation strategies after it adopting imitation strategies. It predicts countries could converge towards innovation and the frontier over time. However, the conversion towards innovation depends crucially on features related to knowledge base conditions: the levels of appropriability, opportunities and accumulativeness (Malerba and Orsenigo, 1996, Malerba et al., 1997). On the other hand, DTF could not explain the conversion phenomena taking place in the UAE's space sector since the proximity distance to the frontier is a determining factor for assessing the ability of countries to innovate and whether countries adopt an innovation or imitation strategy (Danquah and Ouattara, 2014). In the case of the UAE, its frontier level is a distance away from the world technology frontier but the UAE was able to upscale its space technology frontier ladder in recent years.

In Project 1, the innovation pattern analysis revealed that the UAE is gradually converging from an investment- to innovation-based strategy. Throughout the previous years, the UAE adopted several tracks to develop its space sector oriented around and related to building and accumulating indigenous capabilities in design and MAIT of satellites: (1) manufacturing of conventional satellites, (2) space exploration spacecraft, (3) small satellites, and (4) development of R&D capabilities on the ST&I related to space. Three innovation themes were adopted that cut across the four development tracks: (A) a government investment-based strategy, (B) international partnerships, and (C) transfer of technology and know-how. During the previous years, the UAE adopted, diffused and imitated technologies developed and assembled elsewhere but with limited technological development in the country. The conversion towards innovation is not straightforward; it requires governments to counteract several effects to crucially enhance and improve the knowledge base features and conditions (Malerba and Orsenigo, 1996, Malerba et al., 1997, Breschi et al., 2000, Adams et al., 2011, Madu, 1990).

In the UAE, the development of the satellite sector was fully funded by the government. This was critically important since it was not feasible for private organisations or state-owned enterprises to invest in facilities in the UAE or in satellite development projects aimed to transfer technology and know-how to local universities and research centres without financial returns while the space programme was still in its infancy. However, the UAE now needs to ease the appropriability effect, caused by entities relying totally on government funds. It needs to engage relevant organisations to invest and increase their level of R&D activities, which will increase level of opportunity and cumulative conditions, as suggested by Malerba and Orsenigo (1996) and Malerba et al. (1997). Relevant organisations will accumulate advanced capabilities needed to develop innovative technological products and will be qualified to engage in future national and international space projects, opening up new windows of opportunities. Acemoglu et al. (2006) posit that countries will fall into a non-conversion trap if the government does not intervene by introducing policies and strategies since it will not benefit from investment made on innovation over time. This consequence could occur in the UAE's space sector economy. However, the UAE recently introduced policies and strategies to counteract effects or factors that may lead to a slowdown in the conversion and that could have positive impacts on the levels of appropriability, opportunities and accumulativeness to sustain the innovation and development of its space sector.

In Project 2, it was first observed that pioneering and established spacefaring nations have foresight and can identify future required technologies, especially critical technologies to support space exploration missions and other national objectives. Secondly, technology roadmaps are developed and utilised to prioritise which technologies need to be developed over the short and long term. Thirdly, it utilises technology roadmaps to develop implementation plans and to allocate necessary funds accordingly.

It was found that the UAE did not have a national technology roadmap when it started its space activities with the development of three low Earth orbit (LEO) scientific Earth observation (EO) satellites – development of DubaiSat 1 started in 2006, DubaiSat 2 in 2009 and KhalifaSat in 2013 by the Mohammed Bin Rashid Space Centre (MBRSC) – or through procured communications satellites and launched Thuraya 1 in 2000, Thuraya 2 in 2003 and Thuraya 3 in 2007 by Thuraya Telecommunication Company (Thuraya) and Al Yah 1 in 2011 and Al Yah 2 in 2012 by Al Yah Satellite Communications (AlYahsat). Moreover, the space exploration programme in the UAE is still young. It has only one approved deep space exploration project, the 'The Hope' spacecraft or 'Al Amal' (henceforth called 'Al Amal'), and in addition has limitations on resources. These and other factors such as lack of engagement of local universities and research centres in previous satellite development programmes introduce challenges to identify and prioritise which technologies at the system and components levels need to be developed and by which organisations over the short and long term. It is also a challenge if the development of the technology roadmap is linked only with its own national satellites or deep space exploration missions since the scale and number of missions will be small. Hence, a customised technology roadmap needs to be developed for the UAE that is different than the method adopted by pioneering and established spacefaring nations.

Therefore, in Project 2 the attempt was made to develop a method or solution for technology roadmapping customised for the UAE's space sector engaging in capabilities development of universities, research centres, satellite manufacturers and operators, and related aerospace manufacturing firms. The research was drawn on technology roadmapping and foresight techniques and methodologies to scan, identify and prioritise science, technology and innovation (ST&I) areas (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010) for the UAE's space sector. It was based on scanning and assessing global space technological trends, international space agencies' roadmaps, relevant strategies and policies of the UAE, and existing local R&D capabilities on ST&I topics related to space exploration and non-exploration.

In Project 2, I proposed an integrated ST&I roadmap and foresight model framework that can be used periodically to prioritise which R&D activities the UAE needs to invest in and accumulate capabilities for over the short and long term. From Project 2, a global space technology tree consisting of existing and future technologies and a country-specific space ST&I roadmap were developed. The country-specific ST&I roadmap guides the space sector on which R&D activities the main stakeholders, i.e. satellite operators, universities and relevant space or aerospace manufacturing firms in the UAE, need to focus their efforts on. R&D capabilities on space-related ST&I areas act as guides on what to invest in over the short and long term in a coordinated approach at the national level led by the UAESA and in coordination with all relevant stakeholders.

Project 1 revealed that technology transfer is identified as one of the innovation pattern adopted by the UAE across the four development tracks mentioned above. Technology transfer was a strategic option executed with international partners to support the development of the UAE's space sector and building and accumulating indigenous capabilities on design and MAIT of satellites. However, there are ambiguities on the effectiveness, extent and scope of TT programmes and associated technological development capabilities at universities and research centres.

Technology development is not a singular event, as argued by Ounjian and Carne (1987). Technology transfer will continue to be an option in the future to transfer know-how. Therefore, Project 3 discussed strengths and shortfalls of several TT models (Nonaka and Takeuchi, 1995, Gilbert and Cordey-Hayes, 1996, Hill, 1989, Team, 1987, Baskaran, 2001). It then explored challenges and barriers faced during previous satellite TT programmes on resources, organisation culture and the routine activities used to transfer technology and knowledge. In Project 3, a conceptual TT model framework is proposed that could be applied to future space exploration and non-exploration projects that have an element of TT. The model includes success factors needed to maximise benefits gained when executing TT on satellite projects for developing and sustaining indigenous capabilities in the design and MAIT of satellites.

1.2 Thesis structure

This doctorate research follows the 'three papers' as an alternative approach for writing the results of the DBA research. Chapter one presents how the three projects are linked and related based on coherent research topics and themes. The third section addresses the research strategy and methods. The fourth section provides an outline and overview of the three research projects. The fifth section discusses the overall contribution and significance of the research.

Chapters two, three and four present the three research projects in article format as shown in Table 1-1.

Table 1-1: The three DBA research projects

Project Number	Chapter Number	Project Title
1	2	*Innovation Patterns of the UAE's Satellite MAIT Sector*
2	3	*Towards the UAE's Space Technology Roadmapping and Foresight: Scanning and Prioritising ST&I Opportunities*
3	4	*A Technology Transfer Model for the UAE's Satellite Sector*

Chapter five discusses and articulates how the findings and results obtained from the three projects are used to construct a management innovation system, which aims to sustain the development of the UAE's space sector in general but in particular in the design and MAIT of satellites. Chapter six provides concluding remarks regarding the research's contribution to methodology, policy and management practices and provides recommendations to conduct further research on relevant topics.

1.3 Summary of research strategy and design

This doctorate research follows three papers as an alternative approach for writing the results of the DBA research. Although three projects are independent, they are related through coherent themes, which maintain the continuity of the thesis. However, the methodology and data analysis are not intertwined through the three projects due to the nature of the research questions, investigation and analysis for each project.

The overall research questions, objectives, investigations and methods used for the doctorate research projects are illustrated in Table 1-2. Figures 1-1 and 1-2 illustrate how the three projects are interlinked. Project 1 framed the second and third projects. The second and third projects were an extended study on specific innovation phenomena found as result of the investigation and analysis conducted in the first project. The innovation management system was constructed based on the findings and analysis revealed from three projects. The following sections provide an overview on the research methods, data collection and analysis approaches adopted in the three projects.

Table 1-2: Research design (TT=technology transfer)

	Research Questions	Research Objectives	Research Investigations	Research methods
Project 1	• How does the UAE approach the new space technological frontier? • Is there any technological upgrading of the UAE manufacturing high technology satellite sector? • To what extent can the innovation pattern phenomena in the UAE be explained by SIS and DTF theories?	• Identify the main active actors in the UAE space sector and identify their main achievements • Identify the innovation features adopted by the UAE in approaching the new space technological frontier • Identify the technological upgrading features of the UAE's manufacturing high technology satellite sector	• Identify the main innovation patterns adopted by the UAE over the past and present years on the new space technological frontier. • Explore the adopted approaches by the UAE used for upgrading its manufacturing high technology satellite sector • Explore the extent the innovation patterns phenomena in the UAE could be explained by SIS and DTF theories	Literature reviews Stakeholder's Survey Industry publications Capability survey Semi-structured interviews
Project 2	• Which are the most relevant space agencies across the globe? • Which are their current and future technology ST&I topics/areas priorities? • Which specific technologies ['critical technologies' are priorities] to advance priority ST&I areas that are needed for future space exploration missions? • What are the existing R&D activities in space-related ST&I areas in the UAE? • Which are the STI topics and technology development opportunities that the UAESA should prioritise in the near and longer future?	• Scan future technologies related to space • Identify opportunities and prioritise ST&I areas to develop the UAE's space sector • Develop an ST&I roadmap to develop the UAE's space sector • Develop an integrated foresight and ST&I roadmap model framework	• Identify relevant international space agencies • Assess technology roadmap of pioneered spacefaring nations and industry-relevant organisations, and identify critical technologies • Assess UAE's existing research and development capabilities in science and technology topics related to space	
Project 3	• What are the resource challenges and barriers facing TT and know-how on satellite design and MAIT? • What is required from an organisation to operationalise [i.e. routine] TT process to maximise benefit from TT projects? • What needs to be changed in organisational culture to maximise benefit from TT projects to sustain its technological capability development?	• Investigate and explore the challenges and barriers faced during TT and know-how, which impact the effectiveness of the previous transfer technology programme in building national indigenous capabilities • Draw main constructs towards building a conceptual TT model and identify success factors to maximise the benefit of any future TT programme in building national indigenous capabilities	• Analyse semi-structured interviews and identify challenges, barriers and success factors themes • Identify main constructs to develop a TT mode	

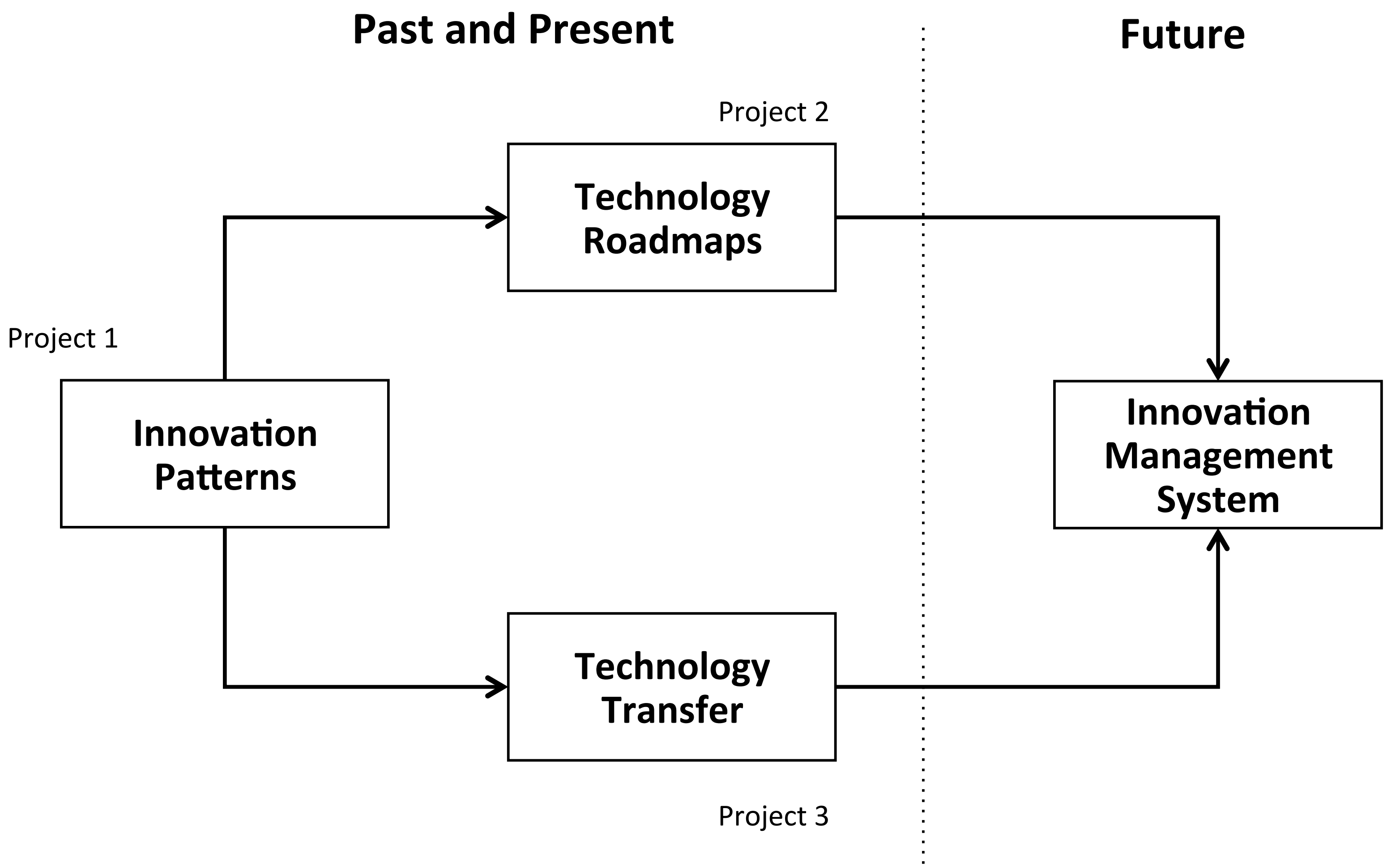

Figure 1-1: Interlinked DBA projects - Illustrative

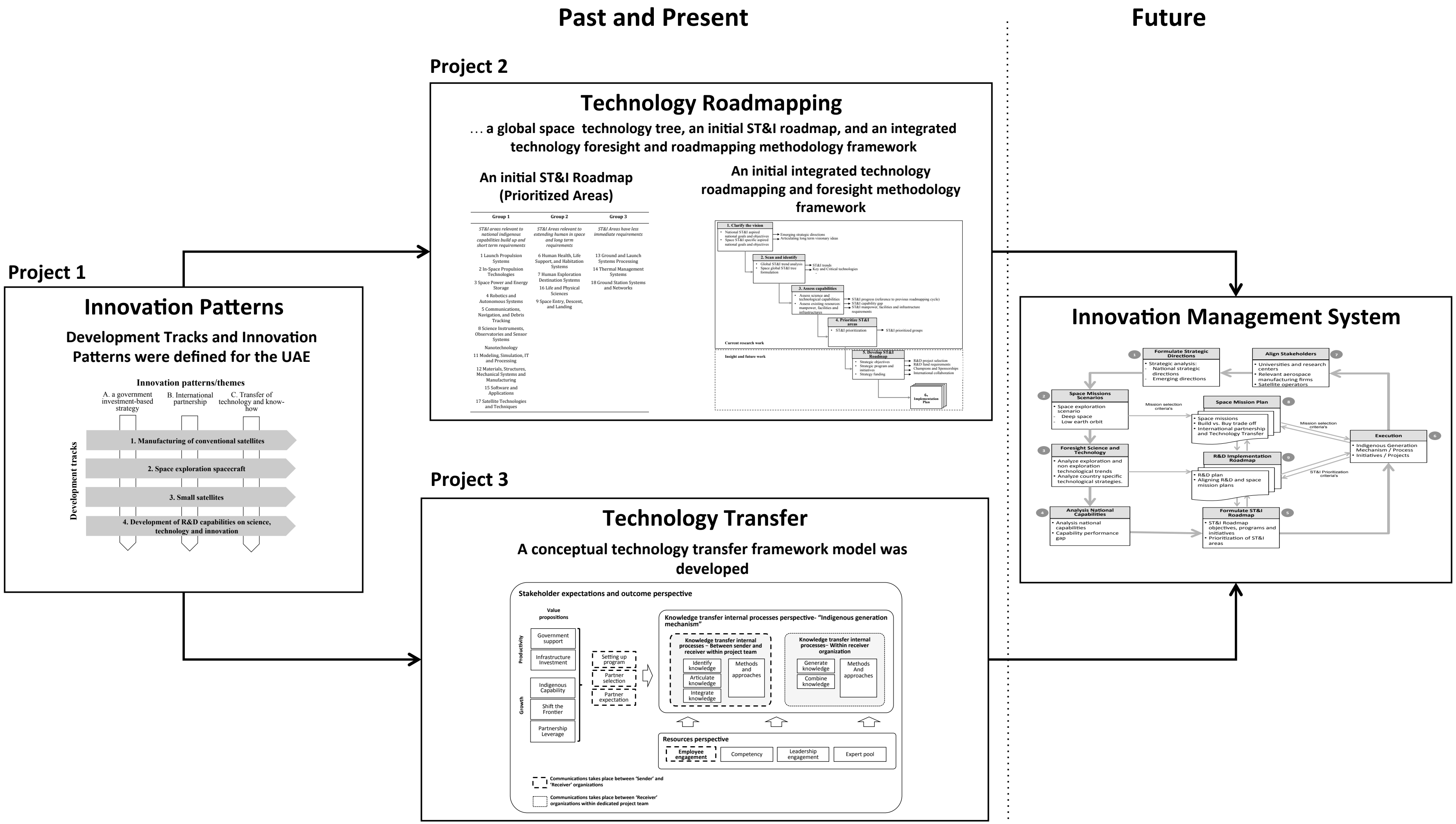

Figure 1-2: Interlinked DBA projects - Illustrative chart showing main deliverables of DBA projects

1.3.1 Research methodologies

This section provides a summary on the methodologies used in the three research projects. Single and multiple cases and mixed methods approaches were used. The single and multiple cases were done on a single country, the UAE; therefore it offers only a single perspective (Guglielmi et al., 2010). Based on the problem, situation, innovation phenomenon of interest and background of each project, I reviewed and referred to the academic literature to identify key theories, concepts and ideas. For more insight, I drew on these to investigate, explain and explore if identified theories might confirm some of the phenomena that were observed from the empirical work. The literature was also used to identify gaps in knowledge that supported the determination of the research questions (Hart, 1998).

The first project consists of a single case study on the UAE. Both SIS and DTF theoretical assumptions were used to explore the past and present innovation patterns of the UAE's satellite sector. It explores if the innovation patterns can be explained within a theoretical assumption of both theories. The study includes a literature review, survey and review of strategies and reports from main actors and stakeholders in the UAE's space sector.

The second project is an extended research study and continuation of the first project. It consists of a single case study on the UAE and includes reviews of the academic literature, industry publications and space agencies' roadmaps and strategies, a survey, a workshop, meetings with senior management, and review of the UAE's strategies and policies. The analysis was conducted within the context of both the technology roadmap and foresight methodologies which are relevant to the research topic of interest.

The third project is a continuation of projects 1 and 2 to investigate challenges and barriers faced during the previous TT projects. The challenges and barriers faced in TT programmes were explored and investigated on resources, culture and routine activities needed to operationalise and sustain the benefit of TT programmes. It consists of four case studies in a single country that included semi-structured interviews. The semi-structured interviews were appropriate for this study since they explore problems that are relatively new, and thus have very little research pertaining to them (Cresswell, 2007). The first case study consists of three satellite projects; the second case study consists of one satellite or spacecraft for a deep space exploration project. A template analysis was firstly used to identify preliminary or *a priori* themes from relevant literature reviews. It was secondly used to encapsulate recurring ideas in interview transcripts and the likely themes that will emerge from interviews (Miles and

Hubermann, 1994, Tesch, 1990). The outcome of the analysis is a thematic and structured framework, which addresses refined and emergent themes related to research phenomena of interest and supports the construction of the initial conceptual framework for TT.

1.3.2 Data collection

Primary and secondary data sources were used in the three projects and are described in this section. The section highlights how data collection and sources are related to the literature review; theoretical assumptions, methods and techniques, and surveys were used for primary data sources.

All three projects followed a common approach. The data collection was shaped around the findings of the literature reviews relevant to the research phenomena and questions in each of the three projects. In Project 1, the literature was reviewed within the context of both SIS and DTF theories. In this research project, relevant data were collected from a survey to explore and gain an insight on the innovation patterns adopted by the UAE over the past and present years, how it approached the new space technological frontier, and if there was any technological upgrading of the UAE manufacturing high technology satellite sector.

In Project 2, the literature reviews were based around technology roadmap and foresight methodologies and techniques, and both secondary and primary data sources were used. The secondary data sources included journals, market reports, technology roadmaps from various sources, and/or strategies of National Aeronautical Space Administration (NASA), and Canadian Space Agency (CSA), UK Space Agency (UKSA) and European space agency (ESA). The primary data sources include two empirical studies, a survey and a workshop, to collect data from local academia, satellite operators and aerospace manufacturing firms. Primary data were collected on existing local R&D capabilities and activities on ST&I areas. Data were collected on future interests of R&D related to space ST&I areas. The workshop aimed to validate and clarify collected data from the survey.

In Project 3, a semi-structured interview was constructed based on identified *a priori* themes from the literature. The questions were shaped around collecting information on challenges and barriers faced during the international transfer of technology and know-how and success factors, in particular on the design and MAIT of satellites.

1.3.3 Research investigation and analysis

To provide answers to the research questions and to achieve the research objectives, different research approaches and methods were used to investigate and analyse the research phenomena addressed in the three projects.

In Project 1, the innovation patterns of the UAE's high technological satellite sector is investigated and explored. The responses of the survey on actors and stakeholders in the UAE's space sector were analysed to identify: the main innovation patterns adopted by the UAE over the past and present years on the new space technological frontier; the approaches adopted by the UAE for upgrading its manufacturing high technology satellite sector; and the extent the innovation patterns phenomena in the UAE could be explained by SIS and DTF theories.

In Project 2, to develop the first UAE ST&I roadmap, the research approach was to scan and analyse global technological trends in the space sector. It presents preliminary work that will ultimately be used towards the development of the first UAE ST&I roadmap. Therefore, the investigations and analysis were based on technology roadmaps and technology foresight methodologies and techniques. Both secondary and primary data sources were used and analysed. In this study, UCINET, a network analysis (NA) application, was used to analyse the collected data. NA techniques are used to establish the position of actors in a network and the relationships among them (Borgatti et al., 2002). In this study, NA was used to understand and analyse which technologies are central and common among space agencies and among relevant actors or stakeholders in the UAE. Relevant to global future technological trends and existing capabilities, gaps were identified and ST&I areas were prioritised over the short and long term.

In Project 3, results obtained from the semi-structured interviews on the single and multiple cases studies were investigated and explored. The encapsulated recurring ideas and new emerging themes from the interviews were used to refine the preliminary and *a priori* themes identified from the literature review, to structure a conceptual framework (Miles and Hubermann, 1994, Tesch, 1990) for transfer of technology and know-how on the design and MAIT of satellites. A qualitative methodology was adopted for Project 3. There are different qualitative methods used in the literature to analyse the transcribed interviews to identify themes and coding, which are fundamental steps in these methods. In this project, I have used the template method to analyse the transcribed interviews. The philosophical assumption when conducting qualitative template analysis follows a hypothetic-deductive approach (Gill and Johnson, 2010). The template analysis method is a common approach used to analyse interview transcripts and begins with *a priori* themes (Strauss and Corbin, 1990). Themes are statements that encapsulate recurring ideas in interview transcripts and there are likely themes that will emerge from interviews (Miles and Hubermann, 1994, Tesch, 1990).

1.4 Summary of research project findings

In the previous section, the research strategy and design were discussed, and the research objective, questions, investigation and research methods were summarised in Table 1-2. This section provides a summary of the descriptive findings and contribution for each of the three projects.

1.4.1 Project 1 overview: *Innovation Patterns of the UAE's Satellite MAIT Sector*

The US and Russia were the first pioneering countries to venture into space after World War II and during the Cold War (Calzada-Diaz et al., 2014, Burzykowska, 2009, Durrieu and Nelson, 2013, Harding, 2014). For the past 50 years, it appears only a few countries, China, Japan, South Korea and India, were able to catch up and close the technological gap with the pioneering countries. And over the previous few years only a very limited number of other countries have been able to innovate and catch up, but at a smaller scale, such as the UAE.

1.4.1.1 Research questions

In this research study, I explored innovation patterns adopted by the UAE over the past and present within the satellite sector and I attempted to answer two related research questions:

- How does the UAE approach the new space technological frontier?
- Is there any technological upgrading of the UAE manufacturing high technology satellite sector?

Each nation goes through a unique approach for development and this development signals the capability for process innovation (Porter, 1990). Exploring the innovation patterns across countries and approaches or processes taken to grow capabilities may enable us to understand why some developing countries were able to innovate and upscale their technological frontier ladder, while others could not.

I wanted to explore the innovation patterns within a theory and therefore I have drawn on the SIS and DTF theories to explore the innovation patterns of the UAE. The two research questions were extended to a much broader question as follows:

- To what extent can the innovation pattern phenomena in the UAE be explained by the SIS and DTF theories?

1.4.1.2 Summary of findings

The UAE has carried out an extensive range of space activities since 2000 with ambitions set significantly higher for the future. Figure 1-3 shows the main historical, current and near future space achievements for the UAE. The UAE has adopted an investment-based strategy where it estalibished universities and research centers (Appendix B, Figure B-1), acquired, diffused and imitated technologies developed elsewhere. Fixed and mobile communication satellite service companies were established, AlYahsat and Thuraya, accordingly. Both companies launched five communications satellites. In 2006, the Emirates Institute for Advanced Science and Technology (EIAST) was established, and in 2015 was encompassed by MBRSC. Two Earth observation (EO), remote sensing (RS) satellites were launched by MBRSC. The year 2014 was an important milestone, as it signifies the new era for the UAE where the UAESA was established and the Emirates Mars Mission (EMM) project was announced. The EMM aims to build a deep space spacecraft to orbit Mars by 2020. In 2015, the National Space Science and Technology Centre (NSSTC) was established as result of collaboration between the UAESA and the Information and Communication Technology (ICT) fund. The NSSTC is a dedicated centre for space-related R&D activities and a new centre to design and build small satellites.

The UAE showed a gradual convergence from an investment-based strategy focused on procuring satellite technologies towards an innovation-based strategy to design and build satellites and to develop R&D capabilities. The convergence from investment- to innovation-based strategy is not straightforward since forces could delay or prevent the convergence from

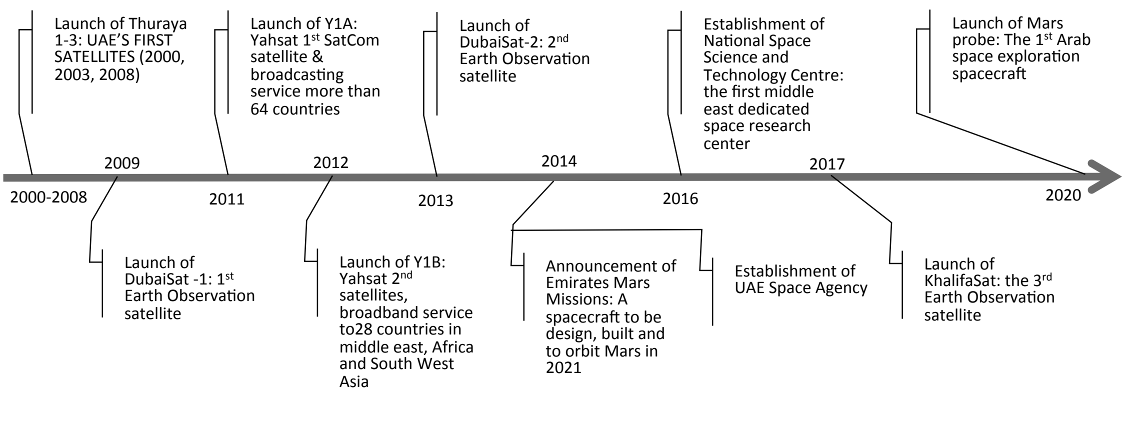

Figure 1-3: UAE's present and near future major space achievements

taking place (Acemoglu et al., 2006). The UAE government intervened and introduced policies and strategies as suggested by Aghion and Jaravel (2015) to undertake technological and institutional changes and interventions in policies. It introduced policies to augment R&D activities, and invest in education; otherwise necessary steps towards convergence would not happen, as argued by Acemoglu et al. (2006).

In 2014, the UAE introduced the National Innovation Strategy (NIS) and in 2015 introduced the National Science, Technology and Innovation Policy (NSTIP). The space sector was one pillar in both the strategy and policy documents. Earlier, it established Khalifa University and Masdar Institute, and in 2015, the government instructed the ICT to fund the establishment of the NSSTC in collaboration with the UAESA. The NSSTC is the first regional dedicated research centre on space-related ST&I topics. The UAE government encouraged local state-owned enterprises to collaborate with local universities. For example, Strata collaborated with Khalifa University on research related to aerospace structures to enhance characteristics and the production process of composite products. AlYahsat collaborated with Masdar Institute on a joint space engineering MSc programme where students design and build CubeSats as part of their research activities.

This research revealed that the UAE was able to accumulate capabilities in design and MAIT of satellites as result of partnering with international organisations to transfer know-how through several satellite TT programmes. As result, the UAE was able to progress and upscale its space technology ladder from only procuring, owning, operating and providing enabled services to building satellites locally for space exploration and non-exploration missions. Although it is expected that the level of R&D activities at universities will increase as result of this shift to innovation-based strategy (Malerba et al., 1997, Breschi et al., 2000), it will have other impacts as well, such as to motivate local talent to pursue careers in the space sector. However, currently, it was observed that the level of R&D activities related to space is still low in the UAE but the UAE was able to attract students to enrol into science, technology, engineering and mathematics (STEM) in general as a result of spending more on education than other developed countries (Appendix A, Figure A-1).

1.4.1.2.1 Innovation patterns

The study revealed that the innovation patterns adopted by the UAE over the previous years could be characterised by three themes – (A) a government investment-based strategy, (B) international partnerships, and (C) transfer of technology and know-how – cutting across four innovation development tracks or patterns: (1) manufacturing of conventional satellites, (2) space exploration spacecraft and (3) small satellites; and (4) R&D capabilities on the ST&I related to space.

International partnerships and transfer of technology and know-how was a strong feature adopted by the UAE to upscale its space technology ladder. MBRSC partnered with Satrec Initiative (SI) to build three satellites (Khalifa, 2015, Pirondini and Al Marri, 2014, Al Rais et al., 2009), initially to build DubaiSat-1 at SI's facility, and then built DubaiSat-2 partially at MBRSC with outside assistance from SI, and the third, KhalifaSat is currently in its final build stage at MBRSC based on mutual international collaboration (see Table 1-3).

Despite the progress made by the UAE over the past and present years, one of the shortfalls in the development efforts was the lack of a national direction guiding the stakeholders to a common vision and objectives. It was observed that local universities and research centres were not engaged effectively in the knowledge transfer to support the development tracks adopted by the UAE, and as a result there was lack in science and technology R&D activities related to space. Moreover, the UAE did not have a technology roadmap guiding the space sector on which technologies need to be invested in and focused on. Also, there is underutilisation of scattered resources at local universities and research centres, which can be attributed to the lack of national direction or entity guiding the development of the sector.

Therefore, in Project 1, two research projects were proposed and executed for the DBA thesis:

- Project 2: To conduct research on the challenges and barriers faced during executing TT programmes.
- Project 3: To develop an ST&I roadmap, since without a roadmap the UAE will face challenges to sustain growth in the space sector, especially on satellite MAIT activities.

Table 1-3: Satellite science projects (cases) – Production years

Cases / Projects	**Type**	**Scientific Objective**	**Years (2006-2020)**														
			6	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
DubaiSat-1	LEO	Earth observation															
DubaiSat-2	LEO																
KhalifaSat	LEO																
Al Amal	Deep Space	Mars Observation															

1.4.1.3 Theoretical findings

The innovation pattern for the UAE was explored within the context of both SIS and DTF theories. DTF could not explain the case of the UAE since it assumes only countries at proximity to the frontier could innovate and those distances away from the frontier could imitate. On the other hand, SIS could explain to some extent the possibility of a country that is not at the frontier in a specific sector adopting innovation strategy, as in the case of UAE, and gradually enhancing its frontier level. However, this is conditional on features related to knowledge base: the level of appropriability, opportunities and cumulativeness.

The government support through funding new projects, as in the case of UAE, is pivotal since it will ease innovation effort by relevant organisations (Malerba and Orsenigo, 1996). This provides an incentive for firms and research centres to deploy their resources and increase their R&D expenditures. This would enable relevant organisations to produce new, innovative products and opportunities. Thus, the level of opportunities and cumulativeness will be increased (Malerba et al., 1997, Breschi et al., 2000). However, the UAE needs to counteract the appropriability effects by finding an alternative source of funds to sustain the future growth of its high technology satellite sector, otherwise it will be very costly to maintain the innovation and development of the sector. The risk is that the economy will not benefit from these initial investments and will fall into non-conversion trap, as discussed by Acemoglu et al. (2006).

1.4.2 Project 2 overview: *Towards UAE's Space Technology Foresight: Scanning and Prioritising Opportunities*

Saritas and Aylen (2010) introduced an overall foresight methodology and suggested that roadmapping could be integrated part of an overall foresight methodology for connecting future with the present. Technology roadmapping is a common feature adopted by pioneering and established space agencies such as NASA, ESA and JAXA (Japan Aerospace Exploration Agency) (Al Hashmi, 2016). It is used to identify long-term technological requirements needed to support its long-term space exploration mission scenarios.

For pioneering and established space agencies such as NASA and ESA (Laurini and Gerstenmaier, 2014, Hufenbach et al., 2014), technology roadmaps tend to be diverse and include complex technologies that are developed by a few countries having prerequisite capabilities or knowledge. On the other hand, emerging space countries such as the UAE have a challenge in defining a roadmap for space ST&I that prioritises which R&D activities to invest in at universities and research centres. Here, the scale of space exploration is smaller than pioneering and established spacefaring nations and availability prerequisite capabilities are at a low level or do not exist in some technological areas. The UAE's space programme is still new since it has only one approved deep space exploration mission. Although there is an increase in R&D activities in the UAE, and the EMM opened up new opportunities to conduct R&D in area, the scope and intensity are still low on topics related to space which is discussed in Project 1 (Al Hashmi, 2016).

In Project 1, I highlighted that without an ST&I roadmap the UAE would face challenges to sustain development of indigenous capabilities and growth in satellite MAIT activities. This challenge should not hinder or delay the UAE from developing an ST&I roadmap until its space programme is defined. It therefore, the UAE needs to adopt a methodology to develop an ST&I roadmap that differs from that adopted by pioneering space agencies given the limitations addressed above.

1.4.2.1 Research questions

The overarching research question for Project 2 is:

- How could the UAE develop a technology roadmap given that it has only one mission and limited R&D activities and capabilities related to space?

In this research study, I attempted to answer the following questions:

- Which are the most relevant space agencies across the globe?
- What are their current and future ST&I topics/areas/priorities?
- Which specific critical technologies are priorities to advance ST&I areas that are needed for future space exploration missions?
- What are the existing R&D activities in space-related ST&I areas in the UAE?
- What are the ST&I topics and technology development opportunities that the UAESA should prioritise in the near and longer future?

1.4.2.2 Summary of findings

The analysis was done in the context of a technology roadmap and foresight techniques and methodologies that are commonly used to identify future complex and critical technologies and to set priorities for science and technology, as argued by Gavigan and Scapolo (1999), Keenan et al. (2003), Popper (2008), and Saritas and Aylen (2010).

1.4.2.2.1 Global technological trends

In this research work, trends were used as a way to get insight and views regarding future development of science and technology (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010). The global space technological trends were scanned based on several secondary sources: space agencies' technology roadmaps and strategic documents; International Space Exploration Coordination Group (ISECG) publications; and the database produced and maintained by the Committee on Earth Observation Satellites (CEOS).

In this study, UCINET, a network analysis (NA) application (Borgatti et al., 2002), was used to understand and analyse which technologies are central, common or limited to agencies. The analysis revealed that NASA is the most central agency followed by ESA (NASA, ESA, CSA and UKSA are actors in the network) since both agencies are connected to a dense or large number of technologies (See Figure 1-4). This indicates that NASA and ESA have very diverse and broad technologies within their technology roadmaps. This is expected since the space programmes of NASA and ESA are bigger in scale than CSA and UKSA. It was observed that the number of technologies ubiquitous i.e. common and technologies that are limited to NASA is more than ESA, CSA and UKSA. UKSA and CSA tend to be niche in their approaches and limited in scope to fewer ubiquitous technologies. For example, air breathing propulsion is limited to both CSA and UKSA and radio frequency communications is limited to UKSA in reference to their technology roadmaps.

The analysis of the CEOS database gave an indication of the technological trend of development sensors for non-exploration satellites. The analysis indicates that optimal imagers, cross-nadir scanning sounders, and imaging radar sensors were the top technological trends.

1.4.2.2.2 The global space ST&I tree

It was revealed during the initial research work of Project 2 that a data matrix that lists and categorises various technology topics is required for the roadmapping exercise. The data matrix is henceforth called the global space ST&I tree. Based on the analysis of the various secondary data sources, a global space ST&I tree was constructed and tiered into three levels. The first level consists of 18 ST&I areas, the second level consists of 82 components, and the third has 422 sub-components.

1.4.2.2.3 Capability of local universities and research centres

In Project 2, a capability assessment survey was conducted, and the analysis revealed the status of existing capabilities of local universities and research centres in the UAE. The capability assessment measured the intensity of research activities relevant to each of the 18 ST&I areas and 82 components. Based on the results of capability criteria-based assessments, the ST&I areas were grouped into three categories to form a capability heat map matrix.

The first category of the capability matrix consists of areas with high relevancy to existing capabilities that require less effort and investment compared to categories 2 and 3. Category 2 requires some effort to increase the existing level of R&D activities or requires moderate investment since it has some relevancy to existing capabilities. Category 3 requires significant effort since local universities and research centres do not conduct R&D activities in these areas, which indicates no relevancy to existing capabilities.

1.4.2.2.4 The ST&I roadmap

The grouping of ST&I areas based on assessment of existing capabilities in the capability matrix does not provide an indication of which ST&I area the UAE should invest in over the long term. It does not indicate if the UAE should or should not invest in ST&I areas related to the third group since there are no existing R&D activities, such as for launch propulsion systems (ST&I Area 1) (See Table 1-4).

In this research work, the ultimate aim is to develop an ST&I roadmap to prioritise which ST&I areas the UAE needs to invest in, to close existing capability performance gaps, to achieve the desired outcomes and goals, and to shift the national technological level closer to the frontier. The desired outcome needs to be relevant to strategic drivers such as national strategic interest and a desire to accumulate a set of indigenous technological capabilities.

Several meetings were arranged with senior management including UAESA board members to get insight on the national direction to support the process of identifying national strategic interests and required indigenous technological capabilities that the UAE wants to accumulate. It was revealed that the UAE needs to capitalise on opportunities and follow the roadmaps related to cutting edge research. However, the UAE may desire to accumulate R&D capabilities for national interests at local universities and research centres on technological areas, which are not cutting edge research. Therefore, the roadmaps in some ways should not follow those of higher-tier agencies.

The ST&I areas were revisited and categorised into three prioritised groups (See Table 1-4) based on a set of evaluation prioritisation criteria. The ST&I groups will guide and prioritise R&D activities and subsequent investment across the various ST&I areas. The first group has strong relevancy to national strategic interests and short-term objectives to build and accumulate indigenous capabilities, the second group has relevancy to long-term objectives such as extending human presence in space, while the third group has less immediate national requirements.

We found that although the UAE currently lacks capabilities in some ST&I areas such as launch propulsion (ST&I Area 1) and in-space propulsion technologies (ST&I Area 2), the UAE may desire to develop capabilities in these ST&I areas as result of prioritisation based on strategic national direction. As result of this prioritisation significant effort and investment will be required for ST&I Areas 1 and 2 since both areas are identified as Category 3 in the capability matrix, i.e. there are no existing R&D activities in these areas. Similarly, the effort and investment to some extent will be less on science instruments, observatories and sensor systems (ST&I Area 8) since these are existing R&D capabilities, as the work is currently being done on the EMM where an infrared and ultraviolet spectrometer is being developed. However, there are ST&I areas that were identified with less priority such as ground station systems and networks (ST&I Area 18) and thermal management system (ST&I Area 14), despite the fact that the UAE has some relevant existing capabilities. Therefore, these ST&I areas will get less funding over the short term unless the priorities are changed in the national strategic direction.

1.4.2.2.5 The proposed initial integrated foresight roadmapping model framework

Based on the research method adopted in this research to scan, identify and prioritise ST&I areas, a model framework was proposed that integrates roadmapping into the foresight exercise and steps as shown in Figure 1-5. The model framework has six steps. The first four steps are covered in detail in this research: 1. Clarify the vision, 2. Scan and identify ST&I trends, 3. Assess existing national capabilities, and 4. Prioritise ST&I areas. This research covers Step 5 to some extent. Step 6 was included as recommendations since it is not covered in detail and subject for further research. The proposed process starts with an activity to articulate national direction and identify new emerging strategic directions (step 1), and then with improved technology foresight and technology scanning activities (step 2) over what was adopted initially in the methodology in Project 2. The global ST&I tree analysis and formulation tree needs to be maintained on a recurring basis by adding new and emerging ST&I areas, components and subcomponents since technology is evolving on continuous basis.

Understanding and acknowledging that country's directions drive prioritisation of the ST&I areas the country wants to focus on, pursue and invest in cutting edge technologies, the UAE could also focus on less complex technological products that the country wants to build and accumulate indigenous capabilities over the long term. A periodic capability assessment (step 3) needs to be conducted to monitor the development of ST&I capabilities at local institutions after executing the ST&I implementations plan (step 6). The prioritisation of ST&I areas (step 4) needs to address the existing capability performance gap which could be related to less complex technological products for the above purpose and as well to target complex or cutting edge technologies. The ST&I roadmap (step 5) cannot be called a roadmap unless it is structured in a format to ease the communication with stakeholders to align them with common strategic objectives, programmes and initiatives included within a budgeted implementation plan (step 6) over a short and long term horizon.

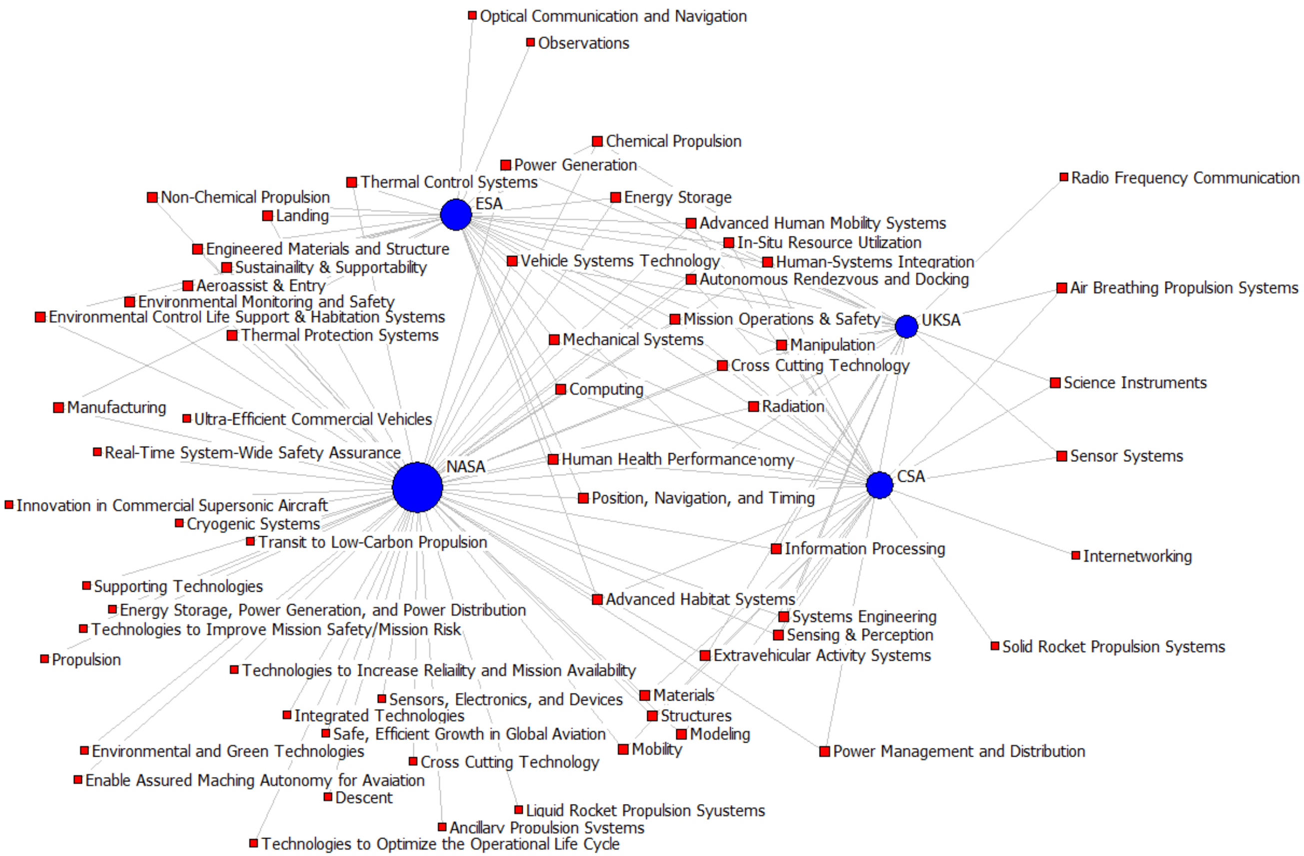

Figure 1-4: Space agencies and ST&I network ties. Circular nodes indicate space agencies; square nodes indicate ST&I Level 2 components – an illustrative example.

Table 1-4: UAE's ST&I prioritised groups

Group 1	Group 2	Group 3
ST&I areas relevant to national indigenous capabilities build up and short-term requirements	*ST&I areas relevant to extending humans in space and long-term requirements*	*ST&I areas with less immediate requirements*
1 Launch Propulsion Systems 2 In-Space Propulsion Technologies 3 Space Power and Energy Storage 4 Robotics and Autonomous Systems 5 Communications, Navigation, and Debris Tracking 8 Science Instruments, Observatories and Sensor Systems Nanotechnology 11 Modelling, Simulation, IT and Processing 12 Materials, Structures, Mechanical Systems and Manufacturing 15 Software and Applications 17 Satellite Technologies and Techniques	6 Human Health, Life Support, and Habitation Systems 7 Human Exploration Destination Systems 9 Space Entry, Descent and Landing 16 Life and Physical Sciences	13 Ground and Launch Systems Processing 14 Thermal Management Systems 18 Ground Station Systems and Networks

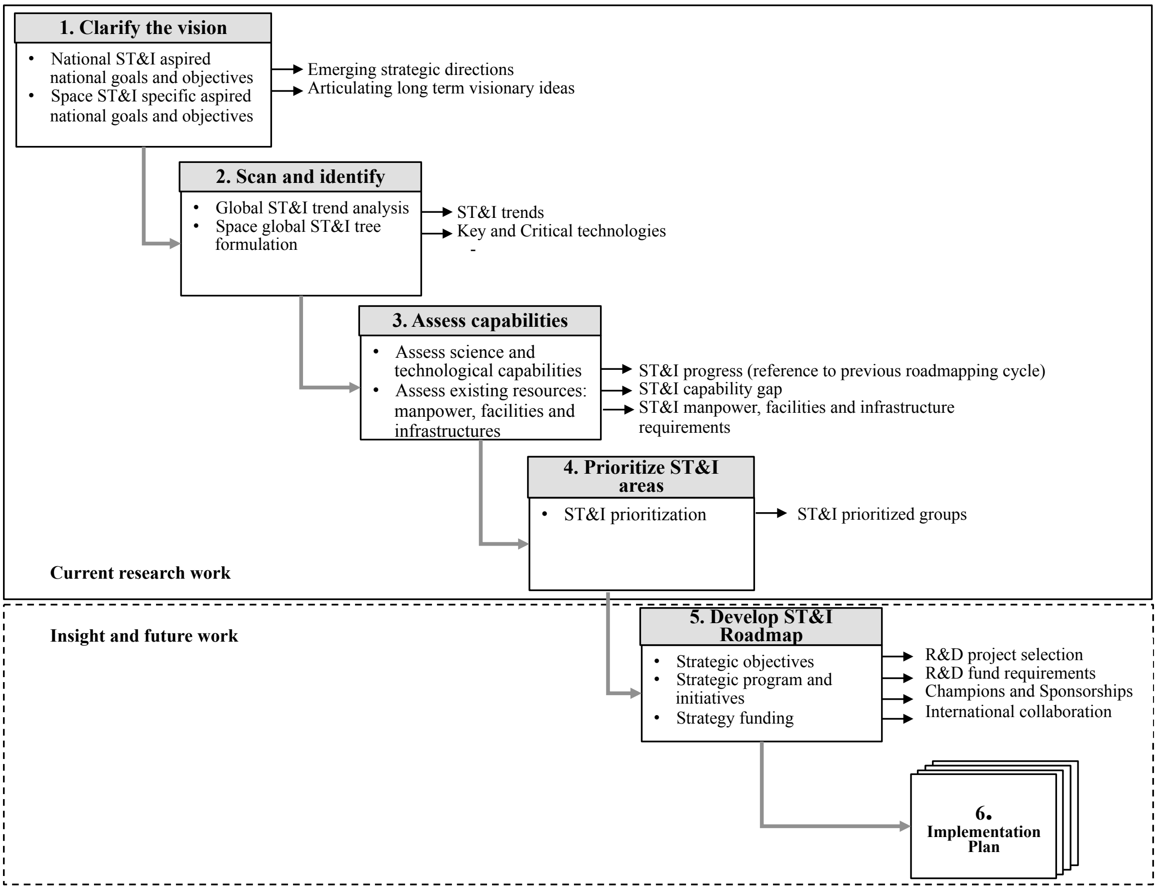

Figure 1-5: The proposed integrated foresight and roadmapping model framework

1.4.3 Project 3 overview: *Technology transfer challenges and barriers: UAE's Satellite MAIT*

Project 3 addresses TT and is linked to both Projects 1 and 2. The research work in Project 1 reveals that TT was a common approach adapted by the UAE to scale up its space technology ladder. Indeed, the project revealed that partnership and transfer of technology and know-how was one of three themes adopted by the UAE to develop its high technology manufacturing satellite sector. Project 3 is linked to Project 2 since R&D is important in innovation systems and in sustaining the development of industry sectors. R&D enhances TT in addition to its conventional role of stimulating innovation for economic growth (Griffith et al., 2004).

Project 3 explored empirically the challenges and barriers faced during TT programmes in design and MAIT of satellites within context of the UAE, an emerging space nation. It establishes a baseline study towards building a conceptual framework model that can be used for future satellite projects considering various success factors to ensure an effective transfer of technology and know-how, accumulate and build national indigenous capabilities across institutions in the UAE inclusive of universities, research centres, satellite operators and relevant manufacturing firms.

1.4.3.1 Research questions

The research objective of this study was articulated around the following:

- To investigate and explore the challenges and barriers faced during transfer of technology and know-how in the design and MAIT of satellites, which impact the effectiveness of the previous TT programme in building and accumulation of national indigenous capabilities.
- To draw main constructs towards building a conceptual TT model and identify success factors to maximise the benefit of any future TT programme in building national indigenous capabilities.

Case study analysis was chosen as a research approach since it is appropriate in describing and exploring new phenomena, and constructing or enhancing existing theories (Eisenhardt, 1989). Four case studies were considered for Project 3, which are basically the four satellite projects listed in Table 1-3.

By analysing the literature, exploring and investigating these TT programme cases, this research study attempts to answer the following research questions:

1. What are the resource challenges and barriers facing transfer of technology and know-how on satellite design and MAIT?
2. What does it require from organisations to operationalise (routinise) TT to gain maximum benefit from TT projects?
3. What needs to be changed in organisational culture to maximise benefit from TT projects to sustain technological capability development?

1.4.3.2 Research findings

Technology will continue to advance, and there will always be a need to transfer knowledge between different international and local partners. This implies that transfer of technology and know-how is not a singular event (Ounjian and Carne (1987)). Therefore, this research attempts to understand the challenges, barriers and success factors that are necessary for effective transfer of technology and know-how when executing future programmes.

1.4.3.3 Theoretical findings

A comprehensive model framework is proposed for the management of TT projects to build and sustain development of indigenous capabilities over time, leveraging existing and future transfer programmes (See Figure 1-6). The model was built based on initial synthesis of the literature related to the TT models (Nonaka and Takeuchi, 1995, Gilbert and Cordey-Hayes, 1996, Hill, 1989, Team, 1987, Baskaran, 2001), processes, and management and insight from the empirical evidence. The empirical evidence was gathered from the four case studies through in-depth interviews conducted with management and technical staff engaged in TT programmes related to satellite development programmes in the UAE.

The proposed TT framework model consists of three perspectives. The *stakeholder and management expectation perspective* consists of attributes grouped under productivity and growth, which are grouped into component attributes. These attributes reflect the value propositions to government as a funding body anticipating that local institutions will accumulate indigenous capabilities over time, the high capital infrastructures will be utilised, innovation will be triggered, and the national technological level will shift closer to the frontier. A structured approach needs to be implemented by setting up TT programmes properly and selecting the appropriate partner.

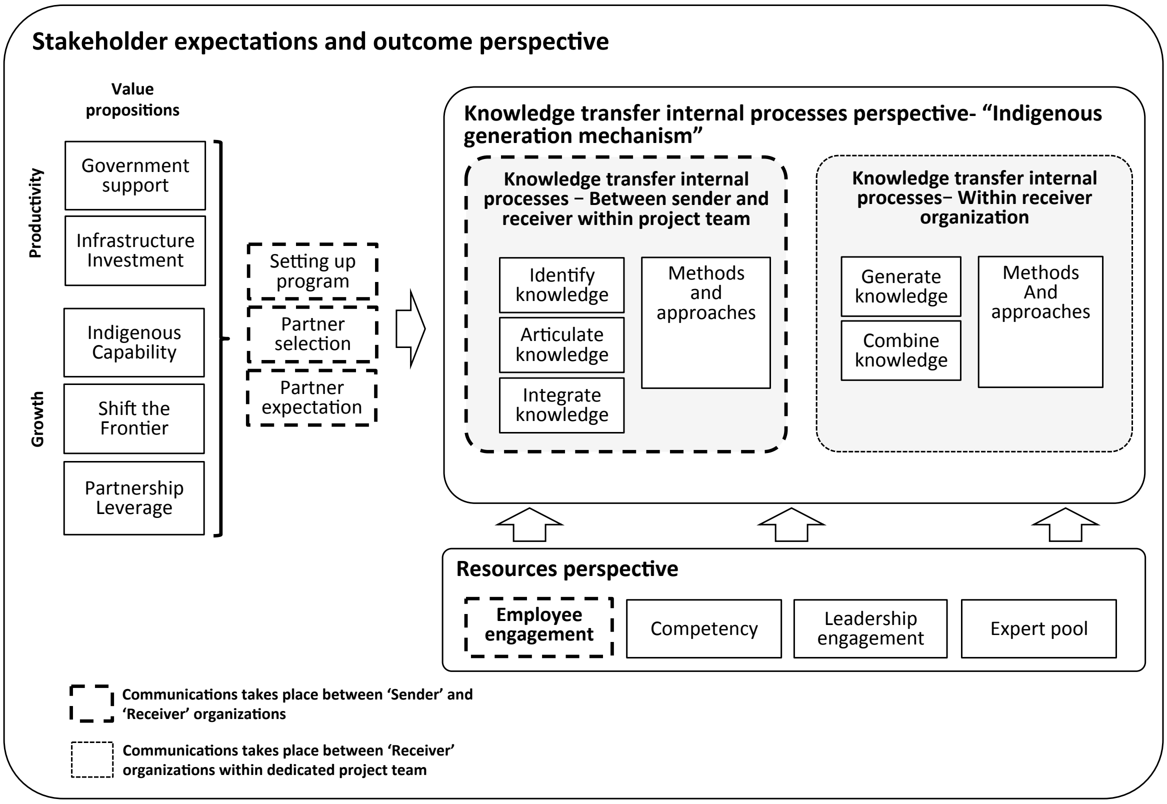

Figure 1-6: The proposed technology transfer model

The *stakeholder expectation and outcome perspective* is the higher order or overarching theme, which is comprised of two themes: the knowledge transfer internal process, and resource perspectives. The factors related to stakeholders' expectations are mainly outcome drivers. The factors related to the routine process of knowledge transfer taking place within a project and within an organisation are defined in this paper as 'indigenous generation mechanism'. The factors related to how organisations deploy and engage their resources, and how they develop competency skills are driving factors that enable and ensure the effectiveness of indigenous creation mechanisms.

In line with Metcalfe (1995), the model has two main actors, the 'sender' and the 'receiver' of the 'technology' which is defined as a combination of artefacts, knowledge and skills. In this article, technology refers to artefacts and additionally it refers to skills, the knowledge of design, assembly and testing that are embedded into production of technological products (Hausmann et al., 2012), which confirm the complexity of technology being transferred. The dotted boxes (Figure 1-6) in the model show the communications areas that take place between sender and receiver organisations and the rest takes place within the receiver organisation. The following sections discuss further details of the architecture of the model.

The core of the model is the internal process for knowledge transfer. We call this process an *indigenous creation mechanism*. There are two types of knowledge generation, personal and organisational knowledge. The model considers that transfer of knowledge takes places in two stages. The first stage takes place between individuals from sender and receiver organisations during the execution of the project where knowledge is acquired and articulated for a particular project. The second stage takes place when articulated knowledge is integrated within receiver organisations. In this stage, new 'corporate' knowledge is generated once it is fully integrated and combined with existing knowledge. The new generated 'corporate' knowledge becomes routine within receiver organisations. If the goal is to reach an independent level where technological products could be designed and built locally, then this becomes a continuous process where countries or organisations go through multiple TT projects.

In the proposed model, the resource perspective refers to the factors that enable and influence the success of knowledge transfer and know-how and drive the development of indigenous capabilities over time: *Employee and leadership engagement, competency and export pool.*

The model acts as a guideline to identify the factors needed to ensure TT programmes are set up appropriately, to identify desired knowledge to be acquired prior to the start of any transfer programmes, and to mutually agree on approaches and methods on how knowledge will be transferred from the sender to the receiver of technology. It also will discuss methods and approaches on how knowledge will be articulated, and then integrated within organisations. This is necessary to ensure new knowledge is generated leading to accumulation of indigenous capabilities to strengthen and shift the national technological level to within proximity to the frontier.

1.5 Significance, originality and value of the research

The overall research study provided several novel contributions to both academia and practitioners. The following are highlights:

- The overall research work filled in several gaps in the literature on topics related to the satellite sector in geographical areas other than developed countries with pioneering and established space agencies.
- This research provided an overview on the development of the UAE's satellite sector over the last 15 years. It broadens the knowledge base of the UAE as an emerging space

nation and on its effort to develop and upscale its indigenous capabilities on satellite and spacecraft MAIT.

- The research study explored, analysed and identified the main innovation patterns of the UAE within the space satellite sector. It revealed the main innovation themes and development tracks, a new research topic that was not adequately covered in the literature.
- The research could be extended include other emerging space countries such as Mexico, Malaysia, Algeria and Nigeria to conduct comparative analysis to enhance our understanding of innovation patterns and development paths adopted by these countries.
- The research study developed a global space technology tree, and identified possible emerging technologies for both academia and practitioners.
- The research study developed a space technology roadmap for the UAE. It is novel since it is the first roadmap developed for the UAE. It is legacy work that will always be referred to since it provides a baseline against which UAESA can identify, define, execute and measure the success of its own programme and its applicability to today's and future space needs.
- The study casts a baseline towards building an integrated ST&I foresight and roadmapping methodology framework to be used periodically to develop the R&D capabilities in a structured and sound way based on prioritised ST&I topics. It extends theories, methods and techniques, work which was not conducted before within the context of the UAE.
- The research proposes a conceptual model framework on TT programmes, the first model developed for the UAE (to my knowledge) that articulates challenges and barriers faced by the UAE in its previous and current TT programmes.
- The research work concludes with an innovation management system to develop the UAE's future high technology space sector, novel work that has an immediate impact on management practices and application within the UAE space agency – a topic that was never researched before.

While writing this thesis, several emerging national strategic directions were addressed by the UAE's government leaders. In 2017 the UAE announced a visionary programme called Mars 2117 to build a habitat colony on Mars by 2117. After announcing the Mars 2117 programme, the Mars Science City and Astronaut Programme was launched in 2017. The type of R&D that will be conducted on the Mars City programme was not defined.

I found this research was still novel since it is a baseline that can be utilised to define and prioritise ST&I areas and R&D activities to support Mars 2117 and the Mars City programme. Chapter 5 illustrates, within the context of the proposed innovation management system, how this novel research can support these strategic directions and the sustainable development of indigenous ST&I capabilities over the short and long term.

CHAPTER 2 Innovation Patterns of the UAE's Satellite MAIT Sector

Innovation Patterns of the UAE's Satellite MAIT Sector[1]

Abstract

The study explored the UAE's innovation development patterns of satellite manufacturing, assembly, integration and testing (MAIT) within the theoretical assumptions of the sectoral innovation system (SIS) and distance-to-frontier (DTF). This article provides an overview of UAE's satellite MAIT development over the past 15 years and reveals that the UAE adopted three innovation thematic patterns – investment-based strategy, partnerships and transfer of know-how – cutting across four innovation development patterns: manufacturing of (a) conventional satellites, (b) space exploration spacecraft; (c) small satellites; and (d) development of R&D capabilities on the science, technology and innovation related to space. The UAE shows signs of conversion towards innovation in satellite MAIT after a development phase of adopting, diffusing and imitating technologies established around an investment-based strategy supported mainly by the government. The results of the study find that while the innovation development patterns of the UAE comply with the SIS, they diverge from the DTF theoretical assumptions.

Keywords: *Innovation system, sectoral innovation system; distance to frontier; R&D; innovation patterns; satellite manufacturing, space, UAE.*

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[1] An earlier version of this paper was presented at the Annual International Conference in Innovation and Entrepreneurship (IE 2016), 12-13 December 2016, Singapore.

2.1 Introduction

The US and Russia were the first countries to venture into space after World War II and during the Cold War (Calzada-Diaz et al., 2014, Burzykowska, 2009, Durrieu and Nelson, 2013, Harding, 2014). While a few countries are closing the technological gap with these countries to become established players, such as South Korea, Brazil and India, only very limited countries were able to upscale their space technology ladder and become niche contributors, such as the United Arab Emirates (UAE), Malaysia and Nigeria.

Since the 1950s the US and Russia maintained their technological frontier in space and related industries, maintained their capabilities in building Low Earth Orbit (LEO) (Jussawalla, 1980) and Geostationary Earth Orbit (GEO) satellites, secured continuous access to space by developing launch vehicles and sites, and sent crewed[2] and uncrewed spacecrafts to explore space. The established players such as Japan and South Korea were able to innovate and build similar capabilities but the scale of their space programme is less than the space power (Amer et al., 2013) of the pioneering countries. On the other hand, the niche contributor focused on a few activities; mainly on satellite value-added services rather than manufacturing satellites. The UAE is a niche contributor country. Over the last 15 years, the UAE has shown signs of conversion towards innovation in satellite manufacturing, assembly, integration and testing (MAIT) after a development phase of adopting, diffusing and imitating technologies established around an investment-based strategy. The UAE achieved several milestones beginning at the lower level of the space technology frontier ladder by initially procuring satellites and was able to build satellites locally and is currently accumulating capabilities to build space exploration satellites.

According to the literature related to the sectoral innovation system (SIS), firms within the same sector are likely to adopt similar innovation patterns. The SIS suggests firms will use similar knowledge bases or types to produce similar goods (Malerba and Orsenigo, 1996, Malerba et al., 1997). The innovation patterns of within-sector similarities or differences according to SIS depends crucially on the specific features of knowledge bases, which relate to the level of opportunity, appropriability and cumulativeness (Breschi et al., 2000). Conversely, the

[2] Manned spacecraft are called ‘crewed spacecraft’ and unmanned spacecraft are called ‘uncrewed spacecraft’.

distance-to-frontier (DTF) literature suggests the sectoral innovation patterns will likely differ across countries according to the level the national technological development has reached compared to world technology frontiers. The DTF literature considers the proximity to the world technology frontier as the main factor which influences whether countries adopt an innovation or imitating strategy (Danquah and Ouattara, 2014).

Although the scope of this research study was limited to satellite manufacturing, the analysis revealed the DTF could not explain technological innovation development patterns in a geographical context with an economy not close to the world technology frontier as in the case of UAE. On the other hand, SIS could explain the possibility of countries that are not at the world technology frontier adopting an innovation strategy rather than using an imitation- or investment-based strategy and could converge towards the frontier over time, as in the case of UAE. However, the conversion to innovation-based strategy is not straightforward for the UAE. It depends on counteracting the appropriability effect, which is caused by relying on government support, as argued by Acemoglu et al. (2006), who say that the economy will fall into the conversion trap and will not benefit from investment on innovation.

The structure of the paper is as follows. Section two briefly reviews related literature on SIS and DTF theories. Section three addresses the research objectives and methods. Section four discusses the space technology frontier ladder and provides an overview of the development of the UAE's satellite MAIT sector. Sections five and six address the research results and discuss the innovation patterns of the UAE's satellite MAIT within the context of the SIS and DTF theoretical assumptions. Finally, the article concludes by highlighting the main findings of the study and identifying further specific research topics to be explored on the innovation approach adopted by the UAE, which is successful in comparison with other countries.

2.2 Related literature

In the context of space technology development, innovation is defined "as the process through which ideas for new, cutting-edge technologies are conceived of, developed and integrated into advanced space missions" (Szajnfarber, 2014). The technological development and changes that firms and nations go through are at heart of innovation systems and technological literature (Aghion and Howitt, 1992, Barro and Xavier, 1997, Aghion and Jaravel, 2015, Antonelli and Fassio, 2015, Malerba et al., 1997, Malerba and Montobbio, 2003).

The main feature of innovation systems is to grow capabilities among actors to generate, diffuse and utilise technologies that have economic value (Carlsson et al., 2002) and which require the development of economic competencies. Carlsson and Eliasson (1994) defined economic competency as the ability to identify and exploit business. For a firm to generate economic competency, it needs to select the type of capabilities it needs to develop, it needs to have organisation and institutions, and technical and functional abilities. 'Absorptive capacity' is an important part of these capabilities; it is the ability of a firm to assimilate knowledge from its environment (Madu, 1990), which defines receiver competency to acquire a technology.

Each nation goes through a unique approach for development which signals the capability for process innovation (Porter, 1990). Exploring the similarity of innovation patterns across countries and approaches taken to grow capabilities may enable us to understand why developed and developing countries and some latecomers were able to innovate and upscale their technological frontier ladder, such as the UAE, while other latecomers could not make progress. The existence of similarities of innovation activities within specific sectors is developed in the SIS literature. It also has its roots in the technological developments and capabilities such as the work of Gerschenkron (1962) and is addressed in this study as DTF.

The innovation theory assumes innovation is a systemic phenomenon and not solely occurring in individual firms, as empirically proved by Freeman (1995). Carlsson et al. (2002) defined a system as "a set of interrelated components working toward a common objective". The components can be a variety of types and actors, however research scholars considered university, industry and government as the fundamental components of an innovation system and referred to it as "The Triple Helix" (Etzkowitz and Leydesdorff, 2000, OECD, 1997). The relationships between these components, properties and behaviours and the flow of knowledge are at the core of the innovation system (Ghiasi and Larivière, 2015). Research scholars recognised the complex functions and interactions between various actors and institutions (Edquist and Hommen, 1999, Carlsson and Eliasson, 1994, OECD, 1997, Carlsson et al., 2002).

The SIS focuses on the creation and development of knowledge within sectors. It provides a platform or framework that is broad, open and flexible (Hu and Hung, 2014). The framework helps to explain the innovation activities by understanding the key characteristics of actors and relationships between them, and defines how knowledge is created, diffused and adopted (Malerba, 2002, Malerba, 2005, Castellacci, 2009). According to the literature on SIS and technological regimes (Malerba, 2005), the pattern of innovation and technological development of within-sector similarity depends on the combination of knowledge features used, such as the level of opportunities, appropriability and cumulativeness conditions (Malerba and Orsenigo, 1996, Malerba et al., 1997, Breschi et al., 2000, Adams et al., 2011, Madu, 1990). Castellacci (2009) further explains that "sectoral differences in productivity are centered on five factors, namely appropriability conditions, levels of technological opportunity, levels of education and skill, the degree of openness to foreign competition, and the size of the market". Moreover, Malerba suggests that the major variables in SIS are knowledge regimes, market structures and the degree of embodied technological changes in the sectors (Malerba, 2002, Malerba, 2005). Despite the complex functions and interactions between various actors and institutions recognised by researchers (Malerba, 2002, Malerba, 2005, Castellacci, 2009), the SIS literature suggests that the combination of these specific knowledge-based features and opportunity conditions will result in similar innovation behaviours and patterns within the same sector that are likely to prevail across countries (Hu and Hung, 2014, Fassio, 2015, Malerba and Orsenigo, 2015, Breschi et al., 2000).

Contrary to SIS, the DTF literature considers the distance to the world technology frontier as the main factor which influences the adoption of imitation or innovation strategies within firms and across countries (Danquah and Ouattara, 2014). The closer an economy is to the world technology frontier, the higher the relative importance of innovation relative to imitation as a source of productivity growth. Gerschenkron (1962) argued in *Economic Backwardness in Historical Perspective* that undertaking large investments and adopting frontier technologies may lead relatively backward economies to rapidly catch up to more advanced economies. However, the tasks performed and the extent of understanding of new technological developments is critically important for convergence to take place from imitation to innovation (Nelson and Nelson, 2002).

Several scholars, including Collins (2015), empirically investigated how imitation can be a catalyst for innovation. Researchers also investigated the technological convergence of some countries while others stayed below the level of the world technology frontier. The strategic aim of developing countries is to create new business opportunities via developments or acquisition of technological capabilities (Hu, 2014), and adopting this approach increases the absorptive capacity that will enable access to a wide range of technological options (Madu, 1990). Collins (2015) discussed the importance of investing in technology developed elsewhere and diffusing it where developing countries can learn to innovate and produce their own products. The embedded knowledge in technological products is absorbed within universities, laboratories and active firms in a specific sector (Hausmann et al., 2012). Moreover, Madu (1990) argued that the ability of firms to assimilate knowledge from the environment increases the 'absorptive capacity' of firms and accordingly their ability to innovate. However, acquisition of technology is not a transaction that occurs once but rather is a collaborative process, taking time and effort by the receiver to attain knowledge and competency, which is critically important for success (Carlsson et al., 2002).

Convergence to innovation strategy is not straightforward since there are counteracting forces affecting the adoption, diffusion and imitation of technologies developed elsewhere. At an early stage of convergence towards the frontier, the appropriability effect plays a pivotal role where government intervention with an investment-based strategy is required otherwise convergence would fail. In their analysis, Acemoglu et al. (2006) revealed that although an investment-based strategy is critically important during convergence, countries need to switch to an innovation-based strategy before reaching the frontier and have another source of cash, otherwise growth will be reduced since the economy is not making the best use of innovation opportunities, and costs to maintain an investment-based strategy will be high. The level of development of the DTF may determine if an economy does not switch from an investment-based strategy. The economy will be stuck in a non-convergence trap and convergence to the frontier will stop (Acemoglu et al., 2006, Aghion et al., 2015, Barro and Xavier, 1997, Aghion and Howitt, 1992, Zeira, 1998). Developing countries need technological and institutional changes and interventions in policies to support the conversion (Aghion and Jaravel, 2015).

The intervention in policies could be in education, policies and R&D, but laggards may never be able to converge to the technology frontier due to objections to costly policies, leading to a roughly bimodal distribution in the technological capabilities of countries (Aghion and Jaravel, 2015). Countries that have less efficient R&D workers will continue to imitate products from more developed countries instead of inventing new products (Collins, 2015). The more educated the workforce, the more benefit could be gained from technology diffusion which would facilitate the switch from imitating to innovating (Collins, 2015). Skilled workers are required for a country to catch up with the technological frontier (Acemoglu et al., 2006, Aghion and Jaravel, 2015, Amable et al., 2008).

The innovation process depends crucially on the amount of resources deployed to invest in R&D (Fassio, 2015). In addition to the conventional role of stimulating innovation to stimulate economic growth, R&D enhances technology transfer (TT) (Griffith et al., 2004). In their study, Griffith et al. (2004) provided evidence from analysis of panel data of 12 OECD countries in which R&D affects innovation rate. R&D is considered a specific feature of innovation required for firms (Fassio, 2015) to "push technological frontiers forward and facilitate future innovation" (Aghion and Jaravel, 2015). According to the SIS literature, Malerba et al. (1997), (Radosevic, 1998) argued that to incentivise firms to invest in R&D, firms needs to have high levels of opportunities, appropriability and cumulativeness conditions.

In space programmes, products installed in spacecrafts are selected based on product heritage[3] (Venturini and Verbano, 2014, Wood and Weigel, 2012a, Belward and Skøien, 2015). The performance of these products is enhanced continuously to meet new space mission capabilities requirements. These innovative products are developed with cutting-edge technologies and are integrated into advanced space missions (Szajnfarber, 2014). This induces firms to invest in R&D, which increases the level of opportunities, according to SIS and technological regimes literature (Radosevic, 1998, Breschi et al., 2000, Malerba and Orsenigo, 1996). The investment in R&D affects the ability of firms to innovate and develop technological frontier products (Cefis and Orsenigo, 2001) and accordingly win future contracts. Madu (1990) argued that R&D plays an important role in learning by increasing the absorptive capacity of firms. Aghion and Jaravel (2015) argued that only through its own R&D can a firm exploit the knowledge created by its competitors, which increases the cumulativeness of capabilities and accordingly increases level of cumulativeness conditions.

Countries with an advanced economy have a very competitive environment (Fassio, 2015). These countries adopt an innovation strategy to produce innovative products to compete with other countries to be at the technology frontier (Fassio, 2015). These countries are able to develop unique solutions for space applications based on conducting R&D at the cutting edge (Hertzfeld, 2002a). Firms gain direct benefit from space programmes through funded R&D and development of contracted space technologies and indirect benefit from commercial spin-off and spill-over effects (Hertzfeld, 2002b, Amesse et al., 2002). The direct and indirect benefits enable firms to benefit from their own innovative effort and allow firms to increase their R&D expenditures (Radosevic, 1998, Malerba et al., 1997, Cefis and Orsenigo, 2001). Since firms

[3] Heritage component: a component or product installed and flown previously in a spacecraft is identified as a product with heritage.

are able to benefit from their own innovative effort, this increases the level of appropriability conditions, and increases their knowledge base and accumulation of capabilities and thus their level of cumulativeness. However, according to Acemoglu et al. (2006), the appropriability effect impacts the ability to converge to innovation if they do not switch to an innovation-based strategy before reaching the frontier and have other sources of cash.

Dewes et al. (2015) argued that governments are responsible for structuring national innovation systems. According to the SIS literature, government support increases the level of opportunities, appropriability and cumulativeness (Malerba et al., 1997, Breschi et al., 2000); however, the success of innovation is conditional on availability of institutional knowledge, which is accumulated from tacit knowledge, equipment and instrumentation, i.e. prerequisite accumulated capabilities. Government support is crucial to incentivise firms and research institutions to stimulate learning and build-up of capabilities by domestic firms (Malerba and Nelson, 2011). India and China transitioned from production to innovation economies as result of government support by investing in engineering education and research institutions (Altenburg et al., 2008). Government support eases innovation efforts (Malerba and Orsenigo, 1996) since it provides an incentive for firms and research centres to deploy their resources and increase their R&D expenditures (Malerba et al., 1997, Breschi et al., 2000).

Countries near to the frontier have the ability to take advantage of external knowledge, and developing countries with less accumulated capabilities will be unable to capitalise on this new knowledge and will fall further behind (Altenburg et al., 2008). Latecomers or catch-up countries will fall behind unless they instil policies to restore education and R&D (Aghion and Jaravel, 2015). If catch-up countries instil policies at least could grow at the same rate and the gap that separates them from the frontier will be stabilised (Aghion and Jaravel, 2015). Investment in R&D and education could facilitate the conversion of latecomer countries to catch-up on the technology ladder by taking advantage of the transfer of technology developed elsewhere (Madsen et al., 2010). It does not necessarily mean these latecomers will be able to close the technological gap, despite the view of Nelson and Nelson (2002) who argue that the more labour adopts new technologies, the faster firms can close the technological gaps.

2.3 Research approach

In this paper, I explore two related research questions. First, how does the UAE approach the new space technological frontier? Second, is there any technological upgrading of UAE manufacturing in the high technology satellite sector? These questions can be extended to a much broader question: To what extent can the innovation patterns phenomenon in the UAE be explained by SIS and DTF theories? The novelty and contribution of this research lie within the aspects that this is the first article addressing the UAE's innovation development of manufacturing in the high technology satellite sector. The article addresses a research topic on the UAE space sector that has not been researched before within the context of SIS and DTF theoretical frameworks.

The data collected for this study were based on a stakeholder capability assessment conducted on the UAE space sector. It was a structured approach where firstly the relevant entities working in the space sector were identified, and secondly the activities and assets of relevant entities were identified, and thirdly the activities were consolidated and clustered into activities according to an upstream or downstream space value chain. The primary data on activities were gathered using a stakeholder survey and followed by interviews to clarify relevant information provided by entities. Secondary data were collected from company websites, news media and industry organisations. The gathered information was analysed, focusing on capturing the technological development and innovation patterns of the UAE space sector.

2.4 Research investigation and findings

2.4.1 Cross-country space technology ladder

For this study, the space technological ladder (STL) of Wood and Weigel (2011) was adjusted to include additional technology groups, building uncrewed and crewed space exploration satellites or spacecrafts, and building satellite/spacecraft launch vehicles. In this research work, countries were broadly categorised into four groups based on their space technological ladder, time of entry, space budget and coverage of the space value chain activities. The characteristics of the groups' industry pioneers, established players and niche contributors are shown in Table 2-1. The fourth group is the laggard countries that have not progressed to acquire manufacturing capabilities to build satellite locally, and are not listed in the table.

Table 2-1: Space technology ladder and frontier countries

Ladder	The Space Technology Ladder	Pioneering Countries	Established Countries	Niche Contributor	UAE Milestones
20	Crewed Spacecraft: Build Locally	*			
19	Crewed Spacecraft: Build through Mutual International Collaboration	*			
18	Uncrewed Spacecraft: Build Locally	*			
17	Uncrewed Spacecraft: Build through Mutual International Collaboration	*			
16	Launch Capability: Satellite to GEO	*	*		
15	Launch Capability: Satellite to LEO	*	*		
14	Exploration Spacecraft: Build Locally	*	*		
13	Exploration Spacecraft: Build through Mutual International Collaboration	*	*		2020: 'The Hope'
12	Exploration Spacecraft: Build Locally with Outside Assistance	*	*		
11	GEO Satellite: Build Locally	*	*		
10	GEO Satellite: Build through Mutual International Collaboration	*	*		
9	GEO Satellite: Build Locally with Outside Assistance	*	*		
8	GEO Satellite: Procure	*	*		2000: Thuraya 1st Satellite
7	LEO Satellite: Build Locally	*	*	*	2017: KhalifaSat
6	LEO Satellite: Build through Mutual International Collaboration	*	*	*	
5	LEO Satellite: Build Locally with Outside Assistance	*	*	*	2013: DubaiSat-2
4	LEO Satellite: Build with Support in Partner's Facility	*	*	*	2009: DubaiSat-1
3	LEO Satellite: Procure with Training Services	*	*	*	
2	Space Agency: Establish Current Agency	*	*	*	UAE Space Agency
1	Space Agency: Establish First National Space Office	*	*	*	

Pioneers are those countries at the highest level of the technological ladder that have achieved their milestones in all categories, as indicated in the table. Established countries are those countries close to the technological frontier and which achieved their milestones in building a launch vehicle, LEO (Jussawalla, 1980) and GEO satellites locally. On the other hand, niche contributors are those countries having capabilities to build LEO satellites locally or through international collaboration.

The ability of firms and countries to develop and add new technological products is dependent on availability and accumulation of prerequisite capabilities (Hidalgo and Hausmann, 2009, Hausmann and Hidalgo, 2010, Hausmann et al., 2012). Hausmann and Hidalgo (2010) empirically concluded that nations couldn't make big jumps but rather move to nearby products which are connected in terms of using similar embedded knowledge, but which require advanced capabilities.

Figure 2-1 shows the progress for four Asian countries through the milestones based on the STL. Although these countries followed unique approaches to gain capabilities, innovate and scale up along the STL, none of these countries was able to make a big jump and build satellites locally without outside support and partnerships to transfer the know-how. Although some countries attempted to accumulate capabilities through building satellites with outside assistance or mutual international collaboration, India, South Korea, Brazil and the UAE succeeded as the result of transfer of know-how and other factors and were able to build satellites locally.

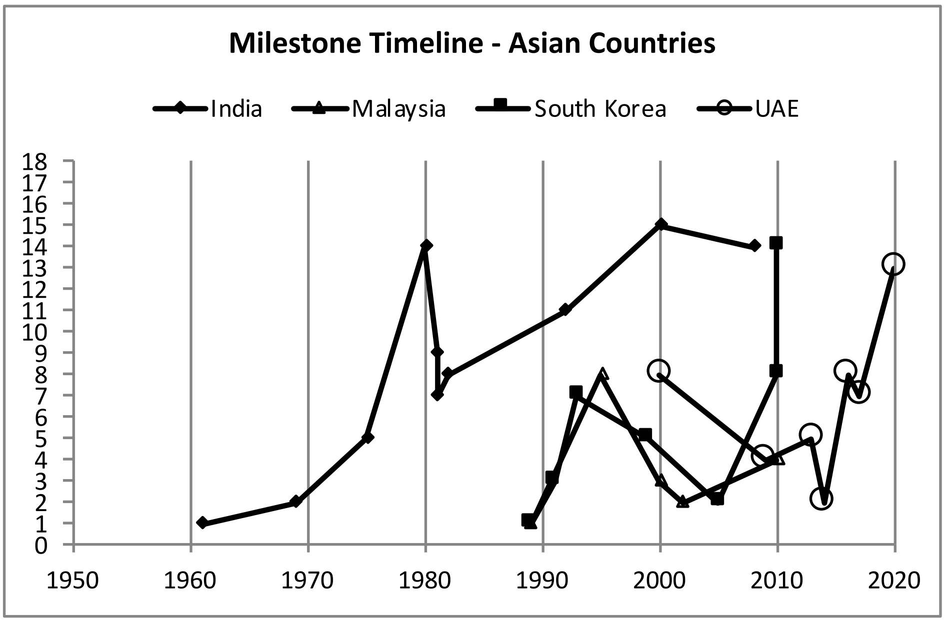

Figure 2-1: First time milestones - Asian countries

India, South Korea and Brazil are examples of established countries that formed the second group or the “second wave” of countries into space. India and South Korea made impressive progress along the STL, as both countries followed an early approach to build their first GEO and LEO satellites with outside assistance. The established countries aim to secure independent access to space, similar to the US and Russia, through acquired manufacturing capabilities of launch vehicles and uncrewed spacecraft. While in 2000 India achieved its first GEO launch capability, South Korea achieved its LEO launch capability in 2010. India, South Korea and Brazil built their space capabilities and progressed along the STL through strategic cooperation to build domestic capabilities in manufacturing satellites, launch vehicles and uncrewed spacecraft.

The third group is the newcomers into space, which consists of Argentina, the UAE, Malaysia and Nigeria. Argentina chose not to build its satellites independently and as a result it did not scale up its technology ladder when compared to the UAE, Malaysia and Nigeria. Argentina instead established a consortium of European companies to operate communication satellites over its territory. For their early LEO satellites, Argentina used foreign investment, political agreements and local manufacturers to build satellites. Malaysia built its LEO satellite programmes based on commercial relations with foreign firms in the UK and South Korea (Wood and Weigel, 2012b, Wood and Weigel, 2014).

The UAE is an exceptional case, and made significant movement up through the STL levels, as shown in Figure 2-1. Both the UAE and Malaysia started their satellite build programme during the same period and both partnered with Satrec Initiative, a South Korean firm, to transfer the know-how in building LEO satellites. However, the UAE was able to progress through the STL and build satellites locally, while Malaysia did not progress. The following sections provide an overview of the UAE’s satellite MAIT development and discusses its innovation patterns.

2.4.2 Overview of the UAE’s satellite MAIT development

The UAE has carried out an extensive range of space activities since 2000 with ambitions set significantly higher, as revealed by the study. Over the previous sixteen years, two fixed and mobile satellite services, Yahsat and Thuraya, were established and launched five satellites in total. In addition, Earth observation (EO) and remote sensing (RS) satellites were launched by Mohammed Ben Rashid Space Centre (MBRSC). The year 2014 was an important milestone for the UAE: the UAE Space Agency was established and the Emirates Mars Mission (EMM) announced ‘The Hope’ or ‘Al Amal’ in Arabic, a spacecraft to orbit Mars by 2020. In 2015, the

UAE announced the establishment of the National Space Science and Technology Centre (NSSTC) within the UAE University.

Figure 2-2 shows the UAE's space activities across the upstream and downstream segments of the space value chain. Most of the UAE's space activities are focused on the commercial value-added services and less on R&D, satellite manufacturing and ground operations. While the upstream segment, R&D and satellite MAIT activities are government-funded, with a limited range of space R&D in academia focused on EO, the satellite and spacecraft MAIT developments are emerging in the UAE through two flagship initiatives, the KhalifaSat and 'The Hope'. There are two major aerospace firms, Tawazun Precision Industry (TPI) and Strata, approved and certified suppliers for Boeing and Airbus structural parts. Neither firm is producing parts for satellite manufacturing yet but both have the required capabilities. The downstream segment encompasses ground operations and value-added services led by commercial entities AlYahsat and Thuraya, which are global leaders in fixed satellite services (FSS) and mobile satellite services (MSS), accordingly.

Although the UAE is gradually moving towards the upstream of space activities as an increased number of initiatives are observed to develop, introduce new R&D activities and build assembly, integration and testing (AIT) facilities and infrastructures in industry and academia have been discussed. The UAE is accumulating capabilities on FSS and MSS, EO and RS

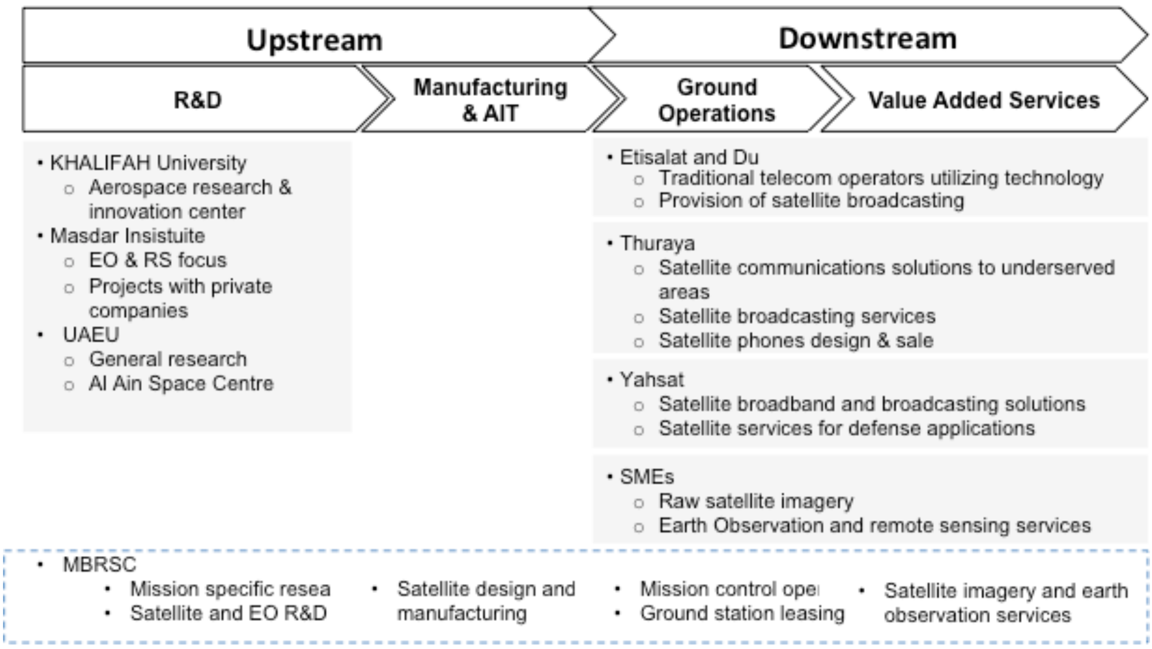

Figure 2-2: Overview of UAE's relevant space activities

services by growing and expanding these services globally. AlYahsat is expanding its broadband and broadcasting coverage to include South America and defence applications. The UAESA is studying the possibility to build a ground station for Deep Space Network (DSN), a niche value-added service, which will be operational by the end of 2019 supporting the EMM project and other international space exploration missions.

2.5 Findings and discussions

Although the scale of the UAE's development of MAIT of satellites is relatively small compared to established countries and significantly lower than pioneering countries, "The UAE has come a long way in space, and is more than likely to emerge as one of the leading space powers in West Asia over the long-term should it be able to address the challenges" (Rajagopalan, 2016). The UAE is closing gaps in achieving several milestones on the space technology frontier ladder. It seems the UAE is shifting gradually from investment-based strategy to innovation-based strategy. The DTF assumes that frontier economics needs to engage in innovation activities since these countries will experience productivity growth through pushing the frontier forward (Griffith et al., 2004, Madsen et al., 2010, Aghion and Jaravel, 2015), whereas a country like the UAE needs to catch up to the frontier through imitation since it experiences productive growth through applications of existing technologies developed elsewhere. However, the UAE is in a transition phase and is converging towards innovation-based strategy and is thus showing some signs of divergence from DTF. But the innovation patterns comply with the SIS predictions that with appropriate combination levels of appropriability, opportunities and accumulativeness countries can adopt innovation rather than imitation strategies.

It appears the UAE adopted a sound approach in accumulating required capabilities to upscale its STL and at the same time develop its R&D capabilities, establishing and introducing institutions and policies. From this study, I identified four innovation development capabilities tracks or patterns that the UAE is pursuing: (A) manufacturing of conventional satellites, (B) space exploration spacecraft, (C) small satellites, and (D) development of R&D capabilities on the ST&I areas related to space to support these development programmes and tracks. I also identified three strategic innovation pattern themes – (1) investment, (2) R&D, (3) partnerships and transfer of know-how – which cut across the four innovation development tracks.

The following sections elaborate on the UAE's strategic innovation pattern themes and innovation development capabilities tracks within the SIS and DTF theoretical assumptions.

2.5.1 Investment and innovation-based strategies

The UAE made good progress in the space sector, as discussed in the previous sections. The UAE was able to upscale its STL from purely procuring satellites to locally building and manufacturing satellites. During this development phase, the UAE adopted an investment-based strategy and gradually shifted towards innovation. Figure 2-3 shows the landscape of space-related activities and infrastructures that were mainly established and funded by the government.

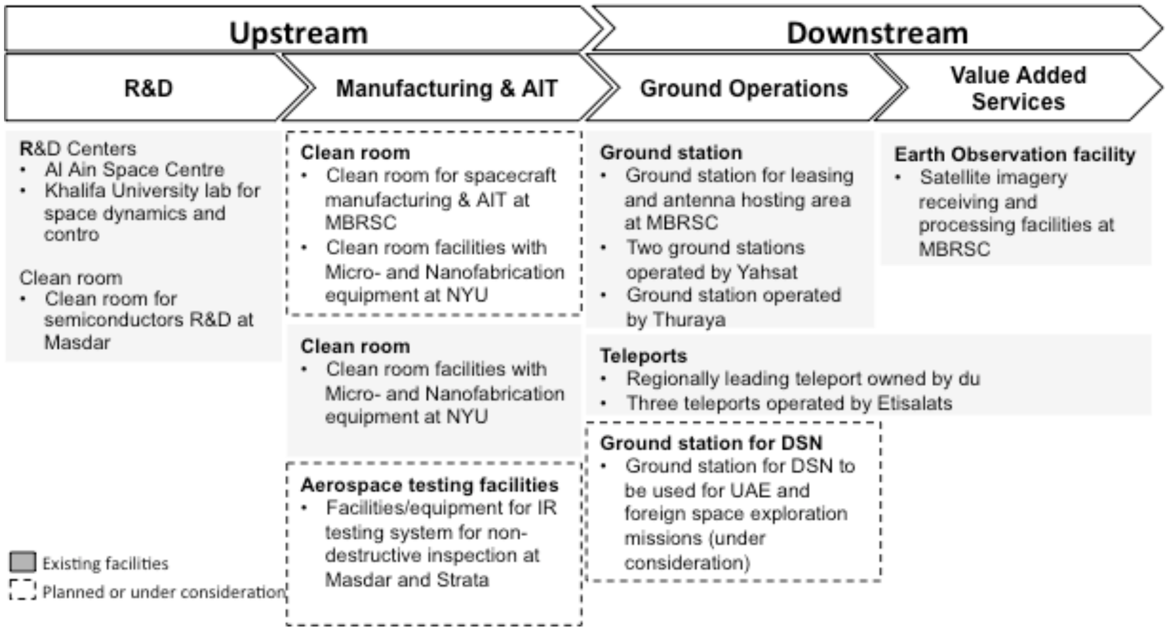

Figure 2-3: Space related facilities & infrastructures in UAE

According to SIS literature, government support will have a positive impact on knowledge features, i.e. opportunities, appropriability, cumulativeness and knowledge-base (Malerba, 2005, Malerba and Nelson, 2011, Fassio, 2015). Indeed, in the UAE the appropriability effect played a pivotal role as result of the government supporting the investment-based strategy. However, the introduction of policies and institutions enabled the UAE to counteract the forces impacting the conversion. Research centres were established within local universities, which supported the accumulation of capabilities in new science and technology areas and increased R&D activities. The recent introduction and funded space programme created new opportunities in science, technology and R&D in addition to building and accumulating manufacturing capabilities of satellite and spacecraft.

However, it appears in the near future that the investment-based strategy by the UAE government to support development of its space sector will not reduce and it will be costly, as argued by Acemoglu et al. (2006), unless alternative sources of cash are introduced. To some extent this situation is similar to other pioneering and established countries in regards to space exploration but not in non-exploration activities.

2.5.2 Research and development

According to DTF literature, the intensity of R&D activities and expenditures are related to the distance from the technological frontier (Griffith et al., 2004, Sabirianova et al., 2005, Acemoglu et al., 2006, Venturini, 2012). Griffith et al. (2004) argue that R&D activities support developing countries to build up 'the absorptive capacity'. The UAE showed signs of some divergence from the DTF but is still in compliance with the SIS theoretical assumptions since the intensity and investment on R&D influenced its opportunity, appropriability and accumulativeness levels. As result of these influences, the UAE was able to upscale its STL and is converging gradually towards an innovation-based strategy.

Table 2-2 shows the existing landscape of R&D activities at universities and research centres. The analysis revealed that MBRSC is the only entity conducting research related to space exploration and software development for satellites and is the only entity having capability in design and MAIT of satellites for scientific purposes. There are academic entities already engaging and leading in space-related R&D activities – Masdar Institute (MI), UAE University (UAEU) and KUSTAR. It seems there are strong R&D interests centred around EO and RS where MI is leading local universities for environment studies while UAEU is leading in land cover for geography and urban planning purposes. KUSTAR is the only university with R&D activities centred on aerospace but they are related to space such as robotics and autonomous systems. University of Sharjah has research capabilities in astronomy, meteor monitoring and tracking, and space science.

Table 2-2: UAE's landscape of R&D activities

Entities	Technology Area	STI and R&D Activities
MBRSC	Space exploration	• Planetary science - study of Mars atmosphere
		• Software development • 3D modelling using DubaiSat images
Masdar Institute (MI)	Earth observation	• Earth observation – development of applications using NASA and ESA satellites data downloaded via its own satellite receiving station
	Remote sensing	• Development of remote sensing-based tool for production of historical solar resource maps of UAE • Real-time solar mapping and visualisation system • Development of models to assess solar resource of specific locations in desert, with high accuracy, using satellite image data
	Nanotechnology	• Enhanced materials and semiconductors, Laboratories: Nano-Electronics and Photonics (NEP) Laboratory and Nano-Optics and Optoelectronics Research (NOOR) Laboratory
UAE University (UAEU)	Remote sensing	• EO - research on geography and urban planning
	Additional space research	• Establishment of new space research
Khalifa Univ. (KUSTAR)	Aerospace structures and aerodynamics	• Aerospace structures in collaboration with Strata - Enhancing characteristics and production processes • Nanomaterials, computational fluid aerodynamics, and UAVs
	Space dynamics and control	• Space dynamics and control
	Robotics	• Research on three main areas of robotics: 1) Aerial, ground, and marine robots, 2) BioRobotics, and 3) grasping and manipulations (i.e. robotics fine motor skills)
	Encryption	• Research on information security which can be relevant for e.g. satellite communications
New York Uni. in Abu Dhabi (NYUAD)	Astronomy and solar dynamics	• Research conducted at NYU Center for Space Science in collaboration with international partners using data from NASA missions • Focus of research is in the fields of astronomy and solar dynamics using seismology, observation, and modelling
	3D printing	• Research and development of a new type of 3D printer
NCMS	Weather related	• Research in meteorology and weather manipulation (cloud seeding) using satellite imagery and remote sensing techniques
Univ. of Sharjah (UOS)	Astronomy & space sciences	• Research on astronomy & space sciences at dedicated center in Sharjah with modern telescopes and spectrometers
Zayed University	Wide range of space R&D areas/topics (scientific articles)	• Earth observation: Development of remote sensing techniques, using hyper spectral analysis, for environmental monitoring, e.g. monitoring of storms
American University of Dubai	Space Debris	• Materials and space debris: Research on orbital debris impact on porous ceramic tiles • Wide range of other scientific articles in the fields related to space
Thuraya	Satellite communications	• Satellite communication handsets and terminals

As result of EMM, the UAE is setting foundations on planetary science and R&D for future space exploration missions. It opens up new windows of opportunities for local universities and research centres to build R&D capabilities where none existed before.

There are industry firms and multiple higher education institutes conducting space-related R&D activities in the UAE. The engagement of TPI, Strata and MBRSC in working with local universities on several R&D initiatives provide an indication of convergence pattern of the UAE towards innovation. The UAE space R&D activities are driven mainly by government support. The initial government support to both Strata and TPI eased the innovation efforts, as argued by Malerba and Orsenigo (1996) and increased the level of its appropriability and opportunities conditions, and increased local universities' accumulativeness level according to SIS literature. While MBRSC and Strata are the only industry firms with R&D activities and programmes, the most prominent academic entities conducting space R&D activities are Masdar Institute and Khalifa University. In 2014, the UAE announced the establishment of Al Ain Space Research Centre under the management of the UAEU, funded by ICT, a commercial-government fund, for five years and is supported by the UAESA (Khalifa, 2015).

Recently, both Strata and TPI were incentivised and deployed their own resources and increased their R&D expenditures, as posited by Malerba et al. (1997) and Breschi et al. (2000). Strata established a research programme in aerospace structure with Khalifa to enhance characteristics and production processes. Strata is collaborating with Khalifa and Masdar on establishing an IR testing facility for non-destructive inspection and testing. These R&D activities with local universities will enable Strata to benefit from their own innovation, and in return increase their R&D expenditures. The UAESA is currently engaging Strata and TPI to manufacture structural components of 'The Hope' spacecraft. Khalifa University is in a unique position to step into space technologies by leveraging its already developed R&D on aerospace technologies.

The space sector is characterised by having long-term technology roadmapping developed by space agencies. However, it is not clear yet how the ST&I roadmap for the UAE will be established absent a national space mission programme and whether it will adopt a push or pull technology option. ESA adopted a pull technology where the technology roadmaps are highly mission-driven with requirements derived from mission needs. It focuses on harmonisation with the EU, industry and national space agencies to prioritise R&D efforts and avoid duplication. The technology roadmap of NASA is driven by push technology, a capability development framework. JAXA's technology roadmap is driven by a technology adaption and outlines a mid- and long-term R&D plan for each of its 200 technology disciplines, involving a 20-year future technology trend prediction. The technology roadmap is interlinked with both a mission roadmap and an R&D plan to synchronise R&D and technology efforts over 10 years.

It seems the level of government support sets the scale for future R&D activities and the UAE's R&D future outlook will still depend on government support and on the UAESA to set the national direction on space R&D and funding requirements and align it with both the UAE's

National Space Strategy and ST&I roadmap. The drivers for future R&D growth in the UAE could be categorised into three groups: (a) Exploration plans and commitments: Ambition level for exploration mission(s) post Mars mission will be the single most important driver of national space R&D; (b) Domestic coordination: Extent of coordination between national space R&D centres and other relevant entities will greatly influence output from space R&D efforts; (c) Partnership participation: Participation in international R&D efforts and the ability to attract other nations' space activities to the UAE's R&D centres can quickly upscale the UAE's space R&D.

2.5.3 Partnerships and transfer of know-how

The study revealed that the stakeholders in the UAE space sector recognised the importance of external knowledge and transfer of know-how to drive growth in R&D activities, innovation, technology and manufacturing capabilities and to enhance its observed capacity through partnerships and collaborations in current and future projects (Aghion and Howitt, 1992, Griffith et al., 2004, Acemoglu et al., 2006, Antonelli and Fassio, 2015). From this study, it was found that the transfer of know-how was embedded into three sorts of partnership patterns in the UAE satellite sector: public-private, private-private and public-public. Although the existing partnerships cover the entire space value chain activity, most of these partnerships are new and at an early development phase.

While the UAESA is currently taking the lead in the domestic and international public-public partnerships, MBRSC is leading the domestic and international public-private partnerships but mainly with international technological firms. On the domestic partnership, the UAESA is currently supporting the establishment of NSSTC, which will be the first Middle East space research centre and will be incubator for space innovators and start-ups to drive the growth of SME and a centre of excellence in the area of space value chain activities. Internationally, the UAESA signed several memorandums of understanding with partnerships focused on scientific missions and joint studies, public outreach activities and technology sharing/transfer and training. The UAESA signed these memorandums with NASA, JAXA and CNES to set a platform for a wide range of collaboration in current projects and to open doors for future projects, to gain opportunities to access leading R&D and technologies, to understand leading processes and to become an active partner in multinational space exploration missions.

The UAE is a niche contributor, starting in 2000 at the lower level of the STL by only procuring, owning and operating satellites at LEO and GEO. These satellites were built at partner or supplier sites without technology transfer of know-how such as in the case of LEO and GEO satellites procured by Thuraya and AlYahsat. In addition, Earth observation (EO) and remote sensing (RS) capabilities were developed at MBRSC. However, in this case the transfer of know-how was embedded into procuring satellite contracts with the intention of accumulating capabilities in building and manufacturing satellites locally. AlYahsat is shifting towards adopting a transfer of know-how when it procures its third satellite and is planning to follow the same approach for its fourth satellite, although the transfer of know-how is limited to design phases and the manufacturing of the satellite is at a partner facility. The UAE is currently getting into the space exploration technology ladder group (refer to Table 2-1) by building uncrewed space exploration spacecraft both locally and at partners' facilities with mutual international collaboration.

In the UAE, the current satellite MAIT capability build-up is concentrated on two government-funded spacecraft manufacturing initiatives. While KhalifaSat is an EO LEO satellite operated by MBRSC, the UAESA is currently building its first spacecraft in partnership with MBRSC and LASP. 'The Hope' is a space exploration orbiter vehicle that will orbit Mars in 2021. The UAE acquired capabilities to locally build LEO satellites at MBRSC through partnership and technology transfer of know-how with South Korea. The UAE was able to scale up the STL, and partner with local firm Emirates Institution for Advanced Science and Technology (EIAST). EIAST was renamed in 2014 as Mohamed Bin Rashid Space Centre (MBRSC) and acquired capabilities to build its first LEO satellite DubaiSat-1, an EO satellite, at a partner facility (Al Rais et al., 2009, Alharmoudi et al., 2011, Al Mansoori et al., 2012, Pirondini and Al Marri, 2014), followed by DubaiSat-2 which was built locally with outside assistance (Pirondini and Al Marri, 2014). MBRSC is now locally building KhalifaSat through mutual international agreement with SI (Khalifa, 2015). The UAE is the only niche contributor country getting into space exploration activities. It entered the space exploration club by having an ambitious project, 'The Hope', a scientific mission to explore Mars (Khalifa, 2015).

The UAE is going through a paradigm shift from procurement of satellites towards pushing its technological frontiers in manufacturing conventional satellites including spacecraft for space exploration. Table 2-3 shows the UAE's MAIT landscape and activities at Tiers 3, 2 and 1 and in addition to building and accumulating capabilities to conduct full AIT of satellites. Although the UAESA is taking the lead in engaging TPI and Strata in manufacturing structural components of satellites, and currently manufacturing prototypes, the table excludes TPI and Strata as Tier 1 suppliers for Boeing and Airbus structural components since they are not yet manufacturing developed products. KhalifaSat is the first LEO satellite built by 100% Emirati engineers at the MBRSC facility with an international mutual collaboration partnership with SI.

Table 2-3: UAE's MAIT landscape

Project/Entities	Planning & supplier selection	Tier 3	Tier 2 & Tier 1	Prime: AIT
The Hope/ MBRSC	Mission, and parts of probe/system design incl. data handling system	University partners & international companies	Parts of software development	Parts of assembly, integration & function testing
	University partners & international companies		University partners & international companies	University partners & international companies
Khalifasat/ MBRSC	Building satellite locally with mutual collaboration to transfer know-how in partnership with Satrec Initiative (South Korea)			
	Satellite design to detailed level	International companies	Parts of software development	Parts of assembly, integration & function testing
	International companies		International companies	International companies
AlYah 3/Yahsat	Specification of system requirements	Orbital ATK & its tier 3 suppliers	Orbital ATK & its tier 3 suppliers	Orbital ATK
	Orbital ATK: System design, tier 2 & 3 selection			

As a result of MBRSC's partnership with international organisations to transfer know-how built around non-exploration satellites (DubaiSat-1, DubaiSat-2 and KhalifaSat), MBRSC was able to get a contract to build a space exploration spacecraft, i.e. Al Amal. The EMM project is a flagship space programme bringing in local and international organisation in partnership to transfer know-how and building capabilities in MAIT of spacecraft. Through the international partnerships between UAESA, MBRSC, LASP, BC and AR on the EMM project, the UAE is enhancing and accumulating its capabilities in the engineering design, planning and procuring of various components of the spacecraft as shown in Table 2-3. The EMM simplified UAEU's creation of partnerships with US universities and knowledge transfer across areas of research. MBRSC is building parts and developing software, a Tier 1 level of activity, and UAE engineers are embedded into engineering design for Tiers 1, 2 and 3 components such as the Emirates Mars Ultraviolet Spectrometer (EMUS) and Emirates eXploration Imager (EXI) with LASP (EMIRS) and Emirates Infrared Spectrometer (EMIRS) with Northern Arizona University (Alrais, A. et al., 2016).

Similarly, Yahsat is shifting towards a similar approach adopted by MBRSC to some extent but with very limited scope on the transfer of know-how since it does not own its own AIT facilities. Yahsat is engaging local universities with private-international partner manufacturing to leverage its procurement of new satellites. Yahsat initiated an offset requirement for Orbital ATK to support the establishment of a master's degree programme in space system engineering at Masdar Institute. Hence, it facilitates national objectives rather than its own.

The innovation development track on small satellites is considered important to sustain capabilities build-up by engaging local universities and developing capabilities in the miniaturisation trends of satellites. There are initiatives and programmes by UAESA, MBRSC and Yahsat to build several CubeSats in collaboration with local universities and in partnership with international organisations. These initiatives will develop small satellite MAIT activities to demonstrate technologies and products that are developed locally and at the same time used for education purposes.

Nayif-1 is the first nanosatellite built locally by students at Sharjah University where MBRSC provided facilities, and knowledge throughout the design and build phases of the satellite. Nayif-1 provided hands-on experience to students in design, integration, testing and operation of a communications satellite. It is the first Emirati nanosat and was scheduled for launch before end of 2015; however, it was delayed to before the end of 2016.

Yahsat is the first firm in the UAE to develop sustainable capabilities at a local university in design and build of small satellites. The small satellite programme was established in collaboration between Yahsat and Masdar Institute and is supported by the UAESA. In this programme building a CubeSat is the core part of Masdar's space systems and technology master's degree. The students develop ideas for CubeSat applications and select one for realisation. Students will lead all phases of the project including the design, integration, construction, testing and operation. The international partner, Orbital ATK, will support the initial two CubeSats by providing component manufacturing and support in the assembly of components. The programme will be followed by another four CubeSats in collaboration with UAESA and ICT to sustain the education programme at Masdar.

Development of small satellites and in particular CubeSats at universities attract students to enrol into STEM programmes and provide engineers to the space industry who are ready to engage in large-scale projects. The Masdar space systems degree attracts around 20 students yearly. The UAESA identified a national strategic objective and is taking the lead to organise a small satellite programme leveraging the existing programmes at Yahsat, Masdar, UAEU and Sharjah University to establish a national small satellite programme to achieve a coherent and sustainable manufacturing and AIT capability build-up in the UAE.

2.6 Conclusion

This article discusses the space technology frontier ladder and the characteristics of pioneering, established and niche countries. We found that the UAE, a niche contributor country, progressed well when compared to other developing countries and was able to upscale its STL from purely procuring satellites to building satellites locally, and currently accumulating capabilities in a new technology group ladder in building space exploration vehicles.

We have provided an overview of the extraordinary development of the UAE's space sector over the last 15 years and addressed and discussed the innovation patterns of the UAE's satellite MAIT sector within the SIS and DTF theoretical assumptions. The study revealed the UAE's characteristics in three thematic innovation patterns: (A) a government investment-based strategy, (B) partnerships, and (C) transfer of know-how, which cut across four innovation development patterns: (1) manufacturing of conventional satellites, (2) space exploration spacecraft, (3) small satellites; and (4) development of R&D capabilities on the ST&I related to space.

While the DTF suggests that countries closer to the technological frontier will adopt innovation rather than imitation strategies, the UAE is an example of a successful country that adopted an investment-based strategy and is gradually converging towards innovation on satellite manufacturing while still a distance from the frontier and while having a low level of economic complexity, as empirically evaluated by (Hausmann et al., 2012). In this study, the SIS was able to explain to some extent how countries that are not at the frontier in specific sectors could adopt innovation strategies, as in the case of UAE, and could be a frontier country over time. This is conditional on having an appropriate level and combination of opportunities, appropriability and cumulativeness conditions for these countries to upscale their technological ladder. Although the UAE during the development phase since 2000 relied mainly on government support and adopted, diffused and imitated technologies based on investment-based strategy, the UAE showed signs of conversion towards innovation. The UAE is establishing and expanding R&D centres, increasing R&D activities, introducing several small satellite initiatives, and recently, introduced a space exploration programme with the Emirates Mars Mission (EMM) as its first flagship programme to build 'The Hope'. These increased the level of opportunities and accumulativeness, which support the UAE to converge gradually towards innovation. However, the UAE needs to counteract these appropriability effects by finding an alternative source of funds to sustain growth, otherwise it will be very costly to maintain the innovation and development of the satellite sector and the risk is that the economy will not benefit from these earlier or initial investments.

The partnerships with international organisations play a pivotal role in the development of the UAE's satellite MAIT sector. As result of these international partnerships the UAE was able to transfer know-how gradually and was able to progress and upscale its space technology frontier ladder from only procuring and providing enabled services to building satellites locally for space exploration and non-exploration missions. These partnerships provided access to R&D and technologies and eased the creation of university partnerships with local and international firms and universities. The public-private CubeSat partnerships can motivate talent to pursue space careers and provide a model for future projects.

The approach adopted by the UAE to transfer know-how is recommended for further research, in particular to explore and compare the innovation approaches of the UAE and Malaysia in transfer of know-how since both had the same initial outside assistance from Satrec Initiative by building satellites at partner facilities. The UAE however was able to upscale its technological ladder and accumulated capabilities to build satellites locally and Malaysia did not. The ST&I roadmap and the adoption of either pull or push technology is another research topic, as without addressing it, the UAE will not be able to progress and sustain the growth in satellite MAIT activities, especially if the scale of the space exploration programme is currently limited to only one mission.

CHAPTER 3 Towards UAE’s Space Technology Roadmapping and Foresight: Scanning and Prioritising Opportunities

Towards UAE's Space Technology Roadmapping and Foresight: Scanning and Prioritising Opportunities

Abstract

Purpose - The purpose of this paper is to scan and analyse global technological trends in the space sector, so the UAE can identify and prioritise space science, technology and innovation (ST&I) areas. Ultimately this work presents preliminary findings that will be used for the development of a model framework that integrates foresight and roadmapping and is used to develop the first UAE ST&I roadmap.

Design/methodology/approach - The analysis is based on secondary and primary data collection. Secondary data include journals, market reports, technology roadmaps from various sources, and/or strategies of space agencies. Primary data collection was through two empirical studies, a survey and a workshop, to collect data from local academics, satellite operators and aerospace manufacturing firms regarding existing research and development (R&D) capabilities in space science and technology and future interests.

Findings – The paper provides a description on a model framework that integrates technology foresight and roadmapping techniques and methodologies to inform an ST&I roadmap for an emerging space country using the UAE as a case study. It proposes that the UAE prioritised its first group of research & development (R&D) activities to invest in selected cutting edge technologies and to build and accumulate capabilities on a landscape of selected ubiquitous technology areas for national strategic interests. Secondly, it invested in activities related to its emerging strategic directions to extend humans in space in-line with Mars 2117 and astronaut programmes.

Originality/value - This is the first paper using solid primary and secondary research to identify technology R&D opportunities and to prioritise key plans of the still-new UAE space sector. Other smaller developing nations entering to the space sector could benefit from the proposed methodology. This study provides a baseline against which the UAE Space Agency (UAESA) can identify, define, execute and measure the success of its own programme and its applicability to today's and future space needs.

Keywords: Space sector, ST&I, R&D, Technology Roadmapping, Foresight.

3.1 Introduction

In recent years, there has been a change in the perception of the space sector. Once a symbol of the technological race in only a very few countries, today space studies have become indispensable means of achieving economic, scientific, political and social goals (Dede and Akçay, 2014, Wood and Weigel, 2011, Pace, 2014, Leloglu and Kocaoglan, 2008). As Jason et al. (2010) argue, space technology and science are already valuable tools in providing practical responses to society's major challenges such as food security, climate change and disaster response. Space is also a high-profile, hi-tech sector, with a proven ability to motivate and inspire new generations into STEM studies hence contributing towards building a highly skilled workforce (human capacity).

It is accepted that investment in science and technology underpins economic growth and development (Innovation Nation, 2008). Recently, studies focused on the identification of science, technology and innovation (ST&I) priorities have become a key part of government policy for many countries. However, the approaches used for the identification, prioritisation and development of ST&I are strongly dependent on the country's policies and various socio-economic factors.

In recent years, interest in the space sector has increased and the number of *emerging space nations* that are engaging or planning to engage in a wide range of space ST&I activities is growing (Leloglu and Kocaoglan, 2008, Esterhazy, 2009, Jason et al., 2010, Wood and Weigel, 2012b). The space sector has been and is still dominated by a limited number of pioneering and established spacefaring nations (Al Hashmi, 2016), *mature space nations,* with well-established space agencies and long-term space ST&I programmes, with, for example, 10 to 30 year technology roadmaps, that provide a clear vision and pathway for the development of key technologies critical to achieve well-defined missions.

Al Hashmi (2016) provided an overview of the UAE's space activities and innovation patterns over the last 15 years as well as a summary of future planned activities. Patterns showing a shift from an investment-based to an innovation-based strategy to grow the space sector are driven primarily by changes in government ST&I priorities and investment. Al Hashmi (2016) discussed how the UAE, considered an emerging space nation, has been more successful than other emerging space nations in climbing the technology ladder and closing the gap with *mature space nations*. However, the UAE's space sector is still young, having only one approved deep space exploration mission, limited human resources and limited R&D capabilities at local universities. The Emirates Mars Mission (EMM) programme will design and build 'Al Amal' spacecraft that will be launched in July 2020 and will reach and orbit Mars in February 2021. Although the EMM opens up new R&D opportunities on a range of ST&I areas that did not exist before in the UAE, the development scope of R&D activities is limited if it is mapped with only one space mission, i.e. the EMM. Further to that, as discussed in Al Hashmi (2016), the UAE space sector comprises a number of stakeholders, with differing priorities, expertise and resources. Therefore, there is a need for a more strategic and co-ordinated approach to identify and prioritise ST&I activities to focus R&D on current and future space technology development and activities if the UAE is to capitalise on in the sector. With that view, this paper represents the first steps towards the development of the UAE's first ST&I roadmap.

In this research study, we attempt to describe the methodology used to answer the following questions to inform the UAE's first space technology roadmap: Which are the most relevant space agencies across the globe? What are their current and future technology ST&I priority areas? What specific technologies are being prioritised to advance such ST&I priority areas? Which is the UAE's current space sector 'state of the art' with regards to ST&I areas, technology and R&D activities and capabilities? Based on that information, what are the ST&I areas and associated technology development opportunities that should be included in the first UAE ST&I roadmap?

3.2 Literature review

According to the literature, methods, approaches or frameworks – such as technology roadmapping and technology foresight – are used to super-forecast and plan for future technologies that could evolve according to predicted market changes. The literature review addresses roadmapping and foresight and previous attempts to combine or integrate both methodologies and techniques.

3.2.1 Technology roadmapping

Technology roadmapping (TRM) originated as a forecasting tool for technology. Motorola in the 1970s became the first company to use TRM to improve alignment between technology and innovation, and to anticipate technology needs alongside future product development (Willyard and McClees, 1987, Richey and Grinnell, 2004). TRM is an effective tool for enabling entities to optimise their investment decisions (Gindy et al., 2006). TRM for ST&I provides a consensus view of the future ST&I landscape for decision makers (Kostoff et al., 2004).

The use of TRM has shifted over the years and has become a part of a process to introduce emerging technological solutions to social goals. TRM is used not only within single enterprises but also to develop and coordinate science and technology developments at national and international levels (Gindy et al., 2006)

ST&I TRM is used to identify opportunities and prioritise which R&D activities countries should invest in over the short and long term. R&D is considered a specific feature of innovation patterns adopted by firms (Fassio, 2015) to "push the technological frontier forward and facilitate future innovation" (Aghion and Jaravel, 2015). The investment in R&D affects the ability of firms to innovate and develop technological frontier products (Cefis and Orsenigo, 2001). TRM is used to identify and prioritise what technologies need to be developed (Galvin, 2004, Petrick and Echols, 2004) to produce cutting-edge technologies. In the space field, these products are "developed with cutting-edge technologies and integrated into advanced space missions" (Szajnfarber, 2014).

3.2.2 Technology foresight

In the early 1980s, Kostoff and Schaller (2001) introduced technology foresight (TF) and described it as the techniques, mechanisms and procedures to support and identify potential areas of basic research. TF facilitates looking forward, supports potential changes and keeps track of societal, technological and economic changes that could be encountered in the future (Yokoo and Okuwada, 2013, Cagnin and Könnölä, 2014, Kostoff and Schaller, 2001, Galvin, 2004, Petrick and Echols, 2004). Saritas and Nugroho (2012) introduced System Foresight Methodology (SFM) to take into account the uncertainty of present and future social, economic and political complex systems.

Although the objective of TF is to enhance decision making and facilitate looking forward to be ready for future changes (Mulgan, 2002), it also refines and provides a common vision and aligns the views of stakeholders (Georghiou and Cassingena Harper, 2011). However, the most common objective for TF exercises are to set priorities on science and technology developments (Kostoff and Schaller, 2001) for various stakeholders at the national level including government, industry and universities (de Almeida et al., 2015, Rijkens-Klomp and Van Der Duin, 2014, Gavigan and Scapolo, 1999). Hence, when TF is used to identify priorities and opportunities in ST&I areas it requires shared and collective views from all relevant stakeholders (Dede and Akçay, 2014).

There are different techniques and methodologies used for foresight studies – SWOT, critical or key technologies, technology roadmapping, megatrends, Delphi survey, relevance tree, scenarios and expert panels (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010).

TRM was used as part of foresight activities (Grupp and Linstone, 1999; Industry Canada, 2000; Emerging Industries and Technologies Forum, 2001). Some scholars attempted to integrate roadmapping and foresight, such Vishnevskiy et al. (2015), to maintain innovation culture and enable future improvements within a single organisation. British Petroleum developed a TF approach by using roadmaps to devise an R&D strategy embracing core business areas of the company approach (Barker, 1995). Saritas and Aylen (2010) posited that roadmapping could be an integrated part of an overall foresight methodology for connecting the future with the present, proven to provide high information content, and more precise and clear actions towards single future targets.

This research attempts to incorporate TRM and TF techniques and methodologies within the space field. Ultimately, this work aims to present preliminary research for the development of a model framework that integrates TRM and TF and is used for the development of the first UAE space ST&I roadmap.

3.2.3 Technology foresight, technology roadmapping and the space sector

Within the space sector roadmapping is widely adopted and the development and adoption of TRM is characteristic of the sector (Neal et al., 2014). The Global Exploration Roadmap (GER) produced by the International Space Exploration Coordination Group (ISECG) (ISECG, 2013a, Caetano and Amaral, 2011) highlights the short- and long-term space exploration missions for the member countries. The ISECG was established in response to the Global Exploration Strategy (GES) which is a the framework for international coordination in space exploration (Caetano and Amaral, 2011). The GES adopts a stepwise approach to enable humankind to reach (1) near Earth objectives, (2) lunar vicinity, and (3) lunar surface, and these destinations are used as tests for mature critical technologies prior to sending humans to (4) Mars vicinity and (5) Mars surface (Neal et al., 2014, Caetano and Amaral, 2011).

These space destination mission scenarios may require advanced and critical technologies that currently do not exist or that require enhanced technologies to meet very harsh environmental conditions on the surface of the Moon and Mars, for example. The pioneering and established spacefaring nations identify critical technologies required over the long term within TRM

(Laurini et al., 2015). For example, it could identify a requirement for new spacecraft propulsion system, star tracking or navigation system, or other critical technologies to enable humans to reach Mars. Figure 3-1 shows Japan's high level illustrative concept of space exploration and how technologies mapped either to spin-in from leading edge technology on the ground or as a return of outcomes to the ground.

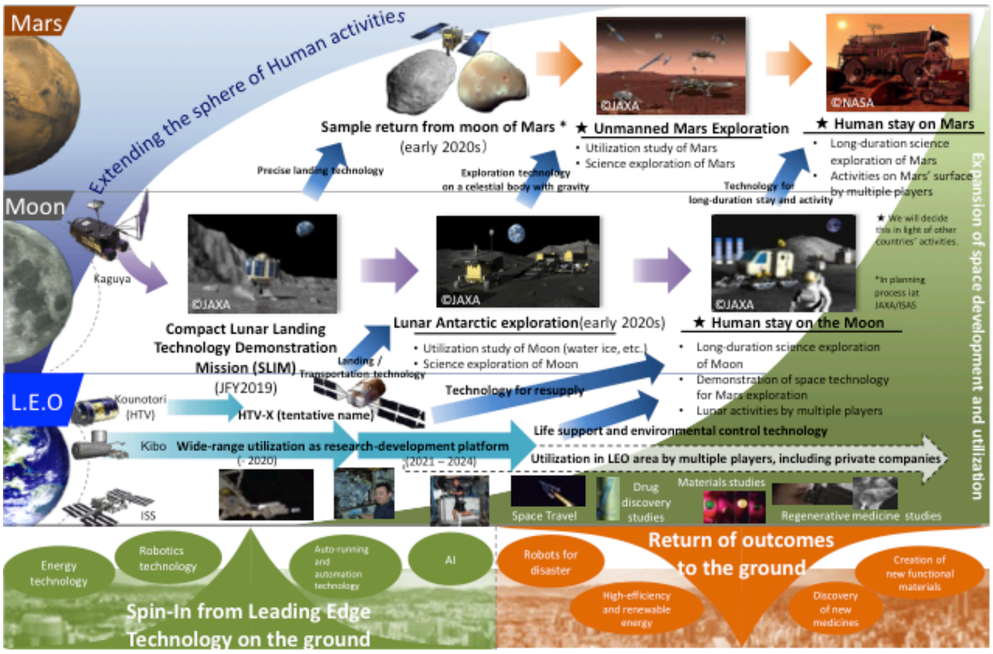

Figure 3-1: TRM for JAXA (ISECG, 2016)

TF is used to assess scientific and technological development (Kostoff and Schaller, 2001, Heiss et al., 2004). Foresight projects combine creative thinking about the future, which requires eliciting expert views on the future of technological trends and changes (Wonglimpiyarat, 2006). This is the case when ISECG elicits expert views from members nominated by space agencies on key and critical technologies needed to be developed over the long term and then publishes them within the GER (ISECG, 2013a, Caetano and Amaral, 2011).

When TF is used to identify priorities and opportunities in ST&I areas it requires a "process which involves intense iterative periods of open reflection, networking, consultation and discussion, leading to joint refining of future vision" (Georghiou and Cassingena Harper, 2011). For example, the technology group within ISECG goes through a process similar to that articulated by Aharonson and Schilling (2016) where it provides a set of options after an open reflection and consultation on a particular critical challenge. ISECG members then identify, select and prioritise a few critical technologies. In this process, nominated experts from member nations work within the technology group to detail existing technology gaps. A good example of this is the case of dust mitigation (Gaier et al., 2016) and liquid oxygen/methane propulsion systems (Hurlber et al., 2016) that were strategically identified as critical technologies needed to be researched in the near term. The purpose of this elicitation process is to jointly define and share a common future vision on a required critical technology and to encourage international collaboration in researching and developing technological solutions for specific technological challenges.

3.2.4 Technology foresight and technology roadmapping, and its relevance to the UAE

Over the previous years, it was observed that developing countries increased their interests in space by either engaging or planning to engage in Earth observation and space exploration, including research and development activities related to space science and technology (Leloglu and Kocaoglan, 2008, Esterhazy, 2009, Jason et al., 2010, Wood and Weigel, 2012c). The UAE is one of these countries where it increased its space activities not only in non-exploration space missions, i.e. Earth observation satellites, but also recently in design and MAIT of spacecraft for a deep space exploration mission.

The UAE was able to upscale its space technology ladder (STL)[4] by accumulating indigenous capabilities in design and MAIT of Earth observation satellites (Al Hashmi, 2016). While DubaiSat-1 (Al Mansoori et al., 2012, Alharmoudi et al., 2011, Al Rais et al., 2009) was procured and built with assistance at partner sites, DubaiSat-2 (Pirondini and Al Marri, 2014) was partially built in the UAE with outside assistance and KhalifaSat is currently being built in the UAE through mutual international collaboration. In 2014, the UAE joined the space exploration community by announcing both the establishment of the UAESA and the first flagship space exploration mission, the EMM project (Khalifa, 2015, Alrais et al., 2016).

While the pioneering and established spacefaring countries have a significant space exploration programme, the UAE has only one planned space mission, the EMM. Although this situation opens up new ST&I development opportunities for the UAE, it limits the scope of space ST&I development. The UAE has non-space exploration communication, Earth observation and

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[4] Space technology ladder is a concept suggested by WOOD, D. & WEIGEL, A. 2011. Building technological capability within satellite programs in developing countries. *Acta Astronautica,* 69**,** 1110-1122. It describes a stepwise process through which developing countries accumulate technological capabilities from only producing to the design and MAIT of satellites locally with limited assistance from international partners.

military satellite programmes but these satellites are procured with limited technological and R&D capability development in the country. An opportunity exists in which the UAE could leverage these non-exploration satellite programmes to develop local technological capabilities by shifting some satellite MAIT activities to local MAIT facilities and by engaging local universities and research centres to conduct relevant R&D activities to build capacity.

Prior to the establishment of the UAESA, space R&D activities were not well coordinated at the national level. Moreover, few universities and manufacturing firms exist in the UAE, which limits the intensity and scope of R&D activities (Al Hashmi, 2016). The UAE is a small country with very limited resources in human capital, especially locals working in R&D activities. These challenges call for a coordinated, focused and a well-structured R&D programme that is aligned within a common vision shared between all relevant space stakeholders. Moreover, the precise nature of future benefits, especially from space exploration, is not easily defined which adds another complex challenge (Leloglu and Kocaoglan, 2008, Jason et al., 2010) when identifying and prioritising ST&I topics.

It is therefore appropriate for the UAE to develop its space-related R&D capabilities within the context of an ST&I roadmap based on the following assumptions:

1. The UAE needs to develop R&D capabilities and not wait to define future space exploration missions.
2. Exploring and identifying the critical technologies already foresighted by international spacefaring nations and other space organisations would give an indication of which space-related ST&I areas the UAE needs to focus on and invest in.
3. The UAE needs to partner and collaborate with international space agencies by developing indigenous capabilities in specific ST&I areas such instrument payloads and other related satellite technologies and applications to participate in future international space exploration missions.

Therefore, for the UAESA to establish a roadmap to develop capabilities in space ST&I areas, it needs to adopt a unique methodology to overcome these challenges.

3.3 Research methodology

3.3.1 Research methods

The analytical approach consists of a combined primary and secondary method to collect and gather data through a survey, workshop and meetings. The participants were drawn from main space actors in the UAE – universities and research centres, satellite operators and manufacturing firms and senior government officials.

During the initial scoping of this research study, I realised a need to develop a data matrix to categorise the wide range of technologies related to the space sector. The data matrix is called the global space ST&I tree. This was necessary to have a sound approach when conducting foresight and to scan, identify and assess technology trends and opportunities. This process requires a predefined list of ST&I areas, i.e. the global space ST&I tree.

The analytical method and processes consisted of five stages, as follows:

1. *Identification and scanning technological trends:* Identify relevant space agencies and relevant space organisations, analyse their ST&I roadmaps and other technology development strategies to identify common ST&I areas of interest/priority and their associated technologies. The purpose of this phase was to identify, consolidate and code key ST&I areas and associated technologies to create a global space ST&I tree.

   Given the volume and complexity of information analysed, such a tree was developed as a means to capture key information in a meaningful and manageable manner to inform the UAE's space ST&I roadmap.

2. *UAE's capability assessment:* In this stage a survey was conducted to identify and map key stakeholders and their national space R&D activities to identify current national ST&I capabilities and to assess their alignment with ST&I areas identified in stage 1.
3. *Development of a criteria scoring system:* In this stage a criteria-scoring system was developed to prioritise the UAE's space ST&I areas to inform national R&D activities.
4. *UAE's ST&I area prioritisation:* Identify and prioritise ST&I areas to inform the UAE's space ST&I roadmap.
5. *Develop ST&I roadmap:* The ST&I roadmap cannot be complete without having national ST&I objective to guide and align stakeholders, and an implementation plan defining the R&D activities within a work programme that will be funded and executed over the short and long term.

In stage 6, the implementation plan was discussed briefly since this work requires solicitation of R&D projects with space stakeholders which is beyond the scope of this research.

Based on lessons learned as result of implementing the five stages of the analysis, the ultimate goal is to develop and propose a model framework that integrates roadmapping, which can be adopted by the UAESA to conduct foresight and roadmap studies on a recurring and periodic basis.

3.3.2 Data collection

Primary and secondary data sources were used in this research study. The secondary data sources included journals, market reports, technology roadmaps from various sources, and/or strategies of the National Aeronautical Space Administration (NASA), and Canadian Space Agency (CSA), UK Space Agency (UKSA) and European Space Agency (ESA). The primary data sources include two empirical studies, a survey and a workshop to collect data from local academia, satellite operators and aerospace manufacturing firms. Primary data were collected on the UAE's existing R&D capabilities and activities on ST&I areas. Data were collected on future interests of R&D related to space ST&I areas. The workshop aimed to validate and clarify collected data from the survey.

3.3.3 Data analysis

Both secondary and primary data sources were used and analysed. In this study, UCINET, a network analysis (NA) application, was used to analyse the collected data. NA techniques are used to establish the position of actors in a network and the relationships among them (Borgatti et al., 2002). In this study, NA was used to understand and analyse which technologies are ubiquitous i.e. common or limited among space agencies to understand the global technological trends. It was used also to analysis existing R&D activities and capabilities relevant to global space ST&I tree areas and trends.

3.4 Findings

3.4.1 Identification and analysis of global ST&I priority and associated technologies: towards the global space ST&I tree

In this research, identification and scanning of key technologies and trends were used as a way to get insight and views regarding future development of science and technology (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010). The key technologies and global space technological trends were scanned based on three secondary sources: (1) space agencies' technology roadmaps and strategic documents; (2) International Space Exploration Coordination Group (ISECG) publications; and (3) the database produced and maintained by the Committee on Earth Observation Satellites (CEOS).

The first source was the technology roadmaps developed by pioneering and established spacefaring nations. These technology roadmaps are long term, which are valuable for identifying critical technologies that are of interest to and which will be developed by pioneering and established spacefaring nations. The second source was the GER and associated work of ISECG (Neal et al., 2014, ISECG, 2013a). In 2013, the second GER iteration was produced and published by the ISECG (Caetano and Amaral, 2011). The GER was considered as a source to provide an overview of long-term future human space exploration missions (Laurini et al., 2015, Neal et al., 2014) planned by international space agencies. Space agencies want to reduce risks associated with human missions to Mars to an acceptable level. This implies a need to develop critical technologies that are mature enough to enable a sustainable approach. The GER and the associated work on roadmapping critical technologies gives insight on future technological trends and identifies critical technologies that pioneering spacefaring nations will pursue over the long term (Neal et al., 2014).

Three benefits could be identified from using GER as source for this study. Firstly, it shares and develops a common understanding of technological challenges facing spacefaring nations in their endeavours to explore space and in particular human space missions. Secondly, it identifies required capabilities and critical technologies needed to reach new frontier space destinations, which are aligned with the defined mission scenarios. Thirdly, it provides a platform for nations to communicate and contribute to innovative solutions to mitigate exploration challenges in a collaborative approach wherever and whenever possible. These mission scenarios and technologies are neither fixed nor final, nor do member nations in the ISECG have any obligations or commitments for a mandatory development sequence.

For non-space exploration missions and technologies, the database maintained by CEOS (CEOS, 2017) was utilised as the third secondary data source. CEOS is a comprehensive database that lists 128 planned Earth orbiting missions spanning from 2017 until 2030 and present and future EO satellite missions, instruments and measurement capabilities.

3.4.1.1 Identify relevant space agencies

For this study, a first selection process was conducted, and the benchmarked countries quickly reduced from 37 space agencies (see Appendix C, Table C-1 and Table C-2) to seven space agencies. The initial selection criteria were: the agency is a member of ISECG, and the agency's size, maturity and technology capability.

The list includes agencies having wide scale space programmes such as NASA and the European Space Agency (ESA), and smaller scale space programmes such as Japan Aerospace Exploration Agency (JAXA), Korea Aerospace Research Institute (KARI), United Kingdom Space Agency (UKSA), Indian Space Research Organisation (ISRO) and the Canadian Space Agency (CSA). NASA and ESA are included since we need to understand the diverse and wide scope of technologies that will be developed over the long term and we used the gathered information as an input to establish a baseline listing possible technologies in the global technology tree.

The second selection shortened the list from seven to four space agencies. It was first based on data availability and quality of available information, and second on robustness of their programmes. The UK, Canada, EU, India, Japan, South Korea and USA were all considered agencies with robust space programmes. In this research I defined robustness as the level to which each organisation defines, funds, executes and historically has successfully accomplished objectives and programmes within their respective roadmaps. While certain agencies, such as JAXA and ISRO have well-funded and successful programmes, they are dependent on external partnerships for one or more key aspects of those programmes. JAXA, KARI and ISRO provide high-level information regarding their research programmes with limited differentiating or ground-breaking research being carried out.

As a result of this assessment NASA, ESA, CSA and UKSA were selected as benchmarking agencies. Table 3-1 summarises the key findings and characteristics for each of the four space agencies. The common features among the four agencies are that their programme is mature, well-funded and successful in the execution of cutting edge research. Their programme provides credible data of current and future research objectives, and they have expansive research objectives. Hence, these countries provide a best baseline against which UAESA can identify, define, execute and measure the success of its own programme and its applicability to today’s and future space needs.

Table 3-1: Space agencies: Landscape, budget Size, ST&I and R&D

Country/ Agency	*NASA*	*ESA*	*Canada*	*UKSA*
Landscape	Pioneer, mature space agency and very diverse (50+ years).	Pioneer, mature space agency, and diverse (30+ years).	Established, relatively mature space agency (20+ years).	Niche, relatively new and small agency (5+ years).
	Leading contributor to international space community programmes (e.g. ISECG)	Represents 22 EU nations. Leading contributor to international space community programmes (e.g. ISECG)	Strong ties to ESA and NASA. Focused expertise in three areas: space robotics, radar technology for Earth observation and advanced satellite communications	Focused on developing UK's space sector
Budget	Larger :	Large:	Medium:	Medium:
	$15B+	~$5B	~$350M (FY16)	~$500M (FY15)
ST&I and R&D	A robust space R&D programme	Second robust space R&D programme	Focused and limited R&D scope	Focused but covering diverse range of R&D topics
	15 ST&I areas, three levels of subtopics	25 ST&I areas, three levels of subtopics	3 high-level ST&I areas, two levels of subtopics	5 high-level ST&I areas, two levels of subtopics
	R&D initiatives part of NASA technology roadmap	R&D initiative part of ESA technology roadmap	R&D initiatives part of the Space Technology Development Programme (STDP)	R&D initiatives part of the National Space Technology Programme (NSTP)

3.4.1.2 International space agencies' technology roadmaps

The TRMs and strategies of CSA, ESA, NASA and UKSA were analysed to understand the technological commonalities and specificities of their programmes: NASA roadmap (Laurini and Gerstenmaier, 2014), ESA roadmap (Hufenbach et al., 2014, Guglielmi et al., 2010) (Ginati and Tobias, 2005), CSA's Space Technology Development Programme (STDP) (Kroupnik et al., 2007), and UKSA's National Space Technology Programme (NSTP) (roadmaps and critical technologies were cited and referenced from ISECG annual meetings)

NA techniques were used to establish the position of stakeholders and the relationships among them in reference to a phenomenon (Borgatti et al., 2002). In this study, NA was used to understand and analyse which technologies are central, ubiquitous or common and limited among agencies:

1. **Ubiquitous technologies:** Those technologies, which are common among space agencies.
2. **Limited technologies:** Those technologies which are not common, and only one or two agencies have interest in it.

Figure 3-2 shows the space agencies and ST&I areas network ties. It shows how space agencies link with ST&I areas where the size of the node represents the degree of centrality. The larger the node, the more ties that agency has, and the more diverse an ST&I area, the more central the node. The analysis revealed that NASA is the most diverse, central and dominating agency linked with the majority of ST&I areas, while ESA is second followed by CSA and UKSA.

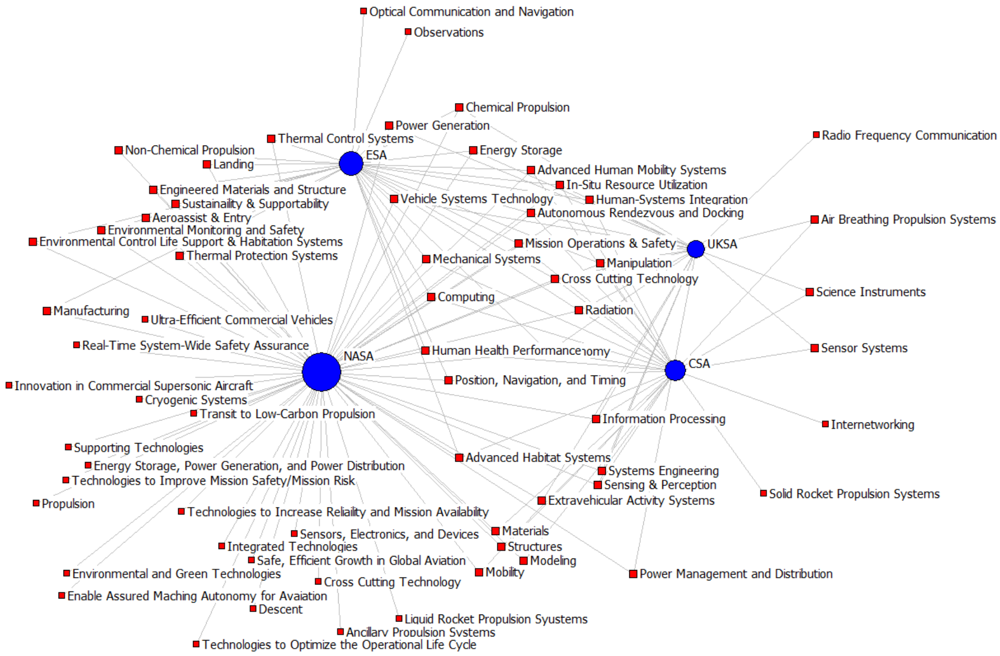

Figure 3-2: Space agencies and ST&I ties. Circular nodes indicate space agencies, square nodes indicate ST&I Level 2 topics

We can observe that the number of technologies ubiquitous and limited to NASA is more than ESA, CSA and UKSA. UKSA and CSA tend to be niche in their approaches and limited in scope to fewer ubiquitous and limited technologies. Moreover, it appears from the network that some technologies are limited to a few space agencies such as solid rocket propulsion systems and air breathing propulsion systems which only UKSA and CSA explore; radio frequency communications is limited to UKSA, and optical communication and navigation, and observations are limited to ESA. The diversity of NASA and ESA reflects the diverse capabilities relevant to their larger space programmes compared to other agencies.

The analysis reveals that the most linked, common ST&I areas among all four space agencies are manipulation, human-systems integration, autonomy, and autonomous rendezvous and docking, in-situ resource utilisation, mission operations and safety.

3.4.1.3 International space exploration programmes technologies

Table 3-2 shows an example of GER's highly applicable critical technologies. While there are highly applicable technologies, which means a technology is completely applicable and considered critical for the development of human exploration needs such as power generation, energy storage, human-systems integration and mechanical systems, there are technologies that are partially applicable to capabilities such as in-situ resource utilisation and technologies to optimise the operational lifecycle.

Table 3-2: GER critical ST&I areas - Illustrative

Launch Propulsion Systems	**Space Power and Energy Storage**	**Robotics, Tele-robotics and Autonomous Systems**
• LOX/Liquid Methane Cryogenic Propulsion System • Advanced Cryogenic Propellant Storage & Liquid Acquisition • Electric Propulsion & Power Processing • Nuclear Thermal Propulsion (NTP) Engine	• High Strength & Autonomously Deployable In-Space Solar Arrays • Fission Power for Electric Propulsion & Surface Missions • Regenerative Fuel Cells • High Specific Energy & Long Life Batteries	• Tele-robotic Control of Robotic Systems with Time Delay • Robotic Systems Working Side-by-Side with Suited Crew • Autonomous Vehicle, Crew and Mission Ground Control Systems • Autonomous Rendezvous, Docking & Relative Navigation
Human Health, Life Support and Habitation Systems	**Human Exploration Destination Systems**	**Entry, Descent and Landing Systems**
• Flight Medical Care, Behavioral Health and Performance • Microgravity Biomedical Counter-Measures • Human Factors and Habitability • Space Radiation Protection/Shielding	• Anchoring Techniques & EVA Tools for Micro-Gravity Operations • Surface Mobility • Lunar & Mars In-Situ Resource Utilization • Dust Mitigation	• Entry, Descent and Landing – Mars Exploration Class Missions • Precision Landing & Hazard Avoidance
Communications and Navigation	**Life Support and Habitation Systems**	**Thermal Management Systems**
• High Data Rate Forward & Reverse Link Communications • Adaptive, Internetworked Proximity Communications • In-Space Timing and Navigation for Autonomy	• Closed-Loop & High Reliability Life Support Systems • Fire Prevention, Detection & Suppression (Reduced Pressure) • EVA Deep Space Suits, including Lunar & Mars environment Advanced EVA Mobility (Suit Port)	• Low Temperature Mechanisms • Robust Ablative Heat Shield - Thermal Protection Systems

The GER addresses five space mission scenarios: near Earth objectives, lunar vicinity, lunar surface, Mars vicinity and Mars surface. The lunar vicinity and lunar surface mission scenarios are used to test critical technologies for enhanced readiness for humans reaching the Mars surface by the 2030s. The GER also identified 13 critical launch and logistics transport capabilities, which mapped to both the mission destination scenarios and technology roadmap (see Appendix C, Figure C-1, an extract from the new release of a GER for critical technologies).

Figure 3-3 shows the extent GER's critical technologies are related to the 13 launch and logistic transport capabilities identified by ISECG. The most centrally connected or central capabilities to the ST&I areas are: lunar surface elements servicing support, crewed lunar lander ascent module, evolvable deep space habitat, NASA ORION, and crewed lunar lander descent module.

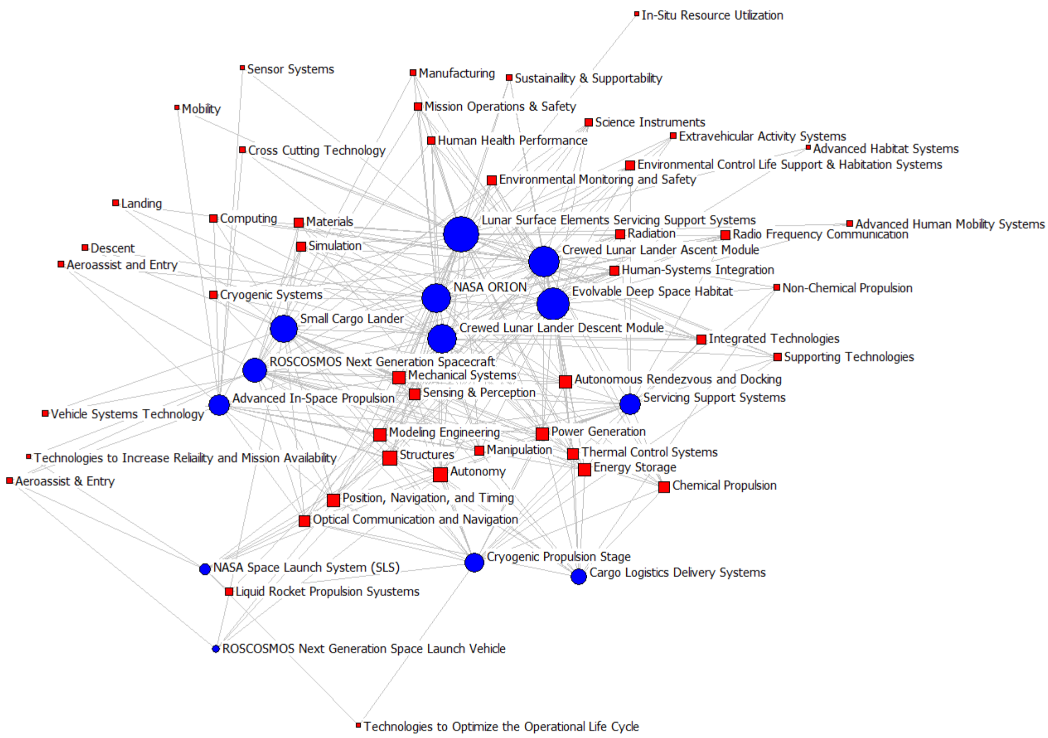

Figure 3-3: ISECG capability and critical technologies ties. Circular nodes indicate capabilities, square indicate ST&I topics

3.4.1.4 International non-space exploration programmes

The CEOS database was analysed. In all, 270 non-exploration missions and 20 key instruments payloads were identified, which were broken down, classified and categorised as an input to the development of the global space ST&I tree, especially for levels 2 and 3. The analysis revealed that the most in-demand satellite payloads in the future are: 1. High-resolution optical imaging, 2. Imaging synthetic radar, and 3. Multi-purpose imaging, which accounts for 36.7 %, 9.3% and 7.7% of all on-exploration mission payloads, accordingly (see Figure 3-4).

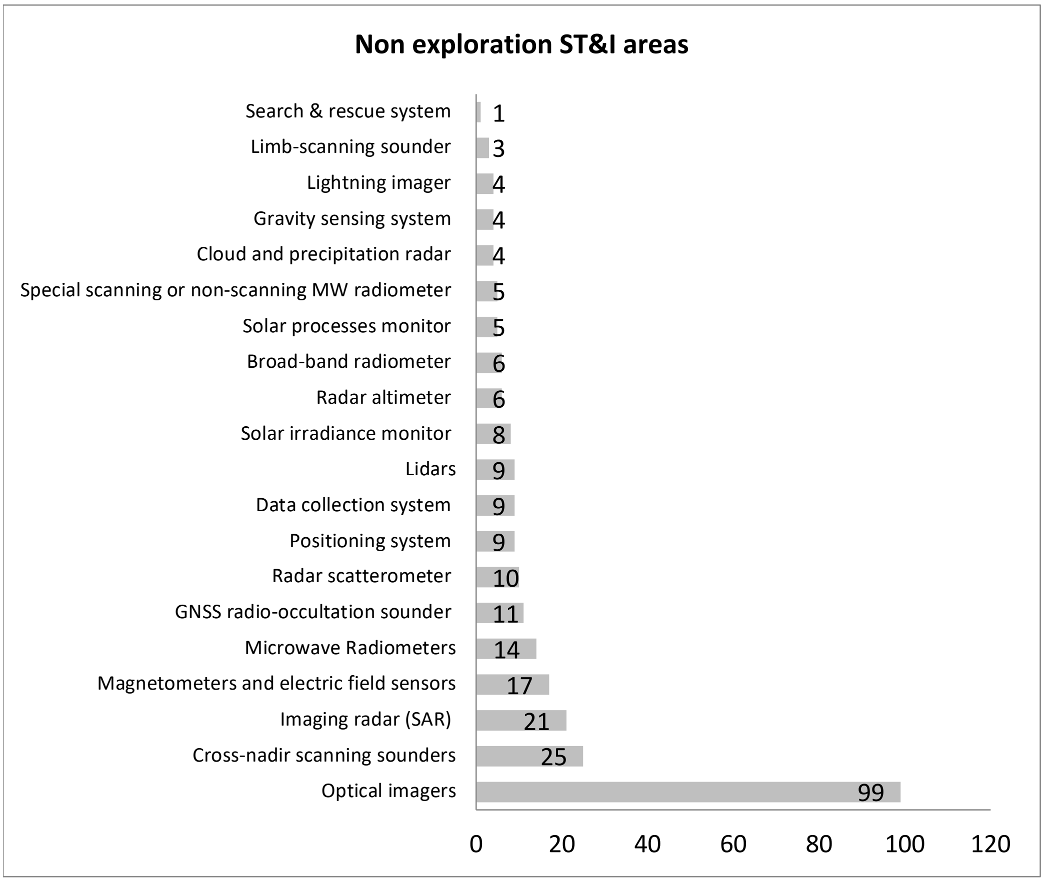

Figure 3-4: Non-exploration ST&I areas

The analysis shows that certain technologies are already in full development and perhaps would not benefit from UAESA involvement, but it could be of interest for national requirements to develop indigenous capabilities to build these locally. However, certain opportunities were also identified that could be of interest, such as Doppler lidar at only 0.7% of missions, and atmospheric/cloud precipitation lidars, at 1.52% each. These provide addressable gaps and opportunities for development.

3.4.1.5 The global space ST&I tree

The space sector covers wide and diverse ST&I areas. Thus, prior to identifying and prioritising ST&I areas, for the UAE in this case, it was appropriate to consolidate, code, classify and categorise technological areas and components to construct a global space ST&I tree.

Space agencies structure their TRM with a wide range of technologies an ‘ST&I tree’, which is a data matrix listing the high level ‘parent’ technology areas and related ‘child’ technology components at a lower level. While the technology trees of NASA and ESA are structured into a very detailed breakdown with three levels, the technology trees for CSA and UKSA are not detailed and are less structured. For example, at level I, NASA structured the technology tree into 15 technological areas, ESA encompassed 25 technological systems, UK addresses only five technology domains and CSA addressed three high-level technological systems (see Table 3-2) (see Appendix C, Table C-3 for an illustrative example of a technology roadmap for ESA).

As result of in-depth reviews and analyses of space agencies, exploration and non-exploration, and ISECG critical technologies and roadmaps, a global space ST&I tree is structured into three levels which consist of 18 areas, 83 components and 422 sub-components as shown in Table 3-3.

Table 3-4 shows an illustrative example of the breakdown for ST&I area 3 ‘Space Power and Energy Storage’ at levels 2 and 3 (see Appendix C, Table C-4 and C-5 for breakdown of ST&I areas 9 and 16).

Table 3-3: Illustrative structure for ST&I Tree

Breakdown/Levels	Description	Number of ST&I areas and components
Level 1	An area that encompasses an overall scientific, technological or engineering discipline required to develop the specific capabilities and/or functionalities.	18 ST&I areas
Level 2	Specific components that enable the development of specific ST&I capabilities and/or functionalities related to level 1.	83 ST& components
Level 3	Specific methodologies, techniques, devices, process or sub-systems that form the key building blocks of an ST&I capability and/or functionality	422 ST&I sub-components

3.4.1.6 Understanding and analysis of UAE’s strategic national interests

It is important to understand existing government directions, strategy and policies related to space to inform the prioritisation of ST&I areas. There are two main relevant documents that

Table 3-4: Illustrative breakdown structure for ST&I tree No. 3 – Space power and energy storage

Level 1	Level 2	Level 3
3.0 Space Power and Energy Storage	3.1 Power generation	3.1.1. Energy harvesting
		3.1.2 Chemical
		3.1.3 Solar
		3.1.4 Radioisotope
		3.1.5 Fission
		3.1.6 Fusion
	3.2 Energy storage	3.2.1 Batteries
		3.2.2 Flywheels
		3.2.3 Regenerative fuel cells
		3.2.4 Capacitors
	3.3 Power management	3.3.1 Fault detection, isolation and recovery
		3.3.2 Management and control
		3.3.3 Distribution and Transmission
		3.3.4 Wireless power transmission

were used as inputs to understand these directions and for the purpose of extracting relevant information related to R&D and ST&I development capabilities and strategic direction. The following sections discusses the findings.

3.4.1.7 The UAE ST&I policy

The UAE ST&I policy assumes that innovation is driven either by science or technology. The policy sets the ST&I priority topics for all industries at a very high level. The UAE ST&I policy contains 24 focused topics and 10 topics are relevant to the space sector, as shown in Table 3-5. Two of the 10 topics, space science and CubeSat/nanosatellites, have a direct link and eight are indirectly linked to the space sector. The policy give priority to life and physical sciences, modelling and simulation, lightweight and miniaturisation, payload technologies and material science, and manufacturing for satellites, However, there is no information publicly available on how and what the UAE is planning to do to ensure relevant laboratories, equipment and facilities are made available to achieve its ST&I policy, which is not a subject of this research paper.

3.4.1.8 The UAE Space Policy and Strategy

From the current work on the UAE National Space Policy and Strategy, the UAE space value chain activities were analysed. Five main segments were identified and shown in Table 3-6 as potential activities seen as critical or which will have a significant impact on the development of the UAE space ST&I.

Table 3-5: Relevancy of national ST&I areas

National ST&I Topics	*ST&I Areas/Components*
Space sciences	• Life and Physical Sciences • Modelling and Simulation
CubeSats and nanosatellites	• Lightweight and Miniature Structures • Payload Technologies • Material Science and Manufacturing
Health information technology and bioinformatics	• Environmental Control and Life Support Systems and Habitation Systems • Astronaut Medical Diagnosis and Prognosis Tools
Water management and economics	• Environmental monitoring sensors • Remote Sensing technologies
Solar and alternative energy technology system	• Solar, Fission, and Fusion Power Generation & Storage • Regenerative Fuel Cells
Robotics and artificial intelligence	• Autonomous Rendezvous and Docking
Petroleum geosciences	• Instrumentation and Sensors • Applications to conduct geoscientific analyses
Additive manufacturing, i.e. 3D printing	• Sustainable Manufacturing processes • Additive Manufacturing Techniques
Aerospace advanced materials, manufacturing maintenance and testing	• Light Weight Structures and Materials • Flexible Material Systems • Design and Analysis Tools
Internet of things and big data	• Payload and Ground Data Processing • Intelligent Data Analysis of large scale mission

The ST&I areas addressed in both the national ST&I policy and National Space Policy and Strategy were used in this research for two purposes. Firstly, it was used to ensure the ST&I areas were addressed in the global space ST&I tree. Secondly, it was used to inform the prioritisation of ST&I areas and components, which is discussed in the following sections.

3.4.2 Capability assessments of UAE's current space stakeholders, resources and activities

In the previous stages I and II, the global space technology trend was scanned, key and critical ST&I areas were identified, and the global space ST&I tree was constructed. In Stage III, a capability assessment was conducted to scan the UAE's R&D current space stakeholder activities. This was a pivotal step prior to identifying and prioritising the short- and long-term R&D activities to inform the UAE's space ST&I roadmap.

Table 3-6: National space strategy – space segments relevant to ST&I Topics

Space Segment	*Definition*
Satellite MAIT	Manufacture, integration or assembly of satellite subsystems and components includes all activities up to launch
Launch vehicle	Operation of launch vehicles and conducting satellite launch operations to LEO orbit or higher
Satellite operators and ground stations	Operation of satellites (own and others), including companies that conduct ground operations to operate ground stations
Data processing/analytics/ storage	Development of enhanced information products via advanced data processing and analytic activities
Application development	Developing applications that utilise satellite data

A survey was designed to explore the existing space-related R&D capabilities, interests and plans in developing space technologies across the UAE's space industry institutions including academic, commercial satellite operators and manufacturing firms. The survey included 11 questionnaire items (see Appendix C, Table C-6) constructed to answer and investigate the following three main topics:

1. *Where are the UAE's institutions now?* Aimed to collect data on current R&D capabilities and activities.
2. *Where do the UAE's institutions want to be?* Aimed to understand the goals and plans of institutions in R&D activities over the next 5 and 10 years.
3. *What do the UAE's institutions need?* Aimed to understand the requirements and needs to achieve ST&I goals.

From the survey results it was found there are specificities and commonalities among local space sector stakeholders relative to current R&D current and interests. While Table 3-7 shows a view of the existing landscape for R&D activities among main space stakeholders, Table 3-8 shows existing R&D activities of main space stakeholders related to level 1 of the ST&I areas.

The analysis revealed that MBRSC is considered as the strong stakeholder having a large scale centre for satellite MAIT activities. There are multiple entities conducting R&D activities related to space. The analysis revealed that there is focus on R&D on Earth observations and remote sensing and applications (ST&I areas: 8 and 15).

MI is leading local universities in Earth observation and remote sensing for environment studies while UAEU leads in land cover for geography and urban planning purposes. KUSTAR is the only university with R&D activities in robotics and autonomous systems, which indicates specialisation in this field. Similarly, University of Sharjah is connected to a few ST&I capabilities related to research in astronomy, meteor monitoring and tracking, and space science (ST&I areas: 8 and 11). The responses to the survey revealed that there are no existing capabilities in some ST&I areas such as launch vehicle propulsion (ST&I area 1) and launch ground systems (ST&I area 13).

Table 3-7: Landscape of R&D activities of main space stakeholders

Entities	Technology Area	STI and R&D Activities
MBRSC	Space exploration	• Planetary science - study of Mars atmosphere
		• Software development • 3D modelling using DubaiSat images
Masdar Institute (MI)	Earth observation	• Earth observation – development of applications using NASA and ESA satellites data downloaded via its own satellite receiving station
	Remote sensing	• Development of remote sensing-based tool for production of historical solar resource maps of UAE • Real-time solar mapping and visualisation system • Development of models to assess solar resource of specific location in desert, with high accuracy, using satellite image data
	Nanotechnology	• Enhanced materials and semiconductors, Laboratories: Nano-Electronics and Photonics (NEP) Laboratory and Nano-Optics and Optoelectronics Research (NOOR) Laboratory
UAE University (UAEU)	Remote sensing	• EO - research on Geography and Urban Planning
	Additional space research	• Embellishment of new space research
Khalifa Univ. (KUSTAR)	Aerospace structures and aerodynamics	• Aerospace structures in collaboration with Strata - Enhancing characteristics and production processes • Nanomaterials, computational fluid aerodynamics, and UAVs
	Space dynamics and control	• Space dynamics and control
	Robotics	• Research on three main areas of robotics: 1) Aerial, ground, and marine robots, 2) BioRobotics, and 3) grasping and manipulations (i.e. robotics fine motor skills)
	Encryption	• Research on information security which can be relevant for e.g. satellite communications
New York Uni. Abu Dhabi (NYUAD)	Astronomy and solar dynamics	• Research conducted at NYU Center for Space Science in collaboration with international partners using data from NASA missions • Focus of research is in the fields of astronomy and solar dynamics using seismology, observation, and modeling
	3D printing	• Research and development of a new type of 3D printer
NCMS	Weather related	• Research in meteorology and weather manipulation (cloud seeding) using satellite imagery and remote sensing techniques
Univ. of Sharjah (UOS)	Astronomy & space sciences	• Research on astronomy & space sciences at dedicated center in Sharjah with modern telescopes and spectrometers
Zayed University	Wide range of space R&D areas/topics (scientific articles)	• Earth observation: Development of remote sensing techniques, using hyper spectral analysis, for environmental monitoring, e.g. monitoring of storms
American University of Dubai	Space debris	• Materials and space debris: Research on orbital debris impact on porous ceramic tiles • Wide range of other scientific articles in the fields related to space
Thuraya	Satellite communications	• Satellite communication handsets and terminals

Table 3-8: R&D current activities reference to ST&I areas (Level 1)

		ST&I Areas (Level 1)																	
Space Stakeholders		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Abu Dhabi University (ADU)	University																		
American Uni. of Sharjah (AUS)	University																		
Khalifa University (KUSTAR)	University																		
Masdar Institute (MI)	University																		
New York University (NYU)	University																		
Paris-Sorbonne Uni. (PSU)	University																		
STRATA	Manufacturer																		
Thuraya	Sat. Ops																		
Tawazun Precision Inst. (TPI)	Manufacturer																		
University of Sharjah (UoS)	University																		
UAE University (UAEU)	University																		
AlYahsat	Sat. Ops																		
Zayed University (ZU)	University																		
Mohamed Bin Rashid Space Centre (MBRSC)	R&D																		

It seems the satellite operators and manufacturing firms in the UAE started to shift towards collaborating with local universities and research centres. AlYahsat is shifting towards supporting local universities to build capabilities in design and manufacturing of satellites. AlYahsat initiated an offset requirement with Orbital ATK to support the establishment of a master's degree programme with a concentration in space system engineering at MI. The UAESA and ICT are currently supporting the development of the NSSTC in UAEU which aims to develop local capabilities in space science, which is considered a weak area in the UAE. In addition, it aims to build capabilities in the design and build of small satellites up to 200 kg while MBRSC works on larger size satellites.

Similarly, the two strong UAE manufacturing firms, TPI and Strata, have capabilities in manufacturing aerospace aluminium and composite structures and have started to shift towards collaborating in establishing research centres within local universities. For example, Strata established research centres dedicated to infrared (IR) and non-destructive testing of composite materials. The UAESA worked with TPI to be a qualified manufacturer for space structure components for the EMM. As a result, TPI is currently working with MBRSC to manufacture structural components for the Al Amal spacecraft.

Based on the existing R&D activities, the ST&I areas were grouped into three categories and shown in Table 3-9 as a 'Capability Heat Map'. The first category consists of the ST&I areas where there are good levels of R&D activities, the second category is areas where there are R&D activities but less than the first category. The third category consists of ST&I areas where there are no current activities in the UAE.

The analysis revealed that there is an interest to grow the R&D activities related to space. MBRSC is under significant expansion to accommodate additional environmental and testing facilities and activities in preparation for the Al Amal project by 2019. MBRSC aims to recruit and develop around 200 engineers and scientists. The local universities are looking forward to introducing new R&D activities related to small satellites for both R&D and education. It aims to provide hands-on experience to students in design and MAIT of satellites and development of Earth observation instrument payloads

Table 3-9: ST&I current capabilities – 'Capability Heat Map'

No.	Technology Area	Categories
3	Space Power and Energy Storage	1
8	Science Instrument, Observations and Sensor Systems	1
12	Materials, Structures, Mechanical Systems and Manufacturing	1
11	Modelling, Simulation, Information Technology and Processing	1
15	Software and Applications	1
17	Satellite Technologies and Techniques	1
18	Ground Station Systems and Networks	1
2	In-Space Propulsion Technologies	2
4	Robotics, Tele-Robotics and Autonomous Systems	2
5	Communications and Navigation	2
6	Human Health, Life Support & Habitation Systems	2
1	Launch Propulsion Systems	3
7	Human Exploration Destination Systems	3
9	Entry, Descent and Landing Systems	3
10	Nanotechnology	3
13	Ground and Launch Systems Processing	3
14	Thermal Management Systems	3
16	Life and Physical Sciences	3

3.4.3 Development of a criteria scoring system

In the previous stage, the existing R&D capabilities were assessed in reference to ST&I areas and components. In this stage, the aim is to prioritise the ST&I areas and components to develop the initial space ST&I roadmap for the UAE. The prioritisation was conducted only on ST&I levels 1 and 2. A set of criteria was required to prioritise ST&I areas to achieve the following objectives: (a) Rank the ST&I within each area (level 1) and component (level 2), (b) down select space ST&I areas that are most relevant to the UAE; and (c) assess required focused efforts and resources based on scale of high, medium and low. For this purpose, four criteria were defined and used to achieve these objectives.

Table 3-10 shows the four criteria and their descriptions. The criteria were selected based on a broad discussion with expertise within UAESA and few relevant stakeholders and insight from the work on the national space policy and strategy documents. The ST&I areas and components are evaluated relevant to (1) national space policy and strategy, (2) international space exploration missions, (3) existing capabilities in the UAE, and (4) potential commercialisation. The Criteria Scoring Matrix was constructed to score all four criteria on a scale of 0-4.

Table 3-10: Capability assessment criteria

Criteria	*Description*
Strategic alignment	Alignment with UAE national space policy and strategy
International missions	Applicability to leverage on international space missions
Feasibility via UAE capability	Feasibility to leverage on local capabilities
Potential for commercialisation	Potential to commercialise the ST&I area and components

Table 3-11 shows the matrix and the definitions of the scoring range for each of the criteria. Since investment in any ST&I needs to be aligned to national space policy and in particular to the national strategy, building on existing capabilities will require less effort and investment. Therefore, criteria 1 and 3 are given more weight than criteria 2 and 4, each 30%. A panel of advisors from the agency and experts from universities engaged in the scoring evaluation process. The scoring evaluation was conducted on the 18 areas (level 1) and 83 components (level 2) of the ST&I. Each ST&I component at level 2 was scored against the four criteria and used to evaluate the overall score of the ST&I area at level 1. Table 3-12 shows an example for scoring ST&I area 3 'Space power and energy Storage' (level 1) and the related three components (level 2) - Power generation (3.1), Energy storage (3.2), and Power management and distribution (3.3). The results of the survey analysis were used to score each ST&I component (level 2).

Table 3-11: The criteria scoring matrix

Scores	*Criteria* Strategic Alignment	International Missions	Feasibility via UAE capabilities	Potential Commercialisation
0	Technology is not directly aligned with the UAE Space Strategy value chain	Technology is not relevant to any ISECG mission scenarios or Earth observation missions	No feasibility for the UAE via local capabilities	Technology has no potential for commercialisation
1	Technology is directly relevant to 1 segment in the UAE Space Strategy (including significant UAE activities or highly attractive and feasible segments)	Technology is relevant to 1-3 ISECG mission scenarios and/or Earth observation missions	Limited feasibility due to limited capability among local industry stakeholders	Technology has limited commerciality as there is limited potential in the market place and/or technology readiness
2	Technology is directly relevant to 2 or 3 segments in the UAE Space Strategy (including significant UAE activities or highly attractive and feasible segments)	Technology is relevant to multiple ISECG mission scenarios and/or Earth observation missions	Moderate feasibility as there is a general capability with limited operational experience in at least 2 ST&I areas (level 3) among industry stakeholders	Technology has a moderate commerciality as there are potential commercial markets but moderate technology readiness
3	Technology is directly relevant to at least 3 segments including one or two highly attractive and feasible segments and/or UAE significant activities in the UAE Space Strategy	Technology is relevant to all ISECG mission scenarios and/or Earth observation missions	Technology has high feasibility development for local industry as there is leading academic/operational experience in at least 2 ST&I areas (level 3) among industry stakeholders	Technology has a high commerciality there are potential commercial markets and high technology readiness
4	Technology is directly relevant to more than 3 segments including at least three highly attractive and feasible segments and/or UAE significant activities in the UAE Space Strategy	Technology is relevant to at least one mission scenario or Earth observation mission and is a critical element in the development of capabilities (e.g. ISECG capabilities or Earth observation instruments)	Technology is highly feasible for local industry as there is proven leading operational experience in at least 2 ST&I areas (level 3) among industry stakeholders	A market for commercialisation already exists.

Table 3-13 shows an explanation of the scoring evaluation on Energy storage (3.2). It was given an overall high score of 3.67 since it is highly relevant to Criteria 1 – Energy storage is a focused area and highly relevant to the five segments in the national ST&I policy and strategy (see Table 3-5 and Table 3-6). Therefore, the strategic alignment criteria (Criteria 1) was given a score of 4. Energy storage is a very attractive, feasible R&D activity and a critical element for existing and future international missions (Criteria 2), therefore, Criteria 2 was given score of

Table 3-12: Overall ST&I area score – Level 1

ST&I Area (Level 1)	*ST&I Component [Level 2)*	*Scores of Criteria*				*Scores (Level 2)*	*Overall Score (Level 1)*
		Cr.1 (30%)	**Cr.2 (20%)**	**Cr.3 (30%)**	**Cr.4 (20%)**		
3. Space power and energy storage	3.1 Power generation	4	4	3	4	3.70	3.67
	3.2 Energy Storage	4	4	3	4	3.70	
	3.3 Power management and distribution	4	3	3	4	3.50	

4. There are existing local capabilities in this area. For example, UOS and MBRSC both have R&D and operational experience in energy storage for flywheel and capacitor technologies. Therefore, Criteria 3 was given a score of 3. Energy storage is already a commercialised (Criteria 4) ST&I area and it therefore was given score of 4. Accordingly, the overall score for energy was 3.7 (4x30%+4x20%+3x30%+4x20%).

Table 3-13: ST&I area score and rationale

ID	*ST&I Area [Level 2]*	*Criteria Rationale*	*Scores*	*Overall Score (Level 2)*
3.2	Energy Storage	1. Relevant to 5 segments including R&D Centers, Sub-Orbital Space Vehicles, Crewed Vehicles, Mission Specific Space Exploration Vehicles, CubeSats, Classical Satellites, Launch Vehicles & Facilities/Sites. Three of the seven segments are UAE significant activities (R&D Centers, Mission Specific Space Exploration Vehicles and Classical Satellites) and one is a highly attractive and feasible activity (CubeSats).	4	3.7
		2. Critical element of the ISECG, relevant to all the ISECG missions scenarios and Earth observation missions. (Score 4	4	
		3. Three stakeholders have capabilities in this field. UOS has leading academic experience in flywheel and capacitors technologies. MBRSC has proven leading operation experience in battery technologies and a general capability with limited operational experience in capacitor technologies. (Score 3)		
		4. A market for commercialisation already exists for energy storage (Score 4).	4	

Similarly, power generation, and power management and distribution were given scores of 3.7 and 3.5 respectively. Therefore, space power and energy storage was given an overall score of 3.67 (3.70 + 3.70+3.50 / 3).

3.4.4 UAE's ST&I area prioritisation

Based on the scoring results, the country-specific ST&I priority areas were categorised into three groups relative to the four criteria and as shown in Table 3-14. The overall scores used to guide the prioritisation and categorisation of ST&I areas are on a high-to-low relevancy measure as follows:

1. Category 1: ST&I areas with an overall score between 0-1.66 are categorised as low relevancy/priority category,
2. Category 2: ST&I areas with scores between 1.67-2.90 are categorised as medium relevancy/priority categories.
3. Category 3: ST&I areas with scores between 2.90-4 are categorised as high relevancy/priority category.

Table 3-14: UAE's ST&I priority categories – at Level 1

No.	ST&I Area	Categories	Effort
3	Space Power and Energy Storage	Category 1	Low
8	Science Instrument, Observation & Sensor Systems		
12	Materials, Structure, Mechanical Systems and manufacturing		
11	Modeling, Simulation, Information Technology and Processing		
15	Software and Applications		
17	Satellite Technologies and Techniques		
18	Ground Station System and Networks		
2	In-Space Propulsion Technologies	Category 2	Medium
4	Robotics, Tele-Robotics and Autonomous Systems		
5	Communications and Navigation		
6	Human Health, Life Support & Habitation System		
1	Launch Propulsion Technologies	Category 3	High
7	Human Exploration Destination Systems		
9	Entry, Descent and Landing Systems		
10	Nanotechnology		
13	Ground and Launch Systems Processing		
14	Thermal Management Systems		
16	Life and Physical Sciences		

The first category consists of ST&I areas the country could leverage based on current or existing capabilities and strength of its local universities and research centres. Category 1 includes ST&I areas that support the development of foundational and/or sustainable space ST&I with high to medium cost benefit and a significant impact to local industry with less investment since there are existing capabilities in the UAE. The second category supports the incremental development of ST&I that would require more effort and with moderate cost benefit, and the third category would require significant effort and investment due to non-availability of local capabilities in these areas, such as launch propulsion systems.

3.4.5 Development of the proposed ST&I Roadmap

3.4.5.1 Prioritising and categorising country-specific ST&I areas and components

The capability heat map (refer to Table 3-9) provides an indication of the existing R&D capabilities at local universities and research centres and the categorisation of ST&I areas provides prioritisation relevant to the four criteria. However, it does not provide an indication of which ST&I areas the UAE should invest in over the short and long term relevant to the new emerging space programmes. It does not indicate if the UAE should or should not invest in ST&I areas related to the third group since there are no existing R&D activities, such as in propulsion technologies.

However, while writing this thesis, several emerging national strategic directions were introduced by the UAE government. In 2017 the UAE announced a visionary programme called Mars 2117 to build an inhabited colony on Mars by 2117. After announcing the Mars 2117 programme, the Mars Science City and Astronaut Programme was launched in 2017. Therefore, the ST&I categories was revisited to re-prioritise the ST&I areas to develop an ST&I roadmap that reflects the new emerging space programme and strategic national requirements.

Several meetings were arranged with senior management including UAESA board members to get insight and to inform the prioritisation of ST&I areas and the roadmap. It was revealed that the UAE needs not only follows the roadmaps related to cutting edge technology on specific topics that has national strategic interest. The UAE may want to accumulate R&D indigenous capabilities at local universities and research centres on technological areas that are not cutting edge for capacity build up. This may be needed for the purpose of establishing a landscape of R&D activities covering several ST&I areas, components and sub-components to support an ultimate goal of accumulating specific and diverse indigenous capabilities, which will form baseline requirements for future space and related programmes.

The criteria scoring matrix shown in in Table 3-11 was revisited and Criteria 1 needs to be redefined and given a higher weight, from 30% to 35%. As result, Criteria 2 and Criteria 4 remained at 20%, and Criteria 3 changed from 30% to 25%. The high/low relevancy score mechanism for categorising ST&I areas remained the same. However, instead of grouping the ST&I areas into categories, the prioritisation was grouped into three groups:

1. Group 1: The first group has strong relevancy to national strategic interests and short-term objectives to build and accumulate indigenous capabilities
2. Group 2: The second group has relevancy to long-term objectives, and in particular to extending human presence in space in alignment with Mars 2117, Mars Science City and Astronaut Program.
3. Group 3: The third group has less immediate national requirements.

Table 3-15 shows the ST&I priority areas in reference to the three groups. The ultimate aim for grouping ST&I areas is to guide and direct the main space stakeholders to increase their level of investment, effort and R&D activities on the prioritised ST&I area activities.

We can observe from Table 3-15 that although the UAE currently lacks capabilities in some ST&I areas such as launch propulsion (ST&I Area 1) and in-space propulsion technologies (ST&I Area 2), the UAE may want to develop capabilities in these ST&I areas as result of prioritisation based on national strategic direction. As result of this prioritisation significant effort and investment will be required for ST&I areas 1 and 2 since both areas are identified as Category 3 in the ST&I capability heat map, as shown in Table 3-6. Similarly, the effort and investment to some extent will continue on science instruments, observatories, and sensor systems (ST&I Area 8) since these are existing R&D capabilities, as the work is currently being done on the EMM where an infrared and ultraviolet spectrometer is being developed. However, there are ST&I areas that were identified with lower priority such as ground station systems and networks (ST&I Area 18) and thermal management systems (ST&I Area 14), despite the fact that the UAE has some relevant existing capabilities. Therefore, these ST&I areas will get less funding over the short term unless the priorities are changed in the national strategic direction.

Table 3-15: UAE's ST&I prioritised groups

Group 1	Group 2	Group 3
ST&I areas relevant to national indigenous capabilities build up and short-term requirements	*ST&I areas relevant to extending humans in space and long-term requirements*	*ST&I areas with less immediate requirements*
1 Launch Propulsion Systems 2 In-Space Propulsion Technologies 3 Space Power and Energy Storage 4 Robotics and Autonomous Systems 5 Communications, Navigation, and Debris Tracking 8 Science Instruments, Observatories and Sensor Systems Nanotechnology 11 Modeling, Simulation, IT and Processing 12 Materials, Structures, Mechanical Systems and Manufacturing 15 Software and Applications 17 Satellite Technologies and Techniques	6 Human Health, Life Support, and Habitation Systems 7 Human Exploration Destination Systems 16 Life and Physical Sciences 9 Space Entry, Descent, and Landing	13 Ground and Launch Systems Processing 14 Thermal Management Systems 18 Ground Station Systems and Networks

3.4.5.2 ST&I roadmap structure

The ST&I prioritisation is one step forward in the development of the ST& roadmap. However, the ST&I roadmap needs to be structured in an executable format commonly used by government entities in the UAE to operationalise and make the roadmap a routine activity. The ST&I priority areas shown in Table 3-16 are the backbone of the ST&I roadmap. The proposed ST&I structure is shown in Figure 3-5 and consists of the following:

1. **<u>ST&I Objectives:</u>** A set of objectives (or one), linked, necessary to achieve overall national ST&I goals.
2. **<u>Measures and Targets:</u>** Measures to be identified and monitored, and to set targets to be achieved over the years as result of implementing strategic programmes and initiatives.
3. **<u>Strategic Drivers:</u>** Strategic directions that aim to drive changes set by government,

agency top management, or national strategies or interests to build up and accumulate capabilities in specific ST&I areas.

4. **Strategic Programmes and Initiative:** A set of overarching programmes and initiatives necessary to close an existing science and technological capability gap in order to achieve ST&I objectives.
5. **Gaps:** Existing local R&D capabilities gaps in ST&I areas at universities, local research centres and industry.

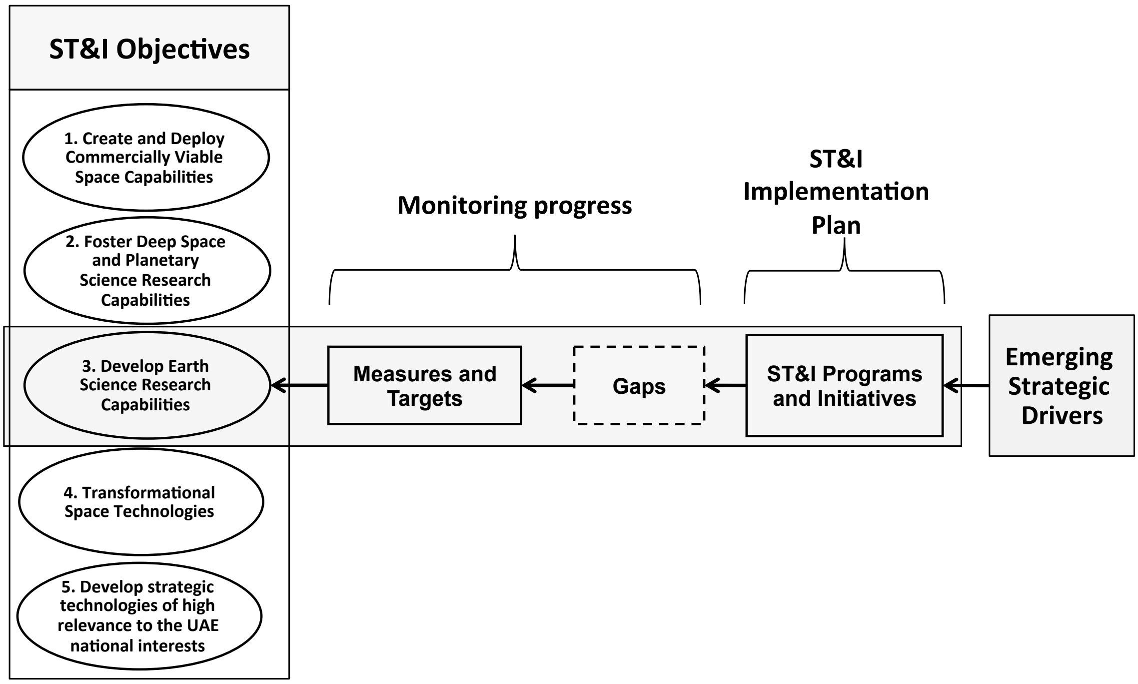

Figure 3-5: The ST&I roadmap structure

Each ST&I objective has one or several programmes, and each programme has several initiatives. The initiatives are more specific and look into what R&D activities need to be done relevant to the objective and prioritised ST&I areas in order to close the capabilities performance gap in reference to both existing capabilities and national strategic directions. Therefore, the implementation plan consists of an overarching set of programmes and specific initiatives that consist of R&D projects to be implemented over the short and long term. In this research, the implementation plan and R&D programmes and initiatives were not developed.

Table 3-16 provides an overview of the ST&I guiding objectives and rationale behind the selection of the objectives. The first objectives guide the investment in R&D activities that may lead to future commercial projects. The second objective aims to develop scientific and technology activities related to planetary research and to extend the presence of humans in space. The third objective aims to guide the continuous development of capabilities in Earth observation activities. The fourth objective aims to build capabilities in developing innovative and cutting edge research activities. However, the fifth objective will direct the development of capabilities in ST&I areas that are not necessary at the cutting edge but that have relevancy to strategic national interests.

Table 3-16: ST&I objectives

ST&I Objectives	Description	Why it is important?	Examples
1. Create and deploy commercially viable space capabilities	Investing in specific ST&I that create and demonstrate capabilities for future commercial purposes	- A paradigm shift into New Space - To engage entrepreneurs and private firms in the development of the space industry - Support the diversification effort of the UAE economy	- Remote Sensing and Data Analytics - Innovative Broadband Services
2. Foster space and planetary research capabilities	Develop a solid scientific & technology backbone in all aspects that relate to deep space, planetary exploration and that extends human presence in space for supporting the UAE National Space Program	- Positioning the UAE at the forefront of space and planetary exploration and sciences through collaboration with international agencies - Support Mars 2117 vision	- Mars atmospheric research - ISECG contributing technology and/or component: Autonomous vehicle system management, In Space Timing and Navigation
3. Develop earth science research capabilities	Expand on the existing UAE scientific backbone in all aspects that relates to Earth observation and Geo-Spatial Information	- Environmental monitoring and sustainability are important for maintaining a healthy Earth for generations to come - Contribute to the global efforts in this field	- Climate science - Desertification studies - Ground water studies
4. Transformational space technologies	Build capabilities in developing new innovative and disruptive space technologies	- Disruptive space technologies play a significant role in reducing cost and making space accessible to all	- Space based energy and storage - Disruptive sensor technologies i.e. Miniaturised in-space propulsion, compact sensors i.e. hyperspectral, polarimetry, and sounding wave
5. Develop technologies of high relevance to UAE national strategic interests	Develop infrastructure to nurture technology that are critical and relevant across other strategically important national UAE sectors	- Building key national indigenous technological capabilities - An independent capabilities to access space - Opportunities to provide regional launch services for small satellites	- Propulsion - Launch services - Guidance and control - Cybersecurity

Figure 3-6 is an illustrative chart showing how each of the ST&I areas could relate to multiple objectives. For example, the UAE may desire to develop capabilities in space debris tracking (ST&I area 5), which is not necessary for developing cutting edge research capabilities but is important for national strategic interest (Objective 5) to engage local universities in establishing ground stations to monitor and track re-entry of space debris into UAE's Earth atmosphere. The UAE may also want to develop a technology to decommission and de-orbit satellites at the end of their lifecycle to a 'graveyard orbit' to commercialise the technology (Objective 1).

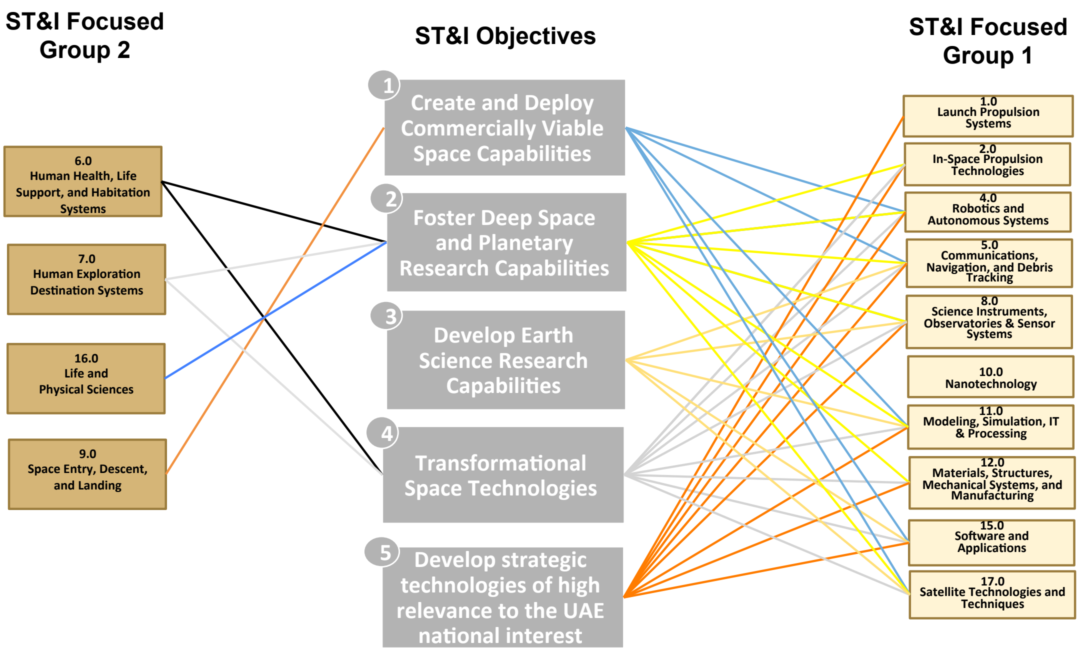

Figure 3-6: ST&I prioritised areas and relation to ST&I objectives - Illustrative

3.5 Discussions and the proposed integrated technology foresight and roadmapping model framework

The purpose of this research was ultimately to conduct preliminary work towards the development of the first ST&I roadmap based on integrating foresight and roadmap techniques and methodologies. A model framework is proposed to operationalise and make the process of developing, updating and executing the ST&I roadmap a routine activity led by UAESA. This study revealed several shortfalls in the initial methodology. It was found important to establish a national ST&I steering committee or forum led by UAESA to bring together and guide space stakeholders into common goals and objectives, and to have shared responsibilities in the implementation of the space ST&I roadmap.

3.5.1 Mitigating shortfalls

There were shortfalls with the methodology adopted to prioritise and develop the ST&I roadmap. These were studied and mitigated to enhance and develop a sound methodology that can be used as a recurring technology foresight methodology to identify and prioritise ST&I topics and to develop a robust ST&I roadmap for the UAE space sector. The following are some of the proposed enhancements relevant to some of the shortfalls:

- The emerging entrepreneurial commercial firms were not included in this research study. The process needs to include firms like Planetary Resources and Deep Space Industry on space exploration and resource mining to enhance the technological scanning and to identify new technological trends that may be overlooked by space agencies due to the nature of their mandates.
- The process needs to engage users of space technologies in shaping the roadmap, prioritisation and project selection process, such as environment, water, oil and municipality/government entities, which were not considered in this study.
- There is a need to monitor and continuously assess the accumulation of capabilities in R&D in order to mitigate any obstacles to the desired goals and objectives.
- The programme and initiatives in the ST&I roadmap need to focus on and invest in applied science and technological prototypes that could lead to commercialisation, and this research study did not go that far in terms of identifying programmes and initiatives as part of eventually developing an implementation plan.

3.5.2 ST&I forum

To structure and sustain the recurring work of the proposed model framework at the national level, it is recommended to establish a steering committee or forum, supported by a project office and expert panel:

- ***The steering committee/forum*:** Establish a steering committee, which needs to set scope, prioritise criteria, and oversee the foresight and roadmapping activities. It may guide and endorse the national ST&I implementation plans. It will recommend policies and guidelines that drive the development of R&D capabilities of prioritised ST&I areas. To recommend and establish separate expert panels to identify technology trends, local and international demands, and critical technologies. To oversee the ST&I implementation plans.
- ***The ST&I project management office*:** To follow up the recommendations set by the steering committee and monitor the execution of the national ST&I implementation plan. To

follow up the work of the expert panels and ensure frequent meetings are organised and necessary reports produced as per steering committee directions.

- ***The expert panels*****:** To support the ST&I scanning, trends analysis and foresight activities, and make recommendations and support the consolidation and prioritisation of various ST&I areas that could be articulated into policies, guidelines and development programmes.

3.5.3 The proposed integrated ST&I foresight and roadmapping model framework

As a result of lessons learned from implementing the methodological approach, a model framework that integrates ST&I foresight and roadmapping is proposed. Figure 3-7 shows the proposed ST&I integrated foresight and roadmap model framework. The following sections describe the five steps of the model framework used to develop and maintain the ST&I roadmap on a recurring basis. The first three steps are covered in detail in this research: 1. Clarify the vision, 2. Scan and identify ST&I trends, 3. Assess existing national capabilities, and 4. Prioritise ST&I areas. Step 5 was discussed to some extent but requires additional information and step 6 was included as an initial thought and is recommended for further research.

Clarify the vision

In 2017 we have seen emerging strategic directions set by the government for the UAE space sector. Therefore, the process starts with an activity to clarify and analyse the national goals and objectives, identify any impact or links with the initial space ST&I roadmap, objectives, programmes and initiatives. Similarly, analyse new goals and objectives set by the government specifically on space. The aim is to identify and articulate new strategic directions.

Scan and identify key technologies/trends

The process then moves to scanning global ST&I trends, and identifying key and critical technologies related to either local or national space exploration and non-exploration missions, including scanning technologies pursued by entrepreneurial commercial firms.

Based on the analysis of global trends, the global ST&I tree is formulated and updated as it was developed, in this case for the UAE as result of this research. However, the tree needs to be maintained by adding new ST&I areas, components and subcomponents. For example, while finalising this research work, I found water propulsion is considered a potential technology by leading space resource mining firms, and the electrical motor drive is a potential for Mars human flight missions. Neither technology was included in the global space ST&I tree. Therefore, both technologies need to be listed as components in the in-space prolusion area (ST&I area 2).

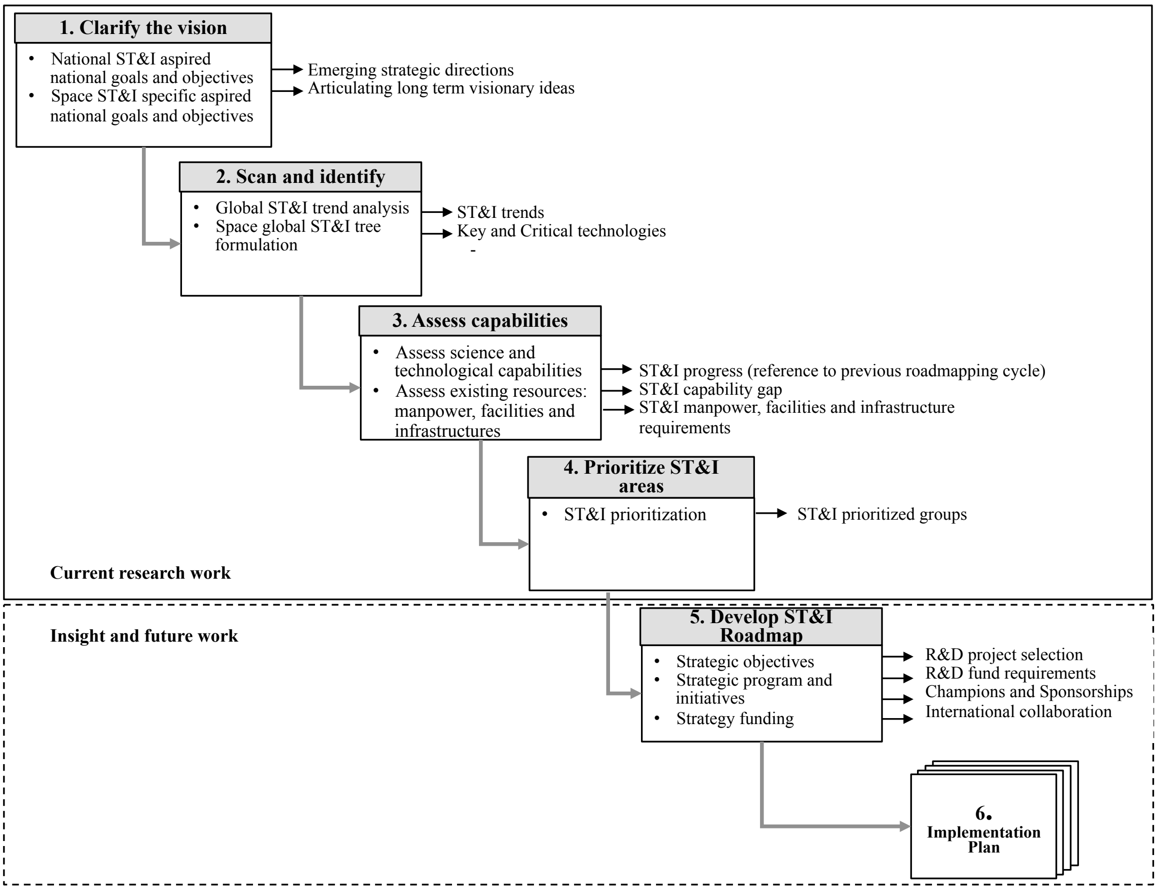

Figure 3-7: The proposed integrated framework

Assess capabilities

Science and technology will continue to evolve, and the performance gap needs to be assessed periodically. In this research, an initial capabilities assessment was conducted and analysed. In this step, an annual assessment needs to be conducted to monitor the capabilities build-up across all areas, but in particular in the ST&I areas that have national interest. For prioritised ST&I areas with national interest the aim should ensure there is sound progress made in accumulating indigenous capabilities in these areas. In other areas an effort should be made be to shift closer to the frontier and in other areas at least an incremental improvement should be made to close existing R&D capability gaps.

The requirement and gaps for manpower, facilities and infrastructures needed by local universities and research centres to increase or introduce new R&D activities needs to be identified. In this research, these gaps were not assessed and subject for future research study.

Prioritise ST&I areas

It is proposed that prior to engaging in foresight activities, the ST&I objectives need to be revisited by a steering committee. As highlighted earlier, the TRM looks to society in broader contexts and innovation is discussed as a potential to change society, i.e. users of technologies, (Yokoo and Okuwada, 2013). Therefore, new emerging directions needs to be accommodated into the process to develop or update the ST&I roadmap and to revisit the prioritisation accordingly.

In this research study, an initial national direction was solicited and incorporated into the prioritisation process but this is a continuous process since we live in a very dynamic world and technology and innovation evolve rapidly. The method adopted in the prioritisation process addresses key and critical technologies but the process does not actually identify the need or engage the potential local or regional users, such as water, oil and gas, or government authorities. In order to have the highest relevancy to industry, it was found that engaging the industry community such as satellite operators, manufacturers and users of space applications such as environmental, water, oil and municipality government entities is required. This is pivotal to ensure the highest relevancy of the R&D emerging from ST&I roadmap that serves both the industry and users.

Technological foresight exercises require eliciting expert views (Wonglimpiyarat, 2006). The network of contacts could include members of a panel of experts coming from relevant local and international organisations. The formal network of contacts could come from the targeted entities, which need to respond to the science and technology capability assessment survey to identify technological capability, R&D manpower and infrastructure gaps. The recurring survey aims to continuously assess the capability developments, primarily by local universities and other space actors investing or engaging in R&D-related space ST&I topics.

The main deliverables of steps 1, 2, 3 and 4 are: an ST&I prioritisation map which groups areas into a set of criteria discussed in the previous sections, a global ST&I space tree and understanding the existing and accumulated capabilities across local universities, research centres, satellite operators and relevant industries. However, the ST&I roadmap cannot be completed without having a mechanism to communicate the strategic objectives to guide stakeholders into common goals and objectives, and to emphasise the responsibilities needed to implement the R&D programme with specific initiatives that need to be implemented over the short and long term in the form of an ‘ST&I Implementation Plan’.

Structure the ST&I roadmap

To complete the work, the ST&I roadmap needs to be structured to ease communication and to ensure a common vision and objectives among stakeholders. Therefore, it is recommended to adopt a mechanism that is familiar to the main stakeholders in the UAE. A mechanism was recommended to structure the ST&I roadmap to set strategic objectives, programmes, specific projects, and identify key measures and targets to monitor the progress on a recurring basis (refer to Figure 3-6). The measures and targets are important to be defined and monitored to ensure that the development and accumulation of R&D capabilities are achieved over time. The ST&I roadmap objectives were defined in this research, but the programme, initiatives, measures and targets were not addressed.

R&D projects need to be selected, defined and planned for implementation over the short and long term in coordination with local universities, research centres and relevant satellite operators. In this research, the work did not solicit R&D projects since it is beyond the scope of this research. However, the ST&I research activities need to either introduce a new activity, fill an existing capability gap or shift the technological frontier.

The ST&I implementation plan

The implementation plan is a portfolio of R&D projects that are recommended after consultation and endorsement from the steering committee (see previous section) and will be implemented over the short and long term. The implementation plan will include an estimated budget and resources or facility needs. The implementation of the roadmap requires periodic monitoring and feedback. This is necessary to ensure each cycle of foresight and roadmapping activities is continuously enhanced through identifying gaps measured by a set of key performance measures.

3.6 Discussion and conclusion

The objective of this paper is to address the technological foresight and scanning techniques and methodologies used to identify ST&I priorities and opportunities for the UAE space sector to develop the first space ST&I roadmap. This research forms a baseline to develop a structured and integrated foresight roadmapping model framework to develop the UAE's space ST&I capabilities over the short and long term. In this research, we generated a number of important propositions and insights, which will lead to an improved understanding of the requirements for a sound approach to an integrated ST&I foresight and roadmapping model framework and a robust space ST&I roadmap.

Implications

The proposed model framework supports the effort to identify and prioritise the most important ST&I areas for the UAE space sector. This was achieved by adopting a unique approach to analysing and identifying foresighted technologies currently pursued by international organisations active in both space exploration and non-space exploration missions. Accordingly, this work leads to the development of a global space ST&I tree. Then, the most important ST&I topics were identified, categorised and prioritised for the first time for the UAE space sector. This was achieved after reviewing and assessing the current R&D capabilities, and understanding national requirements to build and accumulate capabilities on specific ST&I topics related to space.

Through this baseline work, the UAESA can identify, define, execute and measure the success of its own programmes and their applicability to meet today's and future space needs. Other smaller developing nations entering into the space sector could benefit from the proposed methodology as well. Every element of this work is novel for the UAE.

Challenges

Several shortfalls and challenges were identified throughout the research. These were mitigated and enhancements were incorporated into the proposed integrated foresight and roadmap model framework (Figure 3-8). Two challenges were identified during the development process:

- Despite availability of the national ST&I policy for the UAE, there were no guidelines available directing the various sectors on how to prioritise topics of space ST&I topics and R&D activities.
- There was no available technology roadmap that we are aware of that was developed by any of the space stakeholders in the UAE.

Several challenges were identified during the assessment of existing capabilities:

- Stakeholders are not utilising or sharing R&D and manufacturing infrastructures, which are pivotal factors to success and to optimise resources in small countries such as the UAE.
- Low levels of investment by industry in R&D activities and development of future technological products.
- Lack of coordination between universities, satellite operators and manufacturing/industry and other space actors.

- Lack of communication between universities and not being aligned to a common vision, which is pivotal for the success of joint efforts to scale up the national technological frontier level.
- It is expected that during the execution phase, the main challenges will be maintaining engagement of the main space actors and sustaining the management of ST&I roadmap and its outcome as articulated in the implementation plan.

Limitations

To have priority ST&I areas that have a high relevancy to both national direction and industry needs, it is necessary to understand society and local space technology and application user requirements such as water, oil and gas, and government authorities. However, in this research, users for potential space technological products and applications were not included.

Future research

Further research was identified that could be articulated into four research projects using the following research questions:

- How could the UAE achieve its ambitious goals and sustain the development of its high technology satellite sector given limited university, research centre and human capital resources?
- What is the role of education? How could local universities support developing the space sector? How could the UAE attract locals into R&D fields?
- How could the UAE select and shape its future space exploration missions to sustain the development of its space sector? What are the criteria and methodology for selection? And how it could be linked to ST&I prioritisation and roadmap?

CHAPTER 4 A Technology Transfer Model for the UAE’s Satellite Sector

A technology transfer model for the UAE’s satellite industry

Khaled Al Hashmi[5]

Abstract

In an attempt to improve and maximise benefits that could be gained from technology transfer (TT) programmes in design and manufacturing, assembly, integration and testing of satellites (MAIT) in emerging space countries, a conceptual framework model is proposed. The model encompasses factors that need to overcome the numerous challenges and barriers believed to impact the effectiveness of the TT processes and desired national outcomes. The model is based on empirical research undertaken on four case studies, previous TT models in the literature, and on a review of key literature in this area. The model’s architecture consists of factors that are grouped into one outcome and two driver perspectives, these are the high order themes derived from the empirical work. The outcome perspectives refer to factors related to maintaining stakeholder and management expectations, which is an overarching theme. A knowledge transfer internal process called *indigenous generation mechanism* and resource perspectives, consists of individual and organisational factors that act as drivers. The model acts as a guideline to identify the factors needed to ensure TT programmes are set up appropriately, and to identify desired knowledge to be acquired, articulate the execution of transfer programmes, and integrate within organisations. The model confirms the need for a set of technological capabilities, skills and competencies from each TT programme to achieve national objectives needed to sustain technological development of satellites. Limitations of this study as well as policy and management implications are highlighted. This study significantly fills an existing literature gap regarding TT to emerging space countries in the satellite development process and it extends knowledge on the United Arab Emirates in particular.

Keywords: Technology transfer, satellite, indigenous capabilities, space emerging countries.

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4.1 Introduction

Developing countries are realising the importance of space not only to diversify their economies but also to improve their access to satellite data to enhance resource management, citizens' health, land usage and security, and to monitor and recover from disasters (Ercan and Kale, 2017). Wood and Weigel (2011) addressed arguments whether developing countries need only utilise and share data available elsewhere instead of procure or build their own satellites. Some developing countries that are emerging space countries pursue their own goals to build their indigenous capabilities in the design and manufacturing, assembly, integration and testing (MAIT) of satellites, leveraging international partners for transfer of technology and know-how (Wood and Weigel, 2012a). Indeed, transfer of external technology and knowledge is a common innovation pattern adopted by developing countries to acquire productive knowledge and to accumulate capabilities, as in the case of the UAE in developing its satellite MAIT sector (Al Hashmi, 2016).

Technology is not a piece of kit or equipment and it is more than an exchange of artefacts (Amesse and Cohendet, 2001). Technology refers to the productivity knowledge of design, assembly and testing that is embedded into production of technological products (Hausmann et al., 2012). This productivity knowledge, which is tacit in nature, exists in the mind of individuals working within organisations, which confirms the complexity of technology being transferred. Therefore, this paper addresses two research objectives, namely:

1. To investigate challenges and barriers facing emerging space countries when executing technology transfer (TT) programmes in design and MAIT of satellites.
2. To develop a conceptual framework model to guide the management of TT programmes of complex products such as satellite development processes.

The paper attempts to reveal the limited information on the challenges and barriers facing emerging space countries in the transfer of technology and know-how on complex technological development production processes related to the design and MAIT of satellites. The paper discusses strengths and shortfalls of several TT models (Nonaka and Takeuchi, 1995, Gilbert and Cordey-Hayes, 1996, Hill, 1989, Team, 1987, Baskaran, 2001). It offers a comprehensive conceptual framework for the management of TT projects to build and sustain the development of indigenous capabilities over time, leveraging existing and future transfer programmes.

The model is based on an initial synthesis of literature related to the TT models, processes, management and insights from the empirical evidence. The empirical evidence is gathered from the four case studies through in-depth semi-structured interviews that were conducted with management and technical staff engaged in TT programmes related to satellite development in the United Arab Emirates (UAE). These programmes were executed in collaboration with international partners from South Korea and the USA.

This research contributes to the knowledge base by filling an existing gap in a rarely researched topic related to transfer of technology and know-how of satellite MAIT to emerging space countries. It also broadens the knowledge base on the UAE as an emerging space nation and on its efforts to develop and upscale its indigenous satellite and spacecraft MAIT capabilities through international collaboration to transfer know-how.

The second section of the article provides an insight regarding the importance of investment in space technologies by developing and emerging space countries. The third section provides theoretical background to this area of study. In section four we present the empirical research design and data collection, briefly elaborating on the case studies. In section five, we present the results by reflecting on important examples and insights from the case studies. Section six addresses the proposed conceptual model. Section seven discusses important implications to policy and management of TT. Finally, in section eight, we offer a concluding remark.

4.2 Why should developing countries invest in space technologies?

Wood and Weigel (2011) addressed the scholarly debate on whether developing countries should have a satellite development programme or buy satellites and share data from other sources. Regardless of these arguments, we can agree that space technologies bring important benefits to countries and people worldwide. Space is no longer confined to space exploration and scientific research. Space technologies provide navigation and positioning data that we use and rely on in almost every aspect of our daily lives, such as when we travel between destinations via air, sea or land and in the future through driverless cars and 'taxi' drones. We obtain Earth observation (EO) data from remote sensing satellites that we use to monitor natural disasters and identify areas in need of humanitarian aid (Esterhazy, 2009). Also, through EO satellite data, we manage food security, and enhance the management of natural resources and infrastructures (Jason et al., 2010) such as transport systems to facilitate the mobility of people. Space technology supports countries to build capacity in science, technology and innovation (ISECG, 2013b, Leloglu and Kocaoglan, 2008). Space is a high tech profile sector, and has the ability to motivate and inspire new generations into science, mathematics and technology (Esterhazy, 2009). These are some of the socioeconomic and open access benefits brought to the knowledge-based economy (Amer and Daim, 2010, Wood and Weigel, 2011).

As a result of realising the benefit of space products such as EO satellites and applications, countries want to move up the value chain to diversify their economies and develop a new set of competitive capabilities in technological frontier products, such as in building capabilities in satellite development, but it is not without its challenges. Space is becoming crowded with government and commercial satellites making available a wide variety of data and services, especially on EO satellites. From another aspect, space assets are expensive and require high multiple-year investments to replenish assets in space and operate and maintain ground infrastructure.

However, quite a number of developing countries "located in geographic regions that experience a disproportionately large amount of natural disasters" (Wood and Weigel ,2012a) – cyclones, earthquakes or volcanoes – have more vulnerability and difficulty during recovery. Jason et al. (2010) disscussed the limitation of timely access by developing countries to different types of accurate data. Developing countries can realise the benefit of space only if they have timely information about the state of their environment, transport system, agriculture and infrastructure. These and other facts have led governments in developing space countries to pursue investment options of producing their own satellites and data and/or using available data.

4.3 Literature review

4.3.1 Satellite development process and its relation to knowledge transfer

Satellite development is complex and requires multiple year investments to maintain ground infrastructures and satellites. Unless the first satellite is utilised significantly, the investment will not be attractive. It takes five to seven years to develop a satellite. This introduces a challenge in creating and retaining highly skilled engineers and professionals to build and accumulate local capabilities through this long production period. It is a challenge since most of the productivity knowledge of complex products is from tacit knowledge which is contained within the minds of people and organisations and can be difficult to transfer (Hausmann et al., 2012).

A typical satellite project lifecycle or development process, based on NASA's generic approach (Zhang et al., 2015), is divided into two major phases and six project phases, as shown in Figure 4-1. It covers the development process from concept identification to project completion. The project phases provide an orderly and rigorous process to ensure development activities are considered and key project decisions are made in a timely manner. Tacit knowledge is considered significant throughout the lifecycle of the satellite development process, in particular in the formulation phase.

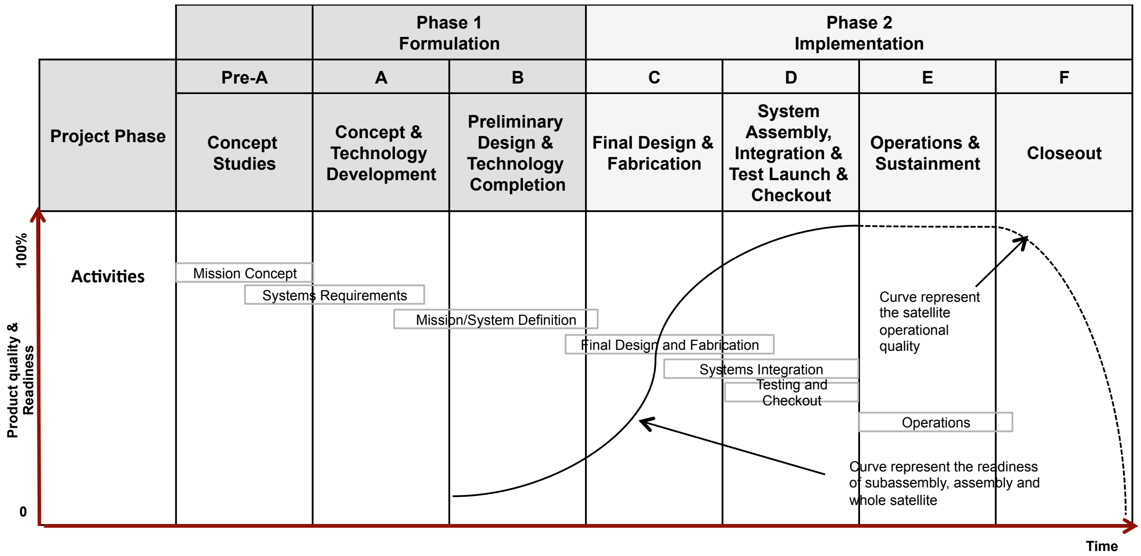

Figure 4-1: Satellite design, manufacturing, assemsbly, integration and testing lifecycle

The concept and technology development phases A and B consist mainly of tacit knowledge where the satellite concept and alternatives on new technology are defined and assessed. In this phase is where innovation ideation takes place: develop mission concepts, draft system-level requirements, and identify potential innovative technologies at a high level such as instruments and sensors to collect unique science data to meet the missions' scientific objectives.

Open innovation must take place at the phase pre-A where lead scientists discuss objectives with broader science community members such as Mars Exploration Programme Analysis Group (MEPAG) (JPL, 2017). Engineers, on the other hand, identify innovative technological solutions to collect unique scientific data. However, Mars mission projects are more complex and differ from low Earth orbit (LEO) or geostationary Earth orbit (GEO) missions as an example, since a 'launch window' for spacecraft opens up every two years for only 14 days

(Preisler et al., 2012). During this period Mars is at its closest proximity to Earth, which allows spacecraft to capture its orbit with lower energy requirements.

Unless space exploration projects start early and allow for development of innovative products such as remote sensors or in-space propulsion, the funded organisations would prefer to use as many heritage components as possible to reduce risks of mission failures. In return, this could affect and limit the generation of innovative ideas to modify and upgrade existing components. In phase B, the satellite is still in its conceptual form, and the design team refines system architecture and operations concepts and investigates alternative components, and interior and external layout. Once the top requirements are identified, technology developments are identified and risk-assessed. In this phase, the preliminary project management and engineering plans are established.

In Phase 1, tacit knowledge is the main feature used for the architecture of the satellite. In this phase, concepts, new ideas and technologies are integrated into the new satellite. However, satellites are complex since each one has unique concepts and architecture since there is no standardisation. During this phase an environment must be created which encourages the implementation of thoughts and new ideas into the development of the satellites.

In implementation phases C and D, this is the explicit domain of the satellite development process. Engineers are trading more with explicit, rather than with tacit, knowledge during these satellite development phases. In phase C, the detailed design of the satellite is completed at all levels. Production of all components including hardware and software and testing engineering models is completed. Selected critical items are pre-qualified. The plans for the assembly, integration and final testing of the system and its parts are finalised.

In phase D, the AIT of flight hardware and software and associated ground hardware and software are completed. Qualification testing and associated verification activities are completed. In this phase, the satellite development is mature, which is also illustrated through the steep increase of the curve as shown in Figure 4-1 by the end of Phase 1. In this, phase interoperability testing between the space and ground segments is completed and the satellite is prepared for flight.

As the development of the satellite progresses from concept to system assembly, integration and testing, the overall subsystem and systems of the satellite reach a high level of quality prior to launching the satellite. The satellite is limited in the number of years it can operate and its functionality starts to degrade whereby the project comes to a close.

4.3.2 Overview of international technology transfer

Distributed productive knowledge is available in the minds of people and embedded into the production of products (Hausmann et al., 2012). Technology is defined as the specialised knowledge needed to produce products and services (Hawkins and Gladwin, 1981). It is cumulative in nature pertaining to characteristics and information related to production processes and product designs (Liu, 1995).

Technology transfer is defined as "the movement of know-how, technical knowledge, or technology from one organizational setting to another" (Bozeman, 2000). For developing countries to advance a new industry such as satellite MAIT, it requires an accumulation in the amount of productive knowledge within their organisations. Transfer of external knowledge is a common feature adopted by developing countries to acquire productive knowledge and accumulate capabilities as in the case of the UAE's satellite sector (Al Hashmi, 2016).

Technology transfer is a common innovation pattern used by developing countries as a tool to accumulate capabilities from external sources (Al Hashmi, 2016). It initially adopts, acquires and imitates technologies developed elsewhere. It then gradually shifts to innovation where it attempts to produce complex technological products (Collins, 2015). The conversion from imitation to innovation is not straightforward (Acemoglu et al., 2006) and requires structural changes in the patterns of interaction inside an organisation (Hausmann et al., 2012), especially by the receiver of the technology. The success of innovation conversion is conditional on availability of institutional knowledge accumulated from tacit knowledge, equipment and instrumentation (Malerba et al., 1997, Etzkowitz and Leydesdorff, 2000, Malerba, 2005, Fassio, 2015).

The transfer of technology is organised on economic activity and the development and production of complex products such as satellites. It includes the transfer of the knowledge and skills required to manage a set of interrelated and technical processes (Hawkins and Gladwin, 1981). Developing countries and firms face challenges and barriers when transferring, acquiring and reassembling the distributed knowledge within an international partner. Knowledge is a result of accumulation of information, experience, expertise and R&D activities (Madu, 1989). The extent to which developing countries can benefit and effectively transfer technology is dependent on the extent receivers understand new technological developments (Nelson and Nelson, 2002) and on their ability to absorb capacity through exploitation of external knowledge, assimilation and application (Cohen and Levinthal, 1990).

4.3.2.1 Objective and management of technology transfer

The objectives of TT are diverse and it means different things among pioneering spacefaring countries (Hertzfeld, 2002b) and emerging space countries that are a distance from the technology frontier. Active firms in countries that are within close proximity to the technological frontier have the ability to take advantage of external knowledge due to their existing innovation structure (Antonelli and Fassio, 2015), absorbed capacity and accumulated capabilities to produce complex products (Hausmann et al., 2012). Therefore, for pioneering or technological frontier space agencies such as NASA (Zhang et al.), ESA and CSA, TT is used to encourage commercial use of advanced technologies to justify expenditure of public money and to augment their return on investment in space missions (Venturini and Verbano, 2014, Hertzfeld, 2002b) through transfer of technologies from an Earth technology to be used in space (spin-off or spin-in) (Amesse et al., 2002, Chambers and Price, 1995, Hollingum, 2001, Hertzfeld, 2002a, Pankova, 2002, Goehlich et al., 2005, Venturini et al., 2013).

However, countries that attempt to catch-up with little absorptive capacity and lower accumulated requisite capabilities, i.e. productive knowledge needed to develop complex products (Hausmann et al., 2012), will be unable to capitalise on new acquired knowledge and will fall further behind (Altenburg et al., 2008). These countries that fall behind the frontier, unless there are policies in place to restore absorptive capacity in education and R&D (Aghion and Jaravel, 2015), could grow at the same rate as the frontiers and the gap that separates them from the frontier will be stable (Aghion and Jaravel, 2015). Only a few developing countries that took steps to establish their space agencies (Ercan and Kale, 2017) were able to emerge as space emerging countries, e.g. South Korea, Iran, Turkey, the UAE and Indonesia, with their own major space projects and programmes (Moltz, 2015).

Based on their empirical work, Wood and Weigel (2012a) provided insight on the evolution of satellite programmes and the common approach adopted by emerging space countries to catch up with the frontier countries by increasing their level of technological capabilities in the production of satellites. Wood and Weigel (2011) present a stepwise approach called a space technology ladder, as shown in Table 4-1. Emerging space countries climb the rungs to increase their technological capabilities, as shown in Figure 4-2 for India, South Korea, Malaysia and the UAE. These countries first procured satellites with limited transfer of knowledge, then

Table 4-1: Space technology ladder – UAE milestones

Ladder	The Space Technology Ladder	UAE Milestones
20	Crewed Spacecraft: Build Locally	
19	Crewed Spacecraft: Build through Mutual International Collaboration	
18	Uncrewed Spacecraft: Build Locally	
17	Uncrewed Spacecraft: Build through Mutual International Collaboration	
16	Launch Capability: Satellite to GEO	
15	Launch Capability: Satellite to LEO	
14	Exploration Spacecraft: Build Locally	
13	Exploration Spacecraft: Build through Mutual International Collaboration	2020: 'The Hope'
12	Exploration Spacecraft: Build Locally with Outside Assistance	
11	GEO Satellite: Build Locally	
10	GEO Satellite: Build through Mutual International Collaboration	
9	GEO Satellite: Build Locally with Outside Assistance	
8	GEO Satellite: Procure	2000: Thuraya 1st Satellite
7	LEO Satellite: Build Locally	2017: KhalifaSat
6	LEO Satellite: Build through Mutual International Collaboration	
5	LEO Satellite: Build Locally with Outside Assistance	2013: DubaiSat-2
4	LEO Satellite: Build with Support in Partner's Facility	2009: DubaiSat-1
3	LEO Satellite: Procure with Training Services	
2	Space Agency: Establish Current Agency	UAE Space Agency
1	Space Agency: Establish First National Space Office	

proceeded to build satellites with partial activities taking place at their facilities before they commenced building satellites independently at local facilities with limited outside assistance.

In this research, TT is considered as a one-way approach to transfer knowledge from an international donor country/firm to a receiver country/firm. As noted by Buratti and Penco (2001) the receiver benefits and gains new technology from the donor through the condition of contracts, patents, license agreements, etc. The common feature for emerging countries to scale up their space technological ladder is through having multiple TT programmes consisting of several projects with either one or multiple international partners, such as is the case of the UAE, Algeria and Nigeria (Wood and Weigel, 2012b, Al Hashmi, 2016).

The work of Wood and Weigel (2011) is aligned with the point made by Cohen and Levinthal (1990) that technological development is dependent on the actual absorptive capacity of the adopter country. An increase in the level of absorbed capacity leads to technological changes and increases the level of technological capabilities, which is needed to progress through the space technology ladder. During early phases in building and accumulating capabilities, it is

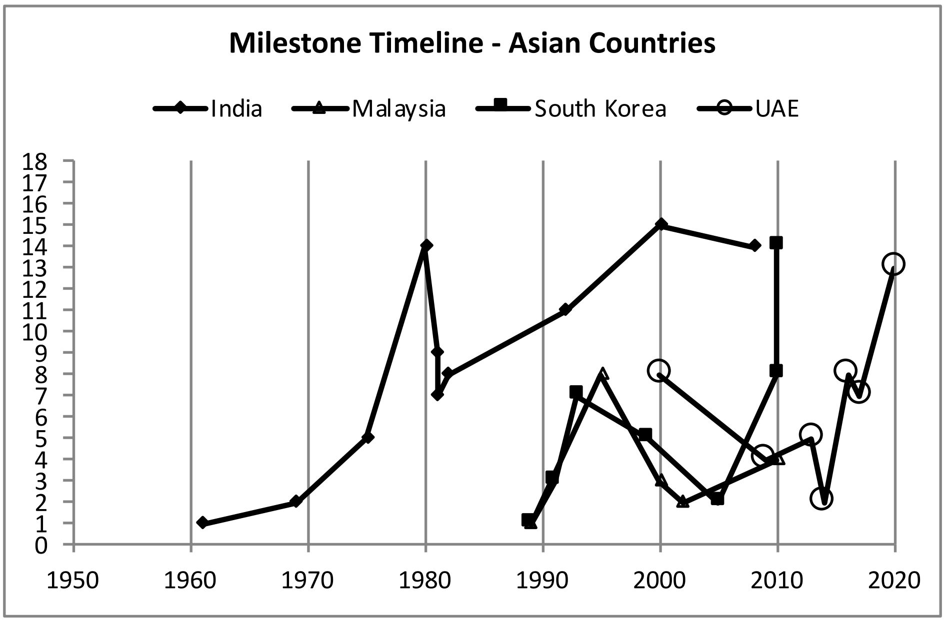

Figure 4-2: Space Technology Ladder - Asian Countries

crucial to benefit from technology imitation to increase the level of technological capabilities (Archibugi and Pietrobelli, 2003, Archibugi and Coco, 2004, Bell and Pavitt, 1992) and knowledge base (Malerba and Orsenigo, 1996, Malerba et al., 1997, Breschi et al., 2000, Adams et al., 2011, Madu, 1990). As in the case of the UAE, during early procurement and production of satellites the focus was on transfer and imitating technologies developed somewhere else (Wood and Weigel, 2012b, Al Hashmi, 2016).

The technology receiver needs to generate a corresponding rate of technical change, otherwise it will not benefit from transfer of knowledge and the gap between the technology receiver and the world technology frontier will continue to widen (Madu, 1989). Nelson and Phelps (1966) argue that when the labour force adopts new technologies faster, it enables firms to close the technological gap. In fact, Acemoglu et al. (2006) state that the economy, in this case the economy of the satellite sector, will fall into a conversion trap if the knowledge base is not enhanced and the sector will not benefit from investment in building technological innovation capabilities.

It seems some late emerging space countries have taken advantage and transferred technologies developed elsewhere. This increased their rate of technical change, as explained through the space technology ladder through the case of UAE which is currently developing the Khalifa Satellite in-country and a deep spacecraft to reach Mars (Al Hashmi, 2016). However, there is scarce literature to addresses the challenges and barriers facing emerging space countries and success factors in the transfer of knowledge on design and MAIT of satellites. The literature is lacking information on how these countries structured the build-up and accumulation of technological capabilities that enabled them to upscale their space technology ladder or national technological frontier level. There is a dearth of information on how these countries are sustaining their satellite development activities based on utilising local institutions, facilities and people.

Based on the template analysis of the literature, this study initially developed a typology to explore the nature of TT. Figure 4-3 shows the initial typology structured into four branches and consists of factors related to: 1. TT barriers, 2. TT challenges facing transfer of knowledge between international partners, 3. TT success factors and 4. methods and mechanisms for transfer of knowledge. The factors can be further grouped into themes as shown and highlighted in colour and in Table 4-3 in first column, factors related to stakeholder management expectation, routine, resources and external factors, which are identified as main themes in the initial template analysis. The following sections discuss TT challenges and barriers.

4.3.2.2 Technology transfer challenges, barriers and success factors

Technology transfer between international partners having different organisational cultures, people and routines is considered knowledge intensive and problematic. There are a number of factors that influence the success of knowledge transfer for product development, including satellites (Ramesh and Tiwana, 1999, Davenport and Prusak, 1998, Nonaka and Takeuchi, 1995, Madu, 1989). Transferring external knowledge needs significant efforts to be made within and beyond the organisation covering the local suppliers (Madu, 1989) of technology and other actors in a sectoral innovation system (SIS). This research did not cover challenges facing the whole space SIS but is limited to challenges and barriers facing developing countries when receiving transmitted knowledge from an international partner through an international mutual collaboration to transfer technology.

Organisations have different communications styles and differ in organisational culture (Kumar et al., 2007). This could cause a mismatch in expectations and understanding between the donor and receiver of technology (Fazal et al., 2017). Some governments impose protection on their indigenous technology and transfer of know-how through different means such as export control (Raz et al., 1983, Sikka, 1996). As an example, the International Traffic in Arms

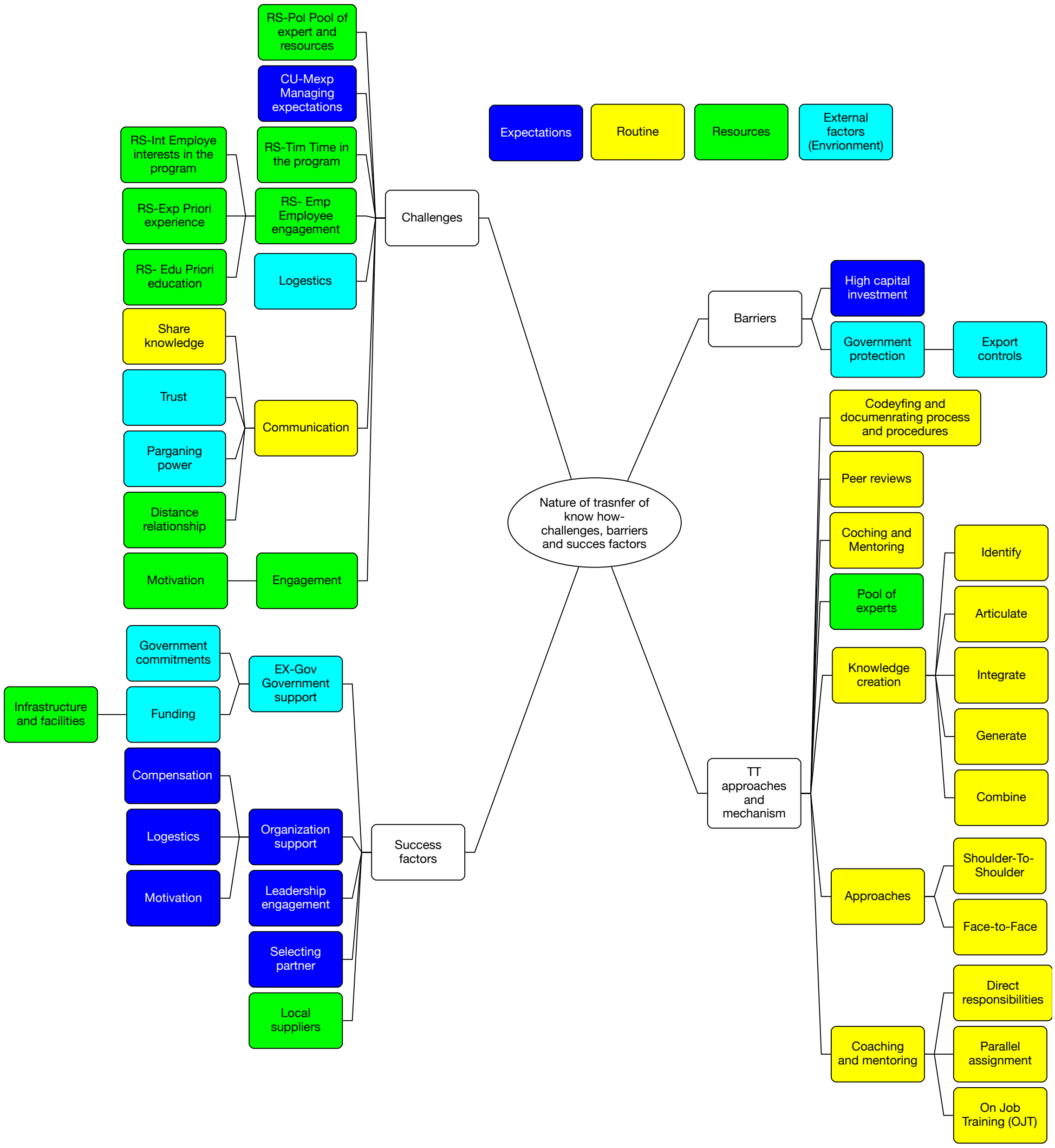

Figure 4-3: Initial typology – Nature of technology transfer

Regulations (ITAR) is imposed by the US government on systems and subsystems related to satellites (Suzuki, 2013) such as on star tracker and in-space propulsion systems. This introduces challenges such as management of stakeholder expectations (Gerrard, 1997, Moody and Dodgson, 2006), and logistics issues between senders and receivers, which could mean an inability to achieve objectives (Wood and Weigel, 2013) to transfer specialised technology and knowledge.

Organisations tends to manage their own knowledge (Jones and Jordan, 1998). In development projects that have an element of international technology transfer, information is gathered, processed and transferred not only between individuals and groups within the sender but also to receiver organisations. Knowledge transferred through a social interaction is called a ‘knowledge conversion’ by Nonaka and Takeuchi (1995). If both parties have previous collaboration experiences and personal connections it eases TT and diffusion (Lasserre, 1984).

A partner having similar prior experience in transferring technology is likely to enhance communications with the receiver and accelerate their learning curve (Lin and Berg, 2001) and reduce transfer costs (Reddy and Zhao, 1990). Establishing effective and formal communication increases trust between both parties (Lin and Berg, 2001, Malik and Bergfeld, 2015, Weiss, 2005). On the other side, an experienced transmitter of technology tends to increase its bargaining power to protect the transfer of its core technologies (Liu, 1995); therefore, selecting a partner is critically important.

There are important factors noted by Szulanski (1996) which are key issues that influence and act as barriers to transfer of knowledge, such as receivers’ lack of absorptive capacity and lack of retentive capacity. Interdependency between partners and active use of absorbed knowledge from receiver organisations influence success of knowledge transfer. People tend to acquire new knowledge by the active re-creation and organisation of their own experience (Polanyi, 1978). This is achieved through different mechanisms and approaches. Shoulder-to-shoulder and face-to-face (Brown and Duguid, 1991, Dougherty, 1992) are examples of successful approaches to articulate knowledge between individuals and within organisations (Nonaka and Takeuchi, 1995).

The receiver country or firm cannot benefit from international TT programmes by merely being exposed to them. Hence, distance between teams is considered a disadvantage due to the lack of individual exchange becoming a challenge to absorb knowledge (Amesse and Cohendet, 2001). Receivers’ lack of motivation (Szulanski, 1996) and an senders’ unwillingness to share information or take risks (Inkpen, 1998, Malik, 2002) when giving direct responsibilities to receiver engineers are some of the issues that impact transfer of knowledge. If individuals from receiver organisations are engaged and motivated, and individuals from sender organisations share knowledge, then transfer of knowledge will take place. These challenges influence the receivers’ ability to absorb and assimilate knowledge (Reddy and Zhao, 1990, Boer et al., 2002).

4.3.2.3 Overview of technology transfer models

Researchers present a diverse number of technology/knowledge transfer models and look into the TT phenomenon from different aspects and areas of interest. In this research study, the focus is on TT models pertaining to production process-related technologies between an international partner and partner in a developing country.

The transfer object is not only the product but also the knowledge of its use and application and what is challengeable is demarcating the transfer object from its environment (Bozeman, 2000). Technology Atlas Team (1987) defined four knowledge carriers or knowledge elements regarded as objects of technology transfer: Orgaware, Humanware, Technoware and Infoware. Technology transfer means the flow of these elements between organisations and individuals (Szakály, 2012).

The limitations on the number of TT models stems from a lack of taking a holistic national view. It lacks incorporation of an objective, identification of the type and extent of productive knowledge needed to accumulate, innovate and shift the national technological frontier and the adopted approach to sustain developments. It lacks the integrating transfer steps and mechanisms, or approaches used to share the knowledge between individuals, and within organisations.

For example, the model proposed by Nonaka and Takeuchi (1995) and Gilbert and Cordey-Hayes (1996) (see Table 4-2) lacks identification of required resources and infrastructures. It lacks a step to identify appropriate technology to match the resource infrastructure of the receiver country. This is addressed by Hill (1989) in his manufacturing strategy model for international transfer of technology. As pointed out by Hausmann et al. (2012), it is easier for a country to reuse what they already know by adding a modest amount of productive knowledge as it moves into a new or related industry. The model proposed by Hill (1989) is more sophisticated. It attempts to map the fit of the corporate objectives and manufacturing strategy factors for the receiver with the embodied knowledge in the intended transferred technology. It also considers how these factors are integrated. Hausmann et al. (2012) state that accumulating bits of productive knowledge will make little sense if industries that require it are not present or if a market is not present. Bommer et al. (1991) extended Hill's model to encompass the purpose and the mode of the transfer such as transfer of proprietary rights, and environmental/external factors such as economic issues, laws and political issues to assure appropriate conditions of the receiver country.

Table 4-2: Technology Transfer models: Process, steps and features in previous studies

	Nonaka and Takeuchi (1995)	Gilbert and Cordey-Hayes (1996)	Technology Atlas Team (1987)	Hill (1989)
Components /steps	SECI model is based on four modes of knowledge conversion: - Socialisation [S] - Externalisation [E] - Combination [C] - Internalisation [I]	The model consists of four steps: - Acquisition - Communication - Application - Assimilation	The model is based on four basic components of technology - Technoware - Humanware - Inforware - Orgaware	The model is based on four major components of technology - Corporate objectives - Marketing strategy - Order-wining criteria - Manufacturing strategy
Features	Focuses on how tacit knowledge is communicated, transferred and converted to explicit knowledge	Similar to Nonaka and Takeuchi (1995), focuses on how tacit and explicit knowledge are transferred, new knowledge generated and diffused	Identified specific factors to map out the fit between transfer of a technology and factors related to receiver country such, as infrastructure	A manufacturing strategy model which incorporates international transfer of technology

However, these models do not encompass organisational environmental success factors required to overcome challenges and barriers, which is discussed in previous sections such as engagement of people and leadership, and institutional infrastructures. It seems the model proposed by Gilbert and Cordey-Hayes (1996) follows what Nonaka and Takeuchi (1995) found: knowledge is created once tacit knowledge is transferred to explicit knowledge through a 'knowledge conversion' process. In other words, knowledge conversion takes place once 'internalisation' or, as stated by Gilbert and Cordey-Hayes (1996), once conversion leads to development of a 'set of routines' or once 'operationalisation' of knowledge has taken place. According to Gilbert and Cordey-Hayes (1996), this process takes place through 'communicating' the knowledge through 'acquisition' of knowledge. This is followed by 'creation of knowledge', which takes place once knowledge is converted through 'socialisation', and 'communication' of tacit knowledge in the form of shared experience and 'skill sets'. Knowledge is created once individuals 'articulate knowledge' where they convert tacit knowledge into explicit concepts, i.e. 'externalisation'. Both models have strength on 'knowledge creation' as articulated and emphasised by Nonaka and Takeuchi (1995) on the 'application' and 'assimilation' of knowledge steps, and by Gilbert and Cordey-Hayes (1996) on 'internalisation' of knowledge steps.

The aim of knowledge transfer is to create a learning organisation (Malik, 2002, Levin, 1997). We know that most of the knowledge is 'tacit knowledge' which constrains the development process. It is hard to transmit and acquire since "it comes from years of experience more than from years of schooling" (Hausmann et al. (2012). It is hard to communicate and articulate since it requires structural changes and changes in the patterns of interactions inside an organisation. It is even harder when knowledge is transmitted between two international partners. It depends on the involvement and commitment of engineers to receive productive knowledge or capabilities, which are modularised at the level of individuals when engaged in transfer of knowledge projects. People recreate and organise their own experience (Polanyi, 1978, Polanyi, 1966) and articulate and codify the knowledge they acquire. Then, these individuals make structural changes within their organisations when they communicate within their organisation. This means explicit knowledge is created by tacit knowledge and vice versa.

Howells (1996) argued if tacit knowledge is liable to codification, then it can be transferred between individuals or groups in a more structured and become an 'organisational routine'. This is in line with the point made by Nonaka and Takeuchi (1995) that knowledge is created by means of social interaction when conversion takes place between individuals within an organisation to transfer tacit and explicit knowledge. As noted by Nonaka (1994) an employee goes through a continuous activity of knowing.

Complex design knowledge is not static and the product goes through redesign and rebuild throughout the product lifecycle. Nonaka and Takeuchi (1995) emphasised the importance of communications between the sender and receiver of technology, which takes place through the four steps proposed in their model. Some researchers looked into communication mechanisms used during these transfer steps when knowledge is articulated and integrated by individuals from sender and receiver. For instance, the work of Spraggon and Bodolica (2012) addresses four communication categories used to transfer knowledge: static virtual, dynamic virtual, canonical face-to-face, and non-canonical face-to-face. Malik and Bergfeld (2015) propose a model also emphasising the importance of communication in the form of a guiding model. The aim of the model is to help managers anticipate risks involved in managing a technology transfer process within a firm.

4.4 Research approach

4.4.1 Research methods

The approach in this research aimed to construct a conceptual model that builds on literature and interviews in multiple case studies. The model attempts to resolve some of the limitations of previous models by taking a holistic view of transfer of technology and know-how and incorporates relevant success factors.

A qualitative methodology was adopted for this study. The philosophical assumption underpins research design and qualitative method to identify themes and coding. There are different qualitative methods used in the literature to analyse the transcribed interviews, identifying themes and coding. In this report, I have used the template method to analyse the transcribed interviews. The philosophical assumption when conducting the qualitative template analysis follows a hypothetic-deductive approach (Gill and Johnson, 2010). The template analysis method is a common approach used to analyse interview transcripts and starts with preliminary or prior themes (Strauss and Corbin, 1990). Themes are statements that encapsulate recurring ideas in interview transcripts and there are likely themes that will emerge from interviews (Miles and Hubermann, 1994, Tesch, 1990).

Following this approach, a coding scheme was initially developed using constructs proposed in the literature as main categories of the data. I have firstly identified an initial proposed coding scheme using constructs based on the literature reviews as main categories of the data, and then listing all incidents in tabulations that represent the constructs proposed. An initial conceptual framework was established to form the basis of the analysis. I then conducted semi-structured interviews to empirically inquire and investigate multiple case studies related to international TT of the satellite development process.

4.4.2 Background of cases

In this research, multiple case studies were used to empirically inquire about and investigate the nature of international technology and knowledge transfer projects of satellite design and MAIT to developing countries like the UAE. Case study analysis was chosen as the research approach for this study since it is appropriate to describe and explore new phenomena within a real life context (Yin, 1994) and to construct or enhance existing theories (Eisenhardt, 1989).

The purpose of the research is primarily intended to explore and verify the challenges and barriers faced by the UAE in the transfer of know-how of satellite MAIT from international partners to local firms or organisations. Secondly, I aim to draw constructs towards building a conceptual TT framework model. The model will guide decision makers to leverage existing and future projects to transfer technologies and know-how to accumulate and build sustainable indigenous capabilities. This was achieved by analysing qualitative data gathered through interviews on multiple case studies.

Table 1-3 shows the list of the four case studies. Cases 1, 2 and 3 consist of the build-up of low Earth observation (LEO) satellites – DubaiSat-1 DubaiSat-2 and KhalifaSat in partnership with Satrec Initiative (SI) (Al Rais et al., 2009, Pirondini and Al Marri, 2014, Khalifa, 2015, Al Harmi, 2016, Al Hashmi, 2016, Rinne, 2004). DubaiSat-1 was built at a partner's facility in South Korea and the UAE organisation sent their engineers to transfer know-how. DubaiSat-2 was built partially in the UAE through mutual international collaboration with SI. KhalifaSat is an LEO satellite currently being built locally at MBRSC facility in Dubai through a mutual international collaboration with SI and it is in the final production project phase and aims to launch in 2018.

Case study 4 is related to the Emirates Mars Mission (EMM) project regarding transfer of know-how in the design and build of 'Al Amal' through mutual international collaboration between UAESA, MBRSC and LASP. Al Amal is a flagship space exploration project which will be launched in July 2020 and will be inserted into Mars orbit in 2021 (Al Hashmi, 2016, Al Rais et al., 2009, Khalifa, 2015). The project is in progress and successfully completed the critical design review (CDR) phase (see Figure 4-1) in May 2017.

4.4.3 Data collection

Empirical data were gathered from semi-structured interviews that were conducted with management and technical staff working in both sender and receiver organisations (see Appendix D, Table D-1) partnered in international technology and knowledge transfer projects. The number of interviewees in qualitative studies may vary based on the mode of the research, ranging from 6 to 60 (Morse, 2000). For this study, the total number of interviewees was 13; considering the scope and topic of the study, this number was considered appropriate. Semi-structured interviews are useful for exploring problems that are relatively new, and thus have very little research on them (Cresswell, 2007) as is the case with this research.

An interview guide was constructed (see Appendix D, Table D-2) and each interviewee was provided with a brief introduction and purpose of the research project. All interviews were audio-recorded, subject to approval by interviewees, directly into NVIVO through a laptop to allow for subsequent analysis. The average duration of interviews was about 35 minutes, ranging from 25 to 45 minutes. The interviews were conducted through face-to-face meetings in the UAE and USA and through teleconference calls. All interviews were labelled and transcribed verbatim in English since it was the original language used in the interviews.

The interviewees answered a few a semi-structured, open-ended questions to get their views and opinions of the topic in question (Cresswell, 2007). The semi-structured questions were constructed based on a framework of analysis initially developed based on literature reviews and attempted to answer questions centred on the following:

1. What are the resource challenges and barriers facing transfer of technology and know-how of satellite design and MAIT?
2. What is required from organisations to operationalise (i.e. routinise) TT processes to get the maximum benefit from TT projects?
3. What needs to be changed in organisational culture to maximise benefit from TT projects to sustain technological capability development?

Following this, I conducted a template analysis of the transcribed interviews. The following section presents the results on the major findings which yield the following summary of issues arising during transfer of knowledge and success factors based on the case studies.

4.5 Results

4.5.1 Mapping common themes

The analysis of the transcribed interviews reveals that there are a number of factors that influence the success of TT in design and MAIT of satellites to receiver organisations in developing countries. These factors were mapped as shown in Table 4-3 against the initial common themes where its typology is shown in Figure 4-3 and discussed in previous sections (see Appendix D, Table D-3 for a sample of a transcribed interview and Table D-4 for analysis of transcribed interviews).

There are factors related to managing expectations of stakeholders including government as in the case of national interests to acquire indigenous capabilities in satellite development. The factors related to the actual transfer of technology and know-how are grouped under the mechanism and processes main theme. The analysis reveals that the TT processes are routine activities which take place in two phases. Transfer takes place first during project execution

Table 4-3: Template analysis

Literature research	Interview research

Stakeholders and Management Expectations
• Selecting technology transfer partner
  - Partner prior experience
• Accepting failure
• Leadership engagement
• Investment/funding infrastructure
• Organization support
• Compensation motivation
Routine
• Communication and collaboration
• Contracts
• Codifying and documenting processes
• Mechanism and processes - transfer of technology and knowledge
  - Identifying knowledge
  - Articulating knowledge
  - Integrating knowledge
  - Creation of knowledge
  - Indigenous creation
• Approaches and methods
  - Direct responsibility
  - Peer reviews
  - Parallel assignment
  - Coaching and mentoring
  - On the job training
  - Face-to-face
  - Shoulder-to-shoulder
Resources
• Pool of experts
• Individuals' time in programme
• Individuals' engagement
• Individuals' interests in programme
• Individuals' prior experience
• Individuals' prior education
External factors
• Government support
  - Government commitment
  - Funding
• Government protection
  - Export control
	Stakeholders and Management Expectations
	• Indigenous capability
	• Government support
	  - Funding
	  - Infrastructure investment
	Routine
	• Setting up the programme
	  - Communications and collaboration
	  - Contract negotiations
	• Selecting technology transfer partner
	  - Partner expectations
	  - Partner prior experience
	• Mechanism and processes – transfer of technology (within executing project)
	  - Identifying knowledge
	  - Articulating knowledge
	  - Integrating knowledge
	• Mechanism and processes - transfer of technology (within receiver organisation)
	  - Generate knowledge
	  - Combine knowledge
	• Approaches and methods
	  - Codifying and documenting processes
	  - Direct responsibility
	  - Peer reviews
	  - Parallel assignment
	  - On the job training
	  - Face-to-face
	  - Shoulder-to-shoulder
	  - Coaching and mentoring
	Resources
	• Pool of experts
	• Individuals' engagement
	  - Individuals' time in programme
	  - Individuals' interests in programme
	• Competency
	  - Individuals' prior experience
	  - Individuals' prior education
	External factors
	• Government protection
	  - Export control

and then second within the receiver organisation by individuals when acquiring new knowledge. They combine it with existing knowledge and new knowledge is generated in a continuous process. As result of maintaining these routine activities over several transfer programmes, indigenous capabilities are developed and sustained. The resources are organisational enabling factors needed to succeed in transfer of knowledge and sustain the development of indigenous capabilities.

4.5.2 Stakeholder and management expectations

Satellite development is complex and embedded with an intense technological knowledge. It takes years for an organisation to gain knowledge and experience in building satellites, as commented on by a senior technologist from a sender organisation. It is directly evident from the multiple case studies here, that as result of success in transferring and assimilating knowledge, it is possible to develop capabilities over time.

> *"From my perspective, it took our organisation 20 years to get there, and over 30 years in instrumentation of spacecraft. It is not happening overnight." [Appendix D, Table D-4, Stat. 1]*

Satellite development is costly and the operational lives of satellites are time-limited. Therefore, emerging space countries need to maximise the benefit gained from these projects to build their indigenous capabilities in a structured approach and over time. A senior manager from a receiver organisation stated that the government expects a return of its investment when providing funds for new projects and establishing MAIT infrastructures in the form of building indigenous capabilities, attracting local students into STEM education and offering job opportunities.

To 'manage expectations' between partners and stakeholders, the receiver organisation needs to 'set up the programme', negotiate and lay down the contract terms and conditions, communicate the extent and content of knowledge transfer, and agree these with the sender organisation. As commented by respondents, this helps to strike a balance and smooth the relationships between partners when the end product could measure the success of programme *[Appendix D, Table D-4, Stat.5].*

Several respondents stated that it is important that the sender be aware of the receiver's requirements, so the conversation needs to start early which likely will help in the TT process and avoid figuring out things as the project progress *[Appendix D, Table D-4, Stat.10].*

Depending on the desire and extent of knowledge transfer the receiver wants to achieve, the receiver organisation needs to select a partner that can meet the expectations as noted by an informant from a receiver organisation.

> *"We looked at the knowledge that we want to obtain and capabilities that we want to develop. Hence, we selected this organisation since we can develop required capabilities. We looked into their level of openness, and willingness to share data and knowledge, we took these into consideration." [Appendix D, Table D-4, Stat.4]*

There are barriers that are beyond the control of partners and which limit the transfer of knowledge such as 'government protection' imposed through export control (Raz et al., 1983, Sikka, 1996) to access design details of some components such as star tracker or in-space propulsion systems. Therefore, 'setting up the programme' for transfer of technology is critically important. The receiver organisation could focus not only on components such as star tracker or sun sensors, as pointed out by a respondent, but also look into what makes satellites different. One respondent from a sender organisation recommended receiver organisations have control over data handling systems and central processing of satellites.

> *"If you ask me what is different between satellites, I would say the central brain, the central processor, and the software that are running inside it. I want you to have that and then you can buy ...other components." [Appendix D, Table D-4, Stat.14]*

To sustain satellite development capabilities, organisations need to look into how projects are managed internally. A matrix and multitasking structure may have a negative impact on retaining an efficient and effective skill set needed to support and sustain satellite development projects.

> *"I feel the matrix approach to organisation structure starts to go down, and latching on a single project through its completion is I think critical. You do not have areas where information is dropped or miscommunication, as much I should say." [Appendix D, Table D-4, Stat.6]*

4.5.3 Routine factors - technology transfer mechanism and process

It was evident from the cases studied that organisations go through the transfer process when executing projects that have elements of transfer of knowledge. Knowledge transfer takes place during execution of multiple projects with support from outside partners and within organisations once knowledge is integrated. Once knowledge is successfully integrated, new knowledge is generated and combined with already embedded knowledge within an organisation's routine activities.

For example, a country like the UAE went through different phases resembling the space ladder steps suggested by Wood and Weigel (2011), as shown in Figure 4-3. The ladder captures only the first time a country achieves a milestone. For example, the UAE achieved its first milestone when it built DubaiSat-1 with support in a partner's facility. Through these ladder steps the UAE went through transfer mechanisms and processes to acquire and assimilate knowledge. As stated by one receiver responder, it starts by procuring satellites with the intent to learn, contribute and build indigenous capabilities. It then progresses to building satellites based on joint development at a partner's and own facilities with support from an international partner under mutual collaboration to transfer knowledge. It then reaches a level when it accumulates required indigenous capabilities to build its own satellite locally in their facilities, independent from partners by developing the whole satellite system.

> "*We went through different phases. The initial project was about learning, contributing and building capabilities. The second project was about joint development and the third project was an independent project from partner and developing the whole system*." *[Appendix D, Table D-4, Stat.2]*

The following section addresses the TT, which takes place during project execution and within organisations in two phases.

4.5.3.1 Technology transfer - within project execution

We know that most knowledge is 'tacit knowledge', hard to communicate (Amesse and Cohendet, 2001) and unable to be articulated since it depends on involvement and commitment of engineers in the development process. Complex design knowledge is not static and the product goes through redesign and rebuild throughout the product lifecycle as, shown in Figure 4-1. Respondents said that communication and collaboration between partners plays a pivotal role in integrating, combining and creating tacit design knowledge in development of new products, such as satellites. However, it is evident from the cases that a lack of 'employee engagement' reduces the degree of involvement and commitment and is considered a key challenging factor to transfer of knowledge. As informants from the sender organisation in case 3 stated, one measure of success in engaging receiver engineers is to let them carry the weight of a particular responsibility through to the finish. The effective level of engagement is conditional on how much time an individual engineer is able to stay in the assigned tasks, as stated by the same informants. A senior manager from a receiver organisation in cases 1, 2 and 3 had their engineers working at a partner facility for more than five years without interruption in order to effectively engage in the transfer of know-how. These engineers are now building the third satellite locally in the UAE facility.

As stated by Nonaka (1994) it is a continuous activity of knowing that employees go through. This is supported by comments from sender respondents that it is critically important that engineers engaged in the design or formulation phase need to continue working throughout the project lifecycle and continue working in the implementation phase of assembly, integrating and testing the satellite. This continuity goes to efficiency as well since competencies are the same in both phases, as argued by one respondent from a sender organisation in case 4:

> *"We found people who design, understand how it built the pieces together and test. Having that continuity, it goes to efficiency as well ... the competencies are the same during the design and when building spacecraft." [Appendix D, Table D-4, Stat.16].*

Howells (1996) argues that if tacit knowledge is liable to codification, it's easier to absorb (Amesse and Cohendet, 2001) and then it can be transferred between individuals or groups in a more structured way and become part of 'organisational routine'. This is in line with the point made by (Nonaka and Takeuchi, 1995) that knowledge is created by means of social interaction when conversion takes place between individuals within an organisation to transfer tacit and explicit knowledge.

Respondents replied to questions related to codifying and documenting the process of design and MAIT and noted that it is a potential mechanism to articulate knowledge. A conversion could take place during project execution if the programme is set up that way with its counterpart, as commented by respondents. In this case the conversion and knowledge transfer could take place when receiver engineers articulate and integrate new with existing knowledge that is already embedded in 'routine activities'.

> *"Potentially that would be easily codified if it was set up that way with its counterpart, and we do not have mechanical design 101." [Appendix D, Table D-4, Stat.18]*

As discussed in the previous section, in the formulation or design phase knowledge is more tacit and in the implementation phase is more explicit. Tacit knowledge is more difficult to transfer than explicit knowledge. At the implementation phase, engineers will be able to see what works about the design and what does not, and how do we work with abnormal processes, as stated by informants from a sender organisation:

> *"During design phase, is mostly paperwork, as we got to AIT phase that where learning would take place where you actually see how things together and see it works or do not." [Appendix D, Table D-4, Stat.23]*

Satellite development is complex since each satellite is unique in its mission and as a result different types of sensors are used to collect necessary data. Therefore, satellites come in different shapes, sizes and there is no standardisation, therefore the overall design for every satellite project starts almost from scratch and in some design cases when using heritage components engineers go back to previous design records rather than start from a blank page.

> *"It is mostly we do it from scratch for each satellite which probably sounds inefficient. We try to go back to previous challenges than starting from blank page. For some components we will not start from blank such as the ultraviolet instrument in this project, but it will be blank page for the satellite." [Appendix D, Table D-4, Stat.20]*

Organisations that went through TT of satellite development projects have an option either to continue leveraging engineers engaged in previous projects or recruit new engineers for new projects. Determining the number of engineers needed for satellite development for the purpose of transfer of knowledge depends on how the programme is set up and what knowledge needs to be transferred and to what extent. If it is an initial programme, consisting of new engineers, there will be less shared responsibilities between sender and receiver organisations; in that case a few engineers are recommended so they can be more focused. Most respondents from sender organisations for both cases recommended focusing on a few rather than rather large numbers of engineers. Respondents from sender organisations in case 2 stated that an optimum number of 10 engineers could be sufficient for the purpose of sharing and transferring knowledge. However, it is difficult to get agreement from receiver organisations since their aim is to train as many engineers as possible.

4.5.3.2 Technology transfer - within organisation

Products are embedded with a distributed set of productivity knowledge available in the mind of individuals (Hausmann et al., 2012) and therefore organisations manage their knowledge on an individual basis (Jones and Jordan, 1998). Engineers use mainly knowledge that comes from their past work experience, as noted by a senior manager from a sender organisation. Organisations rely on their experienced individuals to transfer tacit knowledge to solve complex design tasks within their organisation. While engineers in sender organisations are required to transfer tacit knowledge to an engineering team from the receiver organisation, engineers from the receiver organisation, after articulating knowledge, are required to integrate and transfer new knowledge to the team within their organisation. Both sender and receiver organisations become highly vulnerable to losing knowledge as result of not being able to transfer knowledge to and within their organisation. And, unless a receiver organisation embraces a culture to articulate and continuously integrate acquired knowledge, it will lose opportunities to create new knowledge.

Some respondents addressed ways to articulate knowledge they absorbed by documenting it to integrate, combine and create new knowledge within their organisation and use it to train others:

> *"Create training sessions, saying here what I do, the rationale I do, the tools that I am using, ... conversations I have with system engineering team, was a whole description of system engineering" [Appendix D, Table D-4, Stat.20]*

There are important factors (Szulanski, 1996) on the lack of absorptive capacity and the lack of retentive capacity of receivers as key issues that influence transfer of knowledge. In this research, most of the interviewees from the receiver organisations were engaged in and aware of the setup of projects for all cases. However, the interviewees from the sender organisation involved in case 4 projects were not aware of the setup of the projects related to cases 1, 2 and 3. This situation provided a good opportunity to ask interviewees from the sender organisation questions regarding the receiver organisation's technical and organisational capabilities since it informs about the organisation's ability to absorb and assimilate knowledge (Reddy and Zhao, 1990, Boer et al., 2002), based on previous projects: *What were their expectations in terms of previous absorbed and accumulated knowledge that the client gained from previous satellite development projects and how has this successfully contributed to existing programmes?*

The respondents expected, in general, that clients who went through previous projects to equitably go through each subsystem and the architecture of satellites in detail. They expected the project to be set up where design work is shared and work is split with receivers.

> *"I expected to sit in a room with the client equitable to go through each of the subsystem and talk technically about the subsystem, the details of the subsystem and architecture of satellite and what would be the correct way to move forward and how can we share and split the work" [Appendix D, Table D-4, Stat.9]*

Interview data reveal that both sender and receiver respondents were aware of the challenge facing all design topics from previous cases and in current projects due to the wide scope and complexity of the satellite development process. Hence, a receiver organisation needs several projects and goes through a structured indigenous generation mechanism where it can cover and transfer knowledge on whole systems and subsystems. For example, one receiver informant stated there are topics related to interplanetary missions where knowledge was not covered or required in previous projects but is required for existing and future projects. The respondents' comments explain why receivers need to identify which knowledge needs to be articulated and generated from each project to fill in the knowledge gap.

> *"I think navigation is not an area of our strength and not needed in our previous projects and only needed if you do interplanetary missions and still we will have less knowledge transfer because of ITAR in current project." [Appendix D, Table D-4, Stat.3]*

The following comments from both sender and receiver organisations revealed why some individuals physically available in the programme make more progress than those working off site. A distance relationship between teams is considered a disadvantage due to the lack of individual exchange (Szulanski, 1996) and is a challenge to absorb knowledge.

> *"He is with us every day, he become knowledgeable, he understand day to day details of the mission as we progress", "He will come out of this programme with different level since he came to the programme." [Appendix D, Table D-5, Stat.39]*

> *"We have reached to this level of knowledge in developing the third satellite by our self since our engineers were fully engaged working closely with our partner at their facility for the first satellite" [Appendix D, Table D-4, Stat.2]*

Despite the difficulty in transferring knowledge that is tacit, some scholars believe it could be transferred without being made explicit (Lambe, 2007), through shadowing, mentoring and observation. One informant stated:

> *"I am huge believer in osmosis effect, and just being around it and living it and that is the best way to become skilled and professional at it." [Appendix D, Table D-4, Stat.27]*

> *"A lot comes from coaching, we also brought retirees from other leading organisation, they have decades of experience so they provide much advice as much they could." [Appendix D, Table D-4, Stat.41]*

Interdependency between partners and active use of absorbed knowledge from receiver organisations influence success of knowledge transfer. This is achieved through different mechanisms and approaches to share and support transfer of knowledge. Shoulder-to-shoulder and face-to-face (Dougherty, 1992, Brown and Duguid, 1991) are examples of successful approaches used by engineers to articulate knowledge and combine their individual knowledge. Parallel assignments is another approach where both an experienced engineer and receiver engineer do certain tasks and the results are compared and the receiver engineer is informed how to fix his work through face-to-face and shoulder-to-shoulder communications.

However, these tools will not be effective if there is no ownership by people working in the programme into their assigned tasks. Ownership provides a sense of being responsible and brings knowledge to life. Ownership relates to the degree at which an individual invests energy and time to discern knowledge. Taking ownership in specific tasks supports individuals to articulate knowledge and act as a key factor to generate knowledge since they *"understand the pain associated with doing things right or wrong and finding out how to do it right" [Appendix D, Table D-4, Stat.29]*.

Sharing responsibilities and work is an ideal situation to transfer know-how, as remarked by an informant who is working in a case 4 project. The setup of a case 4 project reminded him of his early experience when his organisation started its first project by sharing responsibility and work between professionals and students. He noted that experienced people were coaching and mentoring and helping other people who are figuring things out.

> *"Twenty years ago, we had a student programme, around 30 students and six professionals, if we to do it just with student we could get a lot done but will not*

have a successful programme. It is the extra level of experienced people working, mentoring and helping other people who are figuring things around. I think this programme like that." [Appendix D, Table D-4, Stat.44]

Another approach of giving direct responsibilities where there is no safety net and if an individual does not perform the work, they will have to hire somebody to fill in the gap, as commented by one respondent.

"In some cases, we perform an analysis and then compare their results, in a way to know if they are getting the right answers, and discuss assumptions to rework what they are doing." [Appendix D, Table D-4, Stat.33]

"He has some tasks in his plate, responsibilities, we are not covering for him, he is doing them, and if not done, I have to hire somebody to fill in the gap." [Appendix D, Table D-4, Stat.34]

One informant revealed a success story where individuals, as result of being giving direct responsibility and being physically available throughout the programme, were motivated and committed and made remarkable progress.

"The idea of sharing responsibilities and work was a successful thing we at our organisation do very successfully" [Appendix D, Table D-4, Stat.33]

"I am not doing the work behind him. I am approaching the relationship as I was doing things in the past, and these are the tool I have used, and slowly we have worked to a point where he do it in his own" [Appendix D, Table D-4, Stat.32]

4.5.4 Resource factors

Lack of motivation (Szulanski, 1996) from receivers and unwillingness to share information or take risks (Inkpen, 1998, Malik, 2002) from senders when giving direct responsibilities to receiver engineers are some of the issues that affect transfer of knowledge. If engineers from receiver organisations are engaged and motivated, and engineers from sender organisations share knowledge, then transfer of knowledge will take place, since knowledge sharing and transfer depends on willingness of individuals to share, as noted by Jones and Jordan (1998).

Project managers of the receiver organisation need to check and monitor the performance of their engineers and try to resolve any issues early in the programme. They need to check the quality of deliverables and tasks, and need to raise their level of performance and satisfaction if someone is falling behind expectations. It helps if they are asked what their tasks are and what they did.

> *"If they are developing a design of a subsystem like EPS, you can tell a good design from bad design, you can tell the difference." [Appendix D, Table D-4, Stat.36]*

> *"I think he pulls their satisfaction by asking them what is your tasks and why you did, by doing this they get engaged again." [Appendix D, Table D-4, Stat.45]*

It is the responsibility of project management teams from both sender and receiver organisations to ensure people from both parties embrace the programme. This requires 'leadership engagement' from receiver organisations to find ways to embrace and generate interest and motivate their people. They need to ensure their engineers are tasked properly and engage them in articulating knowledge through various mechanisms, as discussed before. They need to resolve issues that could face engineers especially when located at a partner country. They need to monitor and check their performance more frequently.

> *"I think there is different way that client's management to be embracing the programme." [Appendix D, Table D-4, Stat.43]*

> *"Make sure these individuals have tasks that are interesting so they become motivated and making progress." [Appendix D, Table D-4, Stat.46]*

People leaving the programme will gain sheer knowledge and experience-based knowledge, as noted by respondents. If there is an organisational culture where engineers can carry back and communicate their knowledge and lessons learned to their organisation, the organisation will maintain creation of knowledge and ingenious capabilities from these programmes.

> *"Anybody who involves himself will leave this programme with important aspects. One is shear knowledge, day to day knowledge, lessons learned, experienced based knowledge, that can carry back and communicate to their organisation if there is a way to do that and if there is culture for them to do that." [Appendix D. Table D-4, Stat.37]*

The majority of respondents pointed out that the readiness, interests and degree of engagement of the people who receive the transfer of technology play pivotal role and are a critical success factor on the success of the programme. For example, an informant stated the following:

> *"It will be straight forward and efficient to have truly interested hard working people from client." [Appendix D, Table D-4, Stat.42]*

People acquire knowledge by the active re-creation and organisation of their own experience (Polanyi, 1978). However, this can be achieved if individuals are motivated and committed and have required skill sets available to them. Some respondents revealed that some individuals become motivated and committed when they are given responsibilities. These individuals feel the value of the knowledge and then develop competency in using the knowledge, which aligns with the research of Leonard-Barton (1995).

> *"I think she was motivated by just giving her responsibility in her area. I think individuals are motivated by different things." [Appendix D, Table D-4, Stat.47]*
>
> *"Those who are not motivated do not have clear assigned tasks per their skill set available to them." [Appendix D, Table D-4, Stat.48]*

4.6 The proposed case study-based conceptual framework

The model was constructed knowing transfer of knowledge is not a singular event, as discussed by Ounjian and Carne (1987). It aims for organisations to have strategic objectives to build and accumulate indigenous capabilities on development of satellites and in particular some components and subsystems independently over time.

The proposed model is formulated from the common themes and factors that were identified (see Table 4-1) and discussed in the previous sections. The themes and factors were restructured and present the main themes as perspectives and the factors as components in the model, as shown in Figure 4-4. The themes and factors were analysed and can be grouped into outcome and driver themes and factors. The outcome factors are related to 'what' factors need to be achieved as a result of investing in capital-intensive and complex processes by the country and the organisation receiving the technology. The driver factors are the 'how' factors required to be either available or developed when executing the knowledge transfer project.

The *stakeholder expectations and outcome perspective* is the higher order, or overarching theme, which is composed of other themes – the knowledge transfer internal process and resource perspectives. The factors related to stakeholder expectations are mainly outcome drivers. The factors related to the routine process of knowledge transfer taking place within a project and within an organisation are defined in this research as 'indigenous generation mechanisms' are mainly driver factors. The factors related to how an organisation deploys, engages its resources, and develops competency skills are driver factors that ensure the effectiveness of indigenous creation mechanisms.

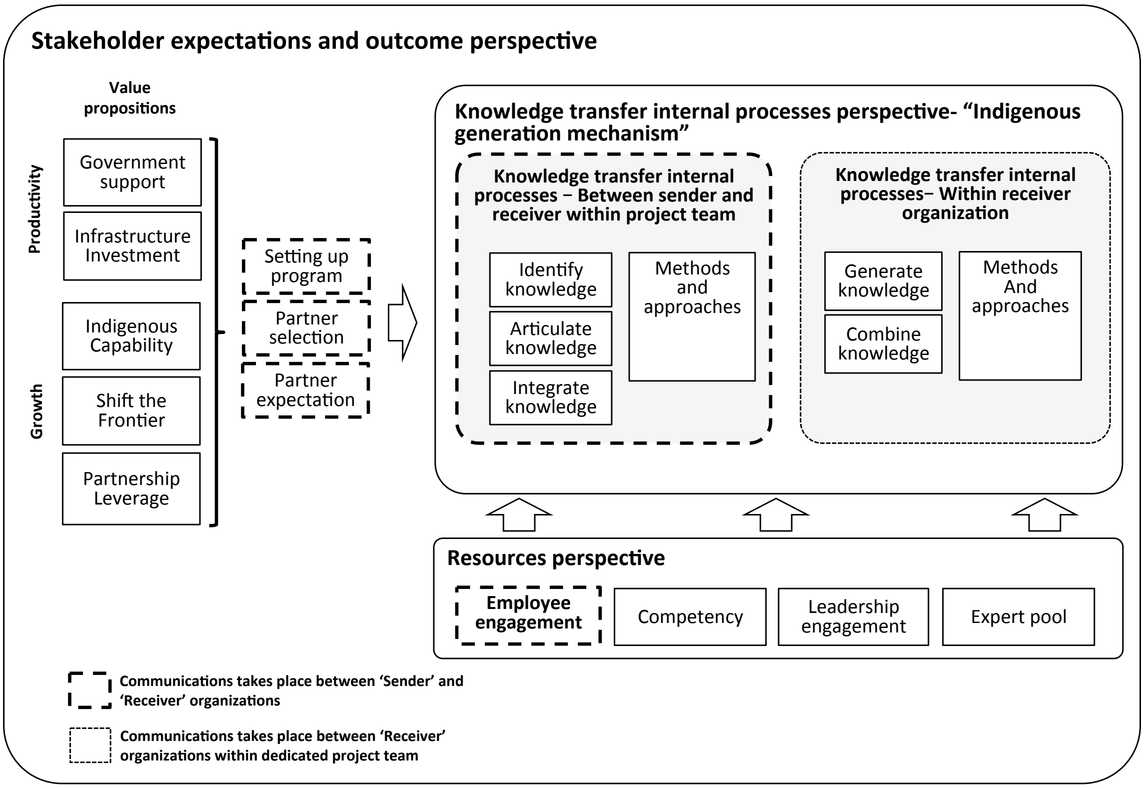

Figure 4-4: Proposed technology transfer model framework

In line with Metcalfe (1995), the model has two main actors, the 'sender' and the 'receiver' of the 'technology', which is defined as a combination of artefacts, knowledge and skills. In this research technology refers to beyond artefacts and it refers to the knowledge of design, assembly and testing that is embedded into production of technological products (Hausmann et al., 2012), which confirms the complexity of technology being transferred. The dotted boxes in the model show the communications that take place between sender and receiver organisations and the rest takes place within the receiver organisation. The following sections discuss the architecture of the model.

4.6.1 Stakeholder expectations and outcome perspective

The *stakeholder expectation and outcome perspective* has value propositions components called: *government support* and *infrastructure*, which are grouped under *productivity attributes;* and *indigenous capability*, *frontier/positioning* and *partnership* grouped under *growth attributes*. Managing stakeholder expectations is critically important since investing in satellite development programmes and transferring technological knowledge is a long-term and capital-intensive economic activity which needs to be sustained and justified. This can only be achieved if TT programmes are structured properly to accumulate required capabilities and enhance absorbed capacity across local institutions gradually to generate indigenous capabilities that will enable an emerging space country to build satellites locally.

The productivity attributes refer to the government support needed to invest in satellite MAIT and R&D infrastructures, to integrate it with existing ones to maximise utilisation through an agreed shared usage by local organisations for national space and related projects. Therefore, generating indigenous capabilities in design and MAIT of satellites requires government support due to the intense capital investments required to *build infrastructure and facilities*. Stakeholders need to ensure the utilisation of infrastructure assets will increase over time through a sustainable programme to develop technological products locally.

The benefits that could be gained and achieved at the end of technological development programmes by local organisations and at the country level need to be clearly identified and agreed. The shift and upscaling of a country's frontier could be achieved by accumulating indigenous capabilities progressively. By doing this, emerging space countries could *upscale their technological ladder* progressively, as discussed by Wood and Weigel (2012a). Knowledge could be generated and accumulated as result of knowledge transfer from each project. This ultimately could increase the level of independence in the development and production of a technological product such as satellite, if projects are structured properly. Thus, the growth attributes refer to the important factors that relate to leveraging international partnerships, aligning existing and future satellite projects as an important approach to transfer knowledge, enhancing absorbed capacity, accumulating and building indigenous capabilities that the country wants through a structured and focused approach, in order to ultimately innovate, shift and upscale the national technological frontier position over time.

Prior to the start of a project that has elements of knowledge transfer, the programme needs to be set up properly and expectations need to be managed by both the sender and receiver of technology, about the type and level of knowledge that will be transferred to individuals and eventually to the organisation.

There are barriers that are beyond the control of partners which limit the transfer of knowledge such as *government protection* imposed through export control (Raz et al., 1983, Sikka, 1996) to access design details of some components such as star tracker or in-space propulsion systems. Satellite development processes and the operational life of satellites are limited in time. Emerging space countries need to maximise the benefit that could be gained from these projects.

Therefore, *setting up the programme* for transfer of technology is critically important to be discussed and agreed on at an early stage prior to signing contracts between sender and receiver organisations.

For each project, the receiver needs to clearly identify the extent and content of knowledge transfer required during the project to accumulate and build required indigenous capabilities in a structured approach. It requires working closely with the sender to manage expectations and not to figure out things after the programme starts. This activity needs to take place during the selection of a partner and scoping of contracts to ensure knowledge transfer can be materialised during the course of the project.

4.6.2 Knowledge transfer internal processes perspective

The objective of transfer is the 'technology'. More precisely, it is the embedded knowledge that is put into the production of a technological product that is the subject of transfer. In our case studies, the technology refers to the complex development process for production of satellite-related technology inclusive of the design, manufacturing, assembly, integration and testing. The core of the model is the internal process for knowledge transfer. We call this process an indigenous creation mechanism. There are two types of knowledge generation, personal and organisational knowledge. The model considers that transfer of knowledge takes places in two stages as shown in Figure 4-4.

The first stage takes place between individuals in sender and receiver organisations during the execution of the project where knowledge is acquired and articulated for a particular project. The second stage takes place when articulated knowledge gets integrated within the receiver organisation. In this stage, new 'corporate' knowledge is generated once it is fully integrated and combined with existing knowledge. The new generated 'corporate' knowledge becomes routine within the receiver organisation. We call this knowledge creation process an *indigenous creation mechanism*. If the ultimate goal is to reach to an independent level where technological products could be designed and built locally, then this becomes a continuous process where countries or organisations go through multiple TT projects.

4.6.2.1 Knowledge transfer internal processes – within executing transfer project

The internal process of knowledge transfer starts by identifying what knowledge an organisation wants to transfer, then how it is articulated and integrated. Project teams and engineers from the receiver organisation are supported by professional engineers from the sender organisation articulating and integrating knowledge.

To successfully generate new knowledge, it must be combined and accumulated with existing knowledge within an organisation; the articulation and integration of knowledge needs to be embedded as part of the tasking activities. The tasking activities are given to the engineers from expert and senior management teams from sender and receiver organisations. This is achieved through continuous communication with individuals through clear design tasks, providing coaching and mentoring on design aspects of subsystems, and assembling and testing, for example. To be effective in transfer of knowledge, receiver individuals need to have direct or shared responsibilities and accountability in articulating and integrating knowledge. This needs to be become a day-to-day, routine activity that is adopted by all project team members.

4.6.2.2 Knowledge transfer internal processes – within receiver organisation

While identification, articulation and integration take place within each project, new knowledge is generated once knowledge is operationalised and internalised and it becomes a routine activity within the receiver organisation when it is combined with existing knowledge within organisations. This is critically important to develop and sustain development and accumulation of indigenous technological capabilities. The method and approaches adopted to transfer technology during project execution or within receiver organisations are similar to some extent, as discussed previously and shown in Table 4-3.

4.6.3 **Resource perspective**

In the proposed model, the resource perspective refers to the factors that enable and influence the success of knowledge transfer and know-how and drive the development of indigenous capabilities over time: *Employee and leadership engagement, competency and export pool.*

The success of knowledge transfer depends on the degree or level of employee engagement. Engineers who were engaged and given clear direct responsibilities were motivated and increased their level of ownership in delivering specific design requirements, as was evident in the case studies. However, this is influenced by the approaches and methods used in transferring the knowledge which influences the success in articulating knowledge that could be absorbed by individuals from receiver organisations. Since knowledge sharing and transfer depends on the willingness of individuals to share with others (Jones and Jordan, 1998, Meyer-Krahmer and Schmoch, 1998), engineers who physically participate, engage fully and embrace the programme could make incredible progress as was evident from the research findings.

The management of the receiver organisation needs to embrace the programme. They need to facilitate the logistics to smooth employee engagement. They need to motivate their engineers, increase their interest to embrace the programme and check their performance on a continual basis. They need to ensure that professional engineers from the sender organisation continuously share and transfer knowledge and try to overcome any issues at an early stage of the programme.

For the receiver organisation to build indigenous capabilities, it needs to identify the skill set required by their engineers from each existing project and future programmes. Each programme needs to incrementally increase the experience level of engineers and this cannot be achieved without having a structured and focused approach, and understanding what sort of skill set needs to be available within individuals and within organisations. Progressively, as an organisation goes through a knowledge transfer programme, it needs to establish an expert pool drawn from their individuals who were immersed and who gained experience to support their future satellite development programmes.

4.7 Policy and management implications for practice

In light of the empirical research work and findings, there are policy and management implications if the objective of a TT programme is to build up and accumulate national indigenous capabilities, and sustain development capabilities of core satellite design and MAIT activities.

From a policy aspect, an overarching organisation needs to coordinate national space and satellite programmes, identify required capabilities and embedded knowledge to be transferred, structure and set up the programmes, and engage various local entities inclusive of academia, research centres and relevant industry firms. This is necessary to enhance the absorbed capacity across the wider local institutions, which need to sustain indigenous capability development. Moreover, the receiver organisation needs to focus on what makes satellites different rather than attempt to build all components of a satellite locally, which is not possible. For example, it is recommended to have control over data handling control systems and central processing of satellites since these activities are critical to build and integrate satellites locally.

From a management implication aspect, it is recommended that an organisation avoids having a matrix organisational and multitasking structure when executing TT projects. This has a negative impact on building capacity since it does not allow dedicated, focused individuals to acquire, articulate and integrate transferred technology and know-how into their organisation. Otherwise, the desired effect of the transfer of technology and know-how will not be achieved during the limited period of the satellite development.

4.8 Conclusion

Technology will continue to advance, and there will always be a need to transfer knowledge, in particular technological products between different international and local partners. This implies that transfer of technology and know-how is not a singular event (Ounjian and Carne (1987). Therefore, this research attempts to understand the challenges, barriers and success factors that are necessary for an effective transfer of technology and know-how.

The proposed TT framework model consists of three perspectives articulating the common themes derived from the literature review and empirical research. The stakeholder and management expectation perspective consists of productivity and growth, which is grouped into component attributes. These attributes reflect the value propositions to government as a funding body anticipating that local institutions will accumulate indigenous capabilities over time, the high capital infrastructures will be utilised, innovation will be triggered, and the national technological level will shift closer to the frontier. To achieve this, a structured approach needs to be implemented by setting up TT programmes properly and selecting the appropriate partner.

These goals could be achieved through capitalising and leveraging existing and future satellite development programmes and international partnerships with leading countries in the space sector to transfer technology and know-how. Therefore, to maximise the benefit that could be gained from existing and future satellite development programmes, an emerging space country like the UAE needs to execute a structured process to generate and sustain development of desired indigenous capabilities. In the proposed model, the process is called an indigenous generation mechanism to ensure required knowledge is defined and articulated and new knowledge and capabilities are generated within receiver organisations when executing future satellite development projects. Through a structured TT programme dependence on international partners will be reduced and limited to a few capability areas. The structured approach will trigger innovation and productivity of complex technological products that will eventually shift the level of the national technological frontier.

Management leadership inclusive of the senior project team for each programme plays a pivotal role in ensuring the forward planning for a continuous supply of human capital to meet the demand for future satellite programmes and to ensure full and physical engagement of the workforce in the transfer programme and to ease logistics issues. As indigenous capabilities are built and accumulated, sets of skills are developed, and the workforce and local institutions will enhance their absorbed capacity. This eventually will mean having an expert pool that local organisations can refer to and utilise for future projects.

If the aim is to develop sustainable indigenous capabilities to support national satellite development programmes including satellites or spacecraft for deep space exploration missions, it is recommended to deep dive into further research for the following critical requirements and integrate it with the proposed model:

1. Identify the technological knowledge and capabilities that are required in order to have control over them, reduce and limit dependence on international partners in all aspects of satellite MAIT.
2. Link and map the R&D activities with the identified and desired indigenous technological knowledge and capabilities that a country such as the UAE wants to retain and have control of. Engage local universities and research centres in future satellite programmes and refocus their research and development activities to specific national requirements.

CHAPTER 5 Discussions and Proposed Space Innovation Management Model

The ultimate aim of the research was to investigate and explore innovation patterns adopted by the UAE in the past and present. The research then attempted to propose an innovation management system, a solution to guide and sustain the future development of the UAE's high technology space sector. Therefore, in this chapter, the main purposes are to conclude the discussions, articulate the contribution of the three research projects, and address a proposal for the future development of the UAE's high technology space sector within a context of an innovation management system called the Space Innovation Management System (SIMS). The SIMS aims to build a common understanding among space sector stakeholders through which the future development of the UAE's high technology sector may be managed more efficiently and effectively. The SIMS can be seen as an explanation on how the three research concepts and results from projects 1, 2 and 3 are linked.

To structure my explanation, I use the SIMS architecture (see Figure 5-1), which may be useful for the UAE Space Agency (UAESA) to consider as a guide to discussing, planning and sustaining the future developments of the UAE's high technology space sector.

Table 5-1 lists the elements of the SIMS architecture. The table indicates the sources of the elements that were extracted from the analysis and results obtained from projects 1, 2 and 3. The table notes the lessons learned from the observed phenomena on the past and present innovation patterns. It shows the ST&I roadmapping and foresight, challenges and barriers faced during previous technology transfer (TT) programmes that shaped the formulation of the proposed management system.

The following sections discuss the SIMS architecture which consists of several stages that were formulated for a comprehensive integrative management system that links activities related to articulating strategic directions which are set by the government, formulation of an ST&I roadmap, and execution of an R&D implementation plan on focused and prioritised ST&I areas.

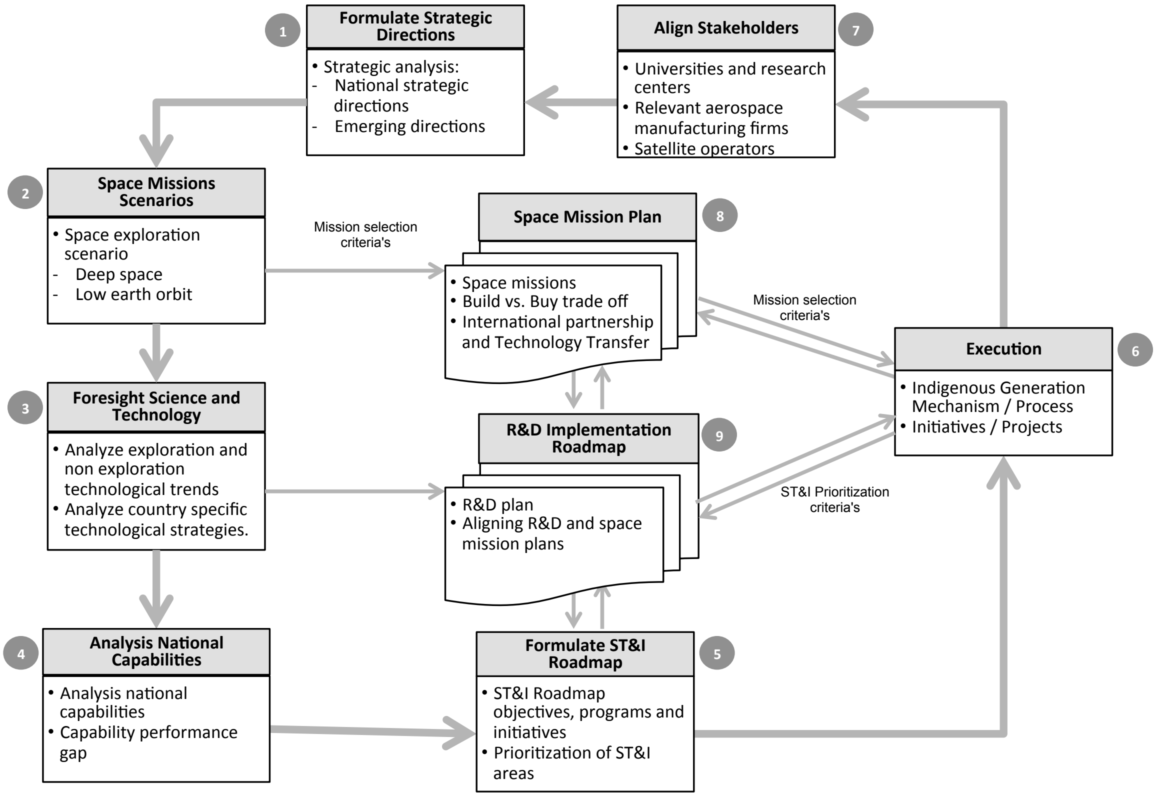

Figure 5-1: Proposed Space Innovation Management System (SIMS)

5.1 Formulating strategic direction

From project 1, it was observed that during the past years the UAE was able to make significant progress to upscale its space technology ladder, however, there was no national unified strategic direction guiding space stakeholders, including local universities, research centres and relevant manufacturing firms into common visions, goals and objectives. For a country with limited resources, especially human capital, setting strategic direction for the main actors or stakeholders becomes necessary for better use of its limited resources in order to accelerate the development of the UAE's space sector. As summarised in Figure 5-1, the SIMS starts with strategic analysis (SIMS Stage 1) to understand, analyse and formulate the following:

- The national strategic direction.
- New emerging national strategic directions.

Table 5-1: Sources of SIMS stages

#	SIMS stages	Sources from Project 1, 2 and 3
1	Formulate Strategic Directions	*Project 1:* addresses the need to overcome the lack of engaging local universities, research centres and relevant manufacturing firms in space projects. Therefore, it addresses the need to have a national strategic direction to guide main space stakeholders into common visions, goals and objectives. *Project 2:* highlights that understanding national interests is a driver to prioritise ST&I areas and formulate ST&I roadmap (Figure 3-7) *Project 3:* considers setting up technology transfer programmes and discussions with international partners is critically important to reflect stakeholders' expectations and ensure knowledge will be able to accumulate indigenous capabilities (Figure 4-4).
2	Space Missions Scenarios	*Project 2:* pioneering and established space agencies develop long-term space exploration scenarios centred on sending crewed or uncrewed spacecraft to the vicinity or surface of the moon and Mars. Aligning future space missions and ST&I roadmap is a common approach adopted by space agencies (Figure 3-7)
3	Foresight Science and Technology	*Project 2:* foresight activity is a core activity in development of an ST&I roadmap and listed as key activity in the proposed integrated foresight and roadmap model framework (Figure 3-7).
4	Analysis National Capabilities	*Project 2:* assessing national R&D capabilities is an activity listed in the proposed technology foresight and roadmap model framework (Figure 3-6). It is considered a critical step to understand the existing capabilities performance gaps at local universities and research centres to set up sound R&D activities as part of an ST&I implementation roadmap to accumulate indigenous capabilities over time.
5	Formulate ST&I Roadmap	*Project 1:* pioneering and established space agencies establish technology roadmaps aligned with space mission scenarios (IMS stage 2). *Project 2:* formulating an ST&I roadmap listed as an activity in the proposed technology foresight and roadmap model framework (Figure 3-7) – to prioritise ST&I areas of national interest. *Project 3:* highlighted the need to identify key technology areas for each future satellite project during the initial setup of the transfer programmes.
6	Execution	*Project 2:* executing an R&D and ST&I implementation plan listed as an activity in the proposed technology foresight and roadmap model framework (Figure 3-7). *Project 3:* the proposed technology transfer model consists of an execution core internal activity called 'indigenous generation mechanism' to define, articulate, integrate and generate new knowledge for each technology transfer programme.
7	Align Stakeholders	*Projects 1, 2 and 3:* highlighted the lack of common objectives or government entity aligning space sector stakeholders in the UAE. *Project 2:* identifies setting up programmes to align various stakeholders is an activity of development and implementation of ST&I roadmap. *Project 3:* highlighted the needs to align stakeholders into common visions, objectives, and understanding on ingenious capabilities the country desires to accumulate over the years.
8	R&D Implementation Roadmap	*Project 2:* R&D implementation of roadmap is an activity listed in the proposed technology foresight and roadmap model framework (Figure 3-7).
9	Space Missions Plan	*Projects 2 and 3:* Addressed the importance of aligning R&D activities and future space missions to develop and accumulate indigenous capabilities on prioritised ST&I areas over time.

5.1.1 National strategic direction

The importance of understanding national strategic direction, and the goals and desired outcomes for the UAE's future space programme were addressed in project 2. Therefore, in this stage, strategic directions, goals and desired outcomes need to be clarified and defined to bring all stakeholders to common goals and objectives.

In this research, the directions were articulated from limited responses collected through interviews with senior government officials and management. For example, on the design and MAIT of satellites, the direction was to focus on technological areas that make satellites different and it has multiple uses for other applications, e.g. the instrument sensor payloads and the 'brain' of the satellites, e.g. on-board computers, are what differentiate satellites. Therefore, there are ubiquitous or common technologies that can be imported without any restrictions such as export control but for the purpose of strategic direction in building and accumulating indigenous capabilities on a landscape of technology areas to be developed locally.

5.1.2 Emerging strategic drivers

In 2017 (while this thesis was being written), the UAE set a new emerging strategic direction – the Mars 2117, which I call it a 'visionary idea' rather than a programme or project. Acknowledging emerging strategic direction that has the potential to shape the future of the UAE space sector is critically important since it will impact the content of the ST&I roadmap and future space projects, as discussed in project 2. Therefore, the SIMS needs to be robust enough to accommodate any new emerging strategic directions.

Mars 2117 is now considered a strategic direction for the national space programme. Although it is still a visionary idea to build human habitats on Mars by 2117, this vision should drive the architecture for the UAE's future space programme. The formulation of future space mission scenarios and prioritisation of ST&I areas, and accordingly R&D activities, should articulate the vision into programmes and projects to ensure the vision could be achieved over the very long term.

In this research, the initial proposed ST&I roadmap was developed prior to the UAE announcing the new visionary idea. However, the methodology adopted in this research scanned the future technological trends for up to 20-30 years, relevant to long-term space exploration mission scenarios such as the journey to Mars proposed by spacefaring countries/agencies which aim to have humans on Mars by 2030. This includes technologies pursued by USA/NASA, Japan/JAXA and Europe/ESA, for human and robotic missions to Mars, and robotic missions to Mars, moon and asteroids. Therefore, the ST&I roadmap is still valid to some extent but needs to be revisited and amended within the context of the Mars 2117 vision.

5.2 Space mission scenarios

In project 2, it was found that pioneered and established space agencies develop long-term space exploration scenarios centred around sending manned or unmanned spacecraft to the vicinity or surface of the Moon and Mars (Neal et al., 2014). However, this research was conducted while the space exploration programme of the UAE was still in its infancy with only one approved project – to design and build a spacecraft called 'the Hope' which will orbit Mars in 2021. In this stage and with the new vision of Mars 2117, the UAE needs to develop scenarios for its future space exploration programme that will articulate the Mars 2117 vision before the launch of 'the Hope' spacecraft to cover the following:

- Deep space exploration missions.
- Small satellite programme for science, technology demonstration and commercial remote sensing applications.
- CubeSat programmes for education and technology demonstration.

Based on the complexity of space missions, especially deep space exploration missions, the UAE could choose either to own and invite other international players to partner in the design and build or participate in other foreign international missions, in particular with technology topics of interest to the UAE.

5.3 Foresight science and technology

There are different techniques and methodologies used for foresight studies such as SWOT, critical or key technologies, megatrends, Delphi, relevance tree, scenarios and expert panels (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010). In this research, key technologies and expert panel techniques and methods were used especially to stimulate insights and views on strategic directions as commonly used in foresight studies (Gavigan and Scapolo, 1999) and in particular on identifying the ST&I areas that have national strategic interests for the UAE. Technology trend analysis was used to understand the future visions on the development of science and technology (Gavigan and Scapolo, 1999) by pioneering and established space agencies based on their long-term integrated technology roadmaps and space exploration missions to identify future key and critical technologies. Foresight scanning using technology trends analysis was an important element of the integrated technology and roadmap framework model proposed and discussed in project 2.

The technology foresight areas need to be defined prior to conducting a recurring or periodic foresight analysis. Therefore, a global space ST&I tree was developed as an outcome of the research in project 2, which is structured into 18 ST&I areas, 83 components and 422 sub-components (see Table 3-3). Therefore, in Stage 3 of SIMS, formulating and maintaining an ST&I tree is important since a continuous process needs to be in place to anticipate technologies, at least in limited areas and components at levels 1 and 2 of the ST&I tree that are critical for future space programmes (SIMS Stage 2) or that have national interests (SIMS Stage 1). It also needs to be amended periodically to formulate an ST&I roadmap (Stage 5 of SIMS) that is robust enough to accommodate new technological trends and national strategic direction.

The research revealed that although the UAE has one space exploration mission, an ST&I roadmap could be developed by looking at what other agencies are doing, by scanning future technological trends and accordingly developing an ST&I roadmap that prioritises ST&I areas and then commences building capabilities at local universities, research centres and relevant manufacturing firms.

In this stage, the horizon is scanned to identify technological trends and opportunities through:

- Analysing technology roadmaps of other international space agencies and preferably to include private firms which were not considered in this initial research.
- Analysing country direction on technology and innovation and identifying relevant topics related to space, e.g. National Innovation Strategy and National Science, Technology and Innovation Policy.
- Analysing technologies required for non-space exploration missions.

Scenarios as a foresight technique could be used to articulate Mars 2117, to build a human colony on Mars within 100 years, a very long-term visionary idea to trigger strategic conversations among space sector stakeholders including local universities, research centres and industry on what could be done. The Delphi survey method could be introduced but was not considered in this research since it is time consuming and labour intensive (Gavigan and Scapolo, 1999). Delphi can be used to record predictions and realisations of a Delphi topic (Gavigan and Scapolo, 1999). In this case, Delphi is used to outline future perspectives of development in science and technology areas (Kanama et al., 2008). Delphi topics could be the ST&I areas identified in the global space ST&I tree. It can be used to provide a technological perspective on the application of a particular technology challenge such as propulsion capability for deep space missions or vehicle autonomy system. A Delphi survey is considered a useful information source for scenarios (Loveridge and Saritas, 2009) when combined with roadmapping (Kanama et al., 2008), since it provides balance between long-term scenarios and what could happen in the future by bringing in political, social and economic contributing factors.

5.4 Analysis of national capabilities

Technological products are embedded with productivity knowledge, i.e. capabilities are available within the minds of individuals and organisations. Countries cannot make big jumps from only procuring and acquiring technologies to producing complex and innovative technological products without accumulating prerequisite capabilities (Hausmann et al., 2012). The research in project 1 reveals that countries take progressive steps, as explained through the space technology ladder, from only procuring to building satellites locally after accumulating prerequisite capabilities acquired through transfer of technology and knowledge from international partners. In project 2, I addressed the importance of assessing and analysing existing national capabilities to formulate an appropriate ST&I roadmap (SIMS Stage 5). The existing national R&D capabilities need to be assessed with reference to the prerequisite capabilities for the desired indigenous capabilities that UAE wants to accumulate in future. This is in addition to capabilities needed to progress through the space technology ladder and enable the country to shift its national technology frontier.

Therefore, the national strategic directions need to be articulated and accordingly identify relevant critical and immediate indigenous capabilities that need to be built up and accumulated to achieve the near- and long-term visions, such as Mars 2117. At this stage, the following activities are addressed:

- Assess capabilities in terms of existing R&D activities against ST&I areas and components across local universities, research centres and relevant manufacturing firms.
- Identify existing capability performance gaps relevant to national strategic direction and drivers, since it triggers the need to build and accumulate indigenous capabilities in a set of prioritised ST&I areas.

5.5 Formulate ST&I roadmap

The research in projects 1 and 2 revealed that over the past years, the innovation patterns and development tracks that we have observed in the UAE's space sector lack a technology roadmap and an overarching entity that guides and brings stakeholders into common goals and objectives. The previous TT and development programmes were limited within the boundary of either a university or a research centre and with limited scope on design and MAIT of satellites. Therefore, this research proposed solutions to accumulate and sustain development of diverse and focused indigenous R&D capabilities in the high manufacturing technological space sector across local universities, research centres and related manufacturing firms. The ST&I roadmap addresses the following:

- The ST&I objectives/themes, programmes and initiatives.
- Prioritised ST&I areas and components.

The ST&I roadmap is proposed to be formulated with objectives, an overarching set of programmes and initiatives (refer to Figure 3-5). While the ST&I objectives are formulated to give an indication on the options that were chosen for the development path to achieve the long-term goals, each objective has one or more programmes, and each programme has several initiatives. The initiatives are more specific and look into what R&D activities need to be done relevant to the prioritised ST&I areas in order to close the capabilities performance gap.

The prioritised ST&I areas need to be identified and defined periodically, relevant to national strategic direction. In this research, an initial ST&I roadmap was proposed recommending the UAE to increase its effort and investment on a set of ST&I areas categorised as Groups 1 and 2 across its local universities and research centres, satellite operators and relevant manufacturing industries (refer to Table 3-15).

The roadmap prioritises ST&I areas that have strategic national interests that are not necessarily at the cutting edge but could be priority ST&I areas that are ubiquitous and common for the purpose of building and accumulating indigenous capabilities over the short term, as in Group 1. In addition, it prioritises areas on advanced or future technologies linked to extending the presence of humans in deep space and related to a very long-term requirement, as in Group 2 (refer to Table 3-15).

5.6 Align stakeholders

The UAE government announced a very ambitious vision for the space sector and it is now oriented around Mars 2117. There is a need to capture the full benefit of programmes already in place such as EMM and newly announced programmes such as Mars Science City. While project 3 addressed the lack of engagement with local universities and research centres in previous satellite programmes, project 2 revealed the importance of having a national ST&I roadmap for the purposes of aligning relevant actors and stakeholders to a common vision, prioritising and directing R&D topics and activities towards scaling up existing capabilities, and developing foresighted space-related critical technologies.

Therefore, at this stage, there is a need to ensure that the main space stakeholders are aware of the visions and national strategic direction and that their strategies and operational activities are linked:

- *Universities and research centres:* Local universities and research centres need to engage with and be key players in the development of the UAE's space sector, guided by the UAESA and backed by the ST&I roadmap and objectives. They need to link their R&D activities and align them to the focused ST&I indigenous capabilities the country desires to build and accumulate over the years. Therefore, local universities need to commence building and accumulating prerequisite capabilities to enable them to become partners in the UAE's future space exploration projects, for example in the design and build of science instrumentation or satellite payloads. Moreover, they need to introduce an education element of space science and technology into their existing curriculums in their aerospace and engineering undergraduate and graduate programmes and increase the intake and number of graduates.
- *Manufacturing industry:* Although space manufacturing is limited in the UAE, there is a need to engage relevant aerospace firms to develop capabilities in manufacturing space products, for example structural components of satellites. For example, both Strata and TPI could be partners in future space projects to design and build composite and aluminium structures for spacecraft structures and components such as electronic boxes, brackets and panels.
- *Satellite operators:* All previous procured communication satellites in the UAE lacked engagement of local universities, research centres and manufacturers. It therefore becomes critical to engage commercial satellite operators in R&D activities at

universities and research centres, to transfer knowledge to non-commercial space exploration programmes in common technological areas of the ST&I tree. The UAESA should guide satellite operators on the indigenous capabilities that it intends to accumulate across local universities and research centres and encourage them to introduce an element of R&D activities in future procured communication satellites or provided services.

In summary, to ensure the full benefits of future programmes are achieved, prime contractors for satellite and space projects need to engage main stakeholders by subcontracting some of the development packages and R&D activities to local universities, research centres and manufacturing firms.

5.7 Space missions plan

In SIMS Stage 2, the potential scenarios for future space missions need to be defined at concept level. And, in this stage, specific space projects are selected based on a set of criteria that emphasise the benefit to the UAE, in particular the indigenous capabilities that will be developed and accumulated across its space stakeholders and the country as a whole. It is recommended that the endorsement of future space programmes needs to ensure clear outcomes in terms of build-up and accumulation of specific indigenous capabilities in reference to a predefined set of prioritised ST&I areas and components.

In this stage, depending on the complexity of the space mission, if any programmes will be executed in partnership with other international partners, the programmes need to be discussed, agreed and set-up properly to ensure effective transfer of technology and know-how.

5.8 R&D implementation plan

In this stage, an ST&I implementation plan needs to be defined and executed to achieve desired goals that articulate the strategic direction set by the country's leadership. The implementation plan needs to identify the R&D programme and initiatives that will be executed over the short and long term and then secure investment. In this research, the implementation plan was not developed; however, an attempt was made to illustrate how the implementation needs to be formulated.

The ST&I implementation plan reveals the short- and long-term projects and elaborates if these projects will transfer knowledge at the cutting edge or if it will advance existing technologies or build and accumulate capabilities on some of the ST&I areas and components that are not necessarily at the cutting edge of technology.

Table 5-2 illustrates an example of how to leverage existing satellite programmes to close capability gaps over the short term. Through these hypothetical programmes, Sat 1, Sat 2 etc., the UAE could develop indigenous capabilities on specific ST&I areas by attempting to build locally rather than buying some of the satellite components. The build trade-off is linked to the setup of transfer programmes and identifying the indigenous generation mechanism where desired knowledge is identified, articulated and integrated within receiver organisations to generate new knowledge. Accordingly, the ST&I implementation plan needs to reflect these factors and in particular the 'build' components.

Table 5-2: Closing the performance gap – leveraging on future projects

BUILD | BUY | Not Applicable

	Possible Spacecraft Technology (Hardware/Software)	Satellite 1				Satellite 2				Satellite 3				Satellite 4			
Primary Sub Systems	Bus System Design	BUILD	BUY	BUY	BUY	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD
	Structure and Thermal	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUILD	BUY	BUY	BUILD	BUILD	BUILD	BUILD
	Power Conditioning Unit	BUILD	BUY	BUY	BUY	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUILD
	Solar Array	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	Battery	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	Harness	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD
	Onboard Computer	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	Radio (Telemetry and Telecommand)	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	Command & data handling software	BUILD	BUY	BUY	BUY	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD
	Guidance and Control (AOCS software)	BUILD	BUY	BUY	BUY	BUILD	BUILD	BUILD	BUY	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD
	System Integration (MAIT)	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD	BUILD
Sensors	Satellite Navigation Receiver	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUILD	BUY	BUY	BUILD	BUILD	BUILD	BUY
	Star Tracker	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	Sun Sensor	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY
	Earth Sensor	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	Inertial Navigation System	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
Actuators	Propulsion System	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY
	INS (Momentum Wheel)	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY	BUY
	INS (Magnotorquer)	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUILD	BUY	BUY	BUY	BUILD	BUY	BUY	BUY
	INS (Reaction Wheel)	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Payload	Radar Instrument	N/A	N/A	N/A	N/A	BUILD	BUILD	BUY	BUY	N/A	N/A	N/A	N/A	BUILD	BUILD	BUILD	BUILD
	Satellite Navigation (GNSS)	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	BUILD	BUILD	BUY	BUY	N/A	N/A	N/A	N/A
	Hyperspectral Technology	N/A	N/A	N/A	N/A	BUY	BUY	BUY	BUY	N/A	N/A	N/A	N/A	BUILD	BUILD	BUILD	BUY
	Payload System Design	BUILD	BUY	BUY	BUY	BUILD	BUILD	BUY	BUY	BUILD	BUILD	BUY	BUY	BUILD	BUILD	BUILD	BUILD

5.9 Executing the plans

In project 3, the challenges, barriers and success factors were explored within the context of four case studies on previous technology transfer programmes. While the strategic direction set the vision and highlighted high level objectives, the ST&I roadmap identified opportunities and prioritised the capabilities the country desired to build and accumulate in a prioritised set of areas and components of the ST&I global space tree. In this step, a structured approach needs to be in place for each satellite programme to ensure technology and knowledge are articulated during project execution and then integrated within receiver organisations where new knowledge is generated on prioritised ST&I areas and components. This process is called indigenous generation mechanism, which is proposed and discussed in project 3 and is shown in Figure 4-4.

The benefit of satellite programmes, defined in stage 8 'Space Mission Plan', will not materialise if relevant stakeholders such as local universities, research centres and local manufacturing firms are not engaged in building R&D capabilities across a landscape of a defined and prioritised ST&I areas and components as defined at the R&D Implementation Roadmap stage. In these stages, the UAE should leverage the future space programme to transfer technology and know-how not only within the boundary of the prime organisation executing a design and build of a satellite but also with local universities and research centres. The engagement, as discussed in project 2, is through subcontracting local universities and research centres to conduct research and develop the selected build components and link these to the country's goals to accumulate indigenous capabilities on prioritised ST&I areas and components.

Project 3 addressed that the content and level of detail of TT needs to be discussed and negotiated with the provider of the technology during the setup of the transfer programmes. For example, Table 5-2 illustrates a case where receivers of technologies could leverage four small satellite programmes to ultimately build and accumulate indigenous capabilities gradually on design and MAIT of satellites. This process starts by conducting trade-offs for either 'build' or 'buy' components. Table 5-2 also shows how at the end of the four satellite programmes, the receiver of technology and a relevant local university or research centre could achieve 100% ability in the design and MAIT of satellites, on a selected set of 'build' components (where the colour shaded box with green reflects the % of 'build' - if 1/3 % of the box shaded with green means partial capability and if 4/4 % of the box shaded green means complete ‘build’ capabilities)

CHAPTER 6 Conclusions

This doctorate research explores the past and present innovation patterns of the UAE and proposes solutions to develop the future of its high technology space sector. The analysis reveals that the UAE adopted three innovation patterns: A) a government investment-based strategy, B) international partnerships, and C) transfer of technology and know-how that were commonly observed four development tracks: 1) manufacturing of conventional satellites, 2) space exploration spacecraft, 3) small satellites, and 4) development of R&D capabilities and.

The research reveals that although the UAE made progress and was able to upscale its technology space ladder over the past and present, it faced challenges and barriers during previous TT programmes. Moreover, the progress was made within receiver organisations that managed the transfer programme and with very limited engagement of local universities and research centres.

The research also reveals that the UAE lacked a technology roadmap to define and prioritise which technologies the UAE needs to invest in and develop. Following analysis from project 1, projects 2 and 3 explored roadmapping and TT respectively. While project 2 drew on a technology roadmap and foresight techniques and methodologies to propose an ST&I roadmap for the UAE space sector, project 3 extended projects 1 and 2 to explore four case studies of technology and knowledge transfer and proposed an indigenous generation mechanism to overcome past challenges and barriers to leverage and maximise benefits from future transfer programmes.

The findings of the three projects are summarised and used as an input to construct a Space Management Innovation System (SIMS) that can be used to develop the UAE's high technological sector in the future (refer to Figure 5-1) to align stakeholders into common objectives and goals. This research contributes to theories, techniques, methodologies, policy and management practice as illustrated and summarised in the following sections.

6.1 Contribution to theories, techniques and methodologies

This research builds on and contributes to existing literature, theories, techniques and methodologies in different ways, as follows:

6.1.1 Innovation theories

The research work in project 1 (Chapter 2) began by exploring the innovation patterns adopted by the UAE to develop its high technology satellite manufacturing sector within the context of both SIS and DTF theories. The DTF considered that countries within close proximity to the frontier would adopt innovation strategies and would be able to produce more complex or pioneering technological products, while countries a distance from the frontier would adopt, acquire and diffuse technologies developed somewhere else. To some extent, these countries will remain distant from the frontier. However, the research revealed that the UAE was able to make progress and converge into adopting an innovation strategy despite being away from the frontier.

In compliance with SIS theories, the study revealed that a country, like the UAE, could initially adopt an investment-based strategy and gradually move towards an innovation-based strategy and shift its technological frontier as result, using enhanced features related to the knowledge base: level of appropriability, opportunities and accumulativeness conditions.

As a result of exploring innovation patterns in project 1, the technology roadmap and TT found interesting phenomena suitable to be explored further due to its high relevancy to the interest of the author and objective of the thesis, and since both phenomena have relevancy to academia and management practices.

6.1.2 Technology roadmap and foresight techniques and methodologies

The research approach adopted in project 2 (Chapter 3) to integrate technology roadmapping and foresight techniques and methodologies enhances and complements the existing literature since it is applied within a context of a new geographical area and a new emerging space country.

The literature addressed different techniques and methodologies used for foresight – SWOT, critical or key technologies, megatrends, Delphi, relevance tree, scenarios and expert panels (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010). Saritas and Aylen (2010) introduced an overall foresight methodology[6] and suggest that roadmapping could be integrated

[6] Saritas and Aylen (2010) suggest five mental acts or stages for the Systematic Foresight Methodology: understanding, synthesis and modeling, analysis and selection, transformation and actions.

as part of an overall methodology in the 'transformation' phase for connecting future with the present, proven to provide high information content, more precise and clear actions towards single future targets.

In this research, the integrated approach of technology roadmapping and foresight provides us an insight of future technological trends, in particular key and critical technologies needed for future space missions, technology roadmapping to identify and prioritise ST&I areas, and components that the country desires to build to accumulate its indigenous capabilities by considering the existing R&D capabilities at local universities and research centres.

Project 2 introduced a methodology to scan future technological trends related to space, identified opportunities and prioritised ST&I areas and components for emerging space countries based on the UAE case study; their future space programmes may be limited in scale compared with pioneering and established spacefaring nations. The methodology was built mainly on analysing trends, identifying key technologies, and utilising expert panels as common for foresight exercises (Gavigan and Scapolo, 1999, Popper, 2008, Saritas and Aylen, 2010). Trends were used as a way to get insight and views regarding future development of science and technology (Gavigan and Scapolo, 1999) as used by pioneering and established spacefaring nations. Trends information was used as an input to identify key technologies and to construct a global space technology tree. And, along with the viewpoints provided by the experts, it supports the selection of ST&I priority areas according to the national strategic interests on key technologies that the UAE desires to accumulate in design and manufacturing, and supports development of the ST&I roadmap.

The approach adopted in the selection of prioritised ST&I areas is based on scoring against a selected set of criteria that takes into account the situation of an emerging space country with limited capabilities and resources, technology readiness, and opportunities for commercialised technologies that will be developed at local universities, research centres and manufacturing facilities.

6.1.3 Technology transfer

The research in project 3 (Chapter 4) contributes to and complements the existing TT literature, in particular the transfer of technology and know-how on the design and MAIT of satellites within the context of a new geographical area and an emerging space country - a topic that was not researched before within the context of the UAE. The research reveals the challenges and barriers faced during past and present design and MAIT of satellite programmes. This led to the formulation of the indigenous generation mechanism as a core internal process in the proposed TT model to maximise benefits from future transfer programmes to build and accumulate capabilities on prioritised ST&I areas and components that the country desires to acquire to sustain its development over the short and long term. The methodology adopted in project 3 extended the literature on transfer of technology and know-how on design and MAIT of satellites.

In Chapter 4, I proposed a structured approach called indigenous generation mechanism to identify and articulate acquired knowledge during the execution of TT programmes by individuals and then generates new knowledge within receiver organisations when individuals return to their organisation.

6.2 Contribution to policy and management practices

6.2.1 Space Innovation Management System (SIMS)

The research interpreted the findings from the three research projects and constructed the SIMS (Figure 5-1). The innovation management system fills in an existing gap in the UAE by guiding stakeholder management in the space sector on the development of the UAE's future high technology space sector, which has been absent during the past years and has policy and management implications.

6.2.2 ST&I roadmap

This research revealed that the initial development of the UAE space activities such as the development of science satellites – DubaiSat 1, 2, and KhalifaSat by MBRSC and procurement of communications satellites – Al Yah 1, 2 and 3 by Thuraya and Al Yah 1, 2 and 3 by Yahsat were executed without having a national ST&I roadmap. More importantly it was executed within the boundary of each organisation and with almost minimum engagement with local universities and research centres.

The development of an ST&I roadmap for the UAE has policy and management implications since it brings stakeholders into common objectives and goals, prioritises which ST&I areas and components the country desires to invest in, build and accumulate over the short and long term. The research work in project 2 resulted in a selection of three groups of priority ST&I areas categorised according to national strategic interests aimed not only to accumulate indigenous capabilities in cutting edge technologies but also technologies that are commonly required to support future space programmes especially on the design and MAIT of satellites.

The immediate policy implications are that for each satellite project an attempt should be made to 'build' rather than 'buy' components or technology developed elsewhere, and to engage local universities and research centres in the 'build' of specific technological components identified as critical and prioritised ST&I areas.

The management practices and approaches on setting up future space projects would need to accommodate the following:

- The UAESA will need to have a capability matrix included in all space project proposals, identifying which components will be 'build' or 'buy', and set short and long term performance targets to develop indigenous capabilities on a structured approach leveraging future satellite programmes. Therefore, within five to ten years the UAE would achieve its desired objectives in building and accumulating indigenous capabilities in specific and prioritised ST&I areas.
- Project managers will need to ensure the 'build' components are scoped properly in TT contracts signed with international partners to transfer know-how on the design and build of these components.
- Proposed solicited or unsolicited R&D projects by the agency or local universities and research centres need to be scoped relevant to the prioritised ST&I areas of the roadmap.

6.2.3 R&D capabilities

The country could incrementally accumulate indigenous capabilities and shift its technology level within proximity to the international frontier by adopting an approach whereby local universities and research centres align their R&D activities and build and contribute to the accumulation of indigenous capabilities relevant the prioritised ST&I areas.

However, the initial step is to understand and acknowledge existing R&D capabilities at local universities and research centres. All relevant stakeholders need to act and collaborate to close the performance gap – the difference between what the UAE desires to achieve against its existing capabilities. Therefore, assessing existing R&D capability performance gaps triggers an immediate need to develop technological capabilities that are not necessarily at the cutting edge but rather that have national strategic interests since acquired knowledge on productivity of these technologies supports the development of complex products in the future. This implies that R&D capability analysis needs to become routine, where the UAESA analyses the performance gaps on a periodic basis.

6.2.4 Technology scanning and foresight

Technology evolves quickly which means the ST&I roadmap needs to be dynamic to accommodate future technological developments. One of the purposes of an ST&I roadmap is to identify and invest in future cutting edge technologies. Therefore, scanning future technology trends as part of technology foresight needs to become a routine management practice, which is considered as one step in the proposed SIMS. The SIMS links the technology scanning stage with the space exploration programme and ST&I roadmap stages as an integrative approach. This approach has both policy and management practice implications:

- Integrating technology scanning foresight and roadmapping ensures investment and innovation on key technology frontiers and critical technologies that are needed in the future to resolve complex requirements for deep space missions.
- Linking future exploration programmes with the ST&I roadmap will ensure technological capabilities will be built and accumulated over time

6.3 Opportunities for further research

This research study has some limitations; however, the findings opened up opportunities to conduct further research to enrich both academia and management practices:

- The main limitation of the research was that it was on a single country and the multiple cases were in a single organisation – a further research opportunity is to conduct comparative analysis on innovation patterns adopted by different emerging space countries.
- The research relied on the space technology ladder as a tool to indicate the progress made by countries. One can argue that the ladder did not consider the complexity of activities since procuring and operating GEO satellites is less complex than building LEO satellites. Others will argue that procuring and operating LEO and GEO satellites are at one common ladder level. Therefore, considering level of complexity of activities related to each step could enhance the structure of the space technology ladder. This may provide a better presentation of progress made by countries to shift their national

technology level towards the frontier – the space technology could be further developed to reflect complexities.

- Space exploration mission scenarios and mission plans are pivotal stages in the proposed management system. In this research, I only briefly illustrated how space missions could be linked to ST&I implementation plans and execution stages since it was not within the scope of this research. Developing a scenario mission planning method for space missions for emerging space countries will firstly contribute to both academic and management practices, in particular to emerging space countries. Secondly, it will enhance the proposed management system by incorporating a method to identify and select potential missions that take into consideration the complexity of space missions, attractiveness and appropriateness to existing and future national desires, and building and accumulation of indigenous capabilities.

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Appendix A

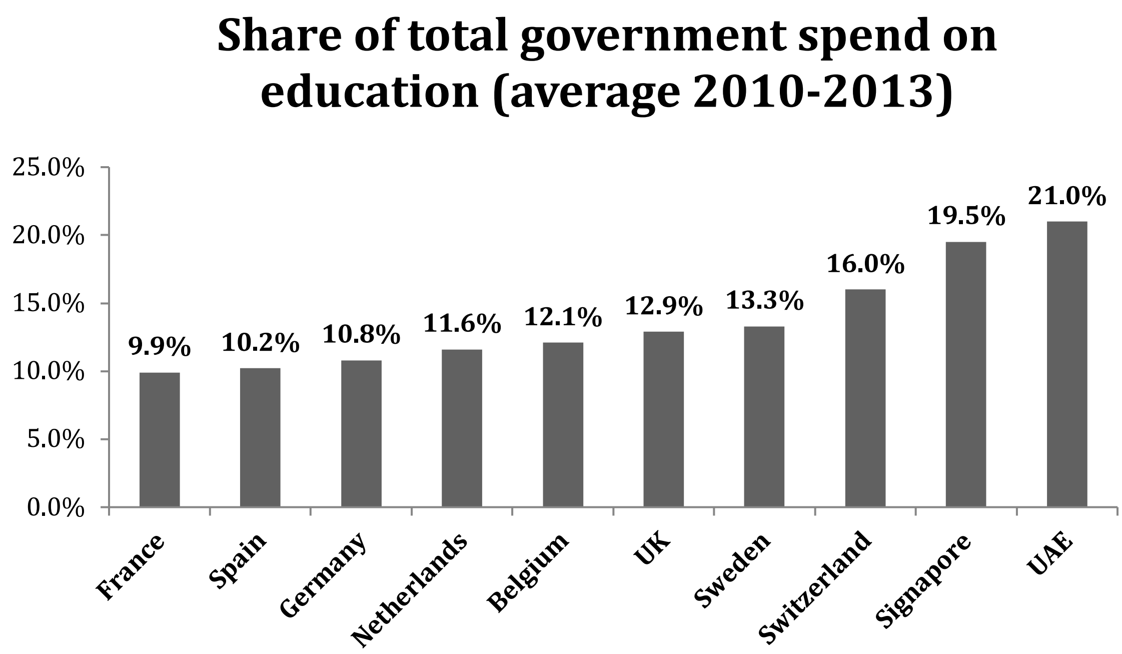

Figure A-1 Overall Government Spend in Education

Appendix B

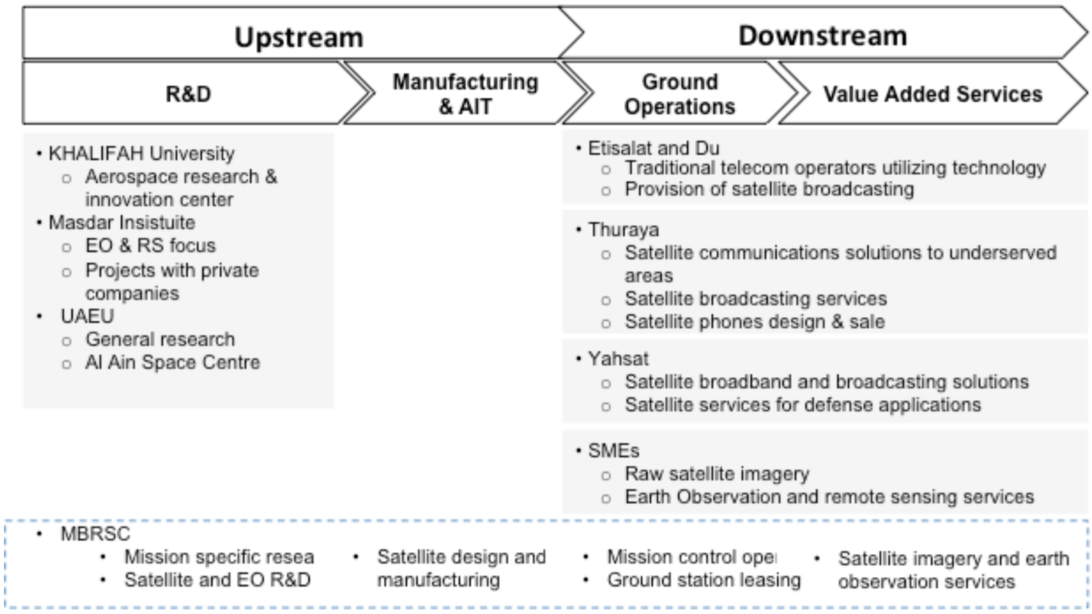

Figure B-1: UAE's Main Government Investments

Appendix C

Table C-1: Space Agencies List

Country	Entity	Type	Country	Entity	Type
Algeria	ASAL	Space Agency	**Kazakhstan**	KazCosmos	Space Agency
Argentina	CONAE	Space Agency	**Malaysia**	NSA	Space Agency
Austria	ALR	Space Agency	**Mexico**	AEM	Space Agency
Azerbaijan	ANASA	Space Agency	**Nigeria**	NASRDA	Space Agency
Belarus	BSA	Space Agency	**Norway**	NSC	Space Agency
Bolivia	ABE	Space Agency	**Pakistan**	SUPARCO	Space Agency
Brazil	AEB	Space Agency	**Peru**	CONIDA	Space Agency
Canada	CSA	Space Agency	**Romania**	ROSA	Space Agency
China	CNSA	Space Agency	**Russia**	Roscosmos	Space Agency
Croatia	CSA	Space Agency	**South Africa**	SANSA	Space Agency
EU	ESA	Space Agency	**South Korea**	KARI	Space Agency
France	CNES	Space Agency	**Sweden**	SNSB	Space Agency
Germany	DLR	Space Agency	**Taiwan**	NSPO	Space Agency
India	ISRO	Space Agency	**Turkmenistan**	TNSA	Space Agency
Indonesia	LAPAN	Space Agency	**UK**	UKSA	Space Agency
Iran	ISA	Space Agency	**Ukraine**	SSAU	Space Agency
Israel	ISA	Space Agency	**USA**	NASA	Space Agency
Italy	ASI	Space Agency	**Venezuela**	ABAE	Space Agency
Japan	JAXA	Space Agency			

Appendix C

Table C-2: Screening Space Agencies

Country	Annual Budget (in USD M)	Org Size (# Staff)	Agency Age (in years)	ISECG Partner	Relevance to the UAE	Data Available (Y/N)	Down-selected (Y/N)
USA	16,800	18,000	56	Y	Y	Y	Y
Russia	5,600	Unknown	22	Y	N	N	N
EU	5,510	2,000	39	Y	Y	Y	Y
Japan	3,230	1,594	11	Y	Y	N	N
France	2,803	2,400	53	Y	N	N	N
Germany	1,779	7,700	45	Y	N	N	N
India	1,300	Unknown	45	Y	Y	N	N
China	1,300	18,561	21	N	N	N	N
Italy	1,030	200	26	Y	N	N	N
United Kingdom	651	70	4	Y	Y	Y	Y
Canada	540	670	25	Y	Y	Y	Y
Bolivia	300	Unknown	2	N	N	N	N
Ukraine	250	Unknown	22	Y	N	N	N
Brazil	202	Unknown	20	N	N	N	N
South Korea	189	Unknown	25	Y	Y	N	N
South Africa	174	Unknown	4	N	N	N	N
Norway	106	39	4	N	N	N	N
Sweden	100	17	27	N	N	N	N
Nigeria	93	Unknown	42	N	N	N	N
Austria	80	Unknown	16	N	N	N	N

Country	Annual Budget (in USD M)	Org Size (# Staff)	Agency Age (in years)	ISECG Partner	Relevance to the UAE	Data Available (Y/N)	Down-selected (Y/N)
Israel	80	UNK	31	N	N	N	N
Iran	71	UNK	11	N	N	N	N
Romania	12	UNK	23	N	N	N	N
Algeria	UNK	UNK	12	N	N	Y	Y
Argentina	UNK	UNK	23	N	N	N	N
Azerbaijan	UNK	UNK	40	N	N	N	N
Belarus	UNK	UNK	4	N	N	N	N
Croatia	UNK	UNK	12	N	N	N	N
Indonesia	UNK	UNK	2	N	N	N	N
Kazakhstan	UNK	UNK	23	N	N	N	N
Malaysia	UNK	UNK	12	N	N	Y	Y
Mexico	UNK	UNK	4	N	N	N	N
Pakistan	UNK	UNK	53	N	N	N	N
Peru	UNK	UNK	40	N	N	N	N
Taiwan	UNK	UNK	23	N	N	N	N
Turkmenistan	UNK	UNK	3	N	N	N	N
Venezuela	UNK	UNK	6	N	N	N	N
Israel	80	UNK	31	N	N	N	N
Iran	71	UNK	11	N	N	N	N
Romania	12	UNK	23	N	N	N	N

Appendix C

Table C-1: Technology Roadmap (Illustrative) - European Space Agency (ESA)

Level 1 Technology System	Level 2 Technology Component	Level 3 Technology Sub-Component	Descriptions
1. Onboard Data Systems	A. Payload data processing	1.A.1 System Technologies for Payload Data Processing	Covers system aspects such as payload processing and storage architectures, algorithms, communication, etc., for Earth observation, science and manned-space applications.
		1.A.2 Hardware Technologies for Payload Data Processing	Covers hardware technologies related to high-speed/high performance equipment (e.g. DSP, mass memories, switches and communication links, digital video, data compression).
		1.A.3 Software Technologies for Payload Data Processing	Covers software technologies related to high-speed/high-performance payload data processing systems
	B. Onboard data management	1.B.1 System	Highly integrated systems, architecture, fault tolerance, onboard operation management and autonomy.
		1.B.2 Onboard Computers	Covers onboard fault-tolerant dependable computers, their main components (microprocessors, I/O) and basic software.
		1.B.3 Data Storage	Covers the development of data storage equipment (mass memories) and modules for spacecraft platforms.
		1.B.4 Onboard Networks and Control/Monitoring	Covers the development of the onboard data communication systems, including onboard command and control data networks for performing monitoring and control across the platform, and wireless systems.
	C. Microelectronics for digital and analogue applications	1.C.1 Methodologies	Rad-hardening by design allowing usage of commercial technologies, System-on-chip design methodologies, Hardware-Software co-design, usage of reprogrammable FPGAs for space applications, high-performance and low power signal processing algorithms and processors, analogue IC design. ASIC and FPGA design (design kit and libraries) and test tools.
		1.C.2 Digital and Analogue Devices and Technologies	Reusable IP cores, ASIC processors, detector readouts and sensor electronics front-ends, standard ASICs and ASSPs (Application Specific Standard Products), FPGAs.
2. Space System Software	A. Advanced Software technologies	1.A.1 Advanced Software Development Methods and Tools	Methods and tools for the software development that are innovative in the commercial world and require analysis prior to adoption in the space domain. This includes for example the OMG (Object Management Group) technologies, new languages, etc.
		1.A.2 Advanced software functions	New functions of the software systems that are anticipated to be needed but that need predevelopment or prototyping before actual space development. Includes autonomy, parallel computing, etc.
	B. Space segment software	1.B.1 Methods and Tools for Onboard Software Engineering Processes	All aspects of onboard software engineering, requirement engineering, automation of the life cycle, testing, model-based development, etc. In particular, it includes software emulators of onboard processors.
		1.B.2 Innovative Software Management Process	Adaptive engineering, new planning approaches, cost estimation methods, distributed development. The focus is on the system aspects of software, the system–software co-engineering. Includes also software–hardware co-engineering.

Appendix C

Table C-4: Illustrative structure for the Space ST&I Global Tree – ST&I Area No. 9

ST&I Area (Level 1)	ST&I Components (Level 2)	ST&I Sub-Components (Level 3)
9. Entry, Descent, and Landing Systems	**9.1 Aeroassist and Atmospheric Entry -** The intra-atmospheric technologies that decelerate a spacecraft from hyperbolic arrival through the hypersonic phase of entry.	9.1.1 Thermal Protection Systems for Rigid Decelerators
		9.1.2 Thermal Protection Systems for Deployable Decelerators
		9.1.3 Rigid Hypersonic Decelerators
		9.1.4 Deployable Hypersonic Decelerators
		9.1.5 Instrumentation and Health Monitoring
		9.1.6 Entry Modeling and Simulation
	9.2 Descent and Targeting - Technologies that bridge the hypersonic portion of the entry sequence with the terminal phase of landing.	9.2.1 Attached Deployable Decelerators
		9.2.2 Trailing Deployable Decelerators
		9.2.3 Supersonic Retropropulsion
		9.2.4 Guidance, Navigation and Control (GN&C) Sensors
		9.2.5 Descent Modeling and Simulation
		9.2.6 Large Divert Guidance
		9.2.7 Terrain-Relative Sensing and Characterization
		9.2.8 Autonomous Targeting
	9.3 Landing - Covers technologies that enable the final preparations for touch down and the landing event, which is complete when the kinetic energy of impact has been dissipated and the vehicle is at zero velocity relative to the surface.	9.3.1 Propulsion and Touchdown Systems
		9.3.2 Egress and Deployment Systems
		9.3.3 Propulsion Systems
		9.3.4 Large Body GN&C
		9.3.5 Small Body Systems
		9.3.6 Landing Modeling and Simulation
	9.4 Vehicle Systems - The system technology capabilities required to develop a comprehensive understanding of components, sub-components, and system level performance inherent to all successful entry vehicle systems.	9.4.1 Architecture Analysis
		9.4.2 Separation Systems
		9.4.3 System Integration and Analyses
		9.4.4 Atmosphere and Surface Characterization
		9.4.5 Modeling and Simulation
		9.4.6 Instrumentation and Health Monitoring
		9.4.7 GN&C Sensors and Systems
	9.5 Aerothermodynamics - Technologies and techniques that enable the understanding of atmospheric interactions with moving objects at high speeds. It encompasses the whole spectrum from takeoff to landing, but also orbital ascent/descent, aeroheating and thermodynamics of propulsion.	9.5.1 Numerical Methods
		9.5.2 Ground Testing Facilities
		9.5.3 Sensor and Measurement Technologies
		9.5.4 Flight Databases
	9.6 Flight Dynamics - Addresses the trajectory and attitude aspects of space missions. This includes the pre-flight trajectory design (mission analysis). In flight, it includes the determination and control of trajectory and attitude of the spacecraft, monitoring of spacecraft AOCS and generation of orbit- and attitude-related command parameters.	9.6.1 Global Navigation Satellite System High Procession Data Processing
		9.6.2 Advanced Flight Dynamic Design, Operations, and Tools

Appendix C

Table C-5: Illustrative structure for the Space Global ST&I Tree – ST&I Areas 16 and 17

ST&I Area (Level 1)	ST&I Components (Level 2)	ST&I Sub-Components (Level 3)
16. Life & Physical Sciences	**16.1 Instrumentation in support of life and physical sciences -** Technology to support assessment of human physiology, biology, biotechnology, exobiology/planetary exploration, fluid science, material science, crystal growth, applied physics, and planetary exploration.	16.1.1 Sensors and Analytical Instrumentation
		16.1.2 Imaging Diagnostics and Image Treatment Technologies
		16.1.3 Cultivation, Processing and Bioprocessing
	16.2 Applied life science technology - Technology that enable the application of advanced and new technologies of the life sciences to specific problems of planetary exploration, planetary protection and human long-term presence in space.	16.2.1 Application of Human Physiology Technologies
		16.2.2 Bioburden/Biodiversity Monitoring
		16.2.3 Biobarriers
		16.2.4 Dry Heat Sterilization
		16.2.5 Low-Temperature Sterilization
		16.2.6 Precision Cleaning and Sterility
	16.3 Applied physical science technology - Technology that enable the specific application of material science technology to use in situ resources for extraterrestrial production of components	16.3.1 Processing and Production
Satellite Technologies and Techniques	**17.1 Telecommunications -** Covers telecommunication techniques and algorithms (coding, modulation, access, synchronization, networking, security etc.), system tools and telecom equipment.	17.1.1 Telecommunications Systems Engineering Tools
		17.1.2 Telecommunications Signal Processing
		17.1.3 Networking Techniques
		17.1.4 Telecommunications Equipment
		17.1.5 Telecommunications Security
	17.2 Radio Navigation - Technologies specific for generating, receiving, exploiting and analyzing the signals from current and upcoming radio navigation systems (GPS, Glonass, EGNOS, Galileo) for satellites.	17.2.1 Navigation System Tools
		17.2.2 Ground Receivers
		17.2.3 On Board Receivers
		17.2.4 Formation-Flying RF Metrology
	17.3 Telemetry, Tracking and Control (TT&C) and Payload Data Modulator (PDM) - Covers both spacecraft TT&C/PDM techniques and technologies, space-link communications (RF, hybrid RF/optical systems, signal coding/modulation, ranging techniques, radio science experiments) and proximity links.	17.3.1 TT&C System Tools
		17.3.2 Deep-Space Transponders
		17.3.3 Near Earth Transponders
		17.3.4 Proximity Link
		17.3.5 High-Speed Downlink PDM
	17.4 Manufacturing, Assembly, Integration, and Testing Techniques - Addresses the technologies and methodologies required to support the MAIT of satellite technologies.	17.4.1 Manufacturing Processes and Techniques
		17.4.2 Assembly Systems Engineering
		17.4.3 Technology Integration
		17.4. Functional Testing Techniques

Appendix C

Table C-6: Survey: Capabilities questionnaire items

No.	Questionnaire Item	Remarks
1	What are the business drivers for your current work?	
2	What products/services do you currently offer?	
3	Which technologies do you possess?	
4	What active areas of research and development (R&D) are you currently pursuing (in-house or out-of-house)?	
5	What forefront space-related technology skills does your organization possess?	
6	What space-related equipment and facilities do you currently have?	
7	What are your goals and specific technically related objectives for the next 5 and 10 years?	
8	Do you have additional space technology aspirations for the next 5 and 10 years?	
9	What space or space-related technologies do you need for your business to meet your goals or aspirations?	
10	What technology skills does your organization need in-house to meet the technology needs listed in question 9?	
11	What equipment/facilities does your organization need in-house (or available in UAE) to meet the technology needs listed in question 9?	

Appendix C

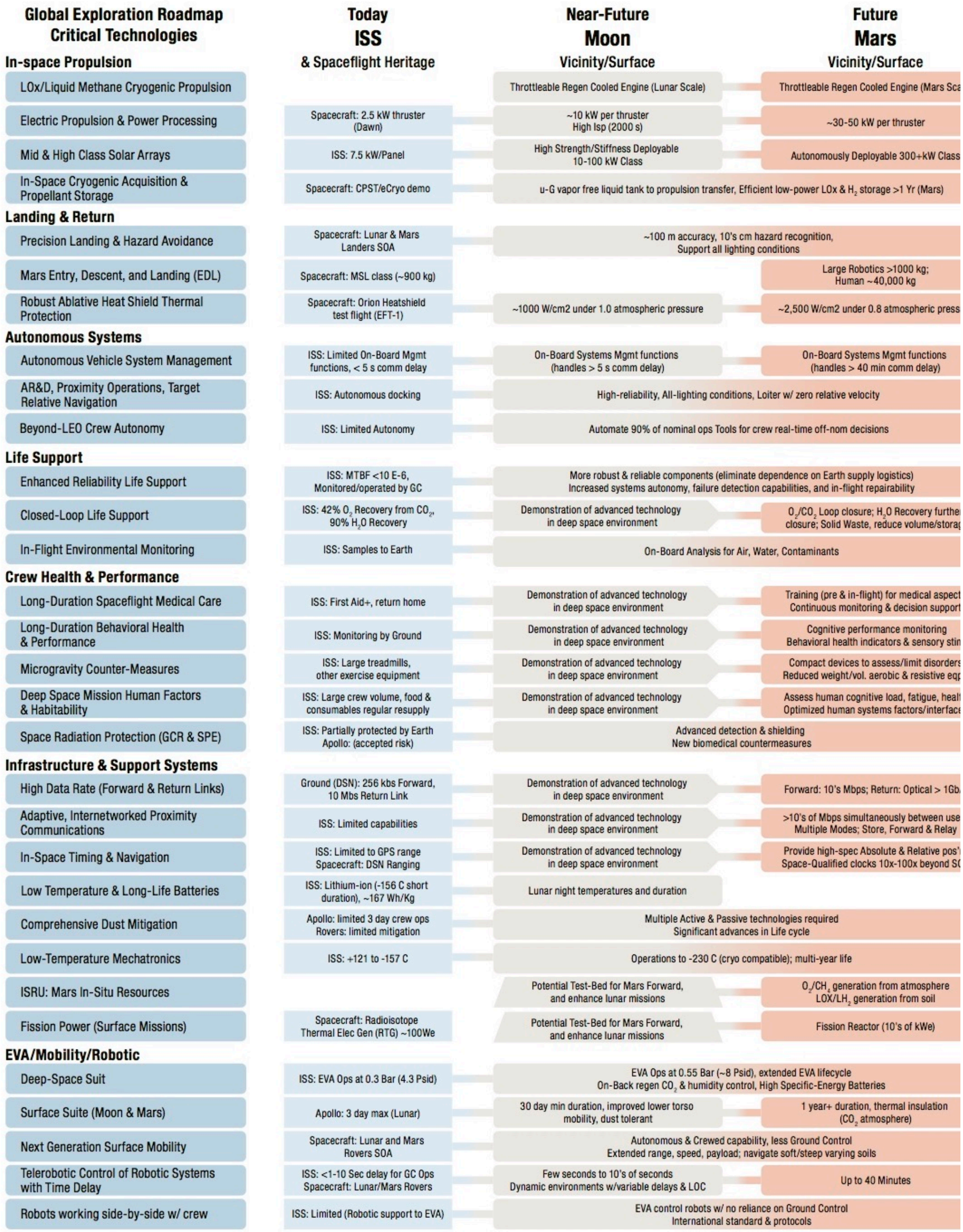

Figure C-1: Global Exploration Roadmap Critical Technologies (Source: ISECG, 2017)

Appendix D

Table D-1 Interviewee Profiles

No.	Case No.	Organisation	Position and Experience [in satellites]
1	Case 2	Sender	Senior management, adviser, over 30 years' experience
2	Case 2	Receiver	Senior management and engineer, over 15 years' experience
3	Case 2	Sender	Senior management and engineer, over 15 years' experience
4	Case 2	Sender	Senior engineer, over 10 years' experience
5	Case 2	Sender	Senior project manager, system engineer, over 25 years' experience
6	Case 2	Sender	Senior engineer, over 15 years' experience
7	Case 1	Sender	Senior engineer, over 20 years' experience
8	Case 1 & 2	Receiver	Senior engineer, over 8 years' experience
9	Case 1 & 2	Receiver	Senior management, project manager, over 10 years' experience
10	Case 1 & 2	Receiver	Senior project manager, over 10 years' experience
11	Case 1	Receiver	Senior management team
12	Case 2	Receiver	Senior engineer, less than 5 years' experience
13	Case 2	Receiver	Engineer, less than 3 years' experience
14	Case 2	Receiver	Engineer, less than 3 years' experience
15	Case 2	Receiver	Senior engineer, less than 3 years' experience
16	Case 2	Receiver	Engineer, less than 1 years' experience
17	Case 1	Sender	Senior management, previously project engineer
18	Case 1	Sender	Senior engineer

Appendix D

Table D-2: Interview guideline and protocol

Name of interviewee:	**Organisation:**	**Place of interview:**	**Date:**
Position of interviewee: Sender: Management/ Technical Receiver: Young Engineer (Receiver)	**TT Project Name:**	**Email of interviewee:**	**Acceptance to record:** **Yes/No**

Instructions:

Main questions: These are the essential questions aimed to elicit information on the main challenges and barriers facing organisations in developing countries when executing technology transfer projects. These questions were constructed to identify these challenges, barriers and success factors to maximise benefit from TT programme in future programmes.

Extra questions: Reword the main question in case requires more clarification and to check validity of the response or when the interviewee does not understand the essential questions.

Probing questions: Ask these questions when needed from the interview to elaborate more on their responses.

Time: 45 minutes expected for each interviewee.

Feedback and clarification: the response as understood by the interviewee will be sent to the interviewee through email for their comments if any.

(Noting that detrimental questions need to be avoided by not asking if effectively worded, double barrelled or complex questions)

Topics	**Main question**	**Probing questions**
1. Origin	1.1 What were the motivations and drivers that shaped the decision to invest in space technology and satellite MAIT?	i.e. political factors such as national pride, geo-political relationships and regional competition
	1.2 What were the benefits expected to be gained from partnering with [xxxx] in building [yyyy] satellite? [xxxx] i.e. LASP, SI and Orbital ATK in building satellite?	1.2.1 Was the project aimed to transfer technology and know-how in building satellites? 1.2.2 How important were the learning opportunities in building local technological capabilities from this TT project?

	[yyyy] i.e. name of the satellite Dubai I, II and KhalifaSat	1.2.3 Was the aim towards individual or organisation level learning initiatives and opportunities?
	1.3 What were your sources for technological information needed to develop your technological capabilities?	1.3.1 Were your TT projects a formal relationship? i.e. licensing, turn-key, or hiring technical consultants 1.3.2 Was it a government driven? In what context? 1.3.3 Did you considered pursuing knowledge individually? i.e. through reverse engineering, literature, conferences etc.? 1.3.4 How effective was this approach compared to the formal TT relationship?
	1.6 How would you define the EMM TT mechanism? Or KhalifaSat, YAH3 and 4	1.6.1 What is the special emphasis on TT mechanism? Is it on design or manufacturing or AIT or all? 1.6.2 Was this TT mechanism option built on prior knowledge and built up on previous accumulated capabilities? To what capacity and extent? 1.6.3 To what extent did this TT project help you to move up the space technology ladder i.e. to build local capabilities in MAIT? 1.6.1 Is there any in-house technological development capabilities?
Topics	**Main question**	**Probing questions**
2. Resource	2.1 What are you doing regarding the limited resources to help establish a technical workforce in satellite or to set up satellite manufacturing facilities? What is your learning approach to build-up capabilities?	2.1.1 What are the challenges that you are facing to retain qualified manpower in the core of the space programme?
	2.2 What are the challenges or obstacles that you are facing in building and maintaining	2.2.1 How the small enterprises (firms) landscape in the country impact the build-up of satellite MAIT?

	infrastructures for satellite MAIT?	2.2.2 Is the issue volume or maturity of the industry? 2.2.3 What are you doing to overcome these issues?
Topics	**Main question**	**Probing questions**
3. Routine (Tacit and Explicit knowledge)	*Satellite designs are not well codified, but require engineering judgment:* 3.1 What have you (organisation) done for your staff to know how to do the routine technological tasks e.g. design of component or subcomponents? Or What was the approach?	3.1.1 Have you considered individual self-learning or learning from experienced staff? Which approach was more effective? What were the challenges that you have faced? How did you resolve it? 3.1.2 How did you communicate the tacit knowledge to your technical staff? (*define tacit as basically knowledge with experience staff and not written*)
(technological capabilities and knowledge learning)	3.2 How much of built up over previous years of experience used or supported you in Al Amal project? (Specific to MBRSC)	3.2.1 Have you codified? Or written the routine technological tasks from previous TT projects? To what extent? 3.2.2 What were the challenges you faced when writing the routine technological tasks?
Topics	**Main question**	**Probing questions**
4. Organisation culture (absorptive capacity) ***(Receiver)***	4.1 How well do you think your organisation acquired and internalised new information about the technology?	4.1.1 Did prior knowledge in MAIT supported you in developing new technological capabilities? i.e. in project X 4.1.2 How intense the effort applied by your organisation to understand the technologies (i.e. design, manufacture, AIT)? 4.1.3 What responsibilities made by your organisation or leadership to ensure this was achieved?
	4.2 Do you intend or plan or explore to leverage your technological capability to offer solutions regionally or internationally such as in satellite MAIT?	4.2.1 Is it an issue of the economy of scale of the industry in the country for this consideration? Or for other purposes? 4.2.2. Would you require support from the government? What would be the role of government?

4. Organisation culture (absorptive capacity) ***(Donor)***	4.1 What allows a latecomer organisation in a developing country to successfully move through the phases from manufacturer to process innovator to product innovator for a particular class of technology?	4.1.1A How was the prior knowledge relevant (Dubai Sat I and II) and was supportive in current project EMM TT? (LASP) 4.1.1B How was the prior knowledge relevant (Dubai Sat I and II) was supportive in current project KhalifaSat? (SI) 4.1.2 What challenges face MBRSC in taking in and acting on new information about technology or MAIT? 4.1.3 How the intensity of effort applied by MBRSC (staff and organisation) in understanding the technology (i.e. design and manufacturing)?
Topics	**Main question**	**Probing questions**
5. Contracts	**Partnership types** 5.1 How do you see the partnership with SI as a private entity seeking 'value for money' than partnering with LASP as a public entity?	
	.. same question to Yahsat (private), but .. than partnering between Orbital ATK and MASDAR on the smalls satellite offset programme	5.1.1 All your projects were turn-key projects, what was TT mechanism? Was there any reverse engineering or licensing options? If TT was limited to staff taking parts in the design? What have changed in YAH4? How this will support you developing satellite MAIT capabilities? Do you intend to shift towards satellite MAIT in the future? How this will impact the economy of scale of satellite industry in the country? i.e. impacting MBRSC
	Export control 5.2 How did it impact the TT process?	5.2.1 How does the legal framework in Korea support you in the transfer of technology and know-how? 5.2.2 and compared to LASP in US? What were the differences and challenges you faced?

	Political pressure 5.3 Do you have government direction to purchase specific components or systems from particular country or companies?	5.3.1 How does this impact the TT process?

Appendix D

Table D-3: An extract sample of a transcribed interview – an interviewee from sender organisation.

Q: What needed by a receiver of technology to acquire the knowledge and information in order to move in building capabilities.
A: I think to build space hardware you have to build space hardware you have to have a role in the project, you have to have significant responsibilities, and you need to have ability to carry out that. I think for the case of people who came to here and stayed with us who have taken on active roles in the programme and I think they will leave with great knowledge an insight, Mohsen is one of these candidate, he is here taking the role and not just coming every once and a will, but he actual taking a role. I think you have to be involved and it can happen while you are here or it can happen in their facility. As long you are having responsibility and role in the programme, I think those two things play together to given the experience.
Q: In your opinion, what was your expectation when you got this project understanding that had thee programme. In term of capabilities
A: I expected to sit a room with staff whom are knowledgeable to go through each of the subsystem and talk technically about the subsystem, the details of the subsystem and architecture of spacecraft, and what would be the correct way to move forward and how can we share and split the work
Q: how the organization retained knowledge is it within organization and individuals
A: So the organization maintains knowledge of process, the individual retain technical knowledge. For example every individual work in the programme has technical knowledge they retain we take advantage of that knowledge, LASP has process around that. For example, you could come and take all of our drawings, that we have built, it is all your, because the knowledge in people heads, their hand on, i did it and worked it. I think that the important element,

Table D-3: An Extract Sample of a transcribed interview – An interviewee from receiver organization

Q. How well do you think your organisation acquired knowledge and internalised it within its organisation?
A: We went through different phases. Phase 1 was about learning, contributing and building capabilities, and phase 2 was about a joint development and phase 3 was independent from the partners and developing the whole system. I think we after these years and going through these phases we have strong team. We have the knowledge that allow us to work with international partners like LASP and US. If we look at the space sector and space business and top nations we have NASA, EU and JAXA and ESA and then other nations such as South Korea.. Because we have no knowledge at the start and due to export control imposed by top nations. Because of export control we went with Satiric Initiative. That was good start and we have selected the right partner. I think the initial study we looked at different market. At that time as a country we did not have relationship and cooperation with Korea 2005-2006. Even we had embassy but small number. We started the cooperation with South Korea. We did not take the traditional route. We looked at the knowledge that we want to obtain and capabilities that we can develop. Hence, we selected SI since we can develop the required capabilities. We looked into at their level of openness, their level willingness in sharing of data and knowledge, we took these into considerations, so taking this approach, we had the bases and the strong foundation that allowed us to prepare this team that could work with their based with advanced nations such as in the EMM project.
Q. Did you negotiate with SI in terms what sort of technology transfer that you would do?
A: Yes, we went through the component level and all the way to basics.
Q. Was that for DubaiSat 1 and 2 ? what was the difference in TT?
A: Yes, it was for both.
Q. What was the difference between TT in D1 and 2?
A: We know the TT is limited to a period and for lifetime. So we have to maximise the benefit of these projects. In our case, in D1, it was initially to build capability to certain level. D2 was an opportunity for TT and to continue and maximise it to achieve at higher level. In order to do this, we did not have replicate to D1, when we decided to build D2,
Q. In terms of the internalising of the process and keeping the knowledge not in individual but in organisation. So what else have you moving from D1 to 2 and Khalifasat. What was the lesson learning, how you internationalised the process and become ownership of your organisation
A: How we are documenting the design, requirements, the way we do is to write the documents; also in terms of knowledge of transfer, we have a team now dedicated from knowledge management. Since at the end day, knowledge is really to capture, something in your head or hand and want to capture it and also document, So now we have TT team doing that. They are coming with methods and tools. It was started since one year. We have two.

Appendix D

Table D-4: Template Analysis of Interviewees [S: Sender, R: Receiver of Technology, No.: project number]

Sub-Statements	Source (Interviewees No., Table D-1)	Main Themes	Sub Themes L1	Sub Themes L2
1. *"From my perspective, it took our organization 20 years to get there, and over 30 years in instrumentation of spacecraft. It is not happening overnight."*	*No.2*	Managing stakeholders' expectations	Indigenous capabilities	
2. *"We went through different phases. The initial project was about learning, contributing and building capabilities. The second project was about joint development and the third project was an independent project from partner and developing the whole system."*	No.2	Managing stakeholders' expectations	Indigenous capabilities	
3. *"I think navigation is not an area of our strength and not needed in our previous projects and only needed if you do interplanetary missions and still we will have less knowledge transfer because of ITAR in current project "*	No.3	External factors	Government protection	Export control
4. *"We looked at the knowledge that we want to obtain and capabilities that we want to develop. Hence, we selected this organization since we can develop required capabilities. We looked into their level of openness, and willingness to share data and knowledge, we took these into considerations"*	No.3	Routine - Internalisation and Operationalisation TT	Partner selection	
5. *"If the expectation are laid out appropriately earlier enough, a good balance can be struck and those product can be a measure of transfer of communication"*	No.3	Routine - Internalisation and Operationalisation TT	Setting up the programme	
6. *"I feel the matrix approach to organization structure starts to go down, and latching on a single project through its completion is I think critical. You do not have areas where information dropped or*	No.1	Routine - Internalisation and Operationalisation	Setting up the programme	

miscommunication as much I should say"		TT		
7. "It is a balance on what we can support and on what is needed. The number 10 comes to my mind. When it comes beyond that it become a a management issue"	No.5	Routine - Internalisation and Operationalisation TT	Partner expectations	
8. "If we are in contract to do this, then we need to ensure we can partner with and work together"	No.3	Routine - Internalisation and Operationalisation TT	Partner expectations	
9. "I expected to sit in a room with the client equitable to go through each of the subsystem and talk technically about the subsystem, the details of the subsystem and architecture of satellite and what would be the correct way to move forward and how can we share and split the work"	No.1	Routine - Internalisation and Operationalisation TT	Partner expectations	
10. "We need to start on things we know how to do, and then these questions started to come if they have relevant knowledge in previous projects. So these conversation slowly started to come"	No.3	Routine - Internalisation and Operationalisation TT	Partner expectations	
11. "We looked at the knowledge that we want to obtain and capabilities that we want to develop. Hence, we selected this organization since we can develop required capabilities. We looked into their level of openness, and willingness to share data and knowledge, we took these into considerations"	*No.3*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge identification
12. "I will look into what are those aspect that make sense to control from micro perspective. Thinks like reaction wheel, start tracker and sun sensors, you can build but other people do"	*No.1*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge identification
13. "The data handling control system, central processing of satellite, I want to control that and I think you want to control that too."	*No.1*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge identification

14. "If you ask me what different between satellites, I would say the central brain, the central processor, and the software that are running inside it. I want you have that and then you can buy and of other components"	*No.1*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge identification
15. "let them carry the weight of a particular responsibility on their own and finish through"	*No.5*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
16. "We found people who design, understand how it built the pieces together and test. Having that continuity it goes to efficiency as well.". "the competencies are the same during the design and when building spacecraft "	*No.3*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
17. "In this case the conversion and knowledge transfer could take place when receiver engineers articulate and integrate new with existing knowledge that are already embedded in 'routines activities'"	*No.3*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
18. "Potentially that would be easily codified if it was set up that way with its counterpart, and we do not have mechanical design 101"	*No.4*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
19. "So I would say witnessing the tests and performing the test, seeing the data, AIT is awesome opportunity and it is fun."	*No.3*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
20. "It is mostly we do it from scratch for each satellite which probably sound inefficient. We try to go back to previous challenges than starting from blank page. For some components we will not start from blank such as the ultraviolet instrument in this project, but it will be blank page for the satellite"	*No.3*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
21. "If you are not in the meeting and engage in the conversation,	*No.3*	Routine - Internalisation	Technology	Knowledge

and if you are in teleconference, you will be an observer"		and Operationalisation TT	transfer process	articulation
22. "I expect they will be involved in writing the test and procedures, either witnessing or observing or both. So I think the AIT will be really straight forward to get know how transferred."	*No.7*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
23. "During design phase, is mostly paper work, as we got to AIT phase that where learning would take place where you actually see how things together and see it works or do not"	*No.1*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge integration
24. "codifying and documenting the process of design and MAIT and pointing that it is a potential mechanism to articulate knowledge"	***No.7***	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge articulation
25. "What he internalizing and findings out how to do it right … focus your effort on these areas and communicating this with the team what is successful about these area and how it did work and why."	*No4*	Routine - Internalisation and Operationalisation TT	Technology transfer process	Knowledge combination and generation
26. "Create training sessions, saying here what I do, the rational I do, the tools that I am using, … a conversations I have with system engineering team, was a whole description of system engineering"	*No.3*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Coaching and mentoring
27. "I am huge believer in osmosis effect, and just being around it and living it and that is the best way to become skilled and professional at it "	*No.3*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Coaching and mentoring
28. "we lived daily terror of being responsible, there was no safety net, .. and every one invested in this programme".	*No.3*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Ownership
29. "He really understand the pain associated with doing things right or wrong and finding out how to do it right"	*No.3*	Routine - Internalisation and Operationalisation	Methods and Approaches	Ownership

		TT		
30. "The idea of sharing responsibilities and work was a successful thing we at our organization do very successfully"	*No.5*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Sharing responsibilities
31. "The idea of sharing responsibilities and work was a successful thing we at our organization do very successfully"	*No.5*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Sharing responsibilities
32. "I am not doing the work behind of him. I am approaching the relationship as I was doing things in the past, and these are the tool I have used, and slowly we have worked to a point where he do it in his own"	*No.5*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Direct responsibilities
33. "In some cases, we perform an analysis and then compare their results, in a way to know if they are getting the right answers, and discuss assumptions to rework what they are doing"	*No.3*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Direct responsibilities
34. "He has some tasks in his plate, responsibilities, we are not covering for him, he is doing them, and if not done, I have to hire somebody to fill in the gap"	*No.3*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Ownership
35. "I am not doing the work behind of him. I am approaching the relationship as I was doing things in the past, and these are the tool I have used, and slowly we have worked to a point where he do it in his own"	*No.5*	Routine - Internalisation and Operationalisation TT	Methods and Approaches	Direct responsibilities
36. "If they are developing a design of a subsystem like EPS, you can tell a good design from bad design, you can tell the difference."	*No.9*	Routine - Internalisation and Operationalisation	Methods and Approaches	Direct responsibilities
37 "Anybody who involve himself will leave this programme with important aspects. One is shear knowledge, day to day knowledge, lesson learned, experienced based knowledge, that can carry back	*No.7*	Routine - Internalisation and Operationalisation	Methods and Approaches	Shear knowledge

and communicate to their organization if there is a way to do that and if there is culture for the to do that"			
38. "they had their engineers working at partner facility for more than five years without interruptions in order to effectively engage in the transfer of know-how. These engineers are now building the third satellite locally in the UAE facility."	*No.2*	Resources	Employee engagement
39. "He is with us every day, he become knowledgeable, he understand day to day detailed of the mission as we progress". "He will come out of this programme with different level since he came to the programme".	*No.3*	Resources	Employee engagement
40. "We have reached to this level of knowledge in developing the third satellite by our self since our engineers were fully engaged working closely with our partner at their facility for the first satellite"	*No.3*	Resources	Employee engagement
41. "A lot comes from coaching, we also brought retire from other leading organization, they have decades of experience so they provide much advise as much they could."	*No.3*	Resources	Expert pool
42. "It will be straight forward and efficient to have truly interested hard working people from client "	*No.5*	Resources	Employee engagement
43. "I think there is different way that client's management to be embracing the programme"	*No.5*	Resources	Leadership engagement
44. "Twenty years ago, we had a student programme, around 30 student and six professional, if we to do it just with student we could get a lot done but will not have a successful programme. It is the extra level of experience people working mentoring and helping other people who are figuring things around. I think this programme like that"	*No.3*	Resources	Expert pool

45. "I think he pulls their satisfaction by asking them what is your tasks and why you did, by doing this they get engaged again"	*No.7*	Resources	Leadership engagement
46. "Make sure these individuals have tasks that are interesting so they become motivated and making progress"	*No.7*	Resources	Motivation
47. "I think she was motivated by just giving her responsibility in her area. I think individuals are motivated by different things."	*No.7*	Resources	Motivation
48. "Those whom are not motivated do not have clear assigned tasks per their skill set available to them"	*No.6*	Resources	Motivation
49. "It is the extra level of experience people working mentoring and helping other people who are figuring things around. I think this programme like that"	*No.3*	Resources	Expert pool