RESEARCH PROPOSAL EXAMPLE

THE FUNCTIONALITY MODEL AS CONCEPTUAL FOUNDATION FOR MANAGEMENT OF TECHNOLOGY (MOT)

1. INTRODUCTION

This introduction presents a context for this dissertation and helps clarify to the reader how fulfillment of the research aims and objectives will make a contribution to management science and practice. To do so, the discussion starts off with a background and purpose of the research project, and then it explains the research focus and gives a brief overview of the project's approach towards a literature research. The introductory section ends with a mission statement and an overview of the proposed research method.

1.1 Background and purpose

Technology consists of a diversity of manifestations, applications and disciplines, and now needs a unified theoretical structure and body of knowledge, so that students and practitioners of Management of Technology [from here onwards described by its acronym of MOT] may benefit by creation of these paradigmatic foundations in their task of strategic technology analysis and management. Given the omnipresence of technology, described by Van Wyk (2000:204) as "technification", the necessity to promote technology literacy among students and practitioners of technology becomes self-evident. Drejer (2002:363) states unequivocally that MOT should be a significant part of organisational management. The management imperatives to understand technological progress and its multiple outcomes are also implied by Gottfredson, Schaubert, and Saenz (2008:68), when they state that market leaders typically outperform market followers on return on assets (ROA), compared in terms of their relative market shares. It is in agreement with the argument that corporate technologies are assets on the balance sheet and include manufacturing tools and processes, products and services, associated intellectual property and subsequent patents, as well as innovations in products and services. This is so, even if General Accepted Accounting Practice (GAAP) still treats research and development (R&D) as an expense on the income statement rather than as an asset on the balance sheet (Ehrbar, 2000:55). To the decision-makers, and technology practitioners, of these corporations, the task and indeed challenge is to pursue a comprehensive understanding of management of technology, which would typically encompass understanding of technology progress and supporting technology intelligence processes, to all aspects involving product and service lifecycles and all processes in the relevant value chains.

Van Wyk (1988:4,7) promotes wider academic and management acceptance of MOT and has been doing so since the late 1970's. He describes MOT as the management discipline which pursues understanding of technology potential and harnessing of such potential to the benefit of organisations (Van Wyk, 2000:205). But the discipline, and the profession it serves, remains obscure, because it lacks respectively an established task sheet for technology executives, a book of knowledge for students and practitioners and the nurturing attention of a "mother science" (Van Wyk, 2008:personal communication). Indeed, Drejer (1997:254) still expresses concern about the confusion surrounding MOT concepts and the discord about practical tools for solutions of technology management problems. According to Gunther Ropohl (1999a:66), "hardly anybody" understands technology, in spite of the clear management imperative to do so. Phaal and Farrukh (2000:1) find little common ground in technology management strategies and practices between different industries. The study of technology, its theoretical foundations and its management principles, are all still poorly understood. It lacks a unified model (Beard, 2002:46) and, according to Van Wyk (2002:15; 2004:10), a scientific paradigm to support on. Stating that the discipline reorganises under the influence of new paradigms and now presents a consolidated set of concepts, Pelc (2002:37) serves as a good example of a new academic stimulus which now characterises MOT. It appears, however, only as a precursor to pending debates about the multi-disciplinary and highly complex nature of MOT. Characteristically of academic debate, the discussion about MOT highlights divergent viewpoints about technology and its origin, history, etymology of terms and definitions, nature, role and educational doctrines. It is a dialogue in dire need of direction, as evidenced by a long time participant to the conversation, Peter Bond (2001); and theoretical structure as "…a unifying perspective to aid in its comprehension…", as stated by Farrell (1993:161). It is not a dialogue lacking definitions of technology, which will be used as sparingly as possible in the unfolding of this research project. Definitions of the notion of technology are in fact in abundance, and have caused lots of disagreement in the wider discourse about MOT, as is shown by Shenhar, Van Wyk, Stefanovic and Gaynor (2004).

The subsequent revival of MOT as an academic discipline creates a formalised structure for scientific discourse about technology and its management, which has led to the establishment of university teaching programmes and the creation of professional societies such as the International Association for the Management of Technology (IAMOT) (Van Wyk, 2000:206), as well as a broadly accepted Credo for MOT (Van Wyk, 2003). More importantly, it spurs efforts to further debate and to formulate a theory of technology (Van Wyk, 1988; 2000; 2002; 2007; Shenhar et al., 2004). These developments, described by

Van Wyk (2002:14) as a "fascinating quest" towards a fundamental theoretical structure for technology, have served as a stimulus for more theoretical work in MOT. Certainly it serves as a clarion call to this author, who is acutely aware of the general lack of technology edification among students and practitioners of MOT, having studied MOT as part of the UNISA M.Tech programme and having published and written on the topics of technology practices and management of technology maturity over the last decade (Zietsman & Lochner, 1998; Lochner, 2005; 2006).

1.2 Research focus

The road is clearly laid out. MOT is a pivotal profession for the 21st century, but it requires a firm theoretical macro-structure to support on. With the focus on technology edification, a term coined by Van Wyk (2008) for what he describes as "corporate technological capabilities" (Van Wyk, 1991:39), this research project probes MOT for its theoretical foundations and assesses it links to a paradigm of technology. According to Van Wyk (2008:personal communication), at least four different models reflect a theory of technology as it stands in service to MOT, i.e. the (1) Functionality model with its holistic focus on functional classification; (2) the Economic model with its focus on techno-economic imperatives; (3) the Thematic model with its focus on individual themes; and (4) the Engineering model with its focus on individual sectoral perspectives. Of these, the Functionality model appears as the most likely candidate to help form a coherent and unifying theory of technology, and it is this model which will consequently serve as the primary theme of this dissertation.

1.3 Approach to literature review

The literature review starts off with a short overview of the linkage between Management of Technology and technology literacy. This is the most fundamental postulation to be made in this research project, i.e. for technology to be understood in its various manifestations, students and practitioners of MOT must have a holistic understanding of technology and its inherent functional characteristics. It is incumbent upon MOT to provide theoretical and practical tools to this end, and to do so in terms of generally accepted research doctrines in the form of a paradigm of technology.

A variation on the theme of technology paradigms is techno-economic paradigms. This is a theme which has been made popular by a school of thought which can be described as Neo-Schumpeterians, with thought leaders such as Giovanni Dosi, Christopher Freeman and Carlotta Perez stating a case for the reciprocity between economics and technical change, as encapsulated by technological revolutions, and the associated formation of a distinctive paradigm for theoretical analysis of this relationship. Perez (2002) suggests a series of techno-economic revolutions, a theme to which she adds the distinctive behavior of respectively financial and production capital. With the age of information and communication technologies [from here onwards described by its abbreviation of ICT] now having reached maturity as the last of her five techno-economic revolutions, the focus of the literature review shifts to a new epoch in technological progress, i.e. that of so-called convergent technologies, and observes its irruption as it merges with the remnants of the outgoing techno-age. What is this phenomenon, and how does it become a major theme within this dissertation? In response to these questions, the literature review will present a case for convergent technologies to become the practical focus of this dissertation.

A next issue that arises is technology and geography. On the one hand, this dissertation appeals to the inherent international character of both the discipline of MOT as well as the discourse about this subject field. On the other hand, this research project is from Africa, and also for Africa and its peers among the larger cluster of Developing Economies. Not only is there adequate evidence to show that these economies do not have the absorptive capacity to benefit from international technology transfers (Wamae, 2006), there is also evidence that South Africa needs to improve her production competence and knowledge generation for technology transfers (Hipkin & Bennett, 2004). In fact, the entire discourse about the Digital Divide as it manifests in Developing Economies is a vindication of the above views, as is sufficiently shown by Lochner (2006). Ultimately though, choosing markets for research data depends on the research model, its data requirements and the vagaries of data collection.

It is Kuhn (1962) who introduces the term paradigm as encompassing the origin, growth and evolution of science. Kuhn is generally acknowledged as having succeeded in meta-formalising paradigms as evolving and competing norms and rules for research, even if, according to Green, Hull, McMeekin and Walsh (1999:780) he stands accused for having lost control of the term and having never defined it precisely.Responding to the debate that followed the first edition of his work, Kuhn (1970:182) describes in a second edition a paradigm as a “disciplinary matrix” consisting of respectively symbolic generalisations, shared heuristics or commitments, shared values and concrete solutions to problems, also known as "exemplars" (IBID.:187). Combined with theory, methods and standards, these components provide researchers with a "map" for research, as well as with directions for "map-making" (1970:109). Although Kuhn demonstrates his assertions almost exclusively with examples from the natural science, paradigms and their functioning are now omnipresent in general academic discourse across all scientific endeavour, and disciplines outside the natural science also have significantly benefitted by paradigmatic guidance for the last half century (Mouton, 1987:74).

Rommel and Christiaens (2006:610-612) argue that the paradigm concept is used too loosely and claimed too easily, without authors having used a systematic framework to show how their claims meet the Kuhnian commitments of a paradigm, i.e. to be conceptual, theoretical, instrumental and methodological. DeGregori (1985:187), on the other hand, argues in his submission about a theory of technology that academics should not be too rigid in the use of intellectual models, because it may stifle the process of selecting technologies to solve problems. However, paradigms must reflect a meta-theoretical and philosophical ontology, and must be seen to represent a comprehensive macro-view of reality (Rommel and Christiaens, OP CIT.:613). This remains a requirement achieved only via the lengthy intellectual road of phenomenology, hermeneutics and heuristics, all of which are building blocks towards epistemology and subsequent theory. Seeking guidance from those who have travelled the road before, the rest of the literature review follows Assefa (2005:9) in his functional interpretation of the building blocks of scientific paradigms, and his exposition of how a paradigm does its work of guiding scientific thought. As depicted in Figure 1, a paradigm has at its foundation a philosophical ontology which dictates its epistemological framework, from where theory originates to guide scientific method, which feeds its scientific outcomes back down towards a body of knowledge at the epistemological level.

Jain and Narvekar (2004) describe it in a shorter manner from the top down:"Methodologies arise out of a set of assumptions that constitute a way of viewing reality also referred to as a paradigm". A particular world view as foundation is shown here with fixed lines, because, as Kuhn (1970:175) puts it, a paradigm "… stands for the entire constellation of beliefs, values, techniques …shared by the members of a given community". Green et al. (OP CIT.:781) describe it as a "whole research perspective". Softer lines distinguish the rest of the paradigmatic components, because observation and conceptualization, and fact as well as assimilation to theory are inseparably linked in the research process.

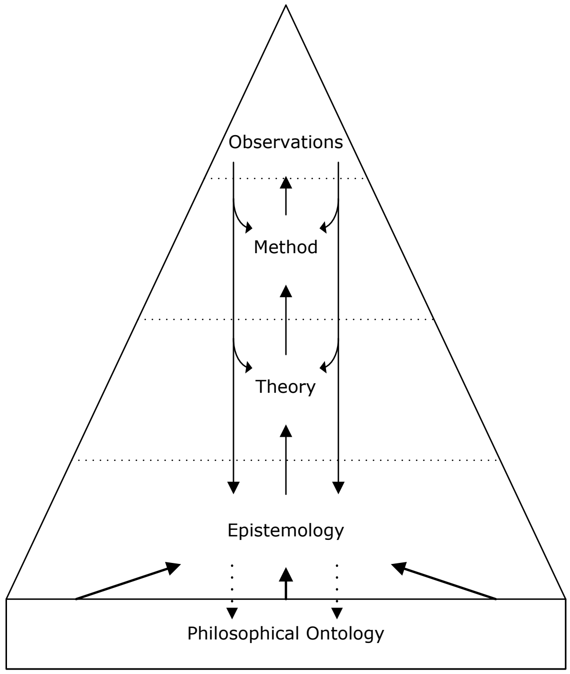

Figure 1: A simplified structure of a scientific paradigm

Source: Author’s own

Anchored to ontological and epistemological foundations, knowledge must be operationalised within paradigms, and must be anchored to theory and method. Van Wyk (2004) and Shenhar et al. (OP CIT.) represent a contemporary school of thought which suggests that a coherent and discernible theory of technology may become the scientific foundation, or an “anchoring discipline” as Van Wyk (2008:personal communication) calls it, for MOT. They accordingly believe that Strategic Technology Analysis [from here onwards described by its abbreviation of STA], may serve as the paradigmatic underpinning for the Functionality model, with the latter to serve as the core theory for MOT. Functionality classification clearly presents the opportunity to link the different elements within an evolving technology paradigm, and specifically to test theory in practice. As to be reviewed here, the work about functionality classification by Van Wyk from 1979 onwards, and others since convinced of the merits of this model, is evidence of all these paradigmatic building blocks. It helps, as Coccia (2005:946) suggests, to understand technology holistically in terms of its evolution, functional components and measurable attributes, and it matches theory to practice.

The literature review is mostly theoretically orientated. With single exceptions the sources of literature here discussed are academic journals and conference proceedings. Where there is no alternative, online sources are used in the prescribed manner to support an argument in the discussion. In single instances direct communications are pursued with authors about views fundamental to this research.

1.4 Aims and objectives of the research

From Drejer (2002) comes the admonition that MOT research and theories be accompanied with a proper contextualization of its use and value to real management problems, because of the large number of divergent research contributions characterising the discipline. Following from this, the overarching aim of this dissertation is to contribute to the formalisation and structuring of a theory of technology which may help to build out STA as a paradigmatic foothold for the discipline of MOT. To do so, this dissertation will continue to build upon the research results of Ropohl (1979), Van Wyk, Haour and Japp (1991), Magee and De Weck (2004), Koh and Magee (2006; 2007), and Van Wyk (1984; 2007; 2008), which show that the Functionality model presents an opportunity to broaden and strengthen the body of knowledge and knowledge tools in service of MOT.

In spite of its simplicity and appeal, and the progress recorded with its practical application, taxonomic conception of technology for proper differentiation and classification of technology processes and functionalities remains until now an unmet challenge to students and practitioners of MOT, who find themselves confronted by a market environment with exponentially growing numbers of technological entities. The status of the Functionality model as described here may very well fit into what Amundson (1998:343) describes as a "cognitive frame", generally viewed as a broader, more fundamental concept than a theory and as a necessary precondition for theory development. Cognitive framing consists of respectively 1) specification and definition of concepts, 2) determination of priority among concepts, and 3) specification of relationships between key concepts. According to Amundson (IBID.:344) there is general agreement in the research community that theory construction indeed happens during this last step of cognitive framing. Certainly, the critical condition for theorising, i.e. the task of explaining why particular relationships are observed, happens in this phase.

Setting the status of the Functionality model as a particular cognitive frame helps to define a structured point of departure for this dissertation, and by default helps to define the way forward. A first objective for this dissertation is therefore to re-examine the theoretical basis for the Functionality model and its key concepts, and to analyse relationships between these concepts, to assess its usefulness as a taxonomic construct. A second objective is to investigate the application of the Functionality model in various permutations and settings, with a focus on an entirely novel class of so-called convergent technologies. To create the linkage between observation, theory and knowledge about technology, the third objective entails conception of a value construct, which is to be established with appropriate statistical techniques, and which is to serve as measurement for testing of the research hypothesis, as well as to be considered as a management metric so that MOT may benefit in practice. This objective also involves qualitative confirmation of the statistical findings. A fourth and final objective is to evaluate the Functionality model in terms of the guidelines for good theories, and to formulate and recommend steps to help to improve the model, its theoretical resemblance and its practical use, which again may serve as increments to the affirmation of a paradigm of technology. Collectively, these research objectives are pursued in order to test the primary research hypothesis, provisionally formulated as that different taxonomic permutations of the Functionality model have different utility values to students and practitioners of MOT.

From these objectives, the following research questions arise:

1. What are the theoretical grounding and attributes of the Functionality model, and is its application as a taxonomy of technological entities only conjecture, or does it indeed have theoretical and practical bona fides?
2. Can the Functionality model in fact be used for a taxonomic classification of selected technological entities representative of the latest techno-economic trend towards convergence?
3. How is taxonomic value to MOT practitioners to be measured, and what metrics or instruments are available to test the research hypothesis?
4. When applied, tested and observed, does the Functionality model meet the requirements for good theory? How can it be improved, given the test results, and what recommendations flow from these insights to improve the theoretical stability of the model and the replicability of its results when applied in practice?

The key to answers on these questions is a properly conceived research model, which complies with all the relevant academic and scientific requirements. A brief overview of this research model follows next.

1.5 Proposed research method

"Management research…cultivates the ground of substance…with the spade of methodology…", according to Duncan (1993:256). Presenting methodological strategies and practices for theory-building in the discipline, Jain and Narvekar's (2004) confirm MOT research as a subset of management research. To this end they present researchers with a contemporary overview of research paradigms, ranging from Positivism as the context-free logical option to Constructivism as beholder of a multiple social constructions. Not uncommon to doctoral projects, this particular research is faced with a paucity of data and applications of the core construct, i.e. the Functionality model, and absolutely so with regard to the emerging class of convergent technologies. Recognising the empirical challenge, this research project will straddle the boundary between the Positivist and Post-positivist research traditions, the first to comply with the requirements of logical-empirical inference, and the second to triangulate experimental data with insights gained via semi-structured and unstructured interviews to be had with knowledgeable experts.

As argued earlier, the Functionality model and its data requirements form the focus of the research model for this project. In response to the first project objective, the Functionality model as a core construct in the operationalisation of STA as a paradigm of technology will be analysed. As is shown in the literature review, the Functionality model has its theoretical roots in General Systems Theory, and it is today applied as a taxonomy for classification and understanding of technological entities. Given that General Systems Theory and the science of classification are both mature fields of scientific enquiry, a theoretical analysis will investigate the common grounds between these two fields of enquiry to assess the bona fides of a notion such as a taxonomy of technological entities.

The second and third research objectives involve data collection and application of theory to practice. As part of the second objective, data collection will focus upon the relevant technological entities to be used in the study, and using STA to analyse and fit these technologies to various permutations of the Functionality model. With more insight and understanding gained of taxonomies in general, and of the Functionality model in particular, the third research objective lies at the heart of this research project. Specifically, it entails practical testing of the value of the Functionality model to practitioners of MOT, in order to test the primary research hypothesis, i.e. that different taxonomic permutations of the Functionality model have different utility values to practitioners of MOT.

In the final phase of this research project, recommendations are to be formulated for theoretical improvement and practical refinement of the Functionality model and its uses. The objective is ultimately to help students and practitioners of technology to have access to a theory of technology with practical utility value, to the extent that its applications incrementally help to build a paradigm of technology with exemplar solutions to real world management of technology problems.

1.6 A learning journey

This voyage started first with intellectual curiosity, and got fed along the route towards Ph.D. research by professional interest about MOT. It is a journey initially stimulated by a working environment in the South African Defence Force where general management of technology practices were limited to the bare necessities, following the end of the Namibian Bush War and the inevitable demobilisation and down-scaling that followed, even if technology was omnipresent and core to its mission. This was the defence force of the early 1990's, and having shifted its focus to support of the South African Police Services (SAPS) for internal stabilisation of pre-1994 South Africa with its political unrest, this author completed a Masters degree about the application of Geographical Information Systems in the SAPS, followed by co-authorship of a peer-reviewed article on the topic. Moving over to the municipal sector, the author participated in the Year 2000 (Y2K) project as an information technology manager for a local municipality, and had the opportunity to observe from a very well placed vantage point the frenzy that followed with the Internet's arrival at the market place. Having subsequently resolved to pursue the fledging discipline of MOT as a subject field in a M.Tech Business Administration degree at UNISA, a mini-dissertation followed about the understanding of MOT practices of companies listed on the Johannesburg Stock Exchange - interrupted for the publication of a peer-reviewed article about IT management practices in the Developing World.

Filling a chair in MOT at the University of Cape Town's Graduate School of Business on his annual summer sojourn to South Africa, Professor Rias van Wyk at the time agreed to act as external examiner of the M.Tech mini-dissertation, and out of this relationship evolved over the past three years the vision of a Ph.D.

about heretofore unexplored vistas in MOT. With several writing projects and research training courses on the credit side of this long-term project, the author nevertheless experienced as comprehensive and invigorating the preceding Ph.D. week at the University Stellenbosch Business School. To its credit this business school, as an outcome of the Ph.D. week, makes available research resources as well as access to academic personnel and forums such as colloquia and leadership events. These served as the final motivation to depart on the last phase of this voyage, which for this author already started at school. Many learning opportunities present themselves on the road ahead, among which the most challenging will be to learn more about the finer detail of technology componentization and trends, the theory and practice of STA, the role of functionality classification as specific niche within STA, and of course the science, art and craft of putting a doctoral dissertation together. It is a long and time-consuming journey; it is not only a journey of learning about technology as inanimate entities (for now), it is also a journey of deeply rooted intellectual emotions, because, as author Margie Orford is quoted about her work in support of jail inmates' stories, "If writing is to work for the reader, then the emotion present in the writing needs to be authentic." (Donaldson, 2008:19).

2. LITERATURE REVIEW

According to Bunge (1974:33), the *raison d'être* of technology knowledge is to be successfully applied for the achievement of practical goals. Guided by Bunge's philosophy, this literature review introduces a general problem statement, then presents a paradigmatic framework for theoretical discourse about the research problem, and concludes with a model which may help to solve the problem in practice.

2.1 Management of Technology and technology edification

Technological change transforms economic inputs and outputs, and generally leads to cost efficiencies in production, or use, of goods and services. But technology cannot be considered as an economic means without taking into account levels of technological knowledge and control over technological processes – after all, technology is "*organized by man*" (Tondl, 1974:5-9, emphasis in the original). In response to technological progress and complexity, Van Wyk (1984:102) too warns management to refine its tools for understanding technology. From a journal editor comes the sigh that it would be far more useful to learn how to better manage technology in the real world than to continue debate academic bona fides (Wolff,

2001) - that in response to the tumultuous entrance of telecommunications technologies into the new century; a sentiment also expressed by Chorafas (2004:3) who in response to the turn of the century ruin of telecommunication stocks laments that "…good management is by no means a widespread practice". So, to understand the management dynamics of technological change, and to leverage such insights for economic benefit, requires technology edification and technological conversant management, notions Van Wyk (2008) still continues to promote. Indeed, the drive towards technology edification cannot be overstated, given the verdict by Van Wyk (2002:15) that management does not comprehensively analyse new technology, does not trace technology developments and has no coherent view of the technological landscape. In fact, Sainio and Puumalainen (2007:1315) report technology development as one of the most obvious business processes challenging management, with the role of technology still lacking in corporate strategic analysis and planning. This scenario is confirmed by Lichtenthaler (2007:1110), who states that two of the most often cited reasons why companies do not understand technological change are in fact management incompetence and a lack of technology intelligence, with the concept technology intelligence used here as a synonym for technology monitoring, technology assessment and technology forecasting. Not only have companies to contend with technological change per se, but also with different and, according to Sood and Tellis (2005:155), faster rates of technological change among different industries, prompting Lichtentaler (OP CIT.:1124) to advise that a comprehensive approach to the study of technological change in companies is required to avoid commercial failure.

2.2 Convergent technologies as the latest manifestation of techno-economic change

Dosi (1982:147) describes the relationship between economic growth and technical progress as "rather evident". Thomas (1985:21) puts into organisational and regional-economic perspective Joseph Schumpeter's description of how "behavioural competition" and "creative destruction" follow when technical innovations with cost or quality benefits hit the market place. From a business perspective upon strategic management of technology, Grobbelaar (1994:132) portrays technical change as one of the major drivers of competition at the marketplace. Pol and Caroll (2004:127) describe it as a basic axiom of economics, while Freeman and Soete (2007:13) associate the bulk of international economic growth and development with accelerated diffusion of technical change and access to codified knowledge. Demonstrating the holistic nature and impact of technical change, Koh and Magee (2007:2) relate information technologies with late 20^{th} century changes in economic, social and cultural aspect of society. The notion of technology as a driver of overall economic change in fact came to be seen as so fundamental to an explanation of economic cycles, that manifestations of these technological breakthroughs have been described as techno-economic paradigms (Perez, 2002:8; Sagasti, 2003).

Focusing on the nature of technical change itself, Van Wyk (1979:294) describes the most basic technological trends driving the ongoing evolution and concomitant change of technology. He points out how the growth of artificial information-processing abilities and the emergence of technologies on micro-scale hold promise to extend human manipulative abilities. Van Wyk (1984:109) predicts how the size of technological entities will increase on the one end of the scale, and decrease on the other. These two developments, i.e. information processing, and micro-scale technologies, would ultimately manifest in what is today known as so-called convergent technologies, that is the convergence of nanotechnology, biotechnology and information technology. Sagasti (OP CIT.) describes this convergence as part of the nature of technological change, involving more actors, becoming more complex and posing more management challenges. Harold Linstone (2004:187) in his editorial on a collection of papers about the transition from the Information to the Molecular age, confirms these changes with his observation of the increasingly rapid technological evolution towards convergent technologies.

Having first started with the Industrial Revolution, technological change has since manifested with increasing complexity and force multipliers, such as steam, railways, electricity, oil, mass production and ICT, the latter described by Perez (2005:14) as an "information revolution" and having led to a global information society. This epoch has now reached maturity, to form a foundation for a next one, with molecular and subsequent convergent technologies as its foundation. Based on semiconductor micro-fabrication and micro-electromechanical systems, as explained by Kautt, Walsh and Bittner (2007:1699), nanotechnologies will revolutionise all aspects of the economy and society in the 21st century, according to Tegart (2004). Wonglimpiyarat (2005:1350) and Kautt et al. (OP CIT.:1698) view the current installation phase of nanotechnology as a first step towards a new Perezian techno-economic revolution, as a portent towards a next Kondratieff wave. They describe nanotechnologies as a basis for technology product paradigms that manifest across borders and across industries; to eventually become, according to Palmberg, Pajarinen and Nikulainen (2007:1), the engine of growth in the 21st century. More studies have been published about the role of nanotechnology as foundation for convergent technologies, of which the most prominent are propositions about its megatrends (Roco, 2002), the US National Science Foundation report on convergent technologies (Roco & Bainbridge, 2003) and an analysis of its policy implications (Roco, 2005), to select only a few among a multitude of nano-related titles. With the exception of the Asian Tigers, the bulk of research and development in this particular field, and reporting of associated research results, are however from Scandinavia, the European Union and North America. The European Union in particular hosts a gateway to the latest news and research about nanotechnology known as Nanoforum.org, from where reports such as *Converging Technologies for Improving Human Performance: Nanotechnology, Biotechnology, Information Technology and Cognitive Science* (Roco & Bainbridge, OP CIT.) can be downloaded for free. The literature review shows however that Developing Economies are not part of this discourse, with single exceptions.

2.3 A perspective upon technological knowledge in Developing Economies

Perez (2001:113) presents an interpretation of economic development for Developing Economies as a process of accumulation of technological and social capabilities, which again depend upon technological learning and a complete understanding of the way technology evolves through these so-called technological revolutions. Hipkin and Bennett (2004) also view technology knowledge and associated competencies as strategic dependencies if Developing Economies were to seek competitive advantage. Representing a Developing Economies perspective, Sagasti (2005) maintains however that there is a large and growing gap between rich and poor countries in their respective capacities to generate and use scientific and technological knowledge. Sagasti also finds growing disparities in economic and knowledge indicators, a phenomenon he describes as the “knowledge divide”. When D’Costa (2006:10) observes that sweeping changes in technological development over the past 50 years did not lead to fundamentally transformed economic structures in Developing Economies, a lack of technology edification may again be postulated as significant variable towards explanation of this phenomenon. Durbin (2006:44-48) refers to this uneven regional development as “technoeconomic injustices” [sic], brought about by a “techno-capitalist ideology” and manifesting as “techno-social” pathologies, which cannot be solved unless the have-nots are economically emancipated. The irony to this is though that Management in Developing Economies has to comply with market expectations about technology edification, for technology to be leveraged in the economic emancipation to follow, even if expressing the mere sentiment goes against the grain of lobby groups opposing globalisation.

2.4 A theory of technology

Schoeman and Van Veuren (1987:121) refer to philosophy as a journey to knowledge of the self. It certainly has been a long journey for science, as shown by Gjertsen (1989:89), who describes in his book about science and philosophy how the debate regarding the nature of scientific argument was initiated by Socrates as early as the fifth century BC. For Gjertsen this debate has remained a topic on the agenda of philosophers ever since, because of their "obsessive" pursuit of correct philosophical method, instead of examining philosophical problems (IBID.:115). Steering through between these views, it is incumbent upon the author to limit this short meander into the philosophy of technology to the single issue that is of relevance to this research project, i.e. tracing the formation of foundations for a scientific paradigm, and a knowledge domain, towards a core theory of technology in support of a paradigm of technology. To help do so, the rest of this section adopts an intellectual framework which deals with theory as the central component within a wider and evolving paradigm of technology, discussed here in stepwise sequence for its philosophical ontology, hermeneutics and epistemology.

2.4.1 A philosophy of technology

Skolimowski distinguishes between a technological philosophy and a philosophy of technology (1974:72, emphasis in the original). The former is a sociological perspective on the nature of philosophy, concerned about the technological feature of society, and the latter is an epistemological approach placing technology within the broader scope of human knowledge, there to be learned about and for its cognitive content to be understood. Skolimowski's argument here is that there cannot be an understanding of technology itself, nor of the philosophy of technology and its body of knowledge, without an understanding of technological progress. The philosophy of technology has therefore as objective to examine the nature and structure of technology, and to promote discourse about its premises, arguments and conclusions. However, Skolimowski also argues that technology is not science, nor applied science, because technological progress happens not to increase knowledge, but to solve technical problems "…science concerns itself with what is, technology with what is to be*…*" (IBID.:76). In his argument for a theory of technology, Farrell (OP CIT.:162) too states that technology is not a division of science, and that it is a subject in its own right which uses science for its outcomes.

A dissenting view comes from Jarvie (1974:90), who submits that science investigates general laws of the universe, and technology works within these laws, which is a contention supported in a later work by Bond (2003:135-137):"Despite the absolute artificiality of many devices, none can contradict the laws of nature…", hence his comparison of "…technics and explanation…" with "…technology and science…". This argument by respectively Jarvie and Bond should in fact be seen as first an ontological statement, because it is an important meta-physical expression, or outlook, about the nature of technology; and secondly an epistemological statement, as it confines technological knowledge and subsequent practical manifestations thereof to what is rationally possible and repeatable with systematic method within a specific scientific body of knowledge and within the confines of natural laws. For thís dissertation, this particular distinction projects its influence deep into the notion of technology literacy, not to further the old philosophical debate, as Shenhar et al. (OP CIT.) put it, of how science and technology relate, but to the epistemological nature of the technology body of knowledge.

Technology knowledge may in fact grow, or evolve, into science, according to Bohn (1994:66). This is the familiar, and more tolerable, positivist conception of knowledge, where knowledge as a core construct either inductively or deductively acts together with theory formation. Gardner (1997:15) relates how practical experience with artefacts and materials is a requirement for scientific conceptualisation about them, and how technological knowledge is essential for subsequent scientific understanding (IBID.:19). This is a observation closely related to Don Ihde's notion that scientific knowledge is instrumentally dependent upon technologies (Ihde, 1997:73). Ropohl (1999a:60) sums up the relationship in the following way:" Thinking is nourished by knowledge, and most of our knowledge nowadays originates from science; thinking is nourished by practice as well, and most of human practice nowadays is affected by technology". This is the world Ropohl (1979:7) earlier almost in exasperation describes as a "technotop".

In an endeavour to sum up the debate within their ranks, Durbin (OP CIT.:4-5) contends that exponents of different views about the philosophy of technology are working towards consensus about what constitutes true knowledge, wanting to help solve the manifestations of socio-technical problems in a "technological culture". In contracts to Gjertsen's verdict about a senseless pursuit of method by philosophers per se, Durbin concludes that philosophers of technology have indeed contributed to academia and to understanding of real world problems (IBID.:288). A view which should be supported from a paradigmatic perspective, as will subsequently be explained. Pending such explanation, the most striking recent contribution from the philosophy of technology appears to have been in the ethics of technology; and with the convergence of technologies, together with the omnipresent military industrial complex and its realpolitik machinations, philosophers of technology may yet [again] become more prominent in the discourse about MOT. Such prominence, which may become a reminder of the technology-out-of-control thesis (Bond, 2003:134), is long overdue, as fittingly highlighted by past Harvard president and chairman of the US National Defense Research Committee, James B. Conant (1952:110):"The history of the last three hundred years is a record of accomplishment in the manipulation of ideas; it is a story of the flowering of the creative powers of the human mind….in the shadow of fusion and fusion bombs, we do well to stress this aspect of modern times".

From an academic perspective, the debate about, and in, philosophy of technology by its thought leaders appears truly wide-ranging, covering phenomenology, heuristics and a subsequent epistemology of technological thought. However, beyond a cursory introduction, such debate falls outside the ambit of this dissertation, attractive and inviting as it is. But yielding a phenomenological base of how technology is seen, and an ontological philosophy about the nature of technology thought, the discourse about a philosophy of technology contributes to the ongoing search towards broader paradigmatic parameters and confirmation of a theory of technology.

What though are the basic building blocks of a paradigm of technology, and what knowledge support structures does a theory of technology require to become emancipated within an overarching paradigm? Intellectual discourse presents at least one formalised avenue for searching answers to these questions, i.e. hermeneutics.

2.4.2 The hermeneutics for Management of Technology

The Merriam-Webster Online Dictionary (2008) defines hermeneutics as the study of methodological principles of interpretation. A hermeneutic framework helps to have systematically drawn the outlines for a structure of thought, or then a paradigm, for technology. More specifically, hermeneutics help to interpret the phenomenon under examination in its widest sense, because a paradigm together with its constituent parts and workings require uncompromising understanding, not necessarily loyalty, of its practitioners and students lest it be replaced by a competing paradigm. Once the outlines of a paradigm of technology, if indeed, is understood, penned down, and tendered to peers within the discipline of MOT, the groundwork is laid for theory-building and theory testing about technology, and for further incremental articulation and specifications of the evolving paradigm under increasingly stringent conditions, in accordance with Thomas Kuhn's guidelines.

Van Wyk (1979) mentions several authors who have tilled the land and sowed the seeds for a paradigm of technology. But Van Wyk (1979; 1984; 1987; 1988; 1989; and onwards to the present) has himself been recognised for consistently putting onto the agenda all the ingredients of paradigm formation for technology, and for systematisation of these and formulation of a theory of technology. Notwithstanding such recognition and the intellectual authority it carries, said theory of technology still lacks paradigmatic essence as is repeatedly shown by Van Wyk himself. This again is described as one of the reasons for the slow gestation of practical procedures for STA (Van Wyk, 1997:26). Moreover, this is not a single horse race, with contenders espousing very different phenomenological views. For example, Peter Bond (2003:128) proposes a thought-provoking Biological Theory of Technology and expresses the need for a new paradigmatic framework for technology in which reconciliation with Nature is pursued; Feenberg (Undated a) cites instrumental and substantive theories as established theories of technology, from which he conjures his Critical Theory of Technology, which opposes technology neutrality and technology determinism with a social-ontological world view; Feenberg (Undated b) sees technology not as the product of technical rationality, but as a combination of technical and social factors, in what he describes as "hermeneutic constructivism"; Callon suggests Techno-Economic Networks (Green et al., 1999) and Elizabeth Dostal works with a Biomatrix theory (Biomatrix, 2008); all of these proposed as candidate theories of technology for better technology analysis and understanding and for enhancement of technology literacy in service of MOT. As stated earlier, there is furthermore recognition of various conceptions of technology from within the discipline of MOT, i.e. the Functionality model, the Economic model, the Thematic model and the Engineering model, with these models competing for theoretical recognition.

Peine (2008:1) describes Giovanni Dosi's description and interpretation of a paradigm of technology as a classical work in the literature about innovation and change, and a consummate contribution it certainly remains. Dosi (OP CIT.:148) first describes "technological paradigms in accordance with the generally accepted Kuhnian version thereof, i.e. as a set of procedures, a definition of relevant problems and of specific knowledge related to their solution, which of course can be seen as closely related to the description of Jain and Narvekar (OP CIT.); and secondly as a "'model' and a 'pattern' of solution of selected technological problems, based on selected principles derived from natural sciences and on selected material technologies" (Dosi, OP CIT.:152 emphasis in the original). To accommodate the problem-solving nature of technology paradigms in the latter definition, on which the focus will be here, Dosi gives this attribute to technical progress, i.e. technology paradigms hold the promise of problem-solving through technical progress and by heuristic guidance and prescriptions. Dosi means therefore that technology paradigms present strong directions of technology changes to respectively pursue or, alternatively, to ignore; and then describes these problem-solving activities as "technological trajectories" (OP CIT.:152). Frietsch and Grupp (2006) and Peine (OP CIT.) are among contemporaries who use Dosi's conception of technology paradigms to respectively analyse the change in modern optical technology from bulbs to opto-electronics and photonics, and the dynamics of open technical systems where multiple industries drive innovation. Green et al. (OP CIT.:781) also leverage the concept to describe bio-technology as a technological paradigm:" ...new processes based on genetic engineering, new products based on genetically engineered organisms, and new approaches to the search for new chemicals…" and describe research and development searching for new molecules as a technological trajectory emerging from this paradigm.

Dosi recognises the weaknesses in his postulation of technological change as a paradigm, when he suggests it may only be taken as an approximation of a paradigm in some cases. Just as well, it may be added, because he recognises that technological knowledge and exposition of associated theories as key paradigmatic substance is not properly articulated in his conception (Dosi, 1982:153). Paradigms are more comprehensive constructs. Kuhn means a paradigm to be a cognitive meta-framework to guide problem-solving in scientific communities; and technical change, or technological trajectories as it were, as an exemplar set of solutions to a practical problem, albeit it of a major kind in a specific technological cluster, cannot constitute a paradigm in the full Kuhnian sense. Peine (OP CIT.:5) admits such when he states that frameworks towards problem-solving that is inherent to Kuhn's paradigms, and the progress it delineates, have remained unexplored in the discourse on a paradigm of technology. Designating technological trajectories as problem-solving activities within technology paradigms is however still a significant contribution to the hermeneutic understanding of the workings of technical change and the evolvement of a paradigm of technology. It lacks explicit ontological guidance and a critical threshold of epistemological substance, but it goes into the heart of understanding the topic of a paradigm of technology and so contributes to the hermeneutic of MOT.

Perez (1985) and her notion of techno-economic paradigms present more substance to the pre-paradigmatic thrust as reviewed here. Based upon Dosi's description of technology paradigms, Perez (1985:7-8) describes as a techno-economic paradigm the predictability of cost behavior of inputs to production over the long term, and specifically its tendency towards least cost combinations serving as a general "guiding model" for investment and technological decisions. Building upon this theme, Perez (2002:8) defines a technological revolution as an "…interrelated constellation of technical innovations…including an …all pervasive low-cost input…". Having grounded her theory in techno-economic paradigms, Perez (1985; 2002; 2004a; 2004b; 2005; 2007) continues to pursue the relationship between cyclical technology changes, financial capital, economics and subsequent development imperatives from a Developing World perspective. Perez certainly makes a major contribution to the hermeneutic of MOT, even if her work appears primarily as a discussion about technology's impact upon macro-economic scenarios.

Grobbelaar (OP CIT.:31-32) condenses hermeneutics to the arts and craft of interpretation, and is the first to propose that management of technology [Grobbelaar does not use the term "Management of Technology", nor its acronym MOT] as an academic pursuit be construed specifically as a hermeneutic, or interpretative, activity. This, according to Grobbelaar, will help to stabilise evolving theoretical models and associated content within the discipline. This demonstrates understanding of what happens within paradigms and serves as guidance for this dissertation, because a new theory, according to Kuhn (OP CIT.:7), requires reconstruction of prior theory and re-evaluation of prior fact, however special its range of applications. Grobbelaar continues to then distinguish between hermeneutics at respectively strategic level, and operational levels. At a strategic level he suggests critical systems heuristics as hermeneutic tool for reflection upon and guidance to conceptual approaches within MOT. At an operational or technical level, technological algorithms are suggested for hermeneutic thought. Combining strategic and operational hermeneutics as constructs for respectively strategic and operational management trajectories, Grobbelaar (OP CIT.:188) then uses these trajectories as foundations to conceptualise a model for strategic management of technology in the firm. It is dated now, but Grobbelaar's net contribution is a model that helps further to generate ontological understanding, i.e. an understanding of what strategic management of technology is at its most basic and practical level, which again helps to characterise the assumptions for an epistemology of technology. Even if they are soft, he draws the outer lines of an epistemology for technology with propositions which clearly directs the firm towards technology learning and technology conversant management, and leaves guidelines for how to think about and interpret the discipline to MOT students.

Pelc (OP CIT.:37) describes technology as an "object of management", and explains how MOT emerges from a multi-disciplinary knowledge base which consists of respectively the management paradigm, the management of technology paradigm, and the technological entrepreneurship paradigm. Pelc's submission helps as an interpretation of MOT, and can be seen as a noteworthy contribution to the hermeneutic of MOT, but his argument of how MOT consists of three integrated paradigms is not convincing and complete enough when evaluated against the structure and workings of a paradigm set as benchmark for this research project. Pelc, in this author's view, makes a more substantive contribution with the introduction of a conceptual map of MOT knowledge, because he so helps to settle down an epistemological framework for a paradigm of technology, which ultimately benefits MOT and its academic emancipation.

2.4.3 An epistemological foundation for Management of Technology

Snyman & Du Plessis (1987:240) defines epistemology as that part of philosophy which examines knowledge creation and validation. Ropohl (1997:66) defines epistemology as the philosophical enquiry of natural science, and Lehman (2004:19) defines epistemology as the abstraction of the fundamental metaphysical or ontological assumptions of a discipline into theories of knowledge acquisition. Epistemology fundamentally translates into questions such as: What is knowledge? How is knowledge acquired, and what do people know? From Figure 1 it can be seen, as Lehman (IBID.:56) puts it, how epistemology consequently structures a paradigm into a functional form, so that it can be put to work in practice and theories be developed from observations; and so that such theories be formulated, tested, accepted or rejected, and true knowledge be separated from false knowledge within these theoretical frameworks. Recognising the key role of knowledge within paradigms, Peine (OP CIT.:3) refers to knowledge creating communities as the constitution of paradigms. Of course, where paradigms differ in content associated with their ontology, epistemology, theories and methodologies, they are in fact different and competing paradigms, some to be successful, others to be falsified and rejected.

Parayil (1997:161) motivates his philosophical examination of technological change with a reference to the epistemological dimensions entrenched in the conceptualisation and ensuing explanation of technology. Parayil identifies in the historiography of technology a trend to indeed treat technology as knowledge, which to him opens the discourse about technological change to philosophical inquiry. Broens and De Vries (2003:458) refer to the epistemology of technology as a sub-discipline of philosophy of technology, because it has its basis in theoretical reflections. For the purposes of this research project, and moving beyond philosophy, the epistemology of technology is treated as a building block for a paradigm of technology, from where contributing thoughts towards a theory of technology is ultimately to be spawned through a deductive and hypothesis-testing research process. According to Broens and De Vries (IBID.:459), not much is written about the nature of technological knowledge as a distinctive kind of knowledge, aside from single classification schemes. In theoretical vernacular this means that there is too little epistemological thought about technology and MOT, which in its turn explains the dearth of a theoretical nucleus for technology and a subsequent paradigm of technology.

As explained earlier, epistemology is about questioning of knowledge and its substance, and questioning of the need and eventual validation of such substance. In the same vein therefore, questions posed to managers of technology, and MOT, qualify as markers towards an epistemology of technology, such as those listed by Van Wyk (1988:342; 2002:18) when he expresses the need for a core theory of technology as a basis for MOT. So too do propositions about MOT, as they literally declare themselves as knowledge submissions to be tested by research methodology within the incumbent paradigm, as is demonstrated by Grobbelaar (OP CIT.:180). Yet another example of an epistemological marker is Tschirky's concept of an enterprise science (2000), conceived to close the gap between management theory and technology realities within the firm. In a significant contribution to MOT's body of knowledge, Pelc (OP CIT.:39) introduces a conceptual map of knowledge in technology management, which he describes as a "knowledge landscape", containing a comprehensive list of MOT concepts with conceptual linkages to the mother disciplines of these concepts. Given its multi-disciplinary nature as management subject, and the outcomes MOT pursues, the introduction of a knowledge map, which shows how MOT leverages from existing science within an evolving paradigm, is a firm element of an epistemological framework and deserves further analysis and utilisation. But the exception among epistemological statements about technology is to be found in the Credo for MOT as described by Van Wyk (2003). The credo is among others a succinct proposition about the nature and extent of a body of knowledge for MOT, so that practitioners and students of MOT may learn about the discipline, and so that a core theory of technology may get the opportunity to mature through scientific processes within the discipline. Evaluated against epistemological guidelines, the credo is purpose-built and directly responds to questions about the nature of technology knowledge, questions of how technology knowledge is acquired and validated, as well as students' and practitioners' grasp of it.

These instances of epistemological manifestations present themselves in different manners, but they have all in common a positive influence on knowledge generation, description, testing and application in MOT, and so in their unique ways contribute to a recognisable epistemology of technology.

2.5 Strategic Technology Analysis and its constituent parts

Van Wyk (2000; 2002; 2004; 2007) and Shenhar et al. (OP CIT.) deal with STA as a fundamental analytical framework for MOT. Van Wyk (2004:19) defines STA as an evaluation of technologies on the basis of their inherent attributes and potency to generate value for organisations. Van Wyk (2007:27) describes STA as a common framework for analysis and understanding of the entire technological landscape and all its constituent parts. Put in the simplest academic terms possible, STA is a theoretically grounded and fault-tolerant conceptual method for understanding of technology. It does not yet constitute a paradigm, but it carries the DNA of a paradigm, given its theoretical foundations and the manner how it becomes a set of tools and techniques for problem-solving. Van Wyk (2004) explains in full how STA evolves into the following constituent parts:

1. An anatomy for technology, which analyses the composition of individual technological entities.
2. A functionality model for a taxonomy of technology, which classifies technological entities into logical categories.
3. A cascade model for description of long-term and evolutionary development trajectories of technological entities.
4. An ecology of technology for contextual understanding and social acceptance of technology.

Van Wyk (2000) uses STA to map and track medical technologies and shows how this analytical framework can be leveraged to promote technology literacy in organisations. For the medical profession specifically, he presents STA as a tool to understand the "…pattern of evolution in medical craftsmanship". Howey (2002) demonstrates how the Cascade model as part of STA can be modified for analysis of computer software technologies, which have consistently posed an analysis problem because of their peculiar intangible nature. STA has been shaping academic courses in MOT, has offered its circle of adherents deeper insight and a more coherent understanding of the larger technological landscape, and has been serving as a tool for corporate technology roadmapping (Van Wyk, 2004:58). Guiding the reader of this research towards deeper insight into technology starts with introduction of respectively the concept of a technological entity, i.e. the most basic subject matter of technological thought, and a more complete discussion of the Functionality model, as a formal frame of reference for thought about technological entities, before demonstrating how the concept is normally put to work within STA.

Van Wyk (2000:206) describes technology as "… means that are made to help people do their work" and then introduces the notion of a technological entity as a fundamental concept to represent every possible instance of such means. He proceeds to subdivide technological entities into hardware as proxy for devices, software as proxy for procedures and "skillware" as proxy for acquired human skills. Van Wyk (2002:17) later describes a technological entity as the most elementary unit of analysis in technology, in others words, as he explains, fulfilling the same role as does an organism in biology. Shenhar et al. (OP CIT.:6) later resolve to use the term "technofacts" as a description of technological entities, to distinguish reproducible technological entities from true artifacts which as artistic objects cannot be reproduced to the exact same quality standards. Van Wyk rightly describes the notion of a fundamental technological entity as a significant philosophical break-through in technology, because the concept at once becomes an ontological statement which presents guidance, or heuristics, in technology thought, and hermeneutics or interpretation of technology thought; and so empowers students and practitioners of MOT to contribute at an epistemological level to a MOT knowledge base, from where theory may be built out.

But what are the requirements of theory, and what needs to happen to have candidate theories subjected to the building processes and quality tests of theories? How does the student of technology follow the roadmap from the epistemology of technology to a position where a theory of technology with its own set of models, rules, techniques, methods, concepts, constructs and terms, becomes available for empirical research, so that it may reciprocate with knowledge formalisation and internalisation, and become part of a distinct paradigm of technology?

Morrison (2003) describes a theory as a relationship between definable, observable and empirically measurable variables or constructs, the latter which can be defined as a concept operationalised with units that are approximated. Naturally, the researcher must explain why variables are chosen, and how they are postulated to be related within the stated context. Beyond its utility value, the most important scientific criterion of a theory, according to Karl Popper (1963), is its falsifiability, refutability, or testability. To Popper, a theory which is not refutable by any plausible empirically observed event is non-scientific. So every genuine test of a theory is an attempt to falsify or refute it. When confirming evidence indeed appears to be found, it should not be construed as having refuted the tested theory unless it was a genuine test which meets the requirements of reliability and validity. In addition to its inherent characteristics, theory also requires models for better understanding of theoretical properties and better understanding of interaction among these properties. So theory also requires modeling to test preconceived ideas about its workings and subsequent outcomes. Thanks to groundbreaking work by pioneers such as Gunther Ropohl and Van Wyk, to name the two most visible thought leaders relevant here, the Functionality model now presents itself as a candidate for explanation of a theory of technology, within STA as a wider paradigmatic framework, as described in the earlier parts of this review.

2.6 General Systems Theory as intellectual basis for the Functionality model

The Seventies of the previous century was a decade characterised by failure of the philosophical profession to debate technology with the urgency and seriousness it deserved, according to Frederick Ferré (1995). It was a decade where the intellectual milieu had to deal with "…the Vietnam War, the growing sense of threats to the global environment, and the rise of feminist, racist, and classist issues in the overall atmosphere of the Cold War…" (Ihde, 1995). It was also a decade confronted with the irruption of a revolution in ICT (Perez, 2002:14); and a period during which Moses Abramowitz's famous 1956 statement about neo-classical ignorance of the reasons for economic growth must have resonated louder than ever amidst technical progress and its inevitable symptoms of increasing automation and changing labour-work relations.

Originating in the German school of philosophy, the argument for functional analysis of technology by Gunther Ropohl is a response to the need for better understanding of technology by philosophers, economists and society at large. As such it is supported by a sentiment that Thinking Man relates to technology, wants to understand and make sense of the technology landscape for technology knowledge and foresight, and subsequently deals in functional ways with such technology as part of their complete socio-economic and political worlds, because "Der Biotop ist zum "Technotop" geworden…" (Ropohl, 1979:7 quotation in the original). Pursuing a consistent and systematic research and analysis framework, Ropohl

(1999a:66) states that he resolved to use General Systems Theory as a "powerful tool" to have formulated his philosophy for understanding technology function, technology process and technology outcome; and for building associated knowledge models [*Sachsystems]*, because, as he explains elsewhere "…Die Allgemeine Systemtheorie ist nichts anderes als eine Theorie der Modellkonstruktion..." (Ropohl, 1999b:4).

Fundamental to his frame of reference is Ropohl's understanding of Ludwig von Bertalanffy's conception of General Systems Theory. To him, General Systems Theory encapsulates hierarchical, structural and functionality concepts, which endows it with an inherent capacity for holistic analysis and systematic description and classification of similarities and differences in, and of, complex systems, whether they be technological, societal, environmental or a combination thereof. Given these, Ropohl introduces his *Eine Systhemteorie der Technik* (Ropohl, 1979) which entails a systems approach for description of technical functions with the input-transformation-output sequence of matter, energy or information central to the notion. Ropohl (1999b:6 emphasis in the original) later explains as follows:"...das Handeln wird dann als die *Funktion* des Handlungssystems verstanden... das Handeln abbildet, transformiert stoffliche, energetische und informationelle Einträge, Zustände und Austräge in Raum und Zeit...". Having demonstrated his conceptualisation of how technology function combines with systems thought, Ropohl (1979:177) first sets these variables into a morphological matrix, and then simplifies it into his technical knowledge systems with functional classes and outputs, as depicted in adapted form in Table 1.

Table 1: Ropohl's technical knowledge systems transformed into functional classes and output

Funktionsklasse		Handlung	Transport	Speicherung
Output		Produktiontechnik	Transporttechnik	Speicherungtechnik
Materie	Materietechnik			
Energie	Energietechnik			
Information	Informationtechnik			

Source: Adapted from Ropohl, 1979:178

Ropohl's 1979 conceptualisation of functional classes juxtaposed to output in the matrix configuration is the forerunner of what was to become the Functionality model. Having made Ropohl's work about functional classification accessible, Van Wyk (1979) explains how functionality becomes an avenue for understanding of evolutionary trends in technology. An aspect central to this explanation is Van Wyk's easy to understand presentation of the basic trends driving technology evolution, i.e. increasing complexity, increasing efficiency, improved size characteristics and improved time characteristics (IBID.:286). While processing, or transformation, as processes are inherent to General Systems Theory, Van Wyk explains here how storage and transportation become processes for dealing respectively with Ropohl's *Raum* and *Zeit*, i.e. space and time. Van Wyk (IBID.:282) also explains how the so-called Zwick triangle, depicted in Figure 2, is derived from General Systems Theory. Reflecting upon Ropohl's use of this three-fold classification [from here onwards described by its abbreviation of MEI], Van Wyk (1984:105) describes MEI as a fundamental and all embracing "technological trinity", because it covers the entire spectrum of existence understood to be part of technology and technology thought.

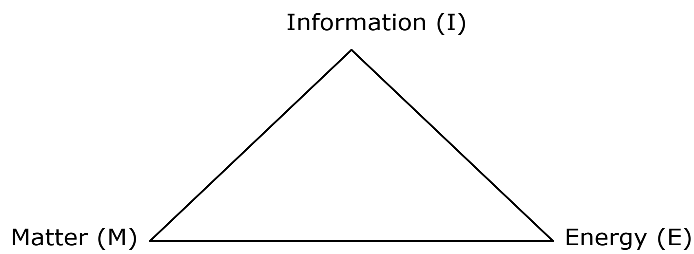

Figure 2: The Zwick triangle

Source: Van Wyk, 1979:283

Van Wyk (IBID.:107) furthermore describes how processing, transportation and storage as types of manipulation provide for deconstruction of all operations, from the simplest to the most complex.

From a philosophical perspective, his *Eine Systhemteorie der Technik* forms part of Ropohl's evolving views towards a *Theorie soziotechnischer Systeme and a Techniksoziologie*, a series of submissions which argue for technology to be understood as bearers of derived act-functions, not as autonomous act-bearers - it is still humans who [inter]act with technology to extract functionality: " Technik ist wohl als Träger abgeleiteter Handlungsfunktionen zu verstehen, nicht aber als eigenständiger Handlungsträger. Es sind nach wie vor die Menschen, die handeln..." (Ropohl, 1999b:17). With this last statement Ropohl provokes philosophical debate beyond the parameters of this research project, but his systemic approach is also exemplified by Helge Majer (1985), a German compatriot. In response to the stasis in theorising about technical developments, Majer introduces an "embodiment approach" and shows how technical progress is systematically measured in terms of quality improvements embodied within technology functions. She too uses input-output relations for measurement of technical progress (IBID.:336), and so helps to entrench a systemic and fundamentally holistic principle underlying current understanding of the Functionality model.

2.7 Contemporary applications of the Functionality model

Having argued the bona fides of the Functionality model since 1979, Van Wyk (1988; 2002; 2004; 2007; 2008) continues to pioneer classification of functionality in a refined version of the nine-cell functional classification matrix, as depicted in Table 2.

Table 2: The nine-cell functional classification

		Ways of handling		
		Process	Transport	Store
Aspects handled	Matter			
	Energy			
	Information			

Source: Van Wyk, 2004:34

Van Wyk has been using this classification scheme as part of STA, specifically for his technology assessment templates and his atlas of technological advance. The model has also been used very effectively to, among others, structure technology scans and technology audits. Pursuing understanding of landmark technologies, Van Wyk (2008) demonstrates in a presentation to investment analysts how, what he now describes as the Functionality "grid", and as depicted in Table 3, can be used to explore technological frontiers. Of course, Van Wyk's work with international corporations is of a strategic nature and proprietary. So in spite of its appeal in simplicity and utility, Van Wyk (1988, 2007; 2008), Wyk, Haour and Japp (OP CIT.), Magee and De Weck (OP CIT.) and Koh and Magee (2006; 2007) are to date the only published examples of how the Functionality model can be used to synthesize particular taxonomic results from among a multitude of competing technological entities on the fast-changing technological landscape.

Given the fundamental role of the Functionality model in the formalization and understanding of a theory of technology, and the incremental contribution this may become to a paradigm of technology in service of MOT, the core aspects of these contributions will be dealt with in more detail below.

Table 3: The Functionality grid used to demonstrate landmark technologies

		Action		
		Process	Transport	Store
Output	Matter (M)	Nanoscale manufacture	Magnetically levitated transport	Super scyscrapers
	Energy (E)	Bio fuels	Superconductive guideways	Torus rings
	Information (I)	Genetic prospecting	Universal interface	Flash memories

Source: Van Wyk, 2008

To Van Wyk (1988:344; 2000:208; 2004:35) the nine-cell classification of technological functions is open to criticism, revisions, practical application and testing. Van Wyk (2000:208) in fact clearly states that the Functionality model is not a true taxonomy, because the choice of function depends on the analyst's perspective, and a particular technological entity can be made to fit different categories. The model also requires further insight into technological hierarchies, such as the one suggested by Steyn and De Wet (1994:12). But then, this does not seem to be a problem that escapes biological or chemical taxonomies either. Carolus Linnaeus developed his classification scheme for animals in 1758, yet the birding fraternity, to name a universally relevant example, is characterised by diagonally opposing views and vigorous debate about taxonomic changes of certain bird species, and recent reclassification and renaming of a number of birds species. In fact, stating that scientific classification currently undergoes major changes, the website Wildbirds.com describes how Dr. Charles G. Sibley did research for over 20 years using DNA from birds' blood, and how he and his associates now propose a new way to classify birds in terms of their newly developed Sibley/Ahlquist/Monroe classification scheme (Wildbirds.com, 2008). Furthermore, Dmitri Mendeleev proposed in 1869 his first draft of what was to become the omnipresent Periodic Table (Wikipedia, 2008), yet Rayner-Canham (2004) discusses the challenges related to the table facing the chemistry fraternity in the 21st century.

With the focus shifting to the Massachusetts Institute of Technology, Magee and De Weck (OP CIT.) indeed find functional type as the most useful attribute of complex engineering systems for differentiation and classification of such systems. Having assessed various classification systems, Magee and De Weck (OP CIT.) add to Van Wyk's functional classification matrix exchange or trade and control or regulate as processes, and value as operand in what they then describe as a Complex Systems Classification Matrix (Table 4).

Table 4: The Complex Systems Classification Matrix

Process/Operand	Matter	Energy	Information	Value
Transform or Process				
Transport or distribute				
Store or house				
Exchange or trade				
Control or regulate				

Source: Magee and De Weck, 2004

Van Wyk's nine-cell classification

Magee and De Weck concedes that this framework too may not be exhaustive, especially insofar it concerns the uniqueness and completeness of functional types, while they recommend further research about relevant quantitative attributes that would promote understanding of complex systems. Koh and Magee (2006) describe technological progress and specifically functional technological capability when they use functional classification, now recognised as a general classification system, to derive a set of functional performance metrics (IBID.:1063) for the Information Technology [IT] industry. With their focus on the Information operand, they define each functional operation, i.e. storage, transportation and transformation as it applies to the IT industry and they allocate to each at least two functional performance metrics, for example, transformation of data is measured as calculations per second and calculations per second per unit cost. They find statistically significant differences in technological progress among the three functional operations, while differences between progress rates for different metrics and for different technological form factors within a functional category appear relatively small. Importantly, they empirically confirm how the wider and more systematic functional approach shows more stability for analysis of long-term technological progress and performance than device-specific analyses (IBID.:1073), in this instance demonstrated with information functionality. Koh and Magee (2007) extend to energy technologies their practice of choosing functional categories, rather than single underlying technological entities or specific form factors thereof, for analysis of technological progress. Showing confidence in the durability of the notion of functional operations i.e. storage, transportation and transformation, their focus is now on the energy operand. Eventually having two operands to compare technological progress of, they show how IT manifests a significantly higher rate of progress in all three functional categories, and how the rate of progress for IT is greatest in transformation and least in transportation whereas for energy the rate of progress is greatest in transportation (IBID.:13). Among several other fascinating conclusions, they also find exponential technical progress in both operands, which is confirmation that new technology builds cumulatively on past knowledge and leverages off technological capabilities (IBID.:15), a notion closely linked to Van Wyk's technology edification and technology conversant management.

From the above literature review it can be seen how the supporting scaffolds for a paradigm of technology are put in place. From here an understanding of the nature and knowledge requirements of a unifying theory of technology can be seen to evolve. Anchored to STA as the evolving paradigm of technology, the Functionality model is then presented as such a candidate theory of technology. It is shown how this model undergoes its first tentative practical analyses. The missing link is a logical argument to connect this model in a more formalised structure to a paradigm of technology that may direct a stronger and more contemporary scientific and practical appeal to corporate managers, and to students and practitioners of MOT.

3.1 RESEARCH DESIGN AND METHODOLOGY

3.1 Research model

From within STA as an evolving paradigm of technology, this dissertation examines the Functionality model as a candidate theory of technology. For that reason this section describes and explains the broad outlines of the research methodology to be followed towards a study of the Functionality model. It first sets out the requirements for theory within the research context, and then provides a general overview of the research model. Next will be a discussion of the research questions, and an overview of the specific research method to be followed in pursuance of these individual objectives.

Table 5 introduces the theories, constructs and concepts immediately relevant to this research. At the basis of this approach is to be found General Systems Theory, with a specific focus upon its interaction with the science of classification. Born out of the vision to systematise and order technology and its concomitant knowledge, comes STA with its constructs, concepts and models for analysis of the technological cosmos, which again consists of hierarchies and technological entities.

Table 5: Theories, models, constructs and concepts for STA

Universum of technological entities			
Strategic Technology Analysis (STA)			
Anatomy for morphological description	Functionality model for taxonomical classification	Cascade model for long term trends	Ecology for stakeholder interests
General Systems Theory		Science of classification	

Source: Author's own

According to Amundson (OP CIT.:342) the fundamental purpose of theory is to define, establish, and explain relationships between concepts or constructs. Interestingly within the context of this research, Amundson (OP CIT.:343) portrays classification systems as non-theoretical knowledge, in the same category as descriptions, data and predictive models. Bailey (1994:15) does not agree that classifications are pre-theoretical, and sees it as a foundation for explanation of phenomena. But to Amundson these various non-theoretical categories of scientific knowledge are indeed essential in the study of scientific knowledge and theory, because "…Categorization is the fundamental building block of defining concepts, which is a necessary precondition for theory construction". Amundson's is a stimulating perspective, and must be seen within the contextual setting he creates for a cognitive frame to serve as a hothouse for fermentation of theories. To Melnyk and Handfield (1998:312), a good theory must ultimately be practical, and one of its immediate benefits should be to serve as guidance in the identification of sequences, constructs and relationships, so that these can be systematically structured and be used to build, test and develop better theories that may help practice. On relationships, Melnyk and Handfield (IBID.:312) define sequence as the order in which events or factors occur in the observed experiment, in other words, depicting the influence of variable A on B; they describe constructs as concepts, or factors, that cannot be observed directly but which identify something that either is common to or unifies a set of observed variables; and they describe relationships as the precise manner in which the various constructs are related to each other.

If it is then a theory of technology that is to be built out from the Functionality model as a particular classification scheme, and that is to be tested and evaluated within the wider paradigm of technology, then the general requirements for good theory must be understood and be pursued in the ensuing research process. Jain and Narvekar (OP CIT.) list and explain these requirements as being the following:

- Uniqueness: the theory is differentiated from other theories.
- Conservatism: new theories can only replace existing theories if their virtues are clearly better than those of incumbent theories.
- Generalizability: the theory should be able to explain phenomena in many domains.
- Fecundity: the theory should have a rich field of investigation.
- Parsimony: the theory should avoid overt complexity; yet it should be sufficiently advanced to capture the fewest yet most important variables and interactions required for explanation.
- Internal consistency: the theory should be developed with mathematics or symbolic logic.
- Empirical riskiness: the theory should have ingrained the logic to be falsified, or refuted.

To meet these requirements, the research methodology for this dissertation is deductive and hypothesis-testing in the Positivist tradition. Seen from the bastion of Kuhnian thought, which serves here as the meta-guide for methodology, the academic framework for this research project is diagrammatically depicted in Figure 3.

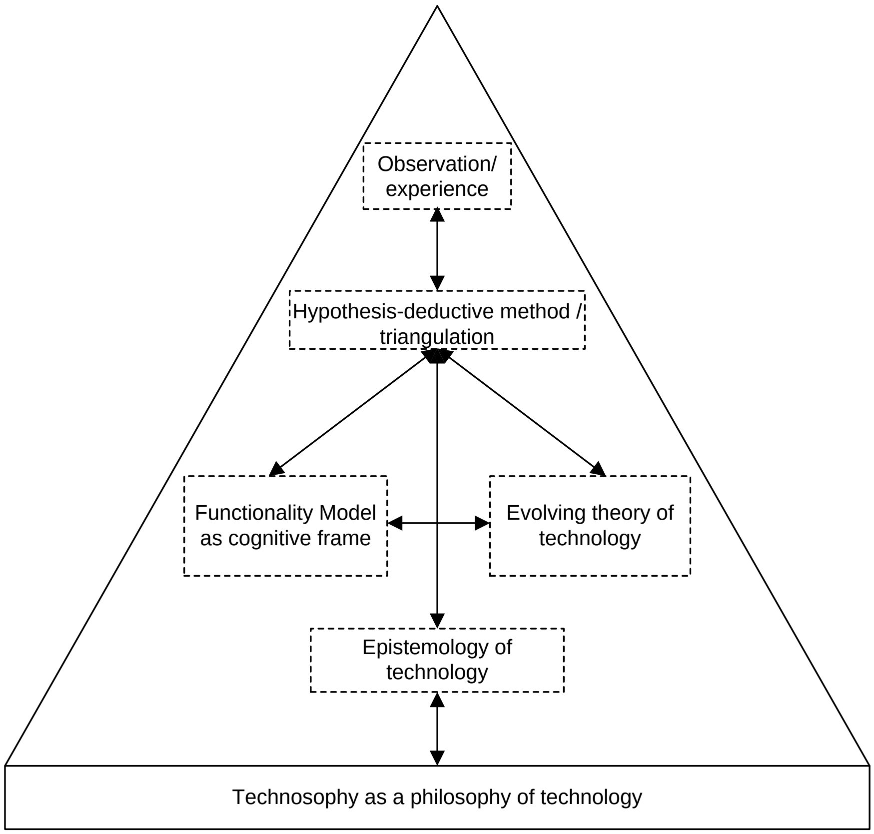

Figure 3: Strategic Technology Analysis as an evolving paradigm of technology

Source: Author's own

Given the relatively disorganised state of the discourse about an evolving paradigm of technology and of its body of knowledge, this study also leans over to the qualitative approach of the Post-positivist tradition so as to tap into expert views about use of the Functionality model in practice. Jain and Narvekar (IBID.) classify Post-positivism as a paradigm with an ontological outlook in accordance with which reality cannot be fully apprehended in the same logical manner of Positivism. Hence its reliance on the qualitative research methods embedded in Grounded theory, one of which is data triangulation.

Endorsed by both qualitative and quantitative research texts, triangulation according to Sands and Roer-Strier (2006:237) encompasses the use of multiple strategies to study the same phenomenon. Handfield and Melnyk (1998:325) suggest data triangulation as a data analysis procedure appropriate for theory validation via experiments and interviews. In research practice, this means data triangulation is applied when data, findings, or generalizations about data are verified with several different research methods. It adds credibility and makes research findings stronger. Data triangulation in this dissertation is therefore to be pursued specifically for inductive inferences about the validity of the Functionality model, and to clarify perspectives that may turn out to be unclear, incomplete or inconsistent at this stage of the research process. Ultimately, empirical scrutiny of a theory of technology will contribute to the creation of knowledge and strengthening of an epistemological foundation for MOT within STA as a paradigm of technology.

3.2 Provisional research questions

Drejer (2002) presents a contingency model to help classify and make MOT theory accessible and usable to students and practitioners within the discipline. This of course is in line with the qualities pursued for theories in general. Matching management choice of solutions to MOT problems, and linking theoretical conceptions to empirical problems in response to specific contingencies, is what forms a paradigm; and it is the overarching aim of this dissertation as well, with STA and MOT as respectively the theoretical and academic-to-practice beneficiaries.

Following from the preceding arguments in this document, the research questions for this study are as follows:

1. *What are the theoretical grounding and attributes of the Functionality model, and is its application as a* taxonomy *of technological entities only conjecture, or does it indeed have theoretical and practical bona fides?*

This question is derived from the primary aim of this study, i.e. to make a contribution to the MOT body of knowledge. It becomes clear from Amundson (OP CIT.:343) that classification as a type of scientific knowledge is only a pre-condition for theory formulation within a particular cognitive frame. So to further pursue the analogy of a hothouse, theory in this juvenile condition requires more time, more intellectual compost, and more labour from the beholder to mature and become ready for the MOT market. Largely therefore a theoretical exercise, the response to this question will contribute to an epistemology for technology. It will question assumptions about the Functionality model and assess its readiness to evolve from scientific knowledge into theory, in other words, to outgrow its cognitive frame and become a theory within STA as a paradigm of technology. As was stated earlier, knowledge creation helps to constitute paradigms. Specifically, the following matters will be investigated:

a. What is the General Systems Theory, what is its epistemological nature and what is its role in contemporary science and practice with its almost inconceivable complexities? Does it still have a role to play, or did reality outgrow its role?
b. What role does General Systems Theory play in MOT literacy and associated knowledge systems?
c. What is the science and history of classification, and what tools does it present for systematisation? What conceptual and empirical roles does it have, and how are these roles applied in practice?
d. What do taxonomies generally do, and what are the major and common properties of taxonomies in service of science?
e. How do taxonomies differ from typologies, and which one of the two constructs is in fact the most appropriate for classification of technological entities?
f. What is the relevance of taxonomic classification of technological entities for MOT? How does it contribute to the MOT body of knowledge? How do taxonomies help to understand technological entities and their evolvement over time?
g. How to taxonomic classification compare with other tools of the trade?

All of this does ultimately require empirical testing. The purpose with the second question is therefore to create an experimental environment for subsequent testing of the research hypothesis and for observation of model behavior.

2. *Can the Functionality model in fact be used for a taxonomic classification of selected technological entities representative of the latest techno-economic trend towards convergence?*

It is shown in the literature research how the Functionality model is successfully used to classify various current technologies and how such classifications contribute to MOT insights. Convergent technologies are however an entirely novel class of technologies, driven by an inevitable assemblage of technology-push and market-pull forces, with few practical applications having completed the very basic requirement for this study to have evolved beyond conceptualisation and proprietorship in their respective lifecycles. To eventually be able to test the research hypothesis, systematically selected examples of convergent technological entities have to be found in institutions working with this class of technologies. The intent is to find with stratified sampling organisations which are suppliers, buyers, or both, of selected nano-scaled convergent technologies, and which would be willing to participate in research experiments for this project. Insights about the selected technologies are consequently to be gained by means of semi-structured and unstructured interviews with technology practitioners in the participating organisations. Using STA as a coherent theoretical framework, the selected technological entities are to be deconstructed and described in terms of their anatomy so as to understand their inherent morphological nature, and then they are to be taxonomically classified by various permutations of the Functionality model. Further matters to be examined during this phase of the research are as follow:

a. What is the best permutation of processes and outputs within the model for classification of these technological entities?
b. Are these processes and outputs the only dimensions which apply, or is there in fact a third, or more, dimensions for a multi-dimensional model?
c. How are these permutations best operationalised in the experimental environment created for observations?
d. What is their conduct in support of a theory of technology?

With various permutations of the Functionality model populated, a next phase of the research pursues testing of the research hypothesis with a construct to be described as a taxonomical value measurement. It involves creation, validation and application of the measurement instrument. This leads to the third research question.

3. *How is taxonomic value to MOT practitioners to be measured, and what metrics or instruments are available to test the research hypothesis?*

This objective poses a pertinent question from a MOT perspective, because theories and models, which are not shown to be of practical value, gather the proverbial dust on library shelves. Devising an instrument for value measurement endeavours to make accessible to the management community a tool for decisionmaking, as well as contributing to the MOT body of knowledge. To do so involves critical examination of the following issues:

a. Is it possible to generate a taxonomic value coefficient, i.e. an indicator that illuminates at once the utility value of understanding the taxonomy of technological entities within a wider paradigmatic framework?
b. What does the notion of utility value mean within the context described in this research project? Does it for example reflect, or respresent, codified knowledge? Alternatively, is utility value the ability of a taxonomy to generate insight, or to advance a predictive analysis of a technology entity on one, or several, of the various hierarchical levels it is found manifested?
c. What is the role of the Functionality model in technology lifecycles, how does the Functionality model evolve into Van Wyk's atlas of technological advance, and what is the practical value of this across technology value chains? In other words, where in the technology lifecycle does the Functionality model first start to show value, and where does it stop to showing value?
d. How does a value metric contribute to the discourse about the Functionality model and MOT in general? How does the value metric differ from, or contribute to, the current examination of an innovation metric by the *Measuring Innovation in the 21st Century Economy Advisory Committee* in the USA?

At the basis of this objective lies the primary research hypothesis, i.e. that different taxonomic permutations of the Functionality model have different utility values to practitioners of MOT. Having tested the hypothesis statistically leaves the researcher with only a quantitative indicator of the theoretical status of the Functionality model. But it may find itself isolated among an abundance of contributions, as Drejer (2002) contends, and therefore requires a market differentiator to promote its value to MOT practitioners. Management, after all, wants to know what it can change to produce better outcomes, according to Duncan (OP CIT.:264), and it is therefore the task of the research community to promote its tools among management practitioners.

Is the Functionality model in fact a theory, does it in other words meet the stated requirements for theory? Does it have the potential to evolve from a cognitive frame into a verified theory of technology within STA as a paradigm of technology? The final phase of the study critically reflects upon the theoretical nature of the Functionality model, and is directed by the following research question:

4. *When applied, tested and observed, does the Functionality model meet the requirements for good theory? How can it be improved, given the test results, and what recommendations flow from these insights to improve the theoretical stability of the model and the replicability of its results when applied in practice?*

Changing back to theoretical mode, the final phase of the dissertation evaluates findings forthcoming from empirical observations and statistical analysis in the preceding phase of this academic venture. Apart from the obvious outcome of concluding about its status as player within the paradigm of technology, another outcome pursued here is to formulate propositions for further research and refinement of the Functionality model for the benefit of its community of practitioners.

3.3 Research process

Given the parameters of paradigmatic activity as described in the research model, the research process follows the familiar sequence of hypothesis-testing deductive research, as shown in Figure 4.

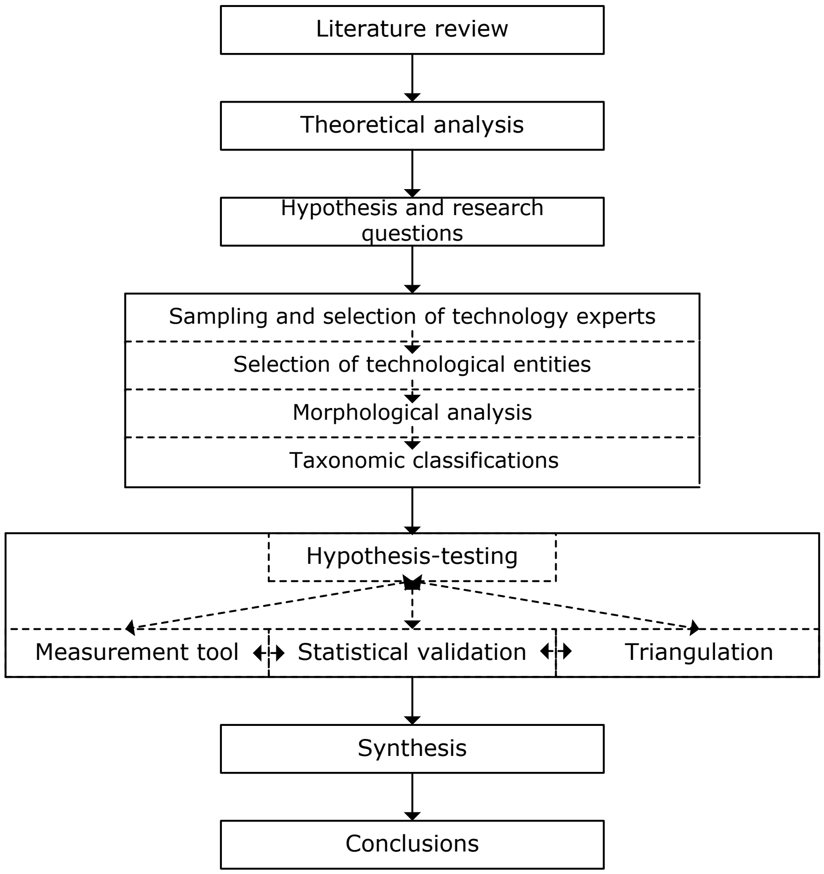

Figure 4: The research process for testing of the Functionality model

Source: Author's own

Mainly theory-driven, the process starts with a literature review and a wider perspective upon the notions of respectively a paradigm of technology and various theories of technology within this paradigm. From here the focus shifts to the research hypothesis and the ensuing research questions. The hypothesis and research questions present the underpinning for a simple data model from where data design and associated data collection processes become clear. The research model in this instance prescribes a sequential design for the data model, as depicted in Figure 4. The sequence starts with selection of technology experts, followed by selection of appropriate technological entities and respectively a morphological analysis and then taxonomical classification of these entities. Having collected and analysed the data, testing of the research hypothesis follows. As shown in Figure 4, statistical testing is to be supported by the qualitative method of data triangulation. The penultimate phase is a complete synthesis of the results of the research experiments and tests, and the final phase concludes the research project.

3.4 Constructs and validity

A key construct in this research is measurement of the value of the Functionality model as a unified and coherent framework for classification, understanding and subsequent knowledge of technological entities. The workings of a latent construct is not directly observable, and has to be approximated by observation of confirmable variables related to the latent construct under examination, according to Schreiber, Nora, Stage, Barlow and King (2006:323). Consequently, to measure value as a latent construct and to test the research hypothesis, a measurement tool is to be constructed and scientifically validated. The most appropriate avenue to pursue for an undertaking like this is to align the process to a recognized statistical framework such as Structural Equation Modeling [from here onwards described by its abbreviation of SEM]. Wikipedia (2008) describes SEM as a confirmatory rather than exploratory modeling technique, and this is confirmed by Schreiber et al. (OP CIT.:325). Thus SEM is suited to theory testing rather than theory development, and so presents to this research project a formal methodology for testing of the research hypothesis and confirmation of the Functionality model as a theory of technology. Two important characteristics of SEM are that it allows for modeling of latent variables such as required for this study, and it allows for falsification of the assumptions underlying modeling, which meets the falsification requirement of Popper. According to Saurina and Coenders (2002:222) SEM is also parsimonious, in other words, this class of techniques belongs to the family of linear models and so avoids overt complexity; and it has the ability to model complex systems where simultaneous and reciprocal relationships may be present.

First however, the central construct must be validated for use in SEM. O'Leary-Kelly and Vokurka (1998:389) describe construct validity as "…the assessment of the degree to which a measure correctly measures its targeted variable". They set out a three step process for construct validity, depicted in Figure 5.

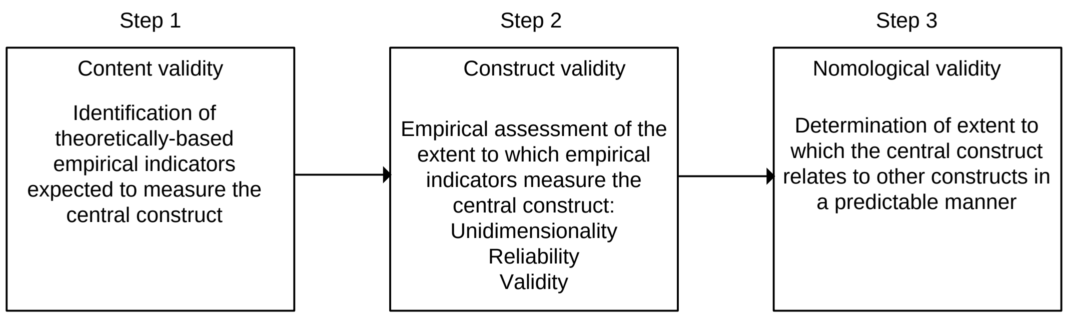

Figure 5: Three-step process for validation of the central construct

Source: Adapted from O'Leary-Kelly and Vokurka, 1998:389

The process to validate a measurement tool is indeed an attempt to demonstrate that a theoretical interpretation of the responses to the measurement is correct. According to Decoster (2005) there are often no criteria from which to obtain an objective measurement of the construct underlying a measurement tool - which is why the tool is being developed in the first place. Two issues to investigate in assessing validity are then whether the definition of the content domain to be assessed is adequate and appropriate; and whether the measurement provides an adequate representation of the content domain it intends to measure. By definition these issues are about the appropriateness of the content sample and can therefore only be solved by content validity (Stuck, 1995:25), which again can only be established by a panel of content experts. This dissertation is to keep as closely as possible to the above guidelines in order to establish construct validity. As it is, a formal research questionnaire is to serve as measurement instrument, and the identified empirical indicators, or content domain, which in this instance are to reflect the intrinsic characteristics of a good classification schema, will be encapsulated in the questionnaire. To assess and pursue content validity, these dimensions are to be put to technology practitioners in participating organisations, who are to serve as content experts. If required, these dimensions are to be refined until they reflect a valid scale of utility value. This objective seems to be the most challenging, but Lochner (2005) and Farrell (2007) present analogies for development of market-related scales for MOT with respectively a MOT competency index and an innovation metric. Hartmann (1999) suggests a Technology Balance Sheet, and Hruby (1999) introduces a Technology Applications Spectrum, both for use by the market as well.

Step Two, as depicted in Figure 5, focuses especially on reliability as key attribute of construct validity. According to DeCoster (OP CIT.) reliability concerns whether the measurement instrument produces identical results in repeated applications. A tool may be reliable but not valid, but it cannot be valid without being reliable, although many theorists now deem the attainment of survey validity as more important than achieving maximum reliability (Rzasa, 2003:26). In practical terms, this would mean that scales lacking validity have systematic biases to them, while those lacking reliability have large random errors associated with their measurement, thereby diminishing chances for obtaining significant results. But whereas reliability is a pure statistical concept, validity requires various building blocks, and ultimately depends on qualitative assessments of its value, as earlier explained (DeCoster, OP CIT.:8).

According to Santos (1999) and Welman and Kruger (2001:141) Cronbach's alpha is a widely used statistical test for reliability of a measurement tool, described as a positive function of the average correlation between items in a scale, and the number of items in the scale. In other words, the higher the average correlation among items in the scale, the lower the "error" or "unique" components of items in a scale, meaning that they are all measuring the same latent construct. Cronbach's alpha ranges in value from 0 to 1, and the rule of thumb is that a measurement tool should only be used if an alpha value of 0.70 or higher is obtained on a substantial sample - defined as having at least 30 respondents. Lower thresholds for Cronbach's alpha are though to be found in the literature (Santos, 1999), and according to Garson (2005) a lenient cut-off of 0.60 is common in exploratory research. A purely statistical measure, Cronbach's alpha is therefore an appropriate measure to be pursued towards reliability in this instance as well.

In accordance with the process prescribed by O'Leary-Kelly and Vokurka (OP CIT.:389), the final step in this process focuses on nomological validity. Wikipedia (2008) defines nomological validity as the interrelationship between constructs and their observable manifestations in a study.. Not surprisingly, Lee Cronbach, in this instance together with Paul Everett Meehl, also contributed to this measure. In order to indeed establish nomological validity of the central construct in this study, a smaller control group of domain experts is to be interviewed about their views on the dimensions of a good classification scheme, as well as the operationalisation of these dimensions in the various permutations of the Functionality model. Complying with the requirements for qualitative research, these views are to be systematised and are to be used for data triangulation in an effort to achieve nomological validity of the central construct for this dissertation.

In combination, these steps are meant to promote scientific rigor, so that the results of this research project may become a bona fide contribution to the MOT body of knowledge. As proposed here, these steps are only broadly outlined, but separately their detailed use for scientific research in the management sciences and in the social sciences have all been firmly established over the last half century and longer. It now depends on the researcher as well as guidance from supervisors and peers, to make them work for this study.

4. PLANNING

4.1 Time plan

Following is an outlay of a five year time plan for this research project. It is based on the understanding that this is a part-time study which faces several significant challenges. The time plan is broadly based upon the research questions that follow from the stated research objectives. Some of the phases will run concurrently so as to optimise time-usage and to leverage opportunities for a richer and more contextual learning experience, as and when such opportunities arise. The plan follows in Table 6.

Table 6: Research phases and time plan

Phase	Period
Phase 1 - further analysis of existing literature resources and publication of a *working paper*, provisionally titled as *A Paradigm of Technology: Fact or Fallacy?*	15 July 2008 – 15 June 2009
Phase 2 involves data collection, specifically about convergent technologies and the analysis of these entities in terms of STA.	15 July 2009 – 15 December 2011
Phase 3 involves the design, validation and application of a taxonomical value measurement.	15 July 2010 – 15 June 2012
Phase 4 involves statistical analysis of data and	15 January 2012 – 15 December 2012

subsequent testing of the research hypothesis.	
Phase 5 presents first a synthesis of the test results and then recommends refinements of the Functionality model.	15 January 2013 – 15 June 2013
Phase 6 concludes the research process and involves writing up of the final chapter.	15 April 2013 – 30 June 2013
Phase 7 involves completion of a paper and subsequent draft for an article provisionally titled as *Convergent Technologies: A Functionality Classification.*	15 July 2013 – 15 September 2013

4.2 Risks and contingency plan

This research proposal involves a novel class of technologies, of which true manifestations are not immediately available, nor accessible for analysis. The following risk table (Table 7) has as point of departure this specific reality.

Table 7: Research risks and provision for alternatives

Risk	**Probability (5-point scale)**	**Impact (5-point scale)**	**Mitigation**
Research proposal not accepted.	2	2	Refine proposal to acceptable standard.
Organisations involving in convergent technologies cannot be convinced to participate in research.	4	5	Consider a different class of technologies of which the analysis would still be meeting the requirements of the study, such as pure examples of nanotechnologies, which are not necessarily converged with biotechnology and/or Information and Communication technologies.
Participating organisations do not have technologies which have been sufficiently evolved in the technology lifecycle to be subjected to STA.	3	5	Consider to either analyse conceptual designs, if these can be found, or a different class of technologies.
Participating organisations are not	3	5	Consider to either analyse technologies already

willing to have market-ready technologies subjected to STA.			on the market, or technologies being pulled off the market.
Practicing technology experts cannot be found to co-operate in STA.	2	3	Consider viable alternative such as MOT and/or engineering students, or seek for retired experts willing to participate.
Technology practitioners cannot be found to participate in value measurement and subsequent data triangulation.	2	5	Consider viable alternative such as MOT and/or engineering students, or seek for retired experts willing to participate.
Sample size too small.	5	3	Postpone follow-up phase and follow up with respondents, or run another survey. Alternatively, change research design and towards smaller sample and case studies.
Analysis gives no meaningful results.	3	5	Consider the scientific merits of the research project and change research approach and, if so required, research topic to meet minimum requirements.
Research resources run out.	3	3	Delay, postpone or go slower on research.

4.3 Areas of related and further research

MOT presents fertile grounds for research, as is evidenced by Drejer (2002). As an evolving paradigm of technology, STA also presents multiple opportunities for further research. The following is a short list describing areas of interest, some of which may become more mature as time goes by, some of which may be immediately appealing to incumbents, and some which may simply expire:

1. STA and technology intelligence: More of the same, or paradigm-to-content? Does STA as paradigm have a place in technology intelligence configurations of organisations, or are they perceived as duplications of each other?
2. STA as a solution for information overflow: Information overflow may be slowly killing the corporate psyche. STA as a technology paradigm presents a structured and meaningful configuration for channeling of technology knowledge towards optimum management utilisation. What is management understanding of information overflow and what is management knowledge about STA as a potential solution to the problem?
3. STA set within a framework of technology roadmapping tools: STA as a distinctive capacity. This can be a comparative analysis of the value of a number of high profile toolsets meant to enhance

understanding of technology trends. This topic may be a natural extension to the research project under discussion in the larger proposal presented here.

4. STA applied – a case study to demonstrate the value of STA on a technology with a controversial public profile. Taking the notion of convergent technologies to the extreme, the USA Defense Advanced Research Projects Agency (DARPA) is busy with a research project which involves micro-electronics inserted at the pupae stage of insect metamorphosis so that they can be integrated into the insects' bodies as they develop, creating living robots that can be remotely controlled after the insect emerges from its cocoon (Turse, 2008:21). Practical tests with the *Manduca sexta* moth are in fact discussed by Reissman, Crawford, and Garcia (2007). This development presents a fitting example of how the *ethos*, *logos* and *pathos* intrinsic to the discipline of MOT and its community of ractitioners can be leveraged to highlight convergence, and its outcomes, to the public at large. The research question that arises is one of how can STA be applied on this class of technologies? What are the anatomical futures of the so-called *cyborg* insect in question, can it indeed be taxonomically classified when technological manipulation has ran its course, and should it be? How can the Cascade model be applied to better understand the contextual setting of this kind of technological entity? Consideration can be given to make this a longitudinal research design and to measure public opinions several times over a number of years.

5. The philosophy of technology – in need of a taxonomic classification? Meant to be a pure philosophical endeavour, this topic may help to structure a multitude of philosophical contributions about technology and MOT, and may help to make more accessible and understandable a rich legacy of views about the role of technology in society.

6. Management of Technology: Quo Vadis? The world faces a new technology paradigm, accompanied by incisive insights into new micro- and macro-dimensions and combinations of bio-technical-cognitive systems in their widest and most holistic sense. The insights and the realisations they bring along for societies will cause a comprehensive impact upon the global psyche, but Africa in particular faces major challenges about, with, and without, technology. It is time for the Credo for MOT to mature, and to become a mantra in educational institutions and corporations of all kinds across the continent. What is its status, how can its status be promoted in practical ways which are typically African and appealing to the continent, so that it can leverage new knowledge to its fullest potential?

4.4 Final remarks

It is the distinct observation of this candidate that there is more research to be done on the topic as explained in this proposal, and that this particular research project may become a theoretical foundation for further enquiry into the nature and value of MOT. This may eventually contribute to more knowledge and understanding of technology and associated management imperatives. If really successful as a scientific enterprise, this research may be, in typically paradigmatic sense, an incremental contribution to the growth of a paradigm of technology. As a constellation of respectively worldviews, knowledge bases, theories and research methods, a paradigm of technology again may contribute to improved understanding of technology and its all-permeating outcomes.

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