Chapter 2

DEFINING TECHNOLOGICAL INNOVATION

2 Defining Technological Innovation

This chapter focuses on the development of definitions in the fields of technology, innovation, and technological innovation. These definitions serve to qualify the assumptions made later in the thesis, as well as setting some boundaries to the innovation audit. Management practises for innovation and technology are covered as well, since they influence the innovation audit procedures.

The importance of innovation in creating competitive advantage and improving organisational growth cannot be understated. Appendix A in the addendum contains four viewpoints on how 'gurus' in the field of innovation perceive its importance. Toffler[1] offers his views on the future and what it holds for business, while Drucker[2] identifies the world population contraction as a serious threat. Burgelman[3] and Moss Kanter[4] offer insights into strategic aspects and generating growth for the future.

It is useful to develop a sound understanding of the dynamics of technology and innovation to be able to audit their respective characteristics. Since different types of innovation are possible, the boundaries to the innovation audit become important. Deciding between radical and incremental innovation can radically alter the questions asked in the innovation audit. Making an informed decision on the type of innovation, as well as the scope of the audit, is therefore only possible through knowledge of innovation and technology and the management of both these disciplines.

The word '*innovative*' is much too often used indiscriminately by the media and general public alike. This can often create the wrong impression and understanding of its real meaning. A technological innovation for instance, is not as many people believe, concerned specifically with computers or electronic products such as cellular telephones or international networks. Neither does technological innovation only occur in complex products, processes or systems. Technological innovation does not have to be complex, but it has to be new[10] and aim to implement the technology it embodies, in the marketplace.

For example:

> Bio-engineering and medicine currently represent some of the most advanced fields in technology, yet few people refer to tablets and pills when talking of high technology. Other even more unrecognised technological innovations include agricultural processes, financial services, manufacturing methods, and many others. High technological products, such as the fresh produce on farms throughout the county, rely on high technology for harvesting and protection from pests. These tomatoes, pears, apples, maize and many more, are each high technology products, for without bio-engineering and mechanical harvesters or sorters, these fruits and vegetables would not reach our tables as fresh and free of defects as they do. Technology influences our lives in many ways every day, and by thinking of technology only as electronics or computers, one would be badly misjudging the concept of technological innovation.

The poor understanding of 'invention' and 'innovation' is illustrated in the following example:

> *Laypersons, probably because of the mystique that surrounds science, generally view invention as a relatively rare event and assume that once it has occurred, the process of innovation can be completed in a straightforward manner. In actuality, the converse situation pertains here. All who have worked in R&D will agree that the R&D community is quite prolific in generating inventions, and companies can rarely afford to fund all promising R&D projects. It is the subsequent path to technological innovation that is typically fraught with numerous obstacles to be overcome, if the R&D invention is to be commercially successful.*
>
> —Noori[5]

The development of a working definition on the concept of technological innovation is imperative to the development of an innovation audit. It will be discussed next.

2.1 Defining Technological Innovation

To define innovation one might return to the Latin origin of the word. Innovation or *'innovare'*, which means *'to make something new'*, leads to several conclusions of its deeper meaning. The Latin concept is quite cryptic and can be better understood when divided into three parts. To make something new one has to:

- Generate or realise a new idea (**invention and creativity**)
- Develop this idea into a reality or product (**realisation**)
- Implement and market this new idea (**implementation**)

The *'to make something new'* refers to replacing old concepts or products with new ones, continually updating and improving them. When introducing a concept such as technology into the meaning of innovation, and defining the term 'Technological Innovation', the following changes to the above occur:

- Generate or realise a new idea, *based on technology, capability or knowledge* **(invention)**
- Develop this into a reality or product **(realisation)**
- *Diffuse*, implement and market this new idea, *technology, capability or knowledge* **(implementation)**

Thus technological innovation is a part of the total innovation discipline. It focuses specifically on technology and how to embody it successfully in products, services and processes. Technology as a body of knowledge might thus be seen as a building block for technological innovation, serving as cornerstone to research, design, development, manufacturing and marketing.

Other definitions of technological innovation may be found in literature, yet they all make some reference to **invention, realisation**, or **implementation.**

For example:

Invention:

> *Creation of new idea for a product process or service ... new combination of pre-existing knowledge.*
>
> — Edosomwan[6]

> *... and demonstrating its feasibility*
>
> — Girifalco[7]

> *... covers all efforts aimed at creating new ideas and getting them to work*
>
> — Roberts[8]

> *Organised creativity*
>
> — Ramanujan & Mensch[9]

The advantages of defining innovation as invention, may illustrate the creativity and novelty side of the process. However without emphasis on the implementation of the invention, innovation will not happen. By defining innovation as invention, only half the complete definition is given and no consideration for the total concept of innovation is made.

Realisation:

> *Industrial innovation includes the technical design, manufacturing, management and commercial activities involved in the marketing of a new (or improved) product or first commercial use of a new (or improved) process or equipment.*
>
> — Freedman[10]

> *Innovation is the specific tool of entrepreneurs, the means by which they exploit change and opportunity for a different business or service. It is capable of being presented as a discipline, capable of being learned, capable of being practised.*
>
> — Drucker [11]

The advantage of specifically including realisation in the definition of innovation lies in identifying a clear time in the lifecycle of innovation, where the invention progresses from idea to reality. The realisation phase transforms the invention into a producible product and therefore plays a crucial part in the process of innovation.

Implementation:

> *Successful exploitation of new ideas…*
>
> — UK DTI Innovation Unit definition (1994)

> *… innovation does not necessarily imply the commercialisation of only a major advance in technological state of the art (a radical innovation), but it includes also the utilisation of even small-scale changes in technological know-how (an improvement or incremental innovation)…*
>
> — Rothwell and Gardiner[12]

> *Innovation is the introduction of a new product, process, or service into the marketplace.*
>
> — Edosomwan[6]

> *… a new technology or combination of technologies introduced commercially to meet a user or market need*
>
> — Utterback & Abernathy[13]

Implementation should be defined in innovation, to indicate the importance to market and the real or perceived need that exists. No invention may claim to be an innovation, before it has been implemented into the market. The acceptance of the invention into the market changes it to the status of innovation. Therefore to define innovation, the following quotes come very close to the truth, as understood in the discipline of innovation.

Innovation:

> *An invention is essentially the creation of a new device. An innovation additionally entails commercial or partial application of the new device … first application of an invention*
>
> — Sahal[14]

> *Innovation is the process by which an invention is first brought into use. It involves the improvement or refinement of the invention, the initial design and production of prototypes. Pilot plant testing and construction of production facilities … diffusion is the process of the spread of the innovation into general use as it is adopted by more and more users.*
>
> — Girifalco[7]

> *… we look upon innovation as the total process from the inception of an idea through to the manufacture of a product and finally to its ultimate sale. It therefore includes invention and the many stages of implementation such as research development, production and marketing.*
>
> — Berry & Taggart[15]

> *Innovation = invention + exploitation*
>
> — Roberts[8]

This selective and non-exhaustive list of innovation definitions, illustrates the three areas identified in this thesis as the basis for the definition of innovation. They can clearly be seen to occur in the definitions of innovation given by Girifalco[7], Berry & Taggart[15] and Roberts[8]. The fragments [see above] under the headings invention, realisation and implementation illustrate the strong foundation for proposing that innovation consists of these three stages. The definition of technological innovation followed in this thesis, will therefore be a mixture of the above, as they are portrayed in the prominent areas of **invention, realisation**, and **implementation**

Thus the **Proposed Working Definition** of **Technological Innovation**:

- *To conceive and produce a new solution (from a scientific and technological knowledge) to a real or perceived need **(Invention)***
- *To develop this solution into a viable and producible entity **(Realisation)***
- *To successfully introduce and supply this entity to the real or perceived need **(Implementation)***

All definitions discussed above may lead one to the conclusion that technological innovation is a highly personal concept, relying heavily on knowledge, educational standards and intelligence. This also illustrates the difficulty of managing innovation, for how does one manage that which is so oppositely understood. These different ideas about innovation are exacerbated by the media referring incorrectly to any new development or idea as 'innovative', while actually meaning 'inventive'.

The three areas of technological innovation as identified in the proposed definition above, warrant a better description. They form a key part of the innovation auditing process and occur as primal entries in the innovation model, which will be developed later in this thesis. A short introduction to **invention, realisation** and **implementation** follows.

2.1.1 Invention

Invention and creativity are very common, and are practised by all of us. Because every human being understands, visualises and communicates information differently, we have no choice in being creative. When learning or reading we transform information into a personalised format to store it better in our brains.[16] This transforming of information into a personalised format, ads a uniqueness to every piece of information and when finally retrieved, manifests itself as new ideas, concepts and techniques. Invention therefore is a natural habit, practised to a greater or lesser extent by all people. This can be proved by the fact that even a simple interaction between two people, usually contains new thoughts, perceptions and even ideas. One of the best ways to improve innovation in an organisation is to hire new, inexperienced people with different perceptions and ways of doing things.

Conversely routine and safety are the suppressers of invention. When routines are formed in our minds, we tend to act along those same paths every day. To break the routine and think more inventive, one should try new things, learn as much as possible and explore continuously. For instance one of Leonardo da Vinci's most valuable traits was his inquisitiveness.[17] He simply had to know everything about anything, enabling him to stay highly creative throughout his life.

2.1.2 Realisation

The part of the innovation cycle where ideas are turned into workable and usable products may be referred to as the realisation phase. Engineers, designers and developers may often be found in the realisation phase. These people are realists, practical, goal orientated, hard workers and sure of themselves. Each of these traits play a part in driving and forcing an invention through the difficult stages of development, design, testing and pre-production to a producible product.

Without the realisation phase ideas would always stay 'blue-sky' ideals, hopes and promises. Realisation combines the skills of engineers with researchers, manufacturers and market 'gurus' to design and produce a working prototype, resembling the initial idea. It is important to note that the final prototype might not exactly constitute the initial ideas, since manufacturability, marketability and natural laws abide for every product.

2.1.3 Implementation

To implement an innovation means convincing someone to use or buy it from the innovator. Ultimately marketing is about convincing customers that a product is better, cheaper, faster, safer, harder etc. than the competitor's. With a new innovation the same holds true, yet the newness can sometimes be a drawback. Markets resist new products and need to be informed about the features of the new product to be able to understand its advantages. Implementation is therefore about developing and convincing the market, or customer, to buy a new innovation.

2.1.4 Conclusion

This concludes the section on the definition of technological innovation. It was found that technological innovation might be defined in a proposed working definition as:

- *To conceive and produce a new solution (from a scientific and technological knowledge) to a real or perceived need **(Invention)***
- *To develop this solution into a viable and produceable entity **(Realisation)***
- *To successfully introduce and supply this entity to the real or perceived need **(Implementation)***

This thesis will follow the definition as proposed above. It will be applied in the development of an innovation model, as well as a methodology for auditing capabilities for technological innovation. To elaborate on the diverse nature of innovation, the different types of innovation will be discussed in the following paragraphs.

2.2 Different Types of Innovation

Technological innovation is a complex process of several distinct stages, many of which require different focuses and different management strategies. Typical aspects of the stages of innovation may include the following:

(a) Should the firm start with the inception of an idea (invention)?
(b) Is it more beneficial to take up a well-developed concept and focus on commercialisation?
(c) Should the firm spotlight an existing technology and aim at perfecting or modifying it?

Managing innovation requires the juggling of many concepts and processes to keep each performing at its peak [Appendix A Burgelman]. To understand the complexity of innovation better, some of its elements requiring different management strategies are reviewed below.

Academics and specialists define many different types of innovation. For instance, different applications, degrees, processes and functions all performed in innovation function. The following are some of the more prominent types:

Marquis[18] defines the following different types of innovation:

- **Radical** innovations: ideas that have impact on or cause significant changes in the whole industry
- **Incremental** innovations: small ideas that have importance in terms of improving products, processes, and services
- **System** innovations: ideas that require several resources and many labour-years to accomplish. Communications networks and satellite operations are good examples

Henderson and Clark[19] define the types of innovation as:

- **Incremental**: — incremental innovation refines and extends an established design, but underlying concepts, and links between them, remain the same
- **Architectural**: — the essence of architectural innovation is the reconfiguration of an established system to link together existing components in a new way
- **Modular**: — it is an innovation that changes a core design concept, without changing the product's architecture or primary function
- **Radical**: — radical innovation establishes a new dominant design and hence a new set of core design concepts, embodied in components that are linked together in a new architecture

Types of innovation which will be discussed further include:

- Revolutionary vs. evolutionary innovation
- Modular vs. architectural innovation
- Process vs. product innovation
- Procedure vs. service innovation
- Disruptive vs. sustaining innovation
- Market pull vs. technology push innovation

Although by no means complete, the different types of innovation do give a certain understanding for the complexity of managing the total system. When so many different variables exist in an equation, great effort is needed to solve or just arrive at a sensible answer. In the following paragraphs, some of the more important types of innovations are described, as well as their possible management procedures.

2.2.1 Revolutionary versus Evolutionary Innovation

Innovation may be classed into two main categories, revolutionary and evolutionary, or often referred to as radical and incremental respectively. Although some extensions to these categories exist they will be elaborated on at a later stage.

Revolutionary or **radical** innovation as it is also known, is accompanied by a high degree of change in human behaviour and paradigms. In essence radical innovators have a completely different way of thinking and doing things. Radical innovation is responsible for most discontinuous product or process changes.

Huiban[20] states that radical innovation typically occurs in small organisations outside the more established industries. This is a contentious issue which many of the bigger organisations such as HP, 3M, DuPont, Pfizer and many others often disprove. What Huiban possibly implies is that disruptive or industry changing innovations often come from outside the industry they disturb. Christensen[23] refers to this type of innovation as the implementation of a disruptive technology. These technologies often find application in niche markets where they 'survive' until a crack or opportunity in the larger market appears. However if the innovation and technology is of sufficient brilliance, these small firms may easily start growing exponentially. The niche market serves as a platform for educating the market and generating resources for further product or technology development. Michelin (steel belt automobile tires) and Apple (personal computers) initially entered niche markets, before they were able to grow to their present size. This afforded them the time and exposure to do the necessary refining and development on their product ranges.

The management of radical innovation is often difficult, since it is prone to failure. Most organisations feel more comfortable to pursue the less risky route of evolutionary or incremental innovation.

Evolutionary or **incremental** innovation, on the other hand, is relatively common and occur throughout large and small organisations. It is often the large firms, with well-developed research facilities, that can capitalise most on incremental innovation. By continuously improving they are able to stay ahead of their competitors, and survive another day.

Incremental innovations build on previous radical innovations. They often focus on introducing new features and abilities to current product lines. These innovations can be managed in a formal way, by focusing on creative problem solving and integrating customer needs into future designs. Incremental innovation is the typical run of the mill innovation needed almost every day. It is most often used to keep up with the competition.

Incremental innovation is often the only way large organisations are able to innovate. However a hidden danger lies in specialising in incremental innovation only, for the field of innovation is dynamic and being locked in may mean relinquishing many opportunities to more flexible competitors. Influencing organisational competitiveness and the bottom line.

2.2.2 Modular versus Architectural Innovation

The terms modular and architectural innovation have been coined to assist understanding and defining the intermittent ground between revolutionary (radical) and evolutionary (incremental) innovation. The two extreme cases of innovation, as discussed above, do not include innovations such as fusion of technology, rearrangement of units or partial radical innovation. Modular and architectural[19] innovations lie between revolutionary (radical) and evolutionary (incremental) innovation, but are not necessarily simply a fusion of the two extremes. They represent a different approach to innovation and could be used as a methodology for implementing innovation, when revolutionary or evolutionary may not fit.

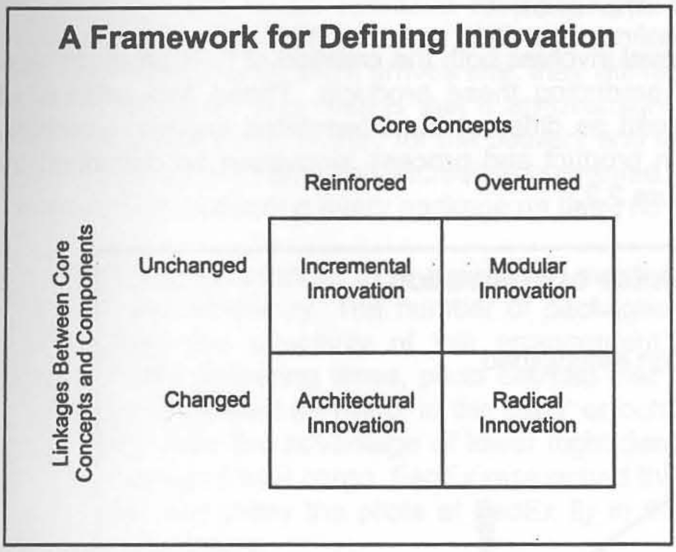

Figure 2.1: A Framework for Defining Innovation, Source: Henderson and Clark[19]

Architectural innovation occurs when existing knowledge or hardware embodied in a product, is arranged differently, creating a completely different product and possibly a different market. The function of the product seldom changes dramatically.

A good example might be the innovation of the low-stress chair, commonly used in front of personal computer desks. — The chair consists of opposing cushioned sections for the knees and buttocks. It has no backrest. When one sits in the chair, a crouching position results, with reduced stress on the occupant's lower back. — This chair is not simply an adaptation of a normal chair, but a rearrangement of the back and buttock rests, into knee and buttock sections. The important issue is that the underlying idea of seating a person has not changed, only the way it is accomplished. It may therefore be classified as an architectural innovation.

Implementing an architectural innovation might require scanning and monitoring a wide variety of customer needs and possibly identifying where current organisational technologies or competencies are utilised. Due to the holistic approach required for architectural innovation to happen innovators will require a wide knowledge base with information gathering and knowledge management systems close at hand.

A **modular innovation** usually takes place in complex products or processes with many sub units and functions. This type of innovation can be a radical innovation of a certain part of a total product. A new personal computer may have a new central processing unit, but without accompanying software, interfaces, memory and buffer units, it could not be regarded as a radical new product innovation. In this case a neural network computer or something completely new, would be considered a radical innovation.

Modular innovation is related to radical innovation in the nature of its implementation. As proposed above a modular innovation represents a radical innovation in a single part of a system. Linking modular innovation directly with radical innovation, but in a diminished capacity.

2.2.3 Process versus Product Innovation

Innovation at the organisational level involves both the creation of new products, and improvement in the process of producing these products. These two aspects of innovation can be actively managed as different but interrelated entities. However, there is a clear time lag between product and process innovation as described by Utterback and Abernathy[21] in Figure 2.2.

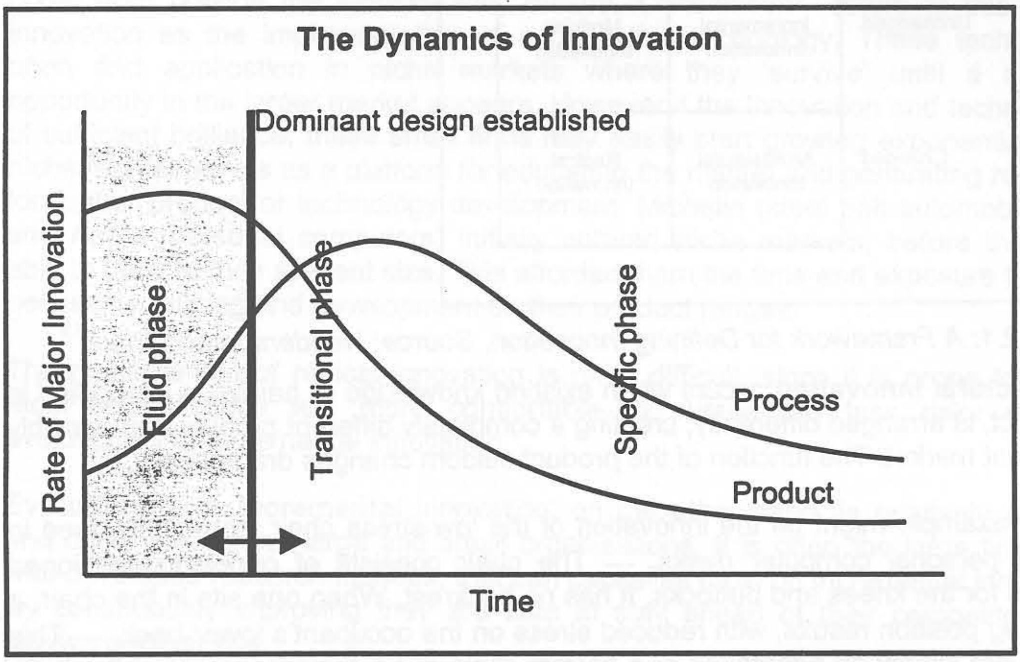

Figure 2.2: Product vs. Process Innovation Dynamics, Source: Utterback[21]

The dominant design innovation-cycle in the figure shows the increasing volume of new products in the section where a dominant design has yet to emerge. As shown in the figure a large amount of product innovation occurs until the dominant design is established. This phase is therefore called the ***fluid phase***.

After the dominant design is establishment, the focus shifts to improving the efficiency of manufacturing and production of the product. This results in higher product innovation and is called the ***transitional phase***.

Finally the product enters the ***specific pattern*** in its lifecycle, where incremental product and process innovation occurs. Specialising the product further with regard to customer needs or demands. This phase is highly dangerous since technology lock-in often occurs, resulting in low firm agility, and ultimately no way of adapting to new demands or technological evolution.

The dynamics of innovation in Figure 2.2 are important when strategic innovation planning is done. Organisations need to take the nature of product and process innovation into account, when developing future strategies.

Process innovation can be described as improving or changing current procedures and techniques used in the production of products. Any improvement to current manufacturing, delivery, packaging, marketing, project management, etc can be considered a process innovation.

A good example of an operation reliant on process innovation would be Federal Express, the overnight package delivery service. FedEx guarantees that if any package delivered by them arrives late, they will refund 25% of the sending costs per hour of lateness. This means that if an overnight package arrives four hours late, FedEx will receive no money for the delivery and the package thus gets delivèred for free. To be able to offer this incredible guarantee, every person in FedEx has to be committed to delivering every package on time, no matter what the circumstances.

For FedEx to accomplish their guarantee, every department by itself is responsible for their own efficiency. The number of packages dispatched across the world can demonstrate the effectivity of this arrangement. When given the opportunity to improve their delivering times, pilots claimed that flying normal flying hours delayed delivery and insisted on flying 'in the gaps' or outside normal flying hours. This they said gives them the advantage of lower flight densities, with less delay on runways and unloading of their cargo. FedEx researched this notion and saw the advantage to be gained, and today the pilots at FedEx fly in the carefully predicted gaps outside normal flying hours.

Typically this type of innovation can be characterised by an improvement in the pilots working procedures, resulting in an improved delivery system. It is therefore a process, rather than a product innovation.

Product innovation is often associated with New Product Development (NPD) and not necessarily with innovation. However, product innovation forms the core of innovative organisation and offers incredible competitive advantage in new as well as established markets. Although related to process innovation, product innovation is much more of a process than a single implementation or improvement. Product innovation is often a shot in the dark with the hope of hitting the right market with the right product at the right price. Good examples of product innovation is not hard to find, but the following is one of the most classical ones:

As discussed by Foster:[22]

> By the late eighteen hundreds the Swiss watch making industry reached its peak in performance and quality. Their workmanship was revered to throughout the world and watches made by them dominated the market. The Swiss however, became too sure in their dominance and failed to spot the possibilities of a certain development. One of their own creative workers in the electronic and crystal impulse generation field started this development. After seeing this new device on a fair in Switzerland, using a crystal instead of a pendulum, Japanese entrepreneurs were ecstatic. They immediately bought the patent from the young designer and set to work on one of the best innovations of the twentieth century, the digital watch. This invention took the world by storm. Suddenly a timepiece made in Japan could keep as good time as an expensive Swiss watch, and at a tenth of the cost. Obviously the Swiss industries collapsed as market share diverted towards the Japanese companies, yet it was the consumer who won in the end. By destroying the Swiss monopoly and introducing new technology better simpler and cheaper products were possible.

This example illustrates how easily an organisation may lose track of possible new innovations in their own research laboratories. A consistent focus on incremental product innovation like the Swiss, may result in a mindset which disqualifies alternatives. A mixture of incremental and radical product innovation is therefore necessary to open the paradigms inside an organisation.

2.2.4 Procedure versus Service Innovation

Writings on innovation often focus on product and process innovation, and do not include enough research on service and procedure innovation. Although service and procedure innovation is important most strategies and methodologies for product and process innovation respectively hold true for them as well. For the sake of completeness these innovation terms are explained to some extent

Procedure innovation (or process innovation) — Innovation that changes the management procedures is a good example of this kind of innovation. This innovation has no direct influence on the products size, shape or features but can cause the process of producing the product to improve. In this way a procedure innovation is a process innovation since it improves the manufacturing or production process.

Service innovation (or product innovation) — In a service organisation the product is supplying a service to the client. In this regard the service becomes the product of the organisation, since it generates income. Organisations like banks and repair service stations have many different types of 'packages' they offer, and each of this represent a certain service to the client.

Procedure and service innovation can clearly be incorporated into the larger picture of process and product innovation. But they are often difficult to manage or audit due to their qualitative nature.

2.2.5 Disruptive versus Sustaining Innovation

Christensen[23] elaborates on the concept of disruptive and sustaining technologies yet his conclusions and remarks may be applied in the field of technological innovation as well. He proposes the existence of disruptive technologies that have the ability to change the industry paradigm as well as the dominant design. The examples Christensen use, are from the computer hard disk industry where a simple size reduction, had a major influence. In this example he also refers to the sustaining technologies which do not necessarily change the current paradigm.

Christensen describes sustaining technologies as those that fall within the limits and boundaries of the current technology trajectories and therefore only serve to incrementally improve the product. These technologies build upon the previous ones and are mostly well known in every organisation in the industry. Although many resources are spent on advancing the current sustaining technologies, they will not enable the organisation to break free of the current paradigm.

For a paradigm breaking technology Christensen propose doing disruptive technology development. In the Hard Disk Storage industry for instance, the shift from five and a half inch drives to three and a half inch drives, were such an paradigm shift. Christensen defines disruptive technologies, as often simpler and of poor quality, than current technology, yet with a definite niche market. The disruptive technology should also have higher limits than the current one. Then when disruptive technologies are turned into disruptive innovation, they often have the power to unsettle powerful industries.

2.2.6 Market Pull versus Technology Push Innovation

In this regard innovation can be seen in two lights, and the distinction lies between listening to the market or the scientists. An innovation starting with an identified customer/market need, is called a **market pull**[33] innovation, while an innovation based on new technology or bright idea is called a **technology push**[33] innovation.

Both these innovations occur frequently but usually in different markets and environments. A technology push innovation, for instance, occurs in a research and development rich environment. On the other hand customer based or service based institutions make mostly use of market pull innovations.

Market pull innovation needs a strong customer base and an information gathering mechanism to qualify their needs. Since the customer/market actually asks for a new innovation, little in the form of direct radical creativity is needed. A well-oiled research and development team however, has to translate the needs of the customer/market into practical product proposals. In this regard the organisation doing the innovation has to continually have good contact with the customer/market to ensure the product meets their expectations.

Technology push innovation on the other hand needs a strong technology base. By doing basic 'blue sky' research, new materials, methods and techniques are discovered. When these new ideas are incorporated into products, technology push innovation occurs. Although a need for this new technology driven products often exists, there might not always be one. When this happens, the customer/market is often ignorant of the characteristics and advantages of the product, and needs to be educated. A lot of market development is usually required to launch such a technology driven product.

Although technology push innovation can have very high rewards, it is extremely expensive and may fail more often than market pull innovation.

2.2.7 Conclusion

The many distinctions between the different types of innovations are one of the reasons why it is difficult to implement a general recipe for innovation. Another, is the many differences between organisations and how they implement their own innovation strategies. To find a sensible and applicable middle road, weighing up the different options correctly will require an enormous amount of research and study, which fall outside the scope of this thesis. The focus will now shift to the applied aspects of innovation, as well as the identification of the key areas defining the discipline of innovation. However the different types of innovation and their management procedures, will influence future conclusions and developments of any kind.

2.3 Management of Technology and Innovation

Technology management is becoming an accepted management practice, and in some cases even the equal of current financial management methodologies. With the increase in importance of technology, it is becoming prudent for senior management to be more aware of new technologies. New technologies have the ability to completely disrupt established industries, and make most, if not every, of their competencies obsolete. Conversely, a specific technology identified early enough and developed into a market leader may be extremely profitable.

The management of technology has been developing as a formal disciple over the past decade or two. Compared to other management disciplines it is in its infancy. When one looks at innovation management it is even less developed than technology management as formal discipline.

Many aspects are hampering the rapid acceptance of technology management in industry. One of these is the difficulty of defining technology itself. Another is finding the value technology management adds to the organisation. It is quite difficult to define the value of an 'undefineable' and 'unquantifyable' discipline.

Due to the increased use of technology in the workplace, especially information technology, technology management will in future years become increasingly important.

If the discipline of technology management is difficult to quantify so much more may the discipline of innovation management be. Innovation management as discipline is often confused or combined with technology management. Although it is possible to combine the two as proposed by Betz,[24] in the statement,

> *...the central concept of managing technological change is the idea of 'technological innovation': Technological innovation is the invention of new technology and the development and introduction into the marketplace...*
>
> — Betz[24]

it may often lead to complications in the implementation of technology or innovation. It may possibly be simpler to make a distinction between technology management and innovation management by looking at the processes they are based on.

Technology management is mainly concerned with the interaction of the organisation and the external technological environment. As such licensing, acquisition, technological status, R&D and technological policies could be classified as pure technological management items. While other, more innovation related areas such as new product development, new process development and innovation policies could be classified as pure innovation related items.

The question arises: which one is concerned with the implementation of technology or which one only with the technology itself? There is no doubt that some overlaps between the two disciplines exist, yet few academics are prepared to stake their reputation on drawing the dividing line.

Some of the differences between the two disciplines are relevant to this thesis and will therefore be reviewed in the rest of this chapter.

2.3.1 The Management of Technology

One of the possible responsibilities of a technological manager might be to ensure that there exists adequate contact between the organisation and the technological world. Another typical function of a technological management department or office, would be to implement far reaching technological plans with regard to current resources employed, as well as future product development. This may include functions such as information system design, production system planning, technology acquisition planning, technological monitoring and scanning, as well as strategic advice on future developments in the technological domain.

Technology may be defined as 'created capability' in the words of Van Wyk.[25] A cryptic, yet accurate definition, showing a general in-depth understanding of the term 'technology'. However, technology often requires a 'gut feel' definition rather than one in words, and is often best understood over time and through personal research.

One important aspect of technology is its tendency to continuously change; this is often referred to as the dynamics of technological change. The management of technology revolves around the dynamics of technological change. In the following section more detail on this subject is given.

2.3.2 Dynamics of Technological Change

The question why and how new technology and innovation happens and how this change manifest itself in reality, leads to the study of dynamics of technological change. A multitude of reasons for change exist yet the limits of technology are often driven by so called barriers of performance. These limits or barriers to technology inhibit the further development of current products and processes. A good example is the limit Intel is reaching in miniaturising their central processing units (CPU's) for new computers. Their CPU's internal architecture is nearing the limit of conductor safety, and therefore they have to investigate other materials or even completely new technologies. This technological limit can be identified as one of the primary drivers in new technology development at Intel.

A complete field of study exists with the specific task of finding and predicting the dynamics of technological change. As with Intel many other technologies have limits, and when these start to impact on development, many new pathways open for managers which need consideration.

As part of these dynamics a renowned Russian economist Nicholai Kondratieff[26,27] discovered a 54-year cycle of commodity prices, which he traced back 300 years. He used this to accurately predict the 1929 stock market crash, three years before it happened. The Kondratieff long wave cycle, as illustrated n figure 2.3, clearly illustrates the cyclic nature of world prosperity. The interaction between economic prosperity and technological innovation is fascinating.

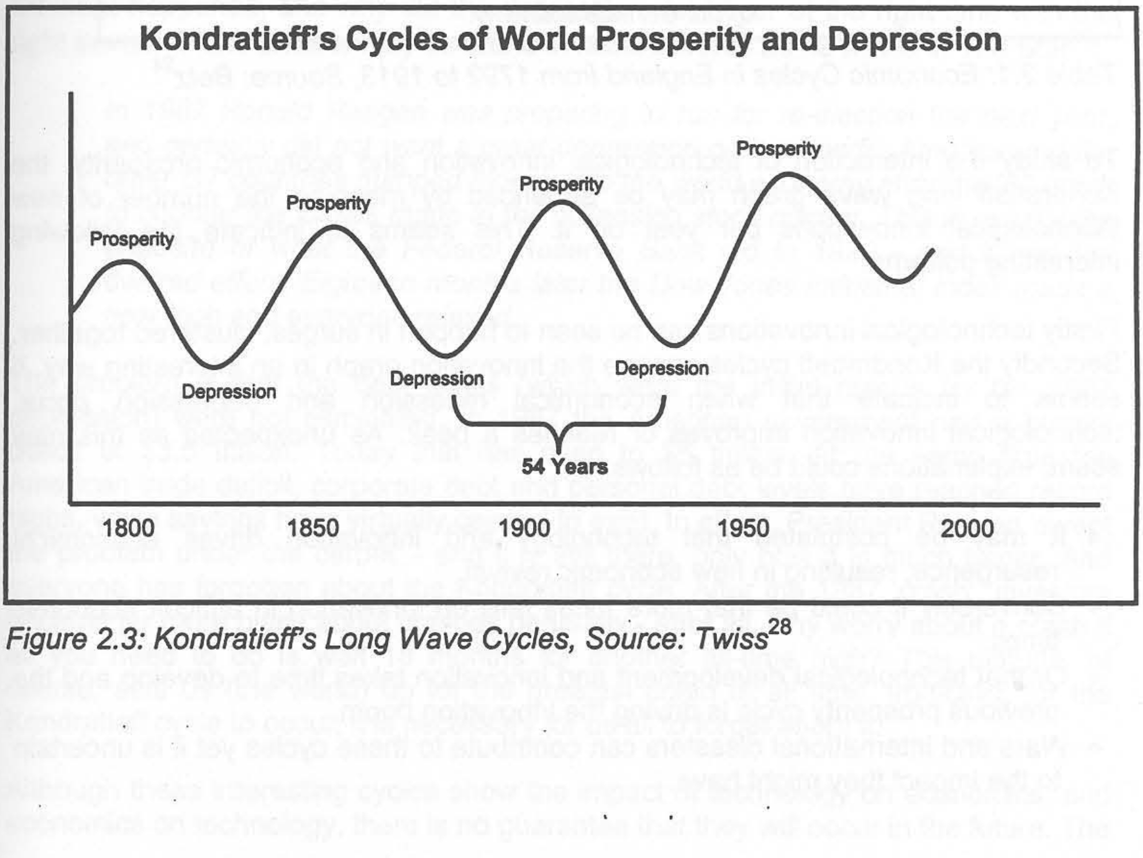

Figure 2.3: Kondratieff's Long Wave Cycles, Source: Twiss[28]

Economic Cycles in England from 1792 to 1913

As identified by Kondratieff:

First wave:
1792-1825 Economic Expansion:
Kondratieff assigns iron, steam power and textile machinery as the reasons for economic expansion.

1825-1847 Contraction:
Due to temporary excess in the expansion cycle.

Second wave:
1847-1873 Economic Expansion:
Due to the beginning of new industries in railroads, steamships, telegraph and coal gas.

1873-1893 Contraction:
Again due to over supply and excess
A temporary economic contraction followed.

Third wave:
1893-1913 Economic Expansion:
The development of new technologies in chemical dyes, electrical lighting, telephones and automobiles.
Followed by continued expansion after World War I.

1930 Contraction:
Temporary excess as well as war debt of the German economy.

Table 2.1: Economic Cycles in England from 1792 to 1913, Source: Betz[24]

To study the interaction of technological innovation and economic prosperity, the Kondratieff long wave graph may be enhanced by mapping the number of new technological innovations per year on it. This seems to indicate the following interesting patterns.

Firstly technological innovations can be seen to happen in surges, clustered together. Secondly the Kondratieff cycles oppose the innovation graph in an interesting way. It seems to indicate that when economical recession and depression occur, technological innovation improves or reaches a peak. As unexpected as this may seem, explanations could be as follows:

- It may be postulated that technology and innovation drives economical resurgence, resulting in new economic revival.
- Conversely it could be that more focus falls on innovation in difficult economic times.
- Or that technological development and innovation takes time to develop and the previous prosperity cycle is driving the innovation boom.
- Wars and international disasters can contribute to these cycles yet it is uncertain to the impact they might have.

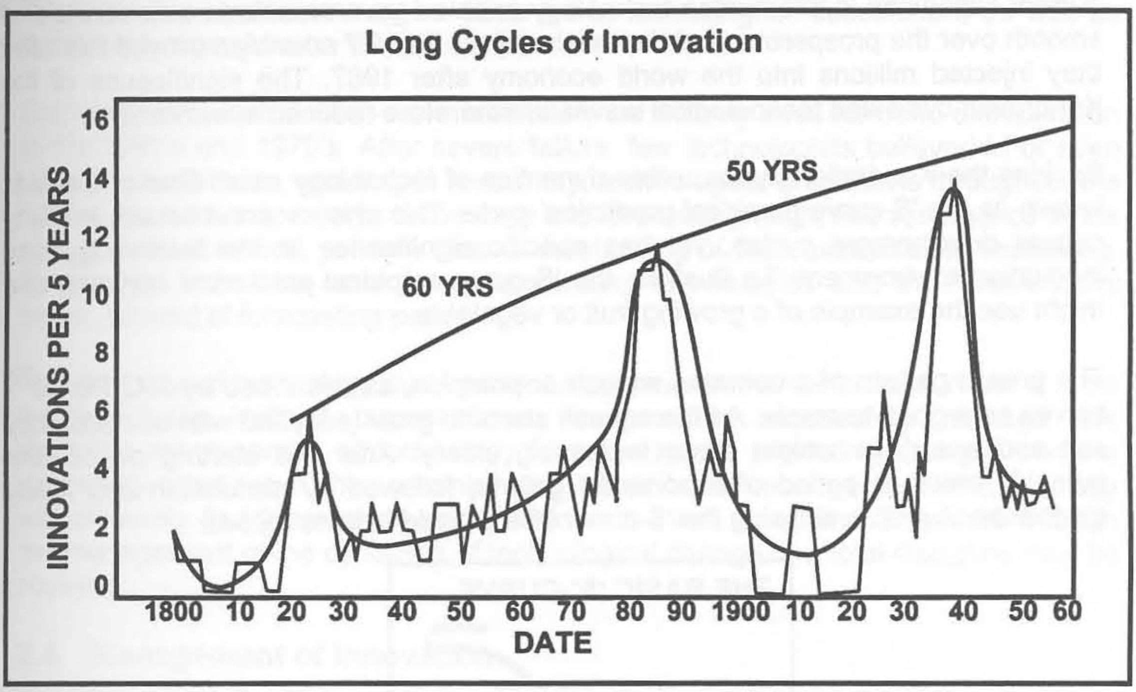

Figure 2.4: Long Cycles of Innovation According to Mensch, Source: Girifalco[26]

As the world enters the new millennium it is interesting to note the surge in the economic environment since the stock market 'crash' in 1987. The Kondratieff cycle indicates that if one were to add 54 years to 1929, reaching the answer of 1983, a Kondratieff depression would have been likely around that time. The depression did come in 1987 but not as severe as was proposed by Kondratieff.

So what happened, and why did the depression not occur at the right time with the right severity? The answer may be found in Milne's words as he writes in The Star[29];

> *In 1987 Ronald Reagan was preparing to run for re-election the next year, and certainly did not want a great depression on his hands. America and the other G7 countries pumped money into the world economy after the '87 crash to counter the losses made in the collapsing stock market. This is exactly the opposite of what the Federal Reserve Bank did in 1929 - and it had the desired effect. Eighteen months later the Dow Jones industrial index made a new high and everyone relaxed.*

The problem is that the debt levels (which were the initial reason for the 1987 depression) were not eliminated. In 1987 the American government had a budget deficit of $3,5 trillion. Today that has risen to $5 trillion. At the same time the American trade deficit, corporate debt and personal debt levels have reached record highs, while savings have virtually ceased to exist. In effect, President Reagan 'swept the problem under the carpet' - and it is still there, only now it is much larger. And everyone has forgotten about the Kondratieff cycle. After the 1987 'crash', investors became far more blasé about crashes generally - after all, why worry about a crash if all you need to do is wait 18 months for another all-time high? This attitude, of course, sets us (the world) up for the greatest crash of all time. Ironically, for the Kondratieff cycle to occur, it is necessary for us all to forget about it.

Although these interesting cycles show the impact of technology on economics, and economics on technology, there is no guarantee that they will occur in the future. The current expansion in information technology enables governments to collaborate and smooth over the prosperous and depressive eras. The G7 countries proved this after they injected millions into the world economy after 1987. The significance of the Kondratieff cycle and technological waves are therefore reduced enormously.

Besides the Kondratieff cycles, other dynamics of technology exist. One of these is known as the 'S-curve empirical prediction' cycle. This phenomenon occurs in many natural development cycles, yet has specific significance in the technology and innovation environment. To illustrate the 'S-curve empirical prediction' concept, one might use the example of a growing fruit or vegetable.

The growth pattern of a common squash or pumpkin, as described by A.L. Porter[30], serves as a good example. As the squash starts to grow (supplied with all necessary soil and water) its weight starts increasing slowly. After the starting period, the pumpkin enters a period of exponential growth, followed by maturation and finally stagnation. A graph, showing the 'S-curve effect' could look as follows:

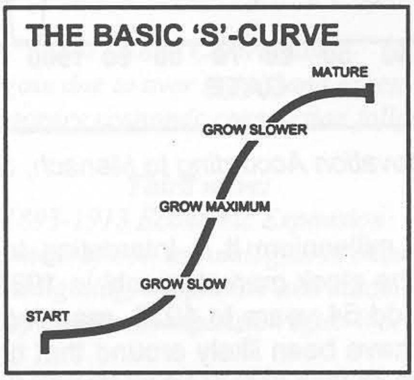

Figure 2.5: 'S'-curve, Source: Porter[30]

Interesting parallels between this natural growth curve and dynamics of technology can be drawn. Technology diffusion into a market is one of the more common processes following the 'S'-curve path. The diffusion process of television sets into the American market might serve as an example, as may be observed in Figure 2.6.

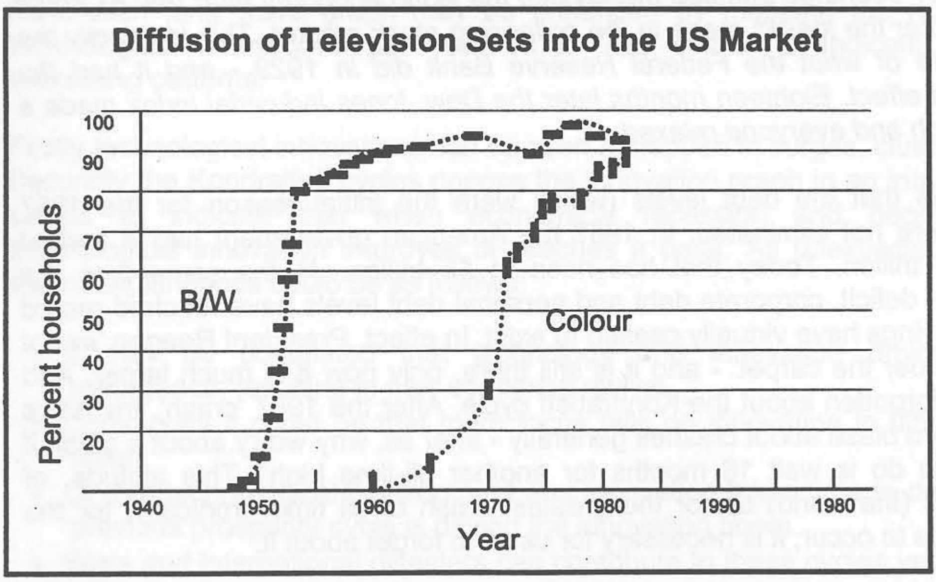

Figure 2.6: Television Diffusion into the USA Market, Source: Girifalco[26]

Other 'S'-curve patterns may be observed in technological substitution, as well as technological progress or development.

Both the Kondratieff and 'S'-curve methods were actively used for trend extrapolation in the 1960's and 1970's. After severe failure, few technologists believed in or even used these methods, resulting in few, if any, technological predictions throughout the 1980's. New development in technology and forecasting might see resurgence in the use of these methods, yet with clear understanding of their extrapolation limitations. They might rather be used for understanding technologies and their interactions better, instead of forecasting per sé.

The discipline of technology management may be instrumental in the survival of most technologically inclined organisations. However, to successfully manage this discipline the dynamics of technology form the key to predicting changes and the necessary reactions. Other administrative areas in the management of technology will ultimately find themselves as extensions to these dynamics. Therefore through the management of the dynamics of technological change, the total discipline may be covered.

2.4 Management of Innovation

Innovation management is often classified correctly as a discipline separate from that of technology management. However, concerns still surface on the actual implementation of the two disciplines in practise. The question arises: how does innovation management influence technology and what relevance does it have in the high technology organisation of the future?

No easy answer exists, yet the beginning of a discipline may be observed in the writings of academics and specialists such as Twiss[28], Tidd[34], Utterback[22], Chiesa *et al*,[31] and others. Twiss and Utterback have been two father figures in defining innovation management as a discipline. It is through their work on innovation models and definitions that the first beginnings of a discipline were formed. By studying these writings on technological innovation, one may come to understand the bigger picture of the discipline.

Management of innovation is not a subject one can discuss in a brief paragraph or two. Due to the diverse nature of innovation, it often has an impact on a large amount of resources and functions inside the organisation, from strategic decision making to employee attitudes and creativity. As yet few organisations have a formal innovation management programme, increasing the importance of elaborating on the subject in this thesis. Innovation auditing and innovation management go hand in hand.

Technological innovation management and its discipline of implementation can be a contentious issue. Betz[32], for instance implies that innovation management should be part of the technology management discipline, while others such as Noori[33] and Tidd *et al*[34] oppose this. To their reckoning technological innovation management should be a discipline in its own right, and technology management could even be made to fall under the umbrella of technological innovation management. Although both these viewpoints have their merits, this thesis is of the opinion that technology management and innovation management forms two distinct management disciplines, and should be addressed as such. However, this does not propose that no overlap between the disciplines exists, but there is enough evidence to suggest that the differences between the two disciplines are relevant.

To describe the functions required in the management of innovation, the nature and structure of the organisation should be taken into account. Project leaders or managers in the new product development environment, might perceive themselves as innovation managers, yet the management of innovation require a more strategic approach as well. A description such as 'chief innovation officer' might be attached to the person in charge of an innovation management discipline. Such a person should therefore have insight into the long-term organisational strategies and architectures of the organisation.

Six key elements were extracted from the work by Utterback,[21] Twiss,[28] Tidd *et al*,[34] and Cheisa *et al*,[31] and are discussed below. They are proposed to form the basis for the innovation management process, which is followed in the development of a competence audit for technological innovation in this thesis. The innovation management function may focus on these six elements, and by continuously improving them improve the total innovation capability of the organisation.

External environment:
Interfacing with technology management as well as marketing and competitive intelligence of the industrial environment, the innovation management function co-ordinates the integration of necessary information for the conception of new ideas and projects, thereby creating an environment rich in knowledge and capable of fostering new innovations.

Organisation:
Assisting general management in planning and strategy formulation as well as information capabilities in the region of innovation and new product development. The innovation management group is able to influence the strategic design of new projects as well as new competencies that are required in the organisation. Aspects such as project mix and the aggregate project plan, new product and process development models, technology competence and innovation audits, all form part of the structure and resource environment that is supplied by the organisation to foster innovation.

Individual:
Improving personal knowledge as well as encouraging creativity and participation in new innovations, lead to improve effectively and efficiency. The innovation management function should, through interface with human resource management, enhance the capabilities of the employees. Innovation capabilities should also be looked for in appointing new personnel and in this function innovation management might offer guidelines.

Invention:
The invention and idealisation process is often the first function people think about when considering the improvement of innovation in the organisation. Although invention is important in its own right, innovation can seldom happen if only one of the three key areas is present. The causality of the three functions: invention, realisation and implementation, relates their significance to each other well. Invention is for instance impossible without market, technology and industry related knowledge, which stems from the implementation of previous innovations.

Realisation:
Realisation forms the second part of the causal map in the innovation new product development process. The realisation process requires the input from

the invention process in the form of technology, prototypes and models. These are then used for the creation and building of feasible and high volume production products.

Implementation:
Implementation might be considered to be the final part of the causal model drawing on the outputs of the realisation process. This function consists mainly of marketing and market education, as well as after sales service when required. It can therefore generate highly valuable information for the development of new products and innovations, closing the three new product innovation functions into a ever revolving loop.

The last three elements invention, realisation, and implementation can be seen as the heart of a new product or service development process. The first three may be described as the innovation-fostering environment. The innovation management functions, influences each of the six areas and improves them on a continuous basis. Through this, exceptional control on the new product development process is possible, resulting in strategic goals being reached faster with better implementation of resources.

The methodology for the management of technological innovation is still in virgin territory. The proposed six elements above is made on the basis of a innovation model which will be developed in the next chapter. Other sources on technological innovation management were used extensively in constructing the model as well as defining the six elements.

2.5 Innovation Management versus Technology Management

The two disciplines of technology management and innovation management have been described above. From these definitions and elements the differences between the two disciplines should be clear. Since the two terms, innovation and technology are understood in a qualitative manner and also on a personal level, there will always be debate on their classifications.

If one regarded technology, it could be classified as a scientific method, discovery or even a certain kind of knowledge. It is not a process like innovation and does not require implementation to be considered a technology. One might think of technology, combined with other methods and ideas, as the input to the innovation process. While the innovation process is where the technology is transformed from static knowledge into practical implemented products.

From the dynamics of technological change and the management of technological innovation, it should be clear that there exits a niche area for both the management disciplines. Some overlap may be necessary but in the end the advantages of splitting technological and innovation management issues, outweigh the advantages of grouping them together.

2.6 Conclusion

In this chapter definitions on technological innovation were discussed as well as the management of technology and innovation.

The management of innovation and technology are both relatively new disciplines and are embroiled in much discussion and development. Implementation of these two disciplines will become more crucial as global communications and international commerce remove old continental barriers. The wave of current business practises focusing on competitiveness, will require improvement in methodologies of innovation. Defining the differences between them is therefore of some importance.

The next chapter will focus on the innovation process as well as the environment in which it could flourish. With the help of an innovation model a holistic overview of the technological innovation process is presented.

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