TRANSITIONING THE KNOWLEDGE ERA – PREPARING FOR NEW FUTURES

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ABSTRACT

The long waves of economic life have been known since the breakthrough work of Kondratieff[1] in the 1930s. Adding technology influences, the transitions of the different techno-economic "waves" can be envisaged as overlapping S-curves. Agricultural-based economies were followed by resourced-based economies, which evolved into industrial economies. Three industrial revolutions took place, with a fourth one in the making. Until the advent of the information economy, these economies existed very much in isolation. Since then, economies became interrelated. We now live in the knowledge era, which is the confluence of these mainstream economies with the bio-economy, nano-economy, hydrogen-economy and neuro-economy. The knowledge economy is rapidly transitioning into the conceptual era. This paper explores the thinking that is required to manage transitions to move from one economic era to another or to exist in the confluence of economies. New knowledge and technology management regimes and behaviour are required to navigate these transitions. Transition management deals with uncertainties; knowledge and technological change, pursuing innovation; creates high level multidimensional future views; suggests change processes at the right scale and feeds into management, policy and governance systems. A transition is the result of developments in different domains. This implies a set of connected changes, which may reinforce each other but take place in several different domains, such as technology, the economy, institutions, behaviour, culture and belief systems. Since transitions are multi-dimensional with different dynamics, multiple developments must come together in several domains for a transition to occur. The ability to identify and predict emerging connected changes that drive transitions is supported by an understanding of how the future will be shaped by these influences. Scenario and possibility thinking can be used to select transitions that lead to sustainable technologies and innovation. This paper presents conceptual thinking on how transition management can be applied together with future thinking and possibility thinking approaches to prepare for expected change because of techno-economic evolution. It uses the transition from the knowledge era to the conceptual era as a driver to develop a thought model of how such a transition should be managed to ensure a sustainable future for business and society.

Key words: Transition management, technology management, future thinking, possibility thinking, techno-economic wave, S-curve, era

INTRODUCTION

The purpose of this paper is to explore the thinking that is required to manage transitions to move from one economic era to another or to exist in the confluence of economies and presents conceptual thinking on how transition management can be applied together with future thinking and possibility thinking approaches to prepare for expected change because of techno-economic evolution. New

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1 Also spelled Kondratiev

knowledge and technology management regimes and behaviour are required to navigate these transitions.

In the 1930s, Konratieff (1935) described the long waves of economic life. This thinking introduced the cyclical nature of economies. The influence of technology driving economic waves was clear. There are five Kondratieff cycles (Allianz Global Investors, 2010) driven by inventions of: the steam engine; railway and steel; electrification and chemicals; automobiles and petrochemicals; and information and communication technology. These led to the development of the clothing industry, mass transportation, mass production, individual mobility and information and communication. The emerging areas of nanotechnology and biotechnology are seen to introduce the 6th Kondratieff cycle. As the understanding developed that technology, to a large extent, drives economies, techno-economic waves were identified that drive economic value in nations. These techno-economic waves typically follow an S-curve, relating them to the life cycles of the various technologies that support them. Figure 1 shows the agricultural economy; followed by a resource-based economy; three, and now the fourth, industrial economies; and the information economy. These techno-economic waves are now supplemented by the emerging bio-economy, nano-economy, hydrogen economy and the neuro-economy (Botha, 2015). They intertwine and resonate with each other to give us what is known as the knowledge economy and knowledge era.

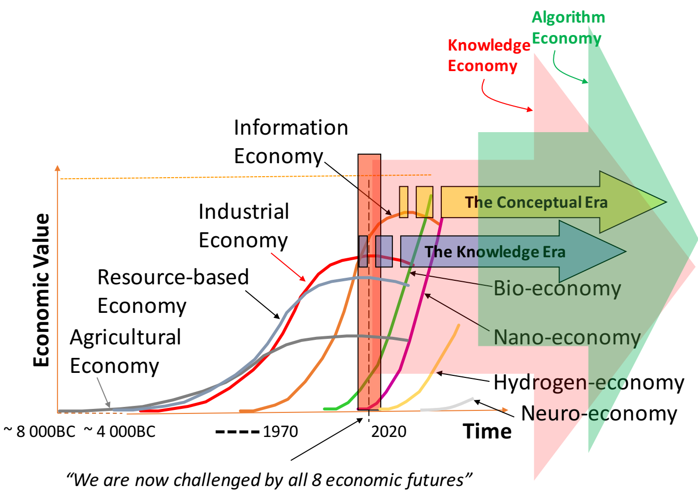


Figure 1: Techno-economic "waves" determining value for nations

The knowledge economy is thus not represented as a single S-curve like the others. It is the confluence of all the other technologies where they interact and influence each other. This leads to the notion that knowledge is both a product or service in its own, or it is embedded deeply into products and services provided by the other techno-economies and adding significant value to these. Each of the established economies represented by techno-economic S-curves developed over time and interacted by influencing the next "wave". Economic decisions are made based on "joining" an emerging economy, "incorporating" elements of the new economy in an older economy and improving it that way, or managing an economic "mixed basket". Metaphorically, these are "waves" on the oceans of our economic endeavour. Like the seafarers of ancient times we must navigate new oceans to discover new resources and markets. Some of the waves are known to us, others are new, unknown, huge, or very small, but full of danger. Yet, we know from experience that where these waves superimpose, they often build up the perfect storm. Storms that have been challenging, but kind to those that came prepared with new ships, and devastating to those that stuck to their old ships that were only proven on the waves in the known oceans.

We are, however, faced with an era beyond knowledge, the conceptual era. This era is driven by the algorithm economy, which is, just like the knowledge economy, not a techno-economic wave on its own. This is the era where applying knowledge will be the main driver. Humans and machines will co-work in the neuro-economy to produce solutions to complex problems. The neuro-economy is an interdisciplinary space that seeks to explain human decision making, the ability to process multiple alternatives and to follow a course of action. It studies how economic behaviour can shape our understanding of the brain, and how neuro-scientific discoveries can constrain and guide models of economics. It is the economy where artificial intelligence will come to its full right.

To transition from the knowledge era to the conceptual era will not only require a well-balanced left- and right brain capability, but will need new forms of transition management. Transition management deals with uncertainties; knowledge and technological change, pursuing innovation; creates high level multidimensional future views; suggests change processes at the right scale and feeds into management, policy and governance systems. We are increasingly challenged not only to know, but to think. This is necessary, since the conceptual era is the “imagine it, have it” era.

Once the wave has “broken” the chaos of white water sets in and transitions take place in an unordered world. Considering the four regimes in the “Cynefin” model (Snowden, 2007), one can perceive of a transition from order (the knowable and known regimes) to an unordered one (complexity and chaos). The knowledge about S-curves alone and how they support transitions in single techno-economic “waves” is no longer sufficient. Very little has been published on intra- and inter-techno-economic wave transitions and the eras that they support.

CURRENT THINKING

Long waves

Kondratieff (1935) states that the cyclical nature of dynamics of “economic life” are complex. Price indices, interest rates, wages, coal consumption, foreign trade, etc. were analysed and found to have very long (48 to 60 years) cycles. Statistical series were used to study the early capitalist economies of Europe. This was interpreted in terms of upswing and depression in these economies. During recessions, a large number of discoveries and inventions in production and communication were made. These were applied at the beginning of the next long upswing which coincided with war and revolution. Intermediate waves (7 to 11 years) related to business cycles were also identified. The long waves originate from causal extra-economic circumstances such as changes in technique (technology), wars and revolutions and the assimilation of new countries into the world economy and fluctuations in gold production. The factor of technique is understood as new discovery or invention in production technology and the economic possibility to use them (innovation in today’s terms).

These long waves representing economic prosperity-recession-depression-recovery, are sustained by technological innovation clustering and corporate organisation. For each wave, measured from one peak to the next, there is an overarching technology (Linstone, 2011). Linstone further states that “the recovery-prosperity upswing is a time for economic growth, consolidation of knowledge, and exploitation of available technologies. The subsequent recession-depression downswing is not only a period of economic decline but, in Schumpeter’s terms, one of ‘creative destruction’, intensifying pace of innovations, culminating with a burst of innovations in the depression". These long cycles brought about that old industries were replaced by new ones; corporate cultures and processes changed; new professions emerged; extended periods of long-term economic growth resulted; and were typically associated with rising equity markets (Allianz Global Investors, 2010)

The S-curve, techno-economic revolution and techno-economic paradigm

The techno-economic paradigm is at the core of general, innovation-based theory of economic and societal development as conceived by Freeman (1993) and Perez (2009). Neo-Schumpeterian theory, or the techno-economic paradigm approach, is a theory that combines Kondratieff's long waves theory with Schumpeter's economic development theory and that focuses within the capitalist development process on technological change. In this dynamic space, the basic concept is that of a trajectory or a paradigm. Which represents the "rhythm and direction" of change in a given technology (Perez, 2009). The trajectory (rhythm) is the well-known technology S-curve. It shows evolution as an initial slow change, followed by rapid change and then ending in slow change again. S-curves are applied for projecting the performance of technologies, to foresee population changes, for market penetration analyses, for micro- and macro-economic studies, for diffusion mechanisms of technological and social inventions, and for ecological modelling (Kucharavy and De Guio, 2007). Together with rhythm, a trajectory also involves directionality within a possibility space (Perez, 2009). This represents the technical paradigm which includes the improvement of a product, service or technology. A paradigm is then a collectively shared logic at the convergence of technological potential, relative costs, and market acceptance, or the techno-economic contribution. The shape of the S-curve is determined by incremental innovations, often following a radical innovation. Innovation becomes a collective process involving other agents of change and including other technologies. One can thus speak of a techno-economic S-curve that adds value to an economy, that depends on many technologies in a major technology paradigm such as agriculture, mining or manufacturing. Perez (2009) states that a technological revolution can be defined as a set of interrelated radical breakthroughs, forming a major constellation of interdependent technologies, a cluster of clusters or a system of systems. A revolution has two basic features: strong interconnectedness and interdependence of the participating systems in their technologies and markets; and the capacity to dramatically transform the rest of the economy and society. Perez mentions that: "The new industries of the revolution expand to become the engines of growth, for a long period while the techno-economic paradigm drives a vast reorganisation and a widespread rise in productivity across the economy". This concept of using S-curves rather than long waves represents a new way of thinking in addition to Kondratieff's and Schumpeter's notions of long waves. Their focus was on the upswings and downswings in economic growth. Schumpeter ascribed such waves to technological revolutions; while Kondratieff did not commit to any particular causal factor. Both approaches tried to explain long-term variations in GDP (Gross Domestic Product) and other economic aggregates. Perez suggested focusing instead on explaining the process of diffusion of each technological revolution and on its transformative effects on all aspects of the economy and society, including among them the impact on rhythms of economic growth. Technology systems overlap and form clusters driving technology revolutions. The techno-economic paradigm represents a best-practice model to enable practical use of the new innovative potential. Evidence was provided by Berry *et al.* (1993) that long waves are driven by the diffusion and decline of techno-economic systems.

The conceptual era

The knowledge economy is rapidly transitioning into the conceptual era (Van der Laan and Inayatullah, 2016). The business world uses the terms “conceptual age”, “creative age”, or “age of imagination” and some refer to it as the “age of intuition” (Pink, 2006). The conceptual age will depend on conceptual thinking. This includes the ability to identify patterns or connections between situations that are not obviously related and exist in the complex space. Pink (2006) calls it “the ability to perceive and imagine, predict and hypothesize, and to conclude and reflect." It is understood that creative thinking resides in the human right brain. It is the part of the brain that deals with colours, daydreaming, 3D construction, rhythm, imagination, synthesis, etc. The left brain, on the other hand, is the part that we develop best with the current educational regimes in the world. It is there where analysis, logic, lists, numbers, words, lines, etc. reside. It has been argued by many that the future is for the right brain oriented. This is far from the truth. A whole-brain approach will be needed to make a success in the conceptualisation age. Although one could make a first order assumption that technology is best understood and managed using left brain processes and innovation is more appropriately supported by right brain users, the need to develop and combine both the logical and imaginative sides is clear.

Conceptualisation is most often related to problem solving. It is linked to a body of knowledge that is well classified and mapped (Gomez *et al*., 2000). Conceptualisation is seen as modelling where the information on the environment is extracted by sensory systems and the relationships and reasoning to arrive at a solution. Concepts are the mental building blocks used by humans to think (just like this paper develops a conceptual thought model). In line with the property of knowledge of being asymmetrical (the same knowledge having different meaning and value for different users), more than one conceptual model for the same solution may exist. Conceptual modelling has traditionally been based on evidence, analysis, synthesis and proof. A concept only has value when it is connected to other concepts, thus connectivity is a major determinant. Some relations could be expressed by functions where the value of the last concept is unique for the preceding concepts. The conceptualisation age, however, will not be about problem solving only, but rather about possibility thinking and finding opportunity. It is harvesting the knowledge accumulated by the knowledge era and creating new opportunities for the economy to the benefit of humankind.

Transition management

Transition takes place as part of future evolution of systems. It is necessary to understand what these transitions are and how they can be managed.

Transitions

Transitions are major, non-linear changes in societal cultures, structures and practices arising from the co-evolution of economy, society and ecology (Loorbach and Wijsman, 2013). Transitions can be viewed from one dynamic equilibrium to another, e.g. fossil based energy to renewable energy. Technology may thus be added to this list. Transitions are the result of interacting developments and change at different levels of scale that, under specific conditions, might over time fundamentally alter dominant practices, paradigms, economies and ways of life. In the past, transitions have had a very long time scale (long waves), but with the emergence of new technologies and their impact on each other and the markets, they have a much more rapid and disruptive impact on economies, business and lifestyles. Transitions are complex, multi-level and multi-stage changes, and may be unexpected, undesirable or unintended. This necessitates the need to be able to be aware of multiple futures and what they may hold for business and the individual or society. Loorbach and Wijsman (2013) state that "there are at least three basic pathways through which existing regimes could change: optimisation (stability), reconfiguration (dynamic) and system innovation (transformative)".

Suarez and Olivia, as quoted by Loorbach and Wijsman (2013) state that there are five types of transition pathways: regular (linear); hyperturbulence (cyclic); specific shock (sharp peak); disruptive (radical change in one dimension) and avalanche (radical change in multiple directions, with knock-on effects). A combination of these transitions may occur. Transitions may further occur in different contexts (Smith *et al*., 2005). Firstly, transitions may be internal or external; secondly they may take place in areas of strong coordination or weak coordination. Such coordination refers to actors or resources. Internal transitions are either based on a reorientation of trajectories or on endogenous renewal. This results from the creation of new knowledge and supply of resources; and could include new technologies. External transitions are either as a result of emergent transformations or purposive. These could depend on regime membership; interdependency of regime members; coherence and flexibility of vision and economic conditions.

Rotmans and Martens (2005) point out that the concept of transitions include broad social, ecological and economic changes and their mutual connection. They define a transition as a "gradual, continuous process of societal change where the structural character of society (or a complex sub-system of society) transforms". They depict a transition as an S-curve, with a predevelopment phase, a take-off phase, acceleration and a stabilisation phase. This definition can easily be broadened to state that a transition is also a gradual, continuous process of economic change where the structural character of the economy transforms. This leads to the substitution of cyclical long waves with techno-economic S-curves, representing economic "waves".

Managing transitions

Transition management deals with uncertainties; knowledge and technological change, pursuing innovation; creates high level multidimensional future views; suggests change processes at the right scale and feeds into management, policy and governance systems (Loorbach and Rotmans, 2010). Martens and Rotmans (2005) describe a transition as the result of developments in different domains. This implies a set of connected changes, which may reinforce each other but take place in several different domains, such as technology, the economy, institutions, behaviour, culture and belief systems. Since transitions are multi-dimensional with different dynamics, multiple developments must come together in several domains for a transition to occur. The ability to identify and predict emerging connected changes that drive transitions is supported by an understanding of how the future will be shaped by these influences. Loorbach and Rotmans (2010) provide generic insights on transition management: it is context specific; it needs frontrunners with original ideas, thinking "out of the box"; it often happens in an unplanned and unforeseen way; creative, innovative ideas need to be stimulated by the right environment; fear for change results in resistance; the unexpected is often the norm, being chaotic; a new language and shared perspectives are often required; continuous integration, re-evaluation and adaptation are required; the process is self-organising, but needs enablement through resources.

Most examples in the literature dealing with transition management consider socio-technical change. It is the aim of this paper to look at techno-economic change as an important component of transition management. To do this, the role of technological transitions was investigated. Technological transitions are defined as “major technological transformations in the way societal functions such as transportation, communication, housing, feeding, are fulfilled” (Geels, 2002). Technological transitions do not only involve technological changes, but also changes such as user practices, regulation, industrial networks and infrastructure. It is also necessary to consider what a technological regime is. Geels (2002) defines a technological regime as “the rule-set or grammar embedded in a complex of engineering practices, production process technologies, product characteristics, skills and procedures, ways of handling relevant artefacts and persons, ways of defining problems; all of them embedded in institutions and infrastructures”. It is clear that techno-economic transitions are dependent on the holistic approach towards technological transitions and technological regimes, taking the market-technology-product relationships into account that defines the value add to an economy.

Technology roadmapping is a useful tool in technological transition management. This is done in the context of transitions of complex systems. Transitions take place from an established paradigm to a new one, and innovation management in this context needs to be based on both technological innovation as well as social innovation (Letaba *et al*., 2015). Transition and complex systems theories and concepts have been applied indirectly to technology roadmapping. Such transitions could be from a lower systems hierarchy level to a higher one, e.g. from components to products to subsystems to full systems. It also highlights transitions from the technology to product to market levels in a typical technology or product roadmap. Roadmaps were classically used to map the development path for new products. They are now also used to map pathways for long-term sustainable systems innovations or technological transitions (McDowall, 2012). As such, they “articulate a vision of the development of an entire system, including the infrastructural, market, policy, educational and regulatory developments as well as technological issues”.

Transitioning into the future

It is critical to be able to manage transitions that will take the world into the future. They need to be understood and a vision needs to be determined of what lies on the other side of the transition.

Transition scenarios

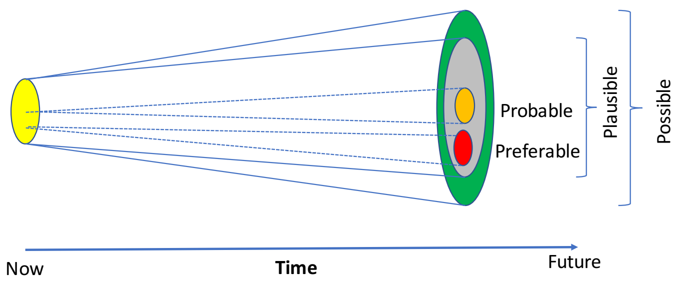
Epprecht *et al.* (2014) illustrate how scenario thinking can be used to select transitions that lead to sustainable technologies and innovation. Projections of trends (or forecasting) may be permissible over the short term, but not for time horizons spanning over decades and generations. Sondeijker *et al.* (2006) state that transition management is a systemic approach, postulated as a new governance model which is concerned with steering and coordinating large-scale system innovations towards greater sustainability. An important part consists of envisioning sustainable future trajectories. The need for a systemic approach like transition management in relation to future thinking is explicitly recognised. Transition management for future change takes place in the complexity regime. Anticipative, as well as adaptive processes must be developed and combined in order to transform a complex, adaptive system from one state to another. Transition management is an ideal approach to apply in an environment where cause-and-effect reasoning is replaced by emergence and sense making. Transitions, like emergence, cannot be controlled, but transitions can be influenced through intentional intervention. This is in line with the notion that although the future is not predictable, it is also not predetermined and can be shaped. Sondeijker *et al*. (2006) defines transition scenarios as "participatory explorations of possible development trajectories that incorporate a structural system's change towards a desired, sustainable future state of the system". One of the basics in scenario planning lies in the fact that weak signals that sometimes cause fundamental changes when they rapidly evolve to high impact on systems are uncovered. Paradigm shifts that are desirable or inevitable can be revealed and catalysed. These scenarios stretch and focus the thinking of people contemplating their future. The value of scenarios lies in the revealing of individually held future images and by combining them.

Future vision

Transition management relies significantly on the role of a future vision (Smith *et al.,* 2005). This vision is used for mapping the possibility space (plausible alternatives); a heuristic (problem-defining tools); frame for target setting and monitoring (common reference point and benchmark); a metaphor for building stakeholder and actor networks (symbols of binding force) and a narrative (motivation) for focusing capital and other resources (investment).

Types of futures

Figure 2 illustrates the different types of future that can emerge from scenario planning or foresighting. It describes the "world view" of what such a future entails and the type of future thinking required. The possible future is the broadest one and indicates what could happen. It is part of possibility thinking for anticipating the future. The plausible future is described by approximating the future and can best be determined using a combination of barriers from the past, drivers of the present and opportunity in the future (Inayatullah, 2008). The probable future is determined following a process where the future thinking space, spanned by technology, behaviour and events are identified and their relevance is determined (Botha, 2015). The preferred future is extracted after scenario planning has been done based on control (technology and behaviour) and uncertainty (events).



Type of future	World view	Thinking required
Possible	"Could happen"	Anticipating
Plausible	"May happen"	Approximating
Probable	"Likely to happen"	Estimating
Preferable	"Want to happen"	Judgemental

Figure 2: Different types of futures, their worldview and future thinking style required
Source: Adapted from (Voros, 2003)

Timing the future

Inayatullah (2008), in his Six Pillars approach also indicates four grand patters of change over time as indicated in Figure 3. The future may progress linearly if based on an ordered transition from the present to the past. This is, however, hardly the case, and the future may evolve in three other ways: cyclical, as also assumed in long waves approaches to the economy; a pendulum, shifting forward and backward; and spiral, in a two-dimensional space, where linear and cyclical are combined.

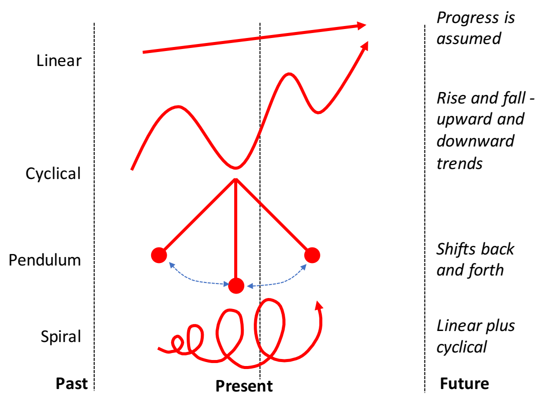


Figure 3: Timing the future

Source: Adapted from Inayatullah (2008)

Possibility thinking

Apart from future thinking for emergence and visioning (Botha, 2016) which is a structured process, there are various other forms of thinking that are important in dealing with transitions. One of the most important in terms of transition management is thinking about possibilities. This provides the broader view of the possible future. Possibility thinking, in essence is enabling the transition from 'what is' to 'what might be'. Craft (2013) outlines the core features of possibility thinking in children as: "question-posing (investigative behaviour), question-responding (investigation response behaviour), self-determination (self-directed actions, self-chosen), intentional action (activity/behaviour with a goal), development (thinking moving forwards), being imaginative ('as if' thinking and going beyond the expected), play/playness (being in an 'as if' space, improvising), immersion (concentration, absorption, orientation), innovation (original/unique outcome/behaviour), and risk-taking (danger, failure, fear, 'going to the edge')." Creativity in possibility thinking is encouraged by a commercial environment where there is reward for the outcome of possibility thinking. Although possibility thinking is mostly associated with childhood development and education, its application in business has been recognised. Friedel and Liedtka (2009) introduce creative possibility thinking in strategic planning. The ability to see new possibilities is fundamental to creating new innovations and to manage transitions. They argue that a skills set of challenging assumptions, making connections, visualising, collaborating, harmonising, improvising, reformulating and playing is required to achieve future success in engineering.

Possibility thinking is often supported by anticipatory thinking. Klein *et al.* (2011) state that anticipatory thinking is the process of recognising and preparing for difficult challenges, many of which may not be clearly understood until they are encountered. It is a form of sensemaking, which often takes the form of retrospectively explaining events and diagnosing problems. It can also take the form of formulating expectancies about future events.

BUILDING A THOUGHT MODEL FOR TRANSITIONING ERAS

A thought model is now conceptualised to support thinking on how transition management can be applied together with future thinking approaches to prepare for transitions resulting from techno-economic evolution. This thought model aims to ultimately assist in the understanding of the transition from the knowledge era to the conceptual era.

Technologies, techno-economic waves and eras

A clear distinction is made in the discussion that follows between technologies, techno-economic waves and eras. A myriad of technologies make up a techno-economic wave or S-curve. These S-curves are assigned to major economic drivers such as agriculture, natural resources, manufacturing, information technology, nanotechnology, etc. as shown in Figure 1. Each of the technologies supporting a techno-economic wave has its own life cycle, also in the form of an S-curve. In the discussion both technologies and techno-economic waves will be addressed. The term "era" is brought in when a long and distinct period exists where overlapping techno-economic waves influence each other and dramatically influence the way business is conducted. It has to do with techno-economic and socio-technical change. An era does not follow the S-curve and is the result of a confluence of techno-economic S-curves. Transitions take place inside (intra) and between (inter) technologies, techno-economic waves and eras.

Transitions in and among technologies

There are several types of transitions between interacting technologies. Examples of transitions are given for when current technologies interact with future technologies.

Interacting technologies

Figure 4 shows a future technology interacting with a current technology. The technology may go through relevance phases typically used in scenario planning (see more in the section that follows on future thinking and transition management). Such relevance is related to the impact the technology will have and the probability that the technology will evolve to make that impact. Over-the-horizon technologies are often labelled as weak signals, since they may not have a high probability of further development or an expected large impact. Emerging technologies will have a good chance of maturing, but are not expected to have a large impact, since they are often evolving incrementally. Wild cards will have a large impact, but are unlikely to evolve. Disruptive technologies, however, have a large impact and are likely to evolve. The point of disruption is when the future technology overtakes the current technology. Transitions from the current technology to the future technology may be made at any of the relevance points or in between.

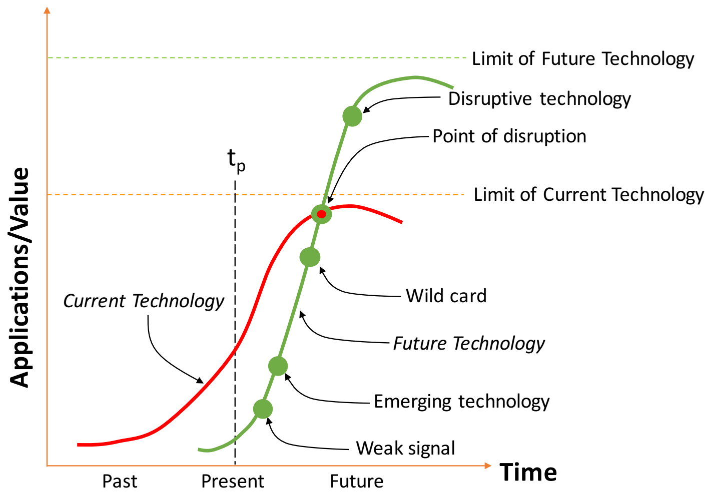


Figure 4: Relevance of future technologies

End-of-life transitions

An end-of-life transition takes place when a current technology is superseded by a future technology at the latest possible transition point as shown in Figure 5. This is an inter-technology transition. This normally means that the current technology is discarded and no further investment is made in it. This may be a very turbulent transition. The beginning and end of the S-curve is a period of chaos. The predictability of the central portion of the S curve contrasts with the unpredictability at its beginning and end (Linstone, 2011).

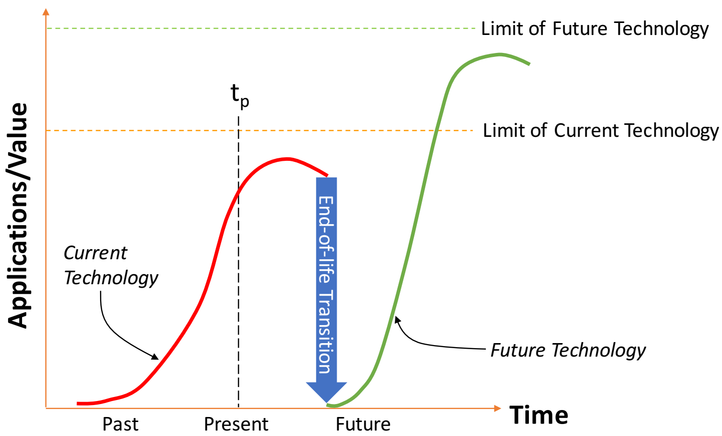


Figure 5: End-of-life inter-technology transitions for technologies

Mid-life transitions

On the other hand, mid-life inter-technology transitions such as shown in Figure 6 take place in an environment of higher stability. In many cases both technologies are pursued and used jointly for a while into the future to add value to an economy, while the current technology is allowed to follow its natural path to maturity and demise. The future technology is then phased in and integrated in solutions.

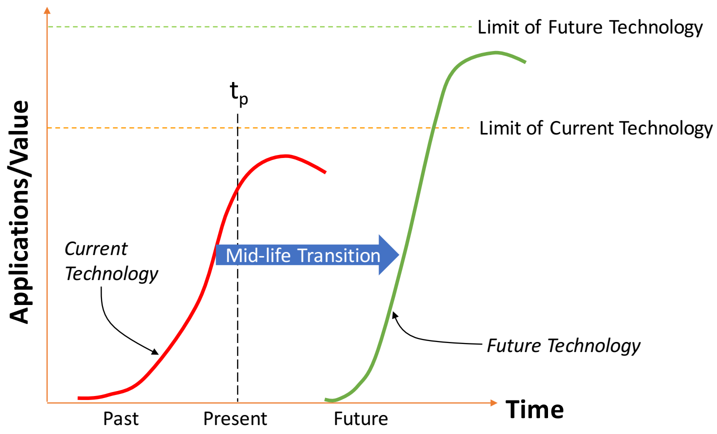


Figure 6: Mid-life inter-technology transitions in technologies

Riding the wave

Figure 7 indicates a situation where no transition is made between the current and future technology and only the current technology is pursued. Continued and increased investment in the current technology drives its application value and it constantly renews itself. Its future limit may be increased, even to such an extent that it may have higher value than the future technology. These intra-technology transitions are often made late in the technology life cycle and are of short duration, since they are intended to keep the technology "alive" close to the level of maturity. This is often the approach followed when a competitive future technology is countered by "riding the wave" of the current technology.

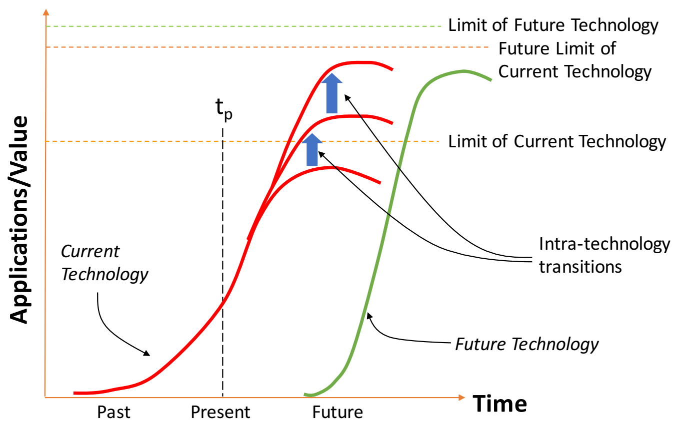


Figure 7: Intra-technology transitions

Strategies for current technologies

Figure 8 shows three investment strategies for managing current technology impacted by a future technology. A reduced rate of investment will mean that the current technology is slowed down and will reach maturity earlier. The transition to the future technology is early. If there is an unchanged rate of investment in the current technology, the transition may take place very late, at the point of disruption where the future technology overtakes the current technology. Another option may be an accelerated investment which may prolong the value of the current technology and no transition may take place (riding the wave). Accelerated investment in the current technology may also increase the limit of the current technology, causing it to be effective for a much longer time.

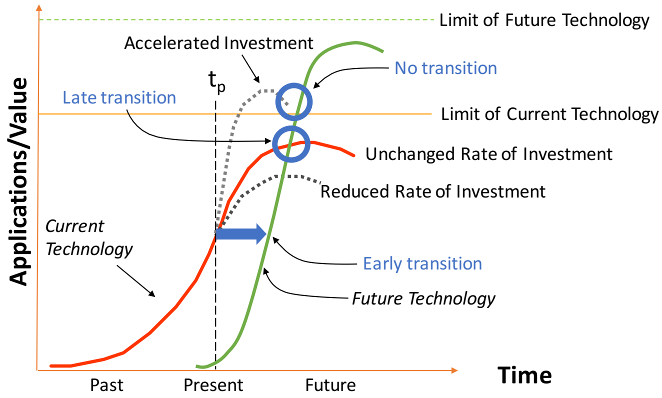


Figure 8: Strategies for inter-technology transitioning to future technologies

Transitions in and among techno-economic waves

Techno-economic waves

Techno-economic waves are the envelopes of many concomitant technologies. They are formed by individual current and future technologies that service the same economy as shown in Figure 9. For example, in the industrial economy there are process technologies and manufacturing technologies, all contributing to the techno-economic value that industry brings to a nation. These techno-economic waves are also logistic waves or S-shaped.

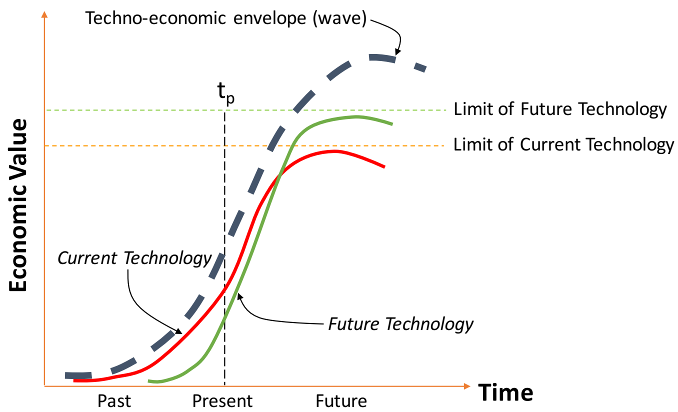


Figure 9: Techno-economic waves comprising multiple technologies

Long economical waves

Long waves with cyclical periodicity as described by early economists like Kondratieff are indeed partially compatible with techno-economic waves. This can be shown by taking two waves as in Figure 10 that are representing different techno-economies, one a current and well-known techno-economy, the other a future (emerging) techno-economy.

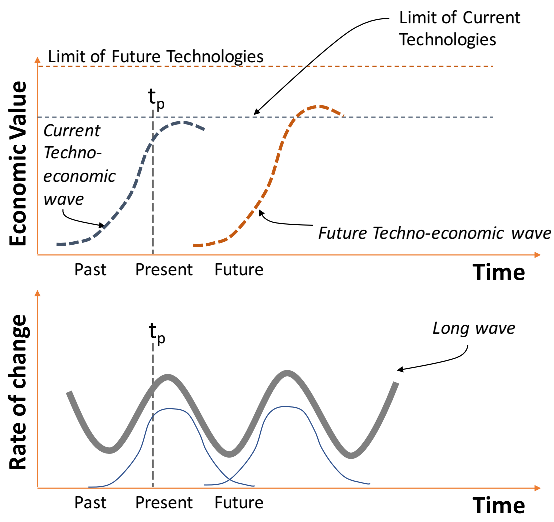


Figure 10: Long waves originating from techno-economic waves

If their rates of change are plotted, the bottom part in Figure 10 describes that rate of change as bell curves. If these derivatives over time are added, a periodic wave as shown in Figure 10 emerges. This is typical of a simplistic long wave based on long periodicity in technological change as described in economics. In reality, fast moving techno-economic waves are not following each other sequentially, but overlap. An example would be S-curves for semiconductors, opto-electronic materials and nanotechnology. This fast overlapping changes the view on long waves totally.

Into the chaos of white water

Figure 11 shows an approximation of what is happening over time if new techno-economic waves are added in rapid succession and they overlap increasingly. The cyclic long wave shows the periodicity where slower transitions take place, but where the confluence is evident and rapid succession of new techno-economies is experienced, a new form of wave is obtained after adding the rates of change at different positions on the timeline.

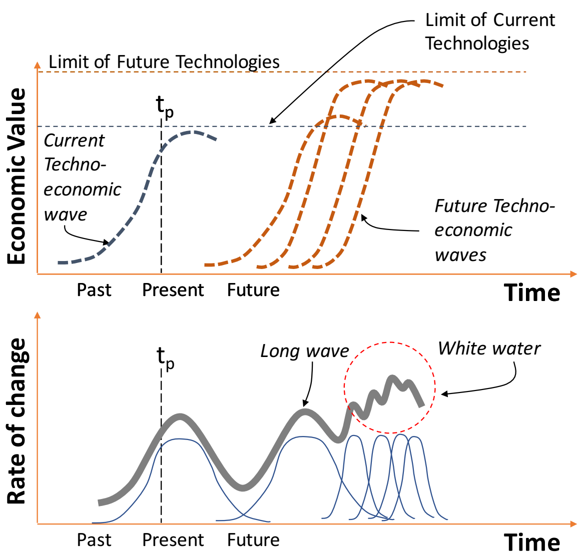


Figure 11: Cyclical long waves transforming into rapid change

This shows an erratic behaviour where prediction based on periodicity is not possible anymore and the accumulative rates of change start escalating fast. This chaotic oscillation is the result of multiple inter- and intra-technology transitions. This state is named the “chaos of white water”, in analogy to a set of waves in the ocean that catch up on each other, builds a large wave through constructive interference and then suddenly breaks into a mass of white water, sweeping forward. It is in this chaos of white water, or at least the complexity of unstructured growth paths, that techno-economies start losing their identity and only exist as an almost indistinguishable part of a larger whole, called an era.

Transition between eras

Figure 12 indicates the transitions over time as techno-economies progress. While the techno-economy follows the S-curve, it is shaped by inter- and intra-technology transitions for the technologies making up the envelope of what is known as the techno-economic curve. There are also inter- and intra-techno-economic transitions by choice in terms of economic value for nations, e.g. a decision to build an industrial economy rather than a resource based economy. This all happens on a linear time scale towards the future. When the overlap of techno-economies cause eras to be formed, a new time scale is proposed.

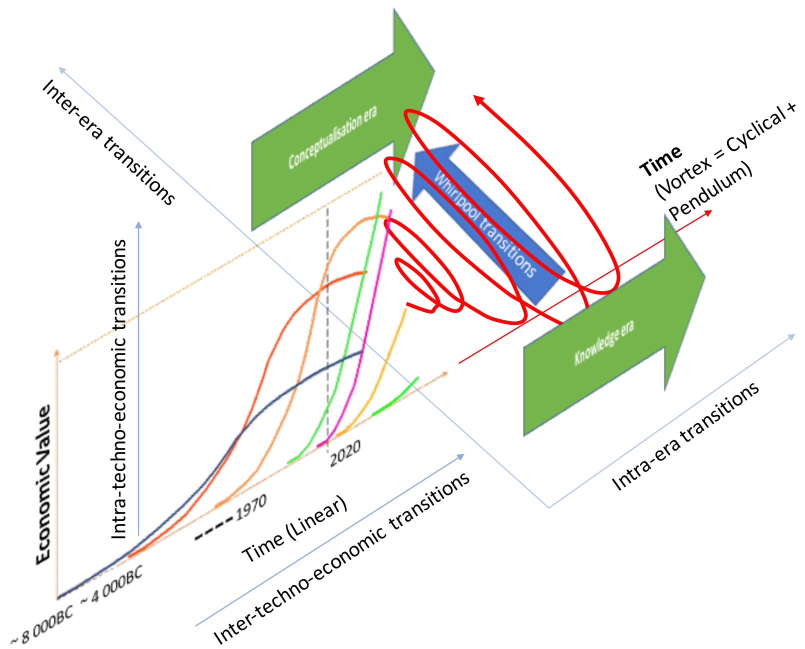


Figure 12: Techno-economic waves culminating in eras as a complex transition regime

This is a combination of a cyclical and a pendulum movement (refer to Figure 3), called a vortex. The spiral is now three-dimensional and not two-dimensional as discussed earlier in the combination of linear and cyclical time. The spiral can be converging (sucking in), diverging (spewing out), or cylindrical (drilling forward). Inter-era transitions take place along this spiral, and are named whirlpool transitions. Intra-era transitions still depend on transitions in individual techno-economic waves, influenced by the inter- and intra-technology transitions.

Knowledge accumulation

Figure 13 shows a representation on how knowledge accumulated over time in the different techno-economies included in this discussion. Knowledge life cycles are still debated and it is not certain whether they also follow an S-curve shape. For simplicity of illustrating the concept, knowledge accumulation is shown in blocks. This is not a real representation of what is known in terms of the knowledge explosion. Knowledge accumulation should rather be associated with the area under the curve, represented by the integral of the curve with respect to time. However, if these knowledge "blocks" are stacked and the increasing rate of change in the techno-economic evolution is considered, a combined knowledge accumulation curve represents all knowledge generated and available to the knowledge era. It is not sure what the combinatorial growth basis of this accumulated knowledge is, whether it is exponential, factorial or double exponential. It seems, however, that an inflection or tipping point is reached when there is a transition from individual techno-economic cycles to an era. The next big transition is now to convert this knowledge into usable and economically valuable concepts in the conceptual era. These may include solutions to existing and future problems, but also the creation of new opportunities and markets. A new way of thinking is required to catalyse these inter-era transitions.

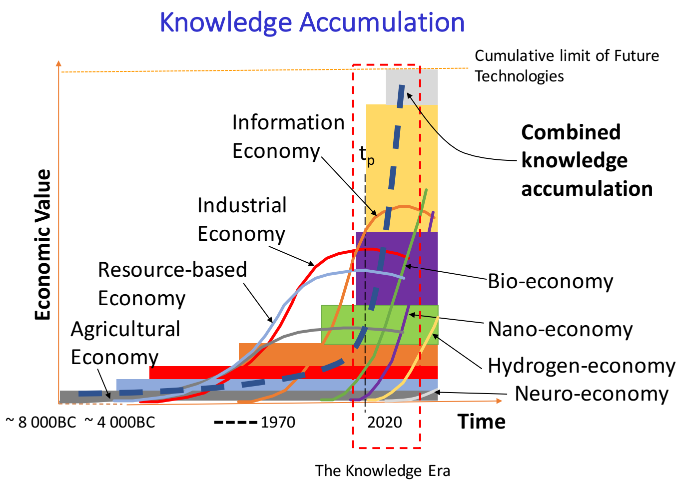


Figure 13: Knowledge accumulation in techno-economic waves leading to the knowledge era

Future thinking and transition management

Future thinking involves a systematic approach to defining a future state of business or life. The ability to do future thinking to influence strategy is an important component of executive function (Botha, 2016; Botha and Pretorius, 2017). Different types of futures and the thinking they require have been described (see Figure 2). Inter-era transition takes place in a chaotic and complex state. Cause and effect analysis does not apply. At the highest level of future estimation, possible and plausible futures have to be described. Figure 14 summarises techniques used to do that. Possibility is best approached through adopting anticipatory thinking using very simplistic methods of asking what you believe in yourself (governed by dreams, hopes, expectations, realism, etc.), what others say and think (their beliefs, consensus, fears, perceptions, etc.) and available facts (studies, articles, market information, trends, etc.)

Approximating a plausible future is done through considering drivers in the present, barriers of the past and opportunities of the future (Inayatullah, 2008). Combining these techniques, one can start to describe some obvious and not so obvious transitions that are expected or must be effected to move from the knowledge era to the conceptual era. This leads to a landscape for the future that is perceived and agreed, but lacks detail.

Deeper analysis is needed to shape this landscape to arrive at a probable future. This includes the use of the future thinking space formed by technology, behaviour of people and events (Botha, 2016). Figure 15 indicates this level of future thinking. The relevance of technology, behaviour and events as factors influencing the future is determined and combined with the perception of a possible and plausible future. This yields a classification of future changing influences as weak signals, emergent, wild cards or disrupting, assisting the determination of technology transition points as outlined in Figure 4, but also applying to behaviour and events.

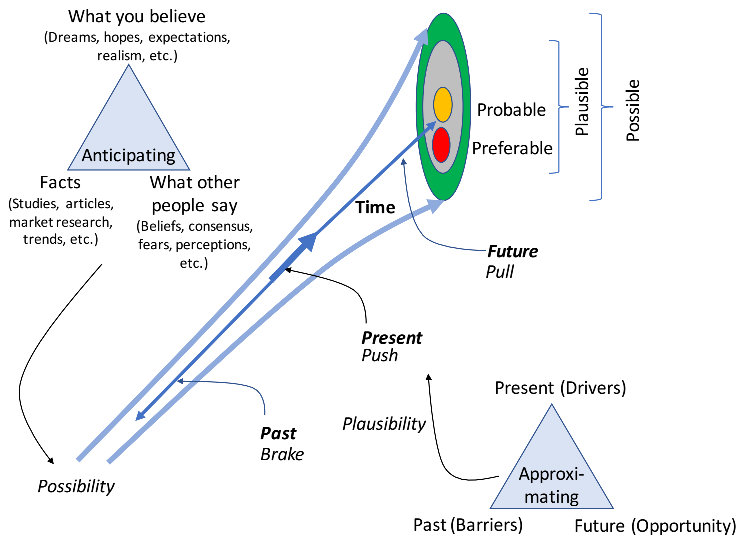


Figure 14: Anticipating and approximating the possible and plausible future

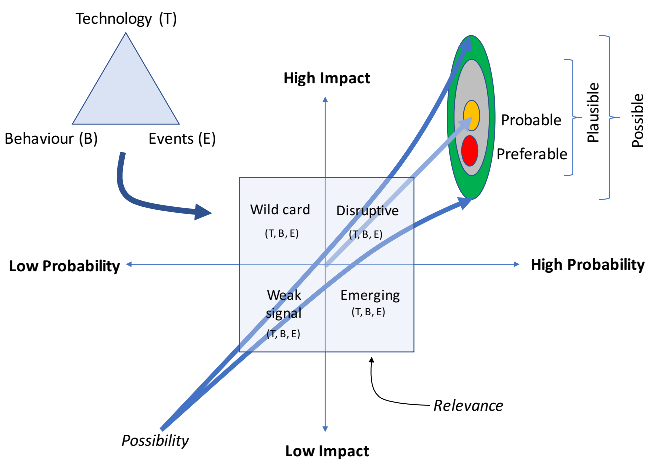


Figure 15: Estimating the probable future through emergence and relevance

Modified scenario thinking and transition management

The role of scenarios in transition management has been highlighted from the literature. The future thinking lens (Botha, 2016) can now be used to determine possible scenarios within the context of a metaphor that can be found with Causal Layered Analysis (Inayatullah, 2004). The scenarios are determined after plotting the control factors (technology and behaviour) on the uncertainty axis presented by events. The future thinking lens considers the inter-factor influences by spinning the future thinking space triangle clock-wise and anti-clockwise and extracting narratives about those cross-influences.

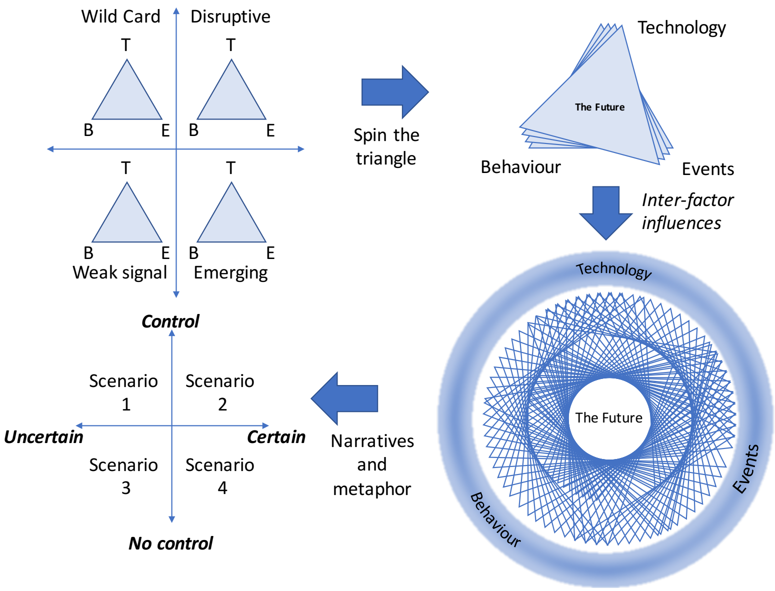


Figure 16: The future lens and scenarios for transitions into the probable future

These scenarios now lead to alternative futures that are all probable. They may have the characteristics as outlined in Figure 17.

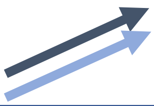
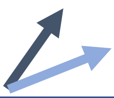
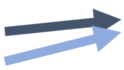
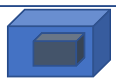
	Parallel (plural) futures	Totally independent, never touch each other, choice must be made
	Alternate futures	Overlap, may co-exist for a while, can be altered
	Divergent futures	Initially together, then flying apart
	Convergent futures	Initially apart, then becoming one, or staying close together
	Embedded futures	N-Dimensional futures

Figure 17: Characteristics of probable multiple futures

In Figure 18, the combination of possibilities with the scenarios as probable (likely) futures, followed by choice being made in assigning a preferable future, is shown. The judgment of a preferable future is required to have a desired arrival point guided by a vision to do back-casting for strategic planning in the present.

Applying all of these future thinking techniques assist in identifying inter- and intra-era transitions in a complex world. These are governed by changes in life-style and work, adoption of new technologies, the preparedness for risk in terms of uncertainty in what events will dominate the future as well as adopting technology management approaches that are aligned with complexity and chaos.

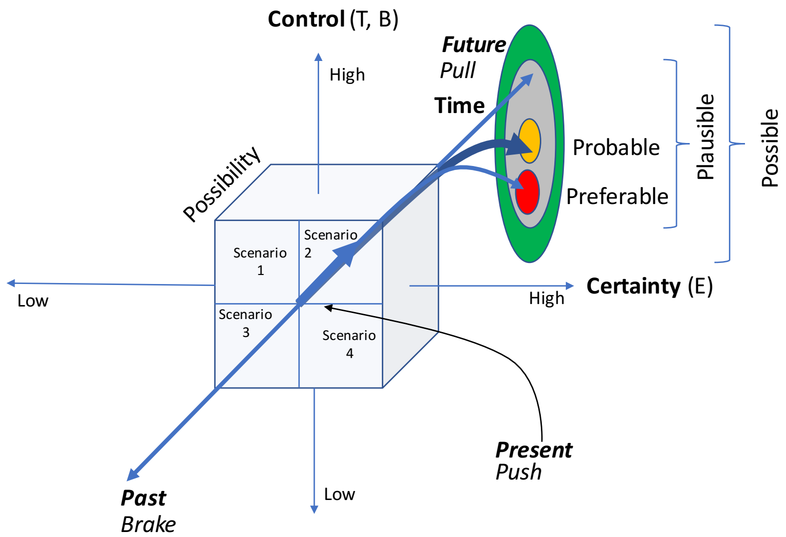


Figure 18: Judging the preferred future through scenarios

CONCLUSION

This paper presents original theoretical thinking on transitions in technologies, techno-economic waves and eras. It suggests links with technology management and future thinking to arrive at an understanding of how transition management can best be applied. The research is at concept level and has not been tested in practical consulting or peer opinion yet. It intends to open academic debate and to forward a thought model on how transitions take place in evolving techno-economies, supporting economic value in nations. It combines technology management understanding of transitions based on technology S-curves as envelopes of multiple technologies, the behaviour of techno-economics within economic value addition, the definition of eras where techno-economics based on logistic evolution become too complex, and the application of future thinking in its broadest form to assist in preparing for transitions in and among technologies, techno-economic waves and eras.

Table 1 summarises the relationships between transition levels as outlined in the paper, the phase of transition, the transition type; and the type of future; and transition management style as a function of future thinking. It also refers to figures that contain schematics explaining the transitions and future thinking that leads to transition management styles.

Table 1: Transitions, types of futures and transition management styles

Transition level	Transition phase	Transition type	Type of future	Transition management style				Explanatory Figures
				Anticipating	Approximating	Estimating	Judgemental	Fig. 2
Era	Inter-era	Whirlpool	Possible	x				Figs. 12 & 14
	Intra-era	Linear	Plausible	x	x			Figs. 12 & 14
Techno-economic wave	White water	Order to unorder	Plausible	x	x			Figs. 11 & 14
	Long wave	Periodical	Probable			x		Figs. 10 & 15
Technology	Inter-technology	End-of-life	Probable			x		Figs. 5 & 15
	Inter-technology	Mid-life	Probable			x		Figs. 6 & 15
	Intra-technology	Riding the wave	Probable			x		Figs. 7 & 15
Combined technology, techno-economic wave, era	All transition phases	All transition types	Preferred				x	Figs. 5, 6, 7, 10, 11, 12, 16, 17 & 18

RECOMMENDATIONS

Preliminary findings indicate that future thinking and transition management is required to supplement technology management for the preparation for different transitions, especially between eras. The thought model developed in this paper is ideal for further development in post-graduate training in technology management and as a core reference for developing consulting products.

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