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TECHNOLOGY INTERACTION DURING CYCLIC CONDITIONS

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Abstract. This paper is an extension of some previous research on the simulation of three technologies that interact during competitive business conditions. The research purpose of this paper is to explore the competitive behaviour of technologies that may occur under cyclic conditions. In this research technology is considered to be the result of innovation that is a rate dependent process. The research method includes a brief exploratory literature review covering aspects of system dynamics and technology growth in systems management is presented. The effects of cyclical changes on technology growth in business are highlighted. In this paper three technologies are considered as a coupled system with the interacting dynamics being modelled using the Lotka-Volterra system of differential equations. The research method also includes a system dynamics simulation approach to explore some cyclic effects possibly caused by seasonal behaviour of a modified version of the three technology system is attempted. Some rather unexpected results caused by small forced cyclical changes are presented indicating the possibility of intermittent near demise of technologies. The uncertainty in forced cyclical influences on technology is addressed in the results of this research using a Monte Carlo multivariate simulation technique and a system dynamics approach as part of the research method. Specifically the uncertainty in the cyclic forced amplitudes is addressed in the system dynamics simulation results. The research method is as a result exploratory and case based and has been shown previously to be especially useful early on in research.

Keywords: simulation, systems management, technology system, system dynamics, cyclic, business competition.

JEL classification: 032, 033, C6.

1. Introduction and research method

This paper is an extension of research presented previously by Pretorius *et al.* (2013). The problem statement in this research paper relates to the cyclic behaviour for instance as part of a double boom cycle that certain technologies such as for example industrial robot technology has shown historically during its establishment in the market. The main aim of this paper is to explore the competitive behaviour of such technologies under cyclic conditions. This may include the behaviour of technologies in dynamic entrepreneurial business contexts.

As practical business examples some competitive relationships between for example technology unemployment and entrepreneurship have been discussed previously by some researchers (Faria *et al.* 2008; Bass 2004). The competitive behaviour of for example information technology as well as energy technology is illustrated by researchers such as Heidrich (2011) with his work on laser radiation technology and Werthen (2011) who focuses on energy technology with PV systems in laser manufacturing.

This current research is aimed as an extension of technology system dynamics (Pretorius *et al.* 2013) research presented previously in this case however exploring further the cyclic effects that may exist in technology systems exhibiting competitive behaviour during technology growth. The focus is specifically also on some potential effects of forced innovation that may include small cyclic oscillatory conditions.

This research relies to a large extent on the view that technology can also be considered as a body of knowledge that can grow or contract in time. This technology is then furthermore the result of an innovation process. In the current approach the time dependent innovation process is modeled as non-linear. To illustrate this Black

(1976) refers broadly to technology as the complement of skills and knowledge to in some sense accomplish a goal. In his research Black also refers to the importance of "developing adequate images of technology and its elements". This can be construed as the effort of creating a model or image of technology.

This current paper then presents such a model of technology based also on previous research (Pretorius *et al.* 2013) that may be useful in interpreting some of the behavioural characteristics of technologies. To further impress upon this argument Erekson (1992) also characterizes technology as a body of knowledge in his efforts to establish some dimensions of the study of technology as a discipline.

Berkhout *et al.* (2006) position technology and innovation as part of a continuous innovation cycle in their research on the development of the mobile telecom industry. They specifically address the cyclic nature of innovation using a Cyclic Innovation Model (CIM). In their case study analysis of the development of a mobile device in the Netherlands context they emphasise the continuous cyclic interaction between product development and technological research as well as market development. This discussion now focuses the attention on the concept of a system.

Blanchard (2008) broadly defines a system as a collection of elements or components functioning together with the aim of achieving a goal or satisfying a need. This means that a system has multiple elements that somehow interrelate and have a purpose. He further states that systems can be classified in different categories such as for example physical or conceptual systems on the one hand and static or dynamic systems on the other hand.

In this paper the focus will be to some extent on considering technology as part of a concept called a body of knowledge and furthermore the dynamic aspect of such a system. Blanchard (2008) as well as for example Hunger (1995) emphasise the system perspective or the so called holistic or big picture view. This somehow relates to the interconnectedness as well as the purpose aspect of a system.

One way of addressing the interconnectedness of systems is the system dynamics approach introduced by Forrester (1971, 1991) already in the 1960s in his research on socio-technical systems. It has been shown in various instances that a socio technical approach can assist in minimising the risk of failure in addressing the societal needs. Refer for example to the work of Baxter *et al.* (2011) on methods to apply socio-technical approaches in a cost effective manner. Berkhout *et al.* (2006) also allude to the socio-technical aspect of the system by introducing for example entrepreneurship and market effects into their Cyclic Innovation Model (CIM).

The system dynamics approach focuses also on the feedback view of the world and not necessarily only on the linear event orientated view (Sterman 2000). This in essence means that decision makers are part of the system and that their decisions affect the system in a feedback manner.

The definition of system dynamics by Wolstenholme (1990) also basically supported by Sterman (2000) as "a rigorous method for qualitative description, exploration and analysis of complex systems in terms of their processes, information, organizational boundaries and strategies; which facilitates quantitative simulation modeling and analysis for the design of system structure and control" emphasizes the simulation and modeling aspects.

The simulation approach in system dynamics is very useful in supplementing the mental models of reality that can be elicited using the system thinking approach put forward by for example Jackson (2003). Jackson specifically positions system dynamics as a complex systems approach. In this current research the simulation capabilities of system dynamics are utilized in attaining transient results of interaction in a three technology system.

In part the attention in this paper will also be on the modeling of forced innovation in addition to inherent or free innovation in the system dynamics model. According to Van der Duin (2006) forced innovation may occur when there are external pressures present such as for instance government legislation or for example increasing and turbulent competition in the market.

On the other hand free innovation is introduced in the presence of needs or circumstances that change in the company or system itself. It is thus implied that free innovation is a function of the system characteristics themselves.

An example of forced innovation is provided by Zhang *et al.* (2013) in their discussion of a case study that considered a government intervention of smart metering deployments in the UK city of Leeds. This is an interesting example of forced technology adoption. They use agent based simulation and aspects of behavioural learning to develop their simulation model.

An interesting example of forced innovation in a University environment is also presented as the decision by the executive to deploy a new computer operating system campus wide without the real input from those staff concerned. What is important in the context of the current research is that they also focus the attention on the field and effects of forced innovation as opposed to free innovation itself. This idea of forced innovation including cyclic behaviour of technologies will also be explored in the technology system considered in this paper.

The objective of the research presented in this paper is to explore the cyclic behaviour of three interacting technologies using and briefly presenting a system dynamics model developed previously (Pretorius *et al.* 2013). The system dynamics model is based on the work of Ahmadian (2008) also incorporating some fundamental aspects of the functioning of a three tier food chain discussed by Mamat *et al.* (2011). The effect of forced innovation as well as uncertainty in parameters associated therewith is briefly addressed.

The research method used is exploratory and case based (Leedy 2005) in nature. The exploratory method is utilised to address for instance the effect of certain technology dynamics parameters and is specifically useful in these instances as indicated for example by Cooper and Schindler (2006).

The system dynamics method (Forrester 1971), systems thinking (Jackson 2003; Meadows 2008) and the computer simulation capabilities of the system dynamics software Vensim (2012) are combined in this research approach to be able to build the technology systems model. The usefulness of the model is also tested on the basis of some comparison of simulation results gained to dynamic hypotheses.

The next sections in the paper will present and discuss the technology system dynamics model developed to address cyclic interaction of technologies also under forced innovation. Some system dynamics simulation results for cases chosen to enhance qualitative comparison with previously published technology growth or other relevant dynamic species interaction examples will also be presented.

2. The technology system dynamics model

In this research paper the technology system dynamics model used as basis for the research is based on one developed and discussed by Pretorius *et al.* (2013). The general technology system dynamics model is shown in Figure 1. It relates to the Lotka-Volterra non-linear system of differential equations and is similar to the model used by Ahmadian (2008).

In the system dynamics model there are three competing or interacting technologies denoted by X, Y and Z respectively. In practical business terms the Finite Element Method (FEM), Computational Fluid Dynamics (CFD) and Entrepreneurship as bodies of knowledge can play the roles of Technology X, Y and Z respectively as they interact in a competitive business environment to provide useful design systems for engineering professionals in the organisation. The parameters Ai denote the growth rate or logistic parameter for technology i when it is living alone, Bi is the limitation parameter for species i related to niche market capacity and Ci as well as Di is the interaction coefficients related to competitive behaviour between the technologies:

$$\frac{DX}{dt} = A1*X - B1*X^2 - C1*X*Y - D1*X*Z,$$
$$\frac{DY}{dt} = A2*Y - B2*Y^2 + C2*Y*Z - D2*X*Y, \quad (1)$$
$$\frac{DZ}{dt} = A3*Z - B3*Z^2 + C3*Z*X - D3*Z*Y.$$

The possibility of cyclic behaviour of technology is explored in the following modified system of non-linear differential equations where some parameter values (B1, D1, B2, B3 and C3) are considered to be zero.

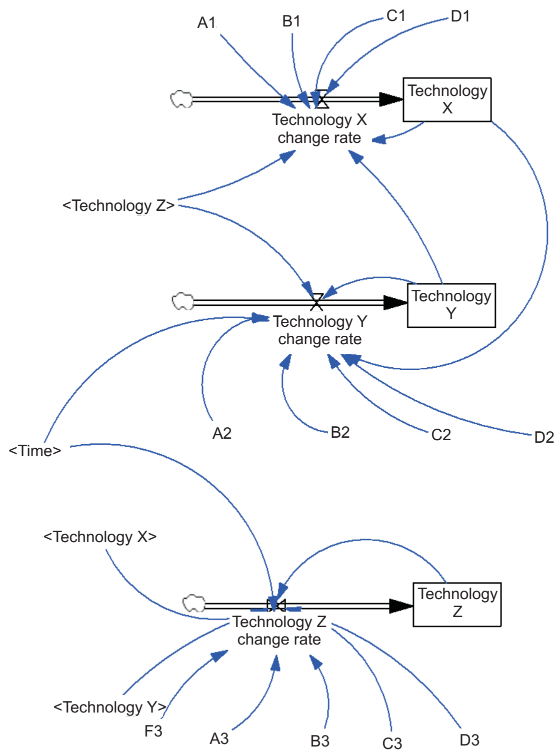

Fig. 1. The technology System Dynamics Model (source: compiled by authors)

All further parameter values shown in the modified equation set (2) are considered to be positive for illustration purposes in this paper. The parameter values actually used in the system dynamics simulation model to do computer simulations in Vensim (2012) are indicated in Table 1.

$$\frac{DX}{dt} = A1*X - C1*X*Y,$$

$$\frac{DY}{dt} = -A2 * Y - C2 * Y * Z + D2 * X * Y , \quad (2)$$

$$\frac{DZ}{dt} = -A3 * Z + D3 * Z * Y .$$

To explore cyclic seasonal or for example forced cyclical entrepreneurial effects in business on innovation, the technology Z change rate, has been supplemented by a small cosinusoidal innovation rate illustrated in equation (3). This forced innovation term that initially has a negative innovation (obsolescence) is added to the basic innovation, Technology Z change rate, to model the effect of a change in business policy aimed at for instance a reduction in technology growth to accommodate possible business resource limitations:

$$I = -F3 * \cos(\omega * t) . \quad (3)$$

In this equation I is the supplementary cyclic innovation rate and w is the cyclic rate in radian/s.

Table 1. Some typical model parameters for equation set (2) (source: compiled by authors)

	Model parameters -equation set (2)					
Certain	A1	B1	C1	D1	A2	B2
	0.5	0	0.5	0	0.5	0
	C2	D2	A3	B3	C3	D3
	0.5	0.5	0.5	0	0	0.5 or 0.45
Uncertain	F3=RANDOM NORMAL(0.001,0.008.0.0.005,0.002)					

The parameter values used in system dynamics simulation of the technology dynamics model are also chosen to be similar to those used by Mamat *et al.* (2011). This is done to be able to compare the simulation results in this paper to those previously published values for deterministic parameters. The results of Mamat *et al.* (2011) as well as Schmoch (2007) were compared at least qualitatively with the results of the current technology system dynamics model. The comparison is referred to under the results section of this paper.

To illustrate the effect of forced cyclic innovation behaviour a sinusoidal forcing function with a small amplitude is subtracted from the last equation in equation set (2). This is done to explore the effect of a policy change in innovation relating to Technology Z in this case. The amplitude of the forced cyclic innovation change is also varied parametrically as shown in Table 1 to generate the results for forced cyclic innovation.

Equations (1) and (2) that form the basis of the technology system dynamics model differ fundamentally. Parameters A2, A3, C2, D2 and D3 in equation (2) have opposing signs from that in equation (1) and there are certain terms in equation (2) that have zero values.

These terms in equation (2) can be viewed as the systems thinking result from relations uncovered in the literature review presented in section 1: The dynamic hypothesis (Forrester 1991,1971) held is that technologies may under certain circumstances show cyclic behaviour. For this case it is then suggested that for example the innovation of Technology X may be positively influenced by Technology X itself through a diffusion coefficient or logistic parameter A1 and negatively influenced by competing Technology Y through the interaction coefficient C1. The other relationships suggested in equation (2) may be inferred in a similar fashion. Details of this are presented by Pretorius *et al.* (2013).

The technology system dynamics model presented in Figure 1 has been implemented in the system dynamics software system Vensim (2012) using the equation set (2) as well as parameter values portrayed in Table 1.

The box variables (e.g. Technology X) in Figure 1 indicate the result of numerical integration of rate variables portrayed by a valve (e.g. Technology X change rate). The arrows in Figure 1 indicate existence of relationships between variables. The three technology system presented has more than 20 relationships making it complex in some sense.

3. Some results and discussion for cyclic technology behaviour

This section explores the effect of a specific combination of technology system dynamic model parameters portrayed in Table 1. This specific set of parameters reflects the possibility of a change from asymptotic behaviour to cyclic behaviour of the technology system as has also been shown previously (Pretorius *et al.* 2013). The system dynamic simulation results presented in this section employ equation set (2) and the technology system dynamics model in Figure 1 programmed in the system dynamics software simulation system Vensim.

The parameter values indicated in Table 1 are used in the current system dynamic simulations to be able to compare at least some of the results with previous research of for example Mamat *et al.* (2011). The initial values for all Technology levels were 0.5 in simulation modelling.

In the case where uncertainty was modelled for forced innovation Technology Z change rate the Monte Carlo multivariate simulation technique with 400 iterations has been employed. The time interval used during numerical integration was 0.01 year for all cases. Only results for the case of D3=0.45 are presented in this paper for discussion purposes.

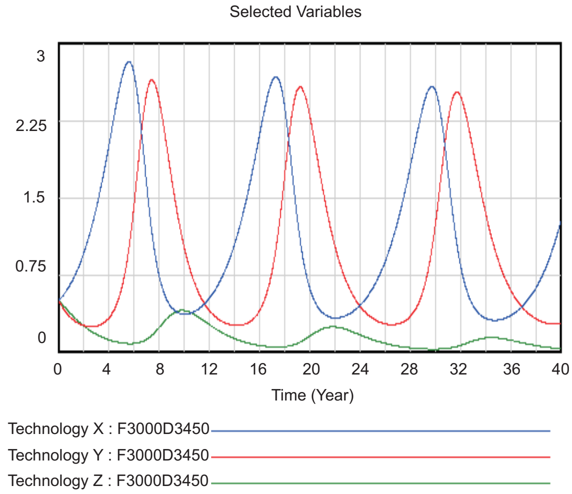

Fig. 2. Simulated transient response for Technology X, Y and Z; D3 = 0.45, no forced innovation

The transient response simulated for Technology X Y and Z are shown in Figure 2. These are the results for the case of no forced innovation. The cyclic nature of the technology system response for this specific parameter set should be evident and is essentially similar to the results for the food chain discussed and produced by Mamat (2011) using direct numerical simulation without a system dynamics approach. This assists in verifying and building confidence in the current technology system dynamics model.

The maximum levels of technology activity for Technology X of approximately 2.8 and 2.7 can be seen for example at year 5.6 and 17.3 respectively. This implies a period of oscillation of approximately 11.7 years for the technology system. It can also be seen that the results for Technology level activity are not sinusoidal such as for linear differential equations.

This has interesting possible technology management implications in the practical business environment when one starts considering for example the utilisation of technology. Upon inspection of Figure 2 the difference in gradient of especially the Technology Y level activities during build up or development of the technology pool and the utilisation or demise phase of the technology pool should be evident. The build-up period is typically shorter than the utilisation period.

In practical business terms this is a useful characteristic of this technology system dynamics model as it predicts a longer phase of technology utilisation indicating possible better business resource utilisation and depending on the pricing policy also more profitability.

The research results of Schmoch (2007) using bibliometrics (Bae *et al.* 2007) and patent analysis are used here as case study evidence supporting the cyclic technology behaviour that is evident from the simulation results in Figure 2. The bibliometric results of more than 30 years provided by Schmoch indicate that industrial robot technology went through a double boom cycle across a period of approximately 15 years.

A simulated period of oscillation of 11.7 years for Technology X may be inferred from Figure 2. This period is in the same order as the 15 years for robot technology and is considered useful validation to increase confidence in the technology system dynamics model.

One can also compare the simulation results provided in Figure 2 in a qualitative manner with results of Faria *et al.* (2008) that describe a cyclical model relating unemployment and entrepreneurship in a business economic environment in a continuous manner. In their model they estimate cyclic periodicity for the US UK and Spain to be between 5 and 10 years by using time series data from the Comparative Entrepreneurship Data base for the period 1972-2004.

This cyclical pattern of relationship between unemployment and entrepreneurship can also be seen as qualitative evidence that the current technology system dynamics model may be useful in predicting the basic cyclical concepts for a technology system.

To this end one just needs to conceptualise unemployment in some sense as part of a body of knowledge known as human development skills and entrepreneurship as that body of knowledge related to new firm and or opportunity creation.

Furthermore the approximate periodicity cycle of 11.7 years predicted for the technology system employing a system dynamics approach is in the same order as the 5 to 10 years periods established for the countries mentioned before (Faria *et al.* 2008). This increases the confidence in the current technology system dynamics as well.

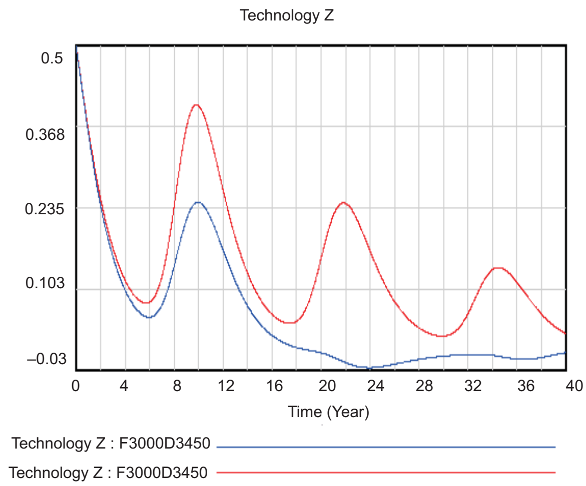

Fig. 3. Influence of forced cyclic innovation on simulated transient response for Technology Z; D3 = 0.45

The influence of forced cyclic innovation with a circular frequency of 0.05 rad/yr on the simulated transient response for Technology Z is shown in Figure 3. In this simulation the amplitude of forced innovation parameter F3 is relatively small at a value of 0.008 and is introduced at its maximum negative level at year zero.

What is evident in this figure is that the activity level for Technology Z falls to unexpectedly low levels just above and below zero in the period between year 18 and 26 in the case of forced innovation whilst the case without forced innovation is able to sustain its predictable cyclic pattern. It has been checked through additional simulation that although very low, positive values are attained for Technology Z levels up to a value of between 0.006 and 0.007 of forced innovation amplitudes.

The effect of the low amplitude forced innovation is also evident from the simulated Technology Z change rate graphs presented in Figure 4. Here the innovation rates for both cases show typical non-symmetrical skewed patterns as a function of time again emphasising the non-linearity of the system dynamics model utilised.

The maximum innovation rates for the case with forced innovation are however generally lower than the case without forced innovation and the Technology Z change rate seems to die out essentially after year 20.

This indicates a rather unexpected Technology Management dilemma that may arise in the practical business environment: Although a very small forced innovation has been introduced as a policy it seems to have the effect that it can destroy innovation rather unexpectedly. This has serious practical implications for organisation survival that is dependent on innovation in a competitive global business environment.

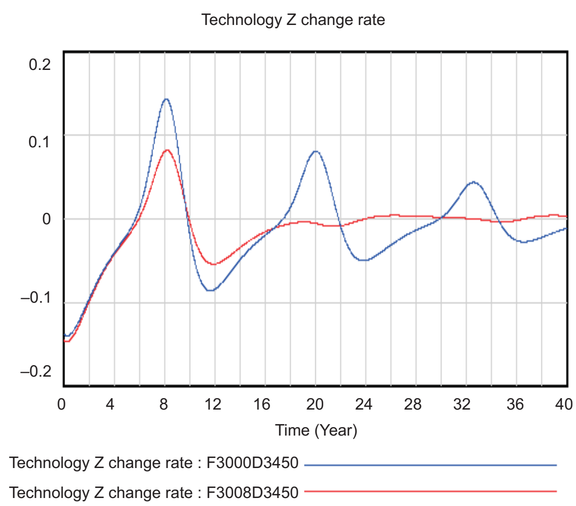

Fig. 4. Influence of forced cyclic innovation on simulated transient response for Technology Z change rate; D3 = 0.45 (source: compiled bu authors)

To explore the effect of uncertainty in the amplitude of forced innovation as a possible business policy against competitive behaviour of new market entrants or other seasonal market effects a Monte Carlo sensitivity analysis has been done on the forced innovation amplitude parameter F3 introduced in equation (3). As indicated in Table 1 this uncertainty has been modelled as normally distributed with a mean value of 0.005 and a standard deviation of 0.002.

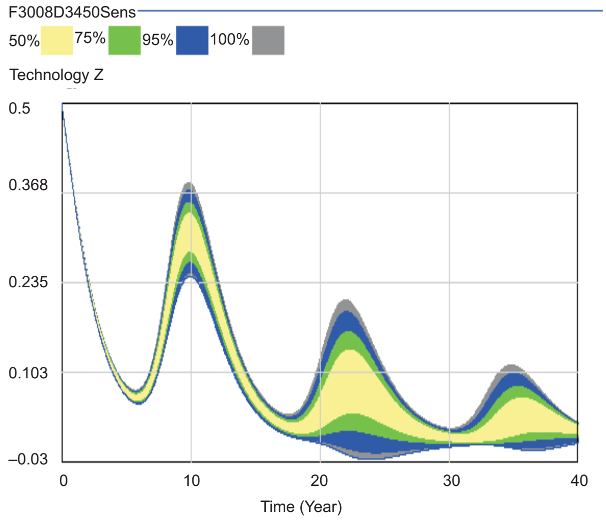

Fig. 5. Technology Z sensitivity trace ranges under uncertainty of forced cyclic innovation parameter F3; D3 = 0.45 (source: compiled bu authors)

The resulting simulated Technology Z sensitivity trace ranges under uncertainty of forced innovation are shown in Figure 5. What is important to note from a Technology Risk Management point of view is the relatively wide range of Technology Z activity levels occurring between the years 30 and 40.

From the confidence levels indicated in Figure 5 it can for example be inferred that there is a probability of approximately 25% that the Technology Z level activity with forced innovation will be lower than 0.05 for the simulated uncertainty range on parameter F3.

4. Conclusions

The literature review conducted resulted in a number of interesting conclusions including establishing a number of additional practical business cases where cyclic technology behaviour was evident. In this respect the direct numerical simulation work done for a three tier food chain by Mamat *et al.* (2011) was useful in verifying aspects of the current technology system dynamics model. The work of Faria *et al.* (2008) was also useful to link the current cyclic technology system dynamics model to entrepreneurship and human skills development in a practical business environment.

Some practical case study examples of competing technologies in a changing business environment include the development of Computer Aided Design (CAD) technology to eventually virtually replace Manual Drafting in for example consulting engineering businesses. Furthermore Computational Fluid Dynamics (CFD) and Finite Element Methods (FEM) technologies are slowly but surely being taken up in more comprehensive Computer Aided Engineering (CAE) solutions to fit the increasingly competitive engineering business environment. These technology growth and competition examples may under certain circumstances be modelled using the technology system dynamics model for Technologies named X, Y and Z based on the Lotka-Volterra approach presented in this paper.

As illustrative examples of the usefulness of the technology system dynamics model to simulate possible cyclic behaviour two cases of system dynamics simulation with the three technology system dynamics model were considered and compared in this research paper: Firstly a case of cyclic technology interaction without forced innovation and secondly a case with a small amount of cyclic forced innovation. One of the rather surprising system dynamic simulation results indicated the near demise of innovation for Technology Z in the years between 18 and 26.

This has some implications in the Technology Management of such a system in the sense that a rather big investment in technology upfront may provide little return during this phase if it is not carefully managed in terms of the correct technology policy and mitigation plans against technology interaction and business competition.

Monte Carlo system dynamics simulation results presented for the uncertainty in forced innovation amplitude parameter provided useful perspectives on probability of demise of the Technology Z. In summary the technology system dynamics model was used effectively in exploring the effect of different innovation policies. This also points to the practical usefulness of the technology system dynamics model in Risk Management on technology projects in product development organisations for instance.

Future research could include aspects of simulation employing the three technology system dynamics model with different forced innovation circular frequencies specifically higher frequencies to explore the effect of smaller periods of forced innovation. The sensitivity studies may be extended to address also the effect of a positive maximum forced innovation amplitude at time zero. This might have the effect of sustaining initially the third Technology Z at higher levels.

Although qualitative data from literature case studies seemed to support the results gained from simulations with the technology system dynamics model it should be of value if the results can be compared to more detailed practical case study results in future research. A future research case study of practical use in a business environment may for instance include a simulation to explore the relationship between entrepreneurship and Information technologies (IT) such as Twitter and Facebook which are currently popular competing social media technologies.

Additional cases that practically illustrate cyclic behaviour of technology might thus be sought and analysed in more detail to further support also from a business resource utilisation view the value of the model presented in this paper. In this instance additional bibliometric analysis of such cases where they exist may provide to be fruitful. Another area that may provide interesting research possibilities could be the system dynamics modelling of entrepreneurship, unemployment and technology to add to the work presented by Faria *et al.* (2008).

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