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A system dynamics approach to technology interaction: From asymptotic to cyclic behaviour

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ABSTRACT

This paper is an extension and elaboration of previous research on the simulation of three competing technologies that interact. A modified version of the three-technology system is investigated, and some initial system dynamics results are reported illustrating the progression from asymptotic to cyclic behaviour. Technology is considered in this research as a result of innovation, a rate-dependent process that may include several non-linearities due to interaction with the environment and social context. Using bibliometrics as a research data source is an interesting way to trace technology growth patterns very effectively. In this research, the existence of cyclic behaviour in two real life technologies is illustrated using bibliometrics. In this paper, a technology system consisting of three interacting technologies is treated and modelled in a coupled manner where the interacting dynamics is described by the Lotka–Volterra system of differential equations. The effect of interaction between the technologies and the period of cyclic behaviour is illustrated parametrically. Furthermore, the possible uncertain diffusion as well as interaction effect for two of the technologies is also addressed in this research using a Monte Carlo multivariate simulation technique and a system dynamics approach. The research method is exploratory and case based.

1. Introduction and research method

1.1. Introduction and background

The focus in this paper is on exploring technology diffusion in competing technologies such as information technology, biomedical technology, energy technology laser technology in manufacturing and others. Along this theme, Heidrich et al. (2011) present and evaluate a process chain to enhance flexible manufacturing of optical components by using laser radiation. They specifically show that it is feasible to ablate and polish fused silica in a time which may be profitable from an industrial application point of view. In essence the technology readiness is illustrated.

Werthen (2011) also focuses on technology competitors in photovoltaic (PV) solar-energy industrial applications. He also addresses the importance of lasers in the manufacture of PV applications. Elements of competing behaviour such as improved manufacturing techniques in the arena related to PV are thus highlighted. Another issue for increased competitiveness in lasers namely quality control is addressed by Franz et al. (2011) when they focus on the alternative use of metrology in discussing the implementation of solid-state lasers to increase the operational speed for materials processing with lasers. Wang and Lan (2007) in their research on market share of Fibre to the x technology in Taiwan focus on analytical technology substitution models in combination with scenario analysis. They also suggest how different technology forecast methods may be combined to improve technology forecasting.

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Some of these competing technologies have been addressed recently in system dynamics (Pretorius and Pretorius, 2010; Pretorius et al., 2012) and bibliometrics (Bae et al., 2007) as well as diffusion modelling (Kim et al., 2006; Pretorius and Winzker, 2010) research. The research presented in this paper is an extension of recent research on simulation of bridging technology dynamics (Pretorius and Pretorius, 2010; Pretorius et al., 2012) and is also based on work presented previously by the authors (Pretorius and Pretorius, 2012; Pretorius et al., 2013). It also illustrates how system dynamics may be used as an alternative to analytical technology substitution models as discussed by, for example, for example Wang and Lan (2007).

The approach that technology can be considered as a body of knowledge as well as the result of an innovation process generally non-linear and time dependent is used extensively in this research. This in essence means that technology can be modelled as the integrated result of a rate-dependent innovation process. This results typically in the diffusion of technologies that can co-exist. Nair and Alsthom (2003) refer to the possibility of co-existence of technologies such as dialysis and transplantation of organs in the medical arena.

This technology diffusion process can be modelled in a number of ways. One way is using the Bass diffusion approach (Bass, 2004) with numerical discretization as illustrated previously in the diffusion of computational fluid dynamics (CFD) technology (Pretorius et al., 2011). The aim in that research was to compare different CFD technologies. In the current research the focus is on the possibility of transition from asymptotic to cyclic behaviour of technologies during and after the technology adoption process.

Another technology modelling approach that has been shown to be effective (Pretorius and Pretorius, 2010; Pretorius et al., 2012), especially in exploratory parametric studies is the system dynamics approach. System dynamics was introduced in the 1960s by Forrester, (1971, 1991) in his pioneering research on modelling socio-technical systems using concepts derived from the theory of feedback control. In socio-technical systems, the focus is on a design process that includes social and organisational issues together with technical factors specifically when analysing and designing organisational systems for the benefit of society. In this approach, the rationale is to include social and technical factors when considering the functionality and use of systems.

When addressing social factors in technology systems and, for example, organisations or equivalent social structures, the issue of resistance to change immediately comes to mind. Resistance to change is a factor that has many implications for organisational sustainability (Potocan and Mulej, 2011; Bauer, 1991; Blin and Munro, 2008). In this context, Potocan and Mulej (2011) point to the existence of culture as, for example, a factor resisting change and competitive forces a factor for change in an organisation. Another case in point is illustrated by Blin and Munro (2008) in their discussion of the effect of virtual learning technology on academic teaching behaviour. In their research, it is illustrated that this type of learning technology at the time had very little impact on the social behaviour of the academics. The implication of this is that the interaction or competition parameter between technologies may have been low at the time for the virtual learning technology.

Failure to adopt a socio-technical holistic approach can increase the risk of a system malfunctioning or not contributing to the aim of the organisation as a system to serve society (Baxter and Sommerville, 2011). It is in this socio-technical system thinking approach that system dynamics may be beneficial to test, for example, the influence of various policy changes on organisational effectiveness.

Wolstenholme (1990) in his research defines system dynamics 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 modelling and analysis for the design of system structure and control." This definition also points to the roots of feedback control as well as the ability of system dynamics to address the inherently complex nature of systems that interact. This element of feedback control leading to the possibility of cyclic behaviour of control systems due to the inherent nature of the system is then at the heart of this paper. Here the rather dramatic effect of changing some technology system parameters leading to different technology behaviours will be explored.

This paper also illustrates the inherent effectiveness of system dynamics to elucidate the complex behaviour of interacting technology systems in a manner that is complementary to the analytical technology substitution model approach used, for example, by Wang and Lan (2007). The systems thinking approach is also discussed and evaluated extensively by Jackson (2003) when he addresses system dynamics as a complex system approach as opposed to hard systems thinking considered more of a simple system approach. In this complex systems approach to system dynamics, one of the early most important processes of the approach is the problem definition phase.

Proper problem definition leads to appropriate dynamic hypotheses about the problem that can eventually be translated into a system dynamics model. A clear goal is one of the most important drivers of success of a modelling process. As problem definition adds to the clarity of purpose, it is or should also be one of the most important parts of the system dynamics modelling process. Good dynamic hypotheses generally indicate the dominant factor influencing part of the system behaviour. It is however also important to realize the role of a good hypothesis in indicating that different dominating factors may exist as illustrated by Mashayekhi and Ghili (2010) in their system dynamics approach to modelling the real estate bubble. This may also have a definite effect in technology systems behaviour as illustrated further on in this paper.

Meadows (2008) adds more fundamental methodological insights on the complex behaviour of systems with her thinking in systems approach to system dynamics simulations. Hunger (1995) focuses on the system or holistic perspective in his work and effectively stresses the relationship between soft and hard systems thinking. Elements of the systems thinking approach are used in this paper to shed light on the system dynamics approach used to model the current technology system.

1.2. Research method

The research method used in this paper is qualitative and exploratory in nature and is useful in the early stages of research as indicated by Cooper and Schindler (2006). A systems thinking approach incorporating system dynamics simulations is used in the research to explore the behaviour