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The technology life cycle: Conceptualization and managerial implications

Margaret Taylor *, Andrew Taylor [1]

University of Bradford School of Management, Emm Lane, Bradford, BD9 4JL, United Kingdom

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ABSTRACT

This paper argues that the technology life cycle literature is confused and incomplete. This literature is first reviewed with consideration of the related concepts of the life cycles for industries and products. By exploring the inter-relationships between these, an integrated view of the technology life cycle is produced. A new conceptualization of the technology life cycle is then proposed. This is represented as a model that incorporates three different levels for technology application, paradigm and generation. The model shows how separate paradigms emerge over time to achieve a given application. It traces the eras of ferment and incremental change and shows how technology generations evolve within these. It also depicts how the eras are separated by the emergence of a dominant design, and how paradigms are replaced at a technological discontinuity. By adopting this structure, the model can demarcate the evolution of technologies at varying levels of granularity from the specific products in which they may be manifest to the industries in which they are exploited.

By taking technology as the unit of analysis the model departs from previous work, which has adopted a product-based perspective predominantly. The paper discusses the managerial and research implications associated with the technology life cycle, and indicates how these inform future research directions. As well as contributing to academic knowledge, the results of this research are of value to those who make decisions about the development, exploitation and use of technology including technology developers, engineers, technologists, R & D managers, and designers.

1. Introduction

In the literature, it is common to see the terms industry life cycle, product life cycle and technology life cycle used interchangeably, ambiguously and often inappropriately. Moreover the discourse is dominated by the product life cycle (PLC) while the technology life cycle (TLC) has largely been neglected. This is only the tip of the iceberg since there are also disconnects and inconsistencies pertaining to the various perspectives on the TLC such that there is no "*single, strong, unified theory of technological evolution*" (Sood and Tellis, 2005: 152). The focus of this paper is to highlight the imprecision and confusion which exists in relation to the TLC and to address the need for clearer conceptualization.

We draw together and extend previous work on the TLC, which represents a wide ranging debate from multiple disciplines and perspectives. We develop an integrated view of this beguiling concept using three distinct entities—the technology application, paradigm and generation. We also depart from previous work by taking technology as the unit of analysis, rather than any product or artefact in which it is used. This facilitates examination of how the 'macro' view of technology evolution (e.g. Anderson and Tushman, 1990) is related to the S-curve perspective (e.g. Foster, 1986); how technology progression occurs within and between the three entities of the TLC; and to what extent progression may be influenced by management action.

Our aim is to increase recognition and understanding of the phases that make up the TLC, arguing that, as firms seek to manage technology, they need to be able to position specific technologies within the life cycle and to understand the implications of this for managerial decisions. Few studies have discussed the links between the TLC concept and the reality of managerial decisions. The paper addresses this gap by pointing towards the challenges associated with the profitable exploitation of technology from the perspective of both developers and users. This dyadic perspective is unusual and important, especially as an individual organisation may act in both capacities.

Finally, we consider how technology progression links with the product focus associated with the PLC and the industry life cycle (ILC), and in the cases of simple and complex products (Tushman and Rosenkopf, 1992). The synthesis of these various perspectives is intended to strengthen the theoretical base on which technology management decisions are made and to create

* Corresponding author. Tel.: +44 1274 234041.
E-mail addresses: M.Taylor4@Bradford.ac.uk (M. Taylor), W.A.Taylor@Bradford.ac.uk (A. Taylor).
[1] Tel.: +44 1274 234325.

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a foundation upon which future research can build. To summarise our analysis we propose a new conceptualization of the TLC.

The next section introduces the life cycle literatures and demonstrates the conceptual imprecision which exists. In Section 3 the TLC is considered in detail from the distinct perspectives that emerge from the literature, followed, in Section 4, by a discussion which explores how the principal perspectives associated with the TLC are linked. A new conceptual model is presented in Section 5. The implications of our work for future research and for managerial decision making are considered in Section 6, before we draw conclusions in Section 7.

2. The life cycle literatures

The streams of literature that are relevant to this work pertain to the industry life cycle, the technology life cycle and the product life cycle. While these concepts are inter-related, it is crucial to understand the distinctions between them so that each is used appropriately in the right context and with accurate terminology. A lack of normalised and consistent terminology (Nieto et al., 1998), separation between the views of different stakeholder disciplines (Nieto et al., 1998), ill-definition and transposition between terms (Routley et al., in press) and ambiguous or unspecified units of analysis (Murmann and Frenken, 2006; Routley et al., in press) have all contributed to confusion and misunderstanding in the field.

It is not uncommon to see synonymous and interchangeable use of the life cycle terms in the literature: industry and product, for example, in Peltoniemi (2011) and Rice and Galvin (2006); product and technology in Cetindamar et al. (2010). Perhaps as a consequence, it is not surprising to read in a Business encyclopaedia that "*to simplify the discussion, both the product life cycle and industry life cycle will be combined and simply called the product life cycle*" (Reference for Business, 2011). This glosses over important distinctions that are critical to the achievement of understanding. One of the underlying causes of this may relate to the dominance of the PLC in the extant literature.

As Table 1 shows, unlike their counterpart "*product life cycle*", both the terms "*industry life cycle*" and "*technology life cycle*" are not widely used. Table 1 represents a search of the ABI Inform academic and trade databases for articles and resources published during the last 20 years which include any of these terms in the citation or abstract. Of all the hits for all terms, around 96% concerned the PLC with approximately 2% relating to each of the TLC and ILC. The papers emanate from a variety of journals across a range of disciplines. While these figures are by no means conclusive, they suggest that the concept of the TLC is underdeveloped from both academic and practitioner perspectives.

One aspect of the confusion surrounding the TLC derives from the nature of technology itself, for which there are differing definitions. Schon (1967) asserts that technology is used to extend human capability and can take the form of a tool, technique, product, process, physical equipment or method. Bohn (1994) sees it as technical knowledge that organisations apply in order to enhance their ability to provide products and services. Emphasising both hard and soft aspects, Drejer (2000) refers to hardware, human resources and organisational aspects within a firm, thereby acknowledging the role of human skills and experiences. Using similar notions Heffner and Sharif (2008) categorise technology into "technoware" or tools, "humanware" or talents, "infoware" or facts, and "orgaware" or methods. The variety of forms which technology may take is articulated as "*a machine, an electrical or mechanical component or assembly, a chemical process, software code, a manual, blueprints, documentation, operating procedures, a patent, a technique or even a person*" (Stock and Tatikonda, 2000: 721). Others link the definition of technology to its physical manifestation in products: "*We use the word 'technology' in the tradition of the technology life cycle literature to mean technology as applied in a particular product context and as embodied in a physical artifact. So technology is not just the knowledge from which products are elaborated, but also includes the physical manifestation of that knowledge within a product.*" (Kaplan and Tripsas, 2008: 791).

These definitions serve to reinforce the inextricability of a technology and the product(s) in which it may be manifest; a situation which arguably forms part of the barrier to a clearer conceptualization of the life cycle of a technology.

A further cause of misunderstanding may be the superficial similarity in structure, shape and terminology between the different life cycles. Fig. 1 shows the most generally recognised form of the PLC which depicts sales volume or revenue plotted against time as a bell-shaped curve with distinguishable stages representing the introduction, growth, maturity and decline of a product (e.g. Urban and Hauser, 1993; Nieto et al., 1998). Introduction represents the phase when the product has first been launched onto the market, during which sales volumes are low. During the growth phase, consumer acceptance of the product builds, and sales volumes increase rapidly. At maturity, sales volumes stabilise before decreasing in the decline phase.

Whilst the PLC has traditionally been used to assist with marketing decisions, it has more recently been used as a framework for other management decisions associated with supply chain strategies (Aitken et al., 2003), supply chain partner selection (Chang et al., 2006), inventory control policies (Hsueh, 2011) and demand forecasting (Chien et al., 2010).

The axes, terminology and shape of the PLC are generally accepted and widely adopted, although there are concerns about its empirical validity. In particular, there is little standardisation over the length and timing of the phases between products or over the sales levels that will be reached (Grantham, 1997). The shape of the PLC varies between products, with some existing in maturity for extended periods, dying at the introduction stage or moving back from maturity to growth (Dhalla and Yuspeh, 1976). Finally, use of the PLC often does not distinguish between product

Table 1
Hits for technology life cycle (and lifecycle), product life cycle (and lifecycle) and industry life cycle (and lifecycle) (01/01/1991 to 18/03/2011) (ProQuest search engine).

	Technology life cycle (TLC)[a]	Product life cycle (PLC)	Industry life cycle (ILC)	Total: TLC or PLC or ILC	% TLC	% PLC	% ILC
ABI Inform Global (journals)	67 (78)	2679 (3440)	88 (94)	2834 (3612)	2.36 (2.16)	94.53 (95.24)	3.11 (2.60)
ABI Inform Trade and Industry	25 (37)	1771 (2763)	15 (16)	1811 (2816)	1.38 (1.31)	97.79 (98.12)	0.83 (0.57)
Total hits	92 (115)	4450 (6203)	103 (110)	4645 (6428)	1.98 (1.79)	95.8 (96.50)	2.22 (1.71)

[a] In searching Proquest, alternative spellings of "life cycle" were considered. Where articles used "life-cycle" (hyphenated) the searches yielded similar total numbers of articles, most of which also appeared in the non-hyphenated results. Where articles used "lifecycle" (one word) these have been added to the hit count to form separate totals for each concept (in parentheses). It should also be noted that some articles appear in both databases used—i.e. Global (journals) and Trade and Industry, so the total number of hits for each term is inevitably inflated.