1C2 Product Development Challenge in IT: going through uncertainty and complexity

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Introduction

Product development is a critical phase in the technological innovation process of an industry. A deeper understanding of the characteristics of each industry is a perquisite to applying the relevant strategic management tools. In this respect, IT seems to be evolving in a radically new innovation pattern compared to other industries. Many analysts describe the high-tech environment in terms of its uncertainty and complexity. However, very few have distinctly characterized these factors nor measured and provide empirical determination. Uncertainty is defined in terms of a combination of technological innovation cycles and the changing market share. On the other hand, complexity is defined in terms of the problem-solving activity where it is shown that a horizontal versus vertical network structure determines the level of complexity. Empirical analysis of the two factors shows that the IT industry exhibits a higher level of uncertainty and complexity as compared to automobile industry. These findings suggest that managers and strategists should adopt new modes of management to succeed in the highly turbulent IT environment.

Section 1: Characterization and empirical determination of uncertainty in IT

Relative turbulent environments would certainly influence product development[1]. A turbulent environment would depend on two main factors: one) the speed of technological innovation, and two) the stability of the technological environment. These two factors might be inter-linked, the evolution of one factor might influence the other. The combination of the two factors might make a product environment unpredictable.

1.1. Technological innovation cycles

We will use the life cycle of products[2] to determine the technological innovation cycle.

The product life cycle might be useful to define different technologies. It might show how fast a technology is brought to the market and how rapid its obsolescence would be.

A shorter product life cycle implies faster technological diffusion, standardization, and maturity periods. In other words, the strategy used to develop new products and technologies might differ depending on the nature of the technology and its product life cycle.

Analytical methodology

For the PC[3], in order to calculate the technological innovation cycle we looked at two main components representing its core technologies used in the PC namely the Intel Central Processing Unit (CPU) and Microsoft DOS and Windows Operating Systems (MS-DOS and MS-Win). We calculated the arithmetic mean of the life cycle of each component, and the general mean representing the PC product. The observed period was from 1982 to 1998.

For passenger cars, we calculated its life cycle by using the difference in time when a full model change of a product line occurs. This means that we looked at the situation when a new car was introduced to the market with major new features, such as a new type of engine, body, axle, etc. A sample of 32 models of five Japanese auto-manufacturers[4] have been studied during a period from 1980 to 1997.

Thus, we calculated the average life cycle of a product line and then the arithmetic mean of the averages.

Results:

According to the results presented in table 1, it is obvious that the innovation cycles in the PC sector are much shorter, more than half compared to the passenger car industry. As a preliminary conclusion, this implies that the speed of major innovations in information technology industry is relatively higher. New products need to be developed and introduced to the market in a relatively short time. Relatively recent products become obsolete faster, IT firms are therefore confronted to bring up new technological solutions in a relatively small period of time.

Table 1 **Technological Innovation Cycle Lead-time**

	Mean	STD
PC	2.3	0.8
Passenger car	5.9*	1.9*
	5.0**	0.9**

* for 32 lines ranging from 3 to 10 year innovation cycle

** for 25 lines of 32 or 78%of the sample, representing 4 to 7 year innovation cycle range

1.2. Stability of the technological environment

Introduction to the concept of stability

The environment that a technology is evolving in has a direct influence on the product development process. The more unstable the environment is the more difficult it is to take a decision on the characteristics of the product to launch in the market. Policymakers too would be unable to make predictions on a long-term basis. Besides, the more turbulent a market is, designers would face high uncertainty to decide on the final specifications and design of the product to be developed. In turbulent markets, in order to adapt to new information in the course of the development process, firms are forced to leave the specifications and design window open as late as possible in order to avoid technological lock-in.

Analytical methodology

The data was compiled based on market share situation in Japan for the period 1983 to 1997 for the PC sector[5] and from 1982 to 1997 for the passenger car sector[6].

We ranked the firms in terms of their market share. Then we calculated the rank correlation coefficient (also referred to as the Spearman rank correlation coefficient) for each year[7]. A value close to +1 means that no significant changes were registered. The greater the correlation value moves away from +1 the grater the changes in the market share rank between two consecutive years. This means that some firms who ranked higher in year t are raking lower in year t+1.

Results

The computed results in fig.1 show that;

1. the automobile industry has a quite linear and uniform curve, and the rank correlation coefficient during the studied period was very close to +1, where the mean of the rank correlation values is 0.98, therefore no major changes affecting the market share environment was observed.

The value of the standard deviation is very small i.e. 0.03, suggesting that the automobile industry is evolving in a relatively stable environment, in terms of its market share.

2. On the other hand, the situation in the PC industry is very different. The results show that the rank correlation coefficient curve of the PC industry is very uneven and fluctuates from one year to year. Firms which have performed well in a certain year in terms of market share were not able to keep their lead for the following year. Existing well established firms are always threatened by new ones. The rapid change in the values indicate the radical changes affecting the market. Many firms are loosing their lead and others are stepping in a very short time.

The standard deviation is relatively high i.e. 0.41, and the mean of the rank correlation values is 0.71, suggesting that the PC industry is evolving in a volatile environment.

Section conclusion

The empirical results show that in the IT industry technological innovations cycles have shorter cycles combined with unstable technological environment lead to an uncertain technological environment.

Section 2: Characterization and empirical determination of the complexity of the Technological innovation process

Definition of complexity

Despite the extensive use of the term "complexity of technology", there is generally no accepted definition.

Most frequently used definitions of complexity characterizes it as a group of subsystems within a general system that interact closely among themselves and are non-decomposable i.e. the alteration of one subsystem or component seriously degrades the functional capability and performance of the whole system [8].

These studies focused on the composition of specific products components. Therefore a technology is said to be relatively more complex when it involves a large number of components that are intimately linked, for example a car which usually requires 20,000 to 30,000 component parts and most of them are highly dependant on each other.

An alternative dimension of complexity

The above explanation would not be useful to describe the level of complexity of different technologies in different industries, and do not necessarily lead to explain the way technological problems are solved within a technological innovation process.

The new dimension requires the analyzes of problem-solving activity of product development. This activity characterizes the natural trajectories of technological progress, and therefore the technological regime followed by a specific industry [9].

Problem solving activity has been well discussed in many academic literature[10]. It is the engine of knowledge creation. It might be defined as follows:

1. *A set of solutions that enables a firm to innovate.*
2. *The ability of a firm to cope with complexity.*
3. *The capability of a firm to integrate (heterogeneous or homogeneous) subsystems to the whole system.*

The problem-solving activity has been originally used to describe traditional industries such as automobile and electronics where the technology used in the product is most of the time proprietary, and where the development and production of the ultimate product and its components usually depends on the leading firm's own network (which is usually the manufacturer). This kind of network structure is called "vertical".

On the other hand, in the case of IT especially with the emergence of the personal computer, the development and production of the ultimate product does not depend anymore on the leadership of one firm. For example, the firm that produces a PC is not able to control the design and development activities of all components integrated in the PC as illustrated in fig. 2.

Therefore there is a need for the firm to interface with many other components and firms not available within its control. This type of network structure is called "horizontal".

A product is horizontally integrated when its design, development and manufacturing depends on a group of heterogeneous standards, e.g. PCs, Networking Products. Therefore, the development of these products would in most cases depend on factors external to one's firm network, thus interoperability (the ability of a system to communicate and work with another) between components is one of the major complex problem-solving activity.

The interoperability complexity problem is relatively very acute in the IT sector since the technology and its respective standards are evolving so fast that it leads to high level of instability and uncertainty.

The level of technological complexity would depend on the structure of the firm's network and the nature of the ensuing problem-solving activity.

The more it controls, the more it has the ability to keep the development of its products within it, then relatively less problem-solving complexity would ensue. Since IT network is different, I would suggest to use the notion of "Horizontal Integrated Problem-Solving" for industries involved in an horizontal type of network versus "Vertical Integrated Problem-Solving" for industries involved in a vertical type of network.

Empirical verification of the network structure and identification of the complexity level
Further to the above definition of the firm's network, a questionnaire was sent to 20 firms consisting of 10 passenger car manufacturers and 10 PC manufacturers. 10 firms responded, i.e. 5 from the automobile industry and 5 from the PC sector. We listed the main components representing core technologies[11] of each sector, and then we asked each firm to put a check mark against each component they generally control through the design, development and manufacturing process, and to leave blank the cases where the activity at that level is negligible or none.

Results
We calculated the arithmetic mean of each process for each firm and then the overall arithmetic mean for the industrial sector of the responding firms.
Since only the values 1 and 0 are used, the results obtained were between these values.
The more a firm controls its network the more the value is close to 1, implying less technological complexity (see fig. 3).

The empirical results show that the automobile industry concentrates all of its processes within their respective firms' network. In contrast, firms in the PC sector have to outsource most of components included in their ultimate product. The degree of the firm network control level is relatively low at 0.30 for the PC sector (see table 2) compared to 0.80 for the automobile industry (see table 3).

Section sonclusion
It is clear from this result that the PC sector has less network control and consequently a high level of problem-solving complexity.
Therefore we may forward that the IT is characterized by a high level of technological complexity.

Table 2: **Passenger Car sector's firm network control level**

	Suzuki	Mitsubishi Motors	Mazda	Daihatsu	BMW	Process Mean
Design	1.00	1.00	1.00	1.00	1.00	1
Development	1.00	0.57	1.00	1.00	1.00	0.86
Production	0.43	0.43	0.29	0.86	0.43	0.38
	0.81	0.67	0.76	0.95	0.81	0.75

μ	0.80	Industry Mean
σ	0.10	Standard Deviation
n	5	Observation

Table 3: **PC sector's firm network control level**

	Fujitsu	Toshiba	IBM Japan	NEC	Sharp	Process Mean
Design	0.44	0.33	0.56	0.22	0.11	0.44
Development	0.11	0.33	0.56	0.22	0.11	0.33
Production	0.22	0.33	0.56	0.22	0.11	0.37
	0.26	0.33	0.56	0.22	0.11	0.38

μ	0.30	Industry Mean
σ	0.17	Standard Deviation
n	5	Observation

Conclusion

The cumulative factors in the computer industry of relatively short technological innovation cycles, unstable and turbulent environment, combined with a volatile market suggest that the IT industry is characterized by a relatively high level of uncertainty. The greatest challenge therefore is to adapt continuously to a combination of relatively high uncertainty with the use of new technologies combined with extreme complexity. The capability to adapt to external and internal uncertainties during a project's evolution therefore becomes a critical source of competitive advantage for the IT industry. This result may have many implications for the successful strategic management of the IT industry.

Notes and references

[1] G. Dosi, *Technological Paradigms and Technological Trajectories: a suggested interpretation of the determinants and directions of technical change*, Research Policy, 1982, p.151.
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S. Russel Craig, Redefining the Formula for Success: Electronics and High-technology Industry Commands Change, Outlook Magazine, Anderson Consulting, August - September 1997.

[2] We will use the product life cycle and technological innovation cycle interchangeably as defined above.

[3] Data had been sourced out from *PC White Paper 92-93* (Japanese version) JEIDA, Japan. Intel and Microsoft.

[4] Mitsubishi Motors, Nissan, Mazda, Daihatsu, and Isuzu.

[5] *Japan Market Share Almanac* (Japanese version),Yano Economic Research Center. Dataquest.

[6] Dodwell Marketing. Toyota Motor Corporation.

[7] *Rank correlation coefficient (also referred to as the Spearman rank correlation coefficient)* used here to calculate the stability of the markets.

$$r_r = 1 - \frac{6\sum d^2}{n(n^2-1)}$$

Where d= difference between the ranks for the paired observations
n= number of paired observations
n (PC): The sample size of the computer market changed from one year to another. Spearman rank correlation coefficient requires the difference between the ranks for the paired observations between two consecutive years. To solve this problem, we assigned fictive numbers representing the last rank in the previous year for firms not listed in the statistics of that year.
n(car) = 7

[8] Stuart A. Kauffman, *The Economy as an Evolving Complex System: The Evolution of Economic Webs*, 1988.
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[9] Research Policy, 1982, *op. cit. Ref. 1*, pp.153-155.

[10] M. Iansiti, *Technology Integration: making critical choices in a dynamic world*, (Boston, Harvard Business School Press, 1998), pp.31-32.
K.B. Clark & T. Fujimoto, *Product Development Performance: Strategy, Organization, and Management in the World Auto Industry*, (Boston, Harvard Business School Press, 1991), p.206.
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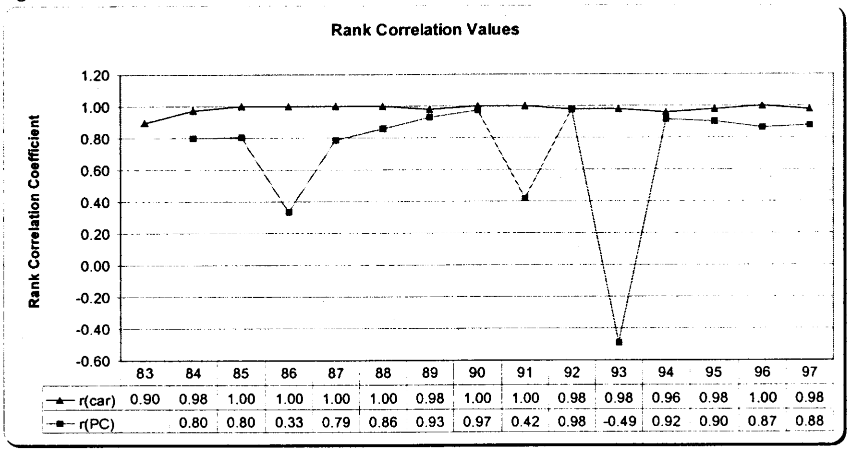
[11] Engine, transmission, brakes, steering, suspension, axle, and tires according to the Japan Motor Industrial Federation and Japan Automobile Manufacturers Association (JAMA) specification documents identifying passenger cars core technologies. And OS, CPU, motherboard, RAM, VGA card, HDD, FDD, CRT, and network card for the PC.

Appendix

Fig.1



	83	84	85	86	87	88	89	90	91	92	93	94	95	96	97
r(car)	0.90	0.98	1.00	1.00	1.00	1.00	0.98	1.00	1.00	0.98	0.98	0.96	0.98	1.00	0.98
r(PC)		0.80	0.80	0.33	0.79	0.86	0.93	0.97	0.42	0.98	-0.49	0.92	0.90	0.87	0.88

Fig. 2: **A case of an horizontal network where the ultimate product is the PC**

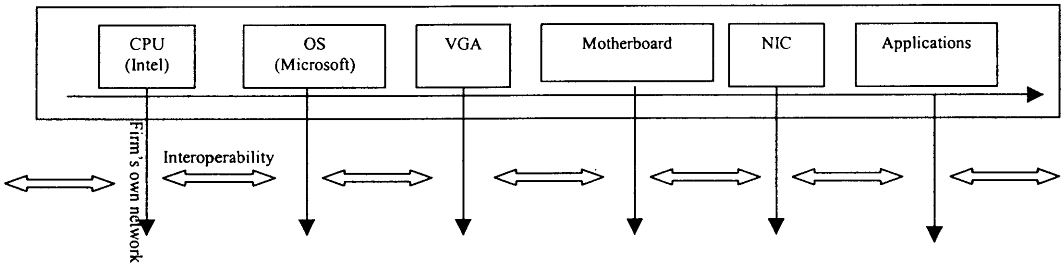


Fig. 3: **Complexity and Network Control level**