source of growth impulses for years to come. Western Europe's backward position in this area cannot be denied. The US contribution in the worldwide production of chips (the building blocks of micro-electronics) is 60%, Japan's is 30%, and a mere 10% comes from Europe. How did this happen? Companies are often accused of lacking a spirit of innovation. The core of the truth surely lies in that, but innovation does not just mean innovative action; there has to be a sufficient number of gifted engineers, and this in turn requires the support of technical universities and colleges. Future-oriented company planning in most European countries is often hindered by a lack of electronics and communications engineers. While our universities report rapid growth, many students chose fields in which they can contribute little or nothing to the continent's economic strength, and in which their professional future is quite uncertain. The choice of study subject is not determined by government decree, but by trends in youth opinion and the ideas put about in our high schools. Until recently, none of this favoured engineering. There has been a shift now – more young people are moving in the direction of engineering sciences. But our colleges today suffer from lack of capacity and lack of funds, and the quality of engineering training is dropping. *Whether an increase in the numbers of well-trained engineers can be achieved may turn out to be a crucial question for Western industry.* Government research policy also does not consistently foster the maintenance of high technological standards. There are too many expensive fields of research which started off in planning and which have now become outdated, but which have continued even though few prospects of practical implementation exist.

Yet pessimism is not an acceptable attitude for European entrepreneurs. Pessimism produces resignation, the worst possible starting point for future-oriented action. Europe has a number of characteristic strengths which need to be reinforced. Compared with the USA, our educational system is superior on almost all levels, the lower and medium qualification levels being the most pronounced. Compared to Japan, the flow of research results from the universities to industry is superior, and so is the overall quality of business management and research management. In addition, most European countries, unlike Japan, are capable of attracting highly qualified immigrants. Compared to the other two regions, Western Europe enjoys the advantage of a management and production work force that is more cosmopolitan and has a better knowledge of foreign languages.

Referring to micro-electronics, and in comparison to the Western countries, Japan is stronger in factory automation than in office automation, stronger in hardware than in software and computer architecture, stronger in chip manufacture than in chip design, and stronger in the manufacture of high-volume, low-cost chips than in highly complex and specialized chips.

It is important to realize that Japan's strength cannot be explained as the effect of a sole cause. A multitude of factors with roots in different places have come together and we are now experiencing the effect of this culmination. We must deal with each of these factors individually. The requirements of the times are not hard to see, they are readily apparent. But the need to act is present at a time in which Western Europeans are having increasing problems in defining their attitude towards technology. They perceive the threatening hazard of growing economic weakness and would like to strengthen their technological prowess, but they move as individual nations rather than as a world region. It is our hope that business, governments and parliaments, as mirrors of public opinion, will find a common base strong enough to offer an equivalent to the two well-performing giants of the USA and the Far East.

Technology life-cycles and business decisions

Durée technologique et décisions commerciales

Technologische Lebensdauer und Geschäftsentscheidungen

技術のライフ・サイクルと企業決定

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Abstract: Although the general phenomena of technology life-cycle have been known for a long time, quantitative description is still controversial. In the majority of cases, an S-curve fits the phenomena well. There are cases, however, that deviate from S-curves significantly. There is also the question of whether in real life the curve is as symmetrical as a pure S-curve. In real-life business situations, these arguments are rather academic. This paper shows that the life-cycle concept can be useful to decision-making in spite of the imperfect status. The authors first show that there may be more than one attribute of a technology that follows the S-pattern. They then point out the danger of using one attribute alone. The authors also illustrate the usefulness of the concept for contingency planning, and the phenomenon of multiple S-curves.

Keywords: technology life-cycles, business decisions, contingency planning, investment decisions, R&D decisions, S-curves.

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Nebojsa Nakicenovic is a Yugoslavian economist whose research interests include the long-term patterns of technological change and economic development and, in particular, the evolution of energy, automotive and aerospace technologies. His recent research is on the analysis of the phenomenological evidence that technological life-cycles and competition of technologies portray regular features. Nakicenovic is currently Acting Leader of the Technology, Economy and Society (TES) Programme at the International Institute for Applied Systems Analysis (IIASA), Laxenburg, Austria and, under this Programme, leads the Dynamics of Technology (DOT) Project. He received his B.A. from Princeton University in 1971 and earned his M.A. and Ph.D in economics and computer sciences from the University of Vienna. After working on nuclear materials accountability at the Nuclear Research Centre, Karlsruhe, FRG, he joined IIASA in 1973 to work in its Energy Programme analysing long-term and global energy perspectives and strategies.

Résumé: Bien que les phénomènes généraux de la durée technologique soient connus depuis longtemps leur description quantitative continue à être contradictoire. Dans la majorité des cas, la courbe S décrit assez bien ces phénomènes. Toutefois il existe des cas où cette courbe S se détache nettement. Une question se pose à savoir si la courbe est dans la pratique aussi symétrique que la courbe S. Dans les situations de la vie commerciale pratique ces arguments s'avèrent purement littéraires. Cet exposé montre que le concept de la durée technologique, malgré ses lacunes, peut être utile à appliquer dans le processus de décision. Les auteurs montrent que plus d'une caractéristique d'une technologie peut donner un exemple de comportement en forme de S. Ils signalent le risque si on ne se sert que d'une caractéristique. Les auteurs expliquent aussi l'utilité du concept de la planification d'un stock, et le phénomène des courbes multiples en forme de S.

Mots-clés: durée technologique, décisions commerciales, planification d'un stock, décisions d'investissement, décisions dans la recherche et le développement, courbes en forme de S.

Zusammenfassung: Obwohl die allgemeinen Phänomene der technologischen Lebensdauer seit langem bekannt sind, ist deren quantitative Beschreibung immer noch widersprüchlich. In der Mehrheit der Fälle beschreibt eine S-Kurvenanpassung die Phänomene recht gut. Es gibt jedoch Fälle die von der S-Kurve bedeutend abweichen. Es erhebt sich auch die Frage ob die Kurve in der Praxis so symmetrisch wie die reine S-Kurve ist. In Situationen des praktischen Geschäftslebens erweisen sich diese Argumente als rein akademisch. Dieser Beitrag zeigt, daß das Konzept der technologischen Lebensdauer trotz seiner Unvollständigkeit im Entscheidungsprozeß nützlich angewendet werden kann. Die Autoren zeigen, daß mehr als ein Merkmal einer Technologie ein S-förmiges Verhaltensmuster aufweisen können.

Sachwörter: technologische Lebensdauer, Geschäftsentscheidungen, Kontingentplanung, Investitionsentscheidungen, Entscheidungen in der Forschung und Entwicklung, S-Kurven.

要約。技術のライフ・サイクルの一般的現象についてはすでにだいぶ以前から知られているが，数量的な説明については依然として議論が分かれている。通例，そうした現象にはS字カーブがよく適合する。しかしながら，S字カーブから著しくはずれる事例もある。また，はたして実際のライフ・サイクルにおいて，カーブが純粋なS字カーブのように対称的であるのかどうかという問題もある。現実の企業状況からすれば，これらの議論はややアカデミックにすぎるきらいがある。厳密に言えばライフ・サイクルの概念はまだ不完全な位置しか持ちえないが，この論文は，それにもかかわらずライフ・サイクルの概念が意思決定にとって有効でありうることを示している。著者たちはまず第一に，S字型のカーブをたどる技術の属性が二つ以上ありうることを証明している。したがって，一つの属性だけを用いることは危険であることを指摘している。著者たちはまた，緊急計画化（コンティンジェンシー・プランニング）にとってのこの概念の有効性を示し，多数のS字カーブが起こる現象を明らかにしている。

キーワード。技術のライフ・サイクル，企業決定，緊急計画化（コンティンジェンシー・プランニング），投資決定，研究開発決定，S字カーブ。

1 Introduction

Solutions and problems are two inseparable partners in real life, in personal affairs, in business, in science and technology, and in national and international politics. Most of the time, problems search for solutions. Occasionally, a solution may be searching for problems.

In business, life is filled with problems searching for solutions. Businessmen are so eager for new promising solutions that they often over-react. When they find that the promise is not there, they drop the 'solution' like a hot potato. The rise and fall of Operational Research is a shining example.

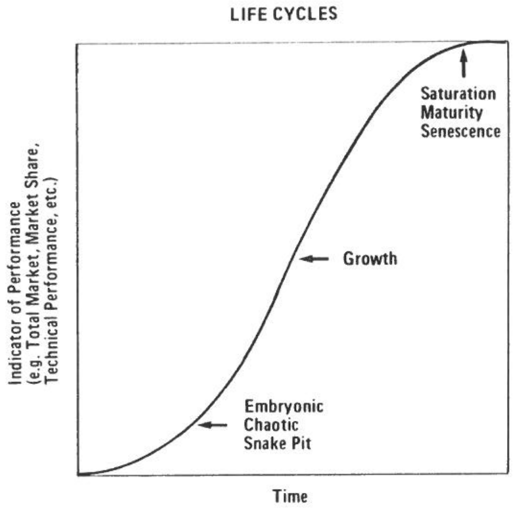
A major, and perhaps the most difficult problem faced by business executives is: how to manage technological change? This problem has been searching for a solution since the industrial revolution, but none has been found. However, general patterns of regularities have been observed, e.g. production capacity for a mature product tends to move gradully from high-wage to low-wage countries, which eventually become exporters to the high-wage countries.

A closely related phenomenon associated with mature industries is the excess capacity problem. Today, there is excess capacity in petroleum refining, steel, aluminium, automobiles, traction equipment, farm equipment, steam turbines, generators, transformers, switchgear, ship-building, textiles, commodity chemicals, semiconductors – the list is long. How did business executives let that happen? Threats of excess capacity are on the horizon even for high-technology products such as commercial airliners, telecommunications equipment, and computers in all sizes except the very largest. There is no indication today that industries not yet affected are sufficiently aware of this danger to take actions before it is too late.

When technologies compete for market share, there seems to be a regular pattern, i.e. the process follows an S-curve (often approximately the mathematically convenient logistic curve). Fisher and Pry [1] at General Electric Co. demonstrated this 26 years ago for binary competition (two technologies competing against each other); Marchetti and Nakicenovic [2] and others extended the concept to multi-component systems and successfully applied the methodology to energy substitution and a number of other cases.

The discovery of these 'regularities' has led to the suggestion that there may indeed be a solution to the difficult question of 'how to manage technologies', i.e. the concept of technology life-cycles. The underlying belief is that technologies behave somewhat like biological systems. There are embryonic, adolescent, and mature stages (Figure 1). Behaviour or characteristics, such as total market, technical performance, cost, market share, and industry structure, vary from stage to stage along the S-curve. Recognizing the need to manage differently for different stages can be a key to success, while ignoring it may invite disaster. Foster [3] has given a number of case histories of business failures due to either ignoring or disbelieving the S-curve phenomenon in technological innovation, e.g. how American Viscose lost out to DuPont in the competition between rayon and nylon for tyre cords and how DuPont subsequently lost out to Celanese in the competition between nylon and polyesters for the same market.

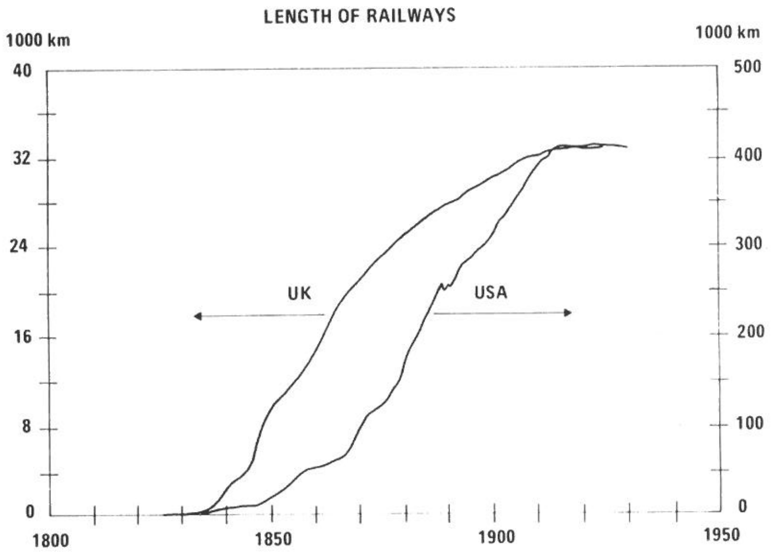
Figure 1 Improvement of technological performance over time shown as an S-shaped growth path indicating three life-cycle phases – the embryonic introduction, growth, and saturation phases



Nevertheless, reactions to the S-curve concept are mixed. Believers tend to consider it as a forecasting tool. When they apply this concept to the case of technological diffusion, e.g. the competition between technologies for market share, they tend to leave a fatalistic impression, i.e. once a technology starts to lose market share to another technology, nothing can be done to reverse that trend. This fatalistic prediction, true or not, is hard for operating businessmen to accept. No-one wants to lie down and 'play dead'. And in history, there are enough examples to show that the trends can be reversed by product or process innovation. Foster makes that point by using the S-curve for technical performance. Whenever the rate of progress slows down, reflected in the sharp increase in the cost-for-unit progress, one should be alert to new technological advances.

However, if one follows this concept blindly, disasters can happen too. Take the large steam-turbine generator business: the rate of technical progress slowed down after Philadelphia Electric's Eddy Stone experience long before the oil embargo. But if utility and manufacturers continue to pump resources after 1973 to advance that technology, or any other technology for the same market niche, they would be wasting a great deal of money (of course, this did happen) because the market has disappeared. The market saturation shows up in a different S-curve, unrelated to the one for technical performance.

Figure 2 Growth of length of railway network in the UK (left-hand axis) and the USA (right-hand axis). While the growth path followed an asymmetric S-shaped curve in the UK, the curve for the USA is more symmetric with a gradual increase between the 1830s and 1870s. *Sources:* References [4] and [6]



Disbelievers can easily argue that there are exceptions to the S-curves. Figure 2 shows such an exception. The growth of the railway network length in the UK follows an S-shaped path, but not a symmetric one. Instead the growth rate increased rapidly until the 1850s and then declined slowly during a period of 60 years. (In fact, the growth of railway network in the UK follows an asymmetric S-shaped curve called the Gompertz function.) This is an interesting counter-example, since the growth of railway networks in the USA and Germany followed symmetric S-shaped paths. Figure 2 also shows the more symmetric growth path for the railways in the USA. Thus, disbelievers can argue that a number of S-curves are not symmetrical; therefore, symmetrical S-curves are useless as forecasting tools. Planners in the electric power industry in the early 1970s certainly did not believe in S-curves at all for forecasting electricity demand growth. The consequences are well-known to us: overcapacity and capital crunch.

In this paper, we address the question of how to use S-curves on a broad basis. We will look at S-curves for total market, market share, as well as technical performance. We will show that when we look at a set of curves for the same market niche, a great deal can be learned for business planning purposes. We will discuss three specific uses for S-curves:

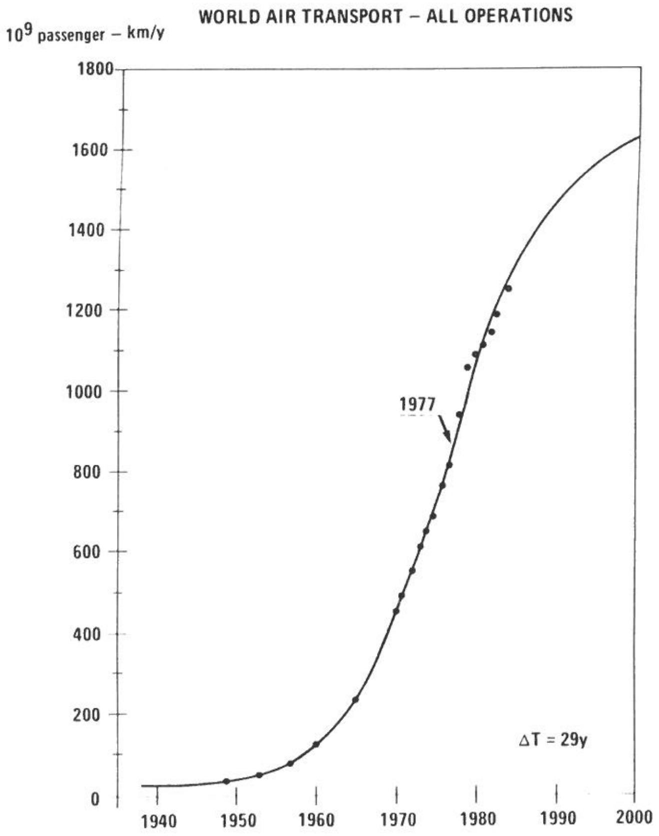
- Investment and R&D decisions,
- Contingency planning,
- Implications of multiple S-curves.

2 Application to investment and R&D decisions

Investment in capacity expansion at the wrong stage of a life-cycle can often lead to excess capacity, depressed prices and reduced profitability. History is filled with such cases. We will illustrate this point with aviation, an industry which may be on the verge of such a mistake.

Figure 3 shows the world air transport market, all operations, measured in 10^9

Figure 3 Growth of world air transport in billion passenger-kilometres per year. *Source:* Reference [6]



passenger-kilometres per year. On a linear plot it clearly exhibits an S-curve behaviour. Figure 4 is the same information on a semi-log plot. [9] The fit of the data to a logistic (or S-) curve is obvious.

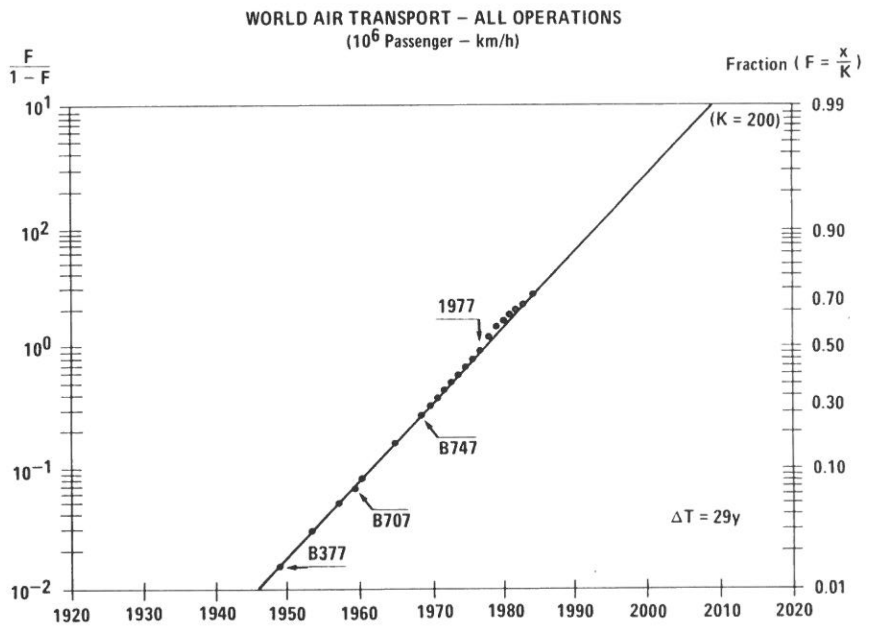
On Figure 4 we have also indicated the years of introduction for three landmark aircraft – the Boeings 377, 707, and 747. If the logistic trend continues, the total market will saturate at about 20 × 10^6 passenger-km/hr. The inflection point apparently occurred in 1977, when the market reached 50% of the saturation value.

What predictions can be made from this plot?

- The market will reach 90% of its 'ultimate' level about the year 2000.
- ΔT, the time required for the market to go from 10% to 90% of the saturation level, for the total market growth is about three decades (29 years).

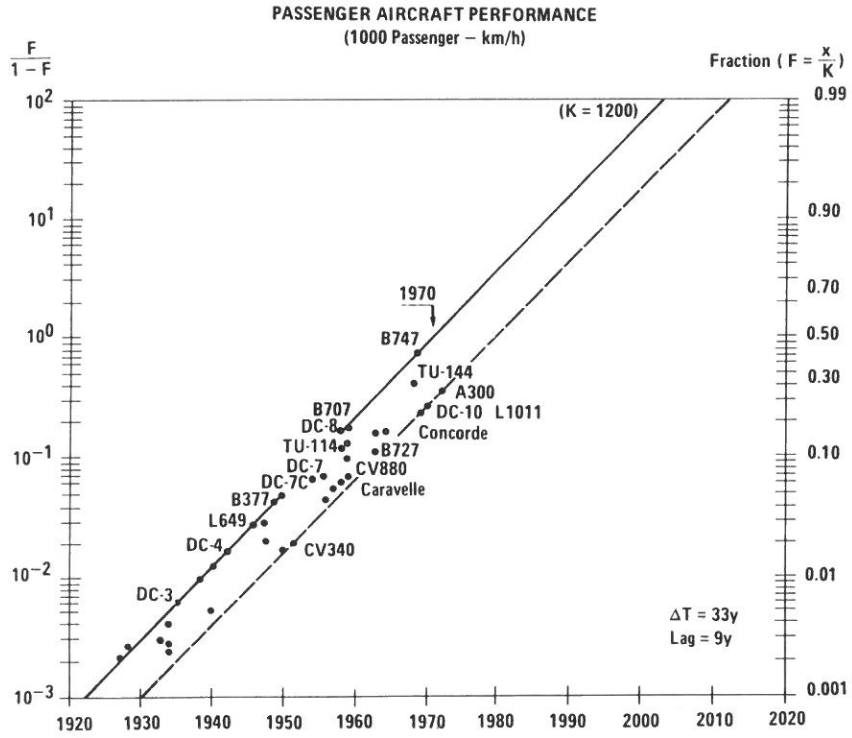
While these implications are interesting, even more can be extracted if we look at the evolution of the technical performance of passenger aircraft, shown in Figure 5. Like the air transport market, the performance of individual aircraft can also be measured in passenger-km/hr. Instead of following closely a straight line, there is a band, the left line representing the performance of the best aircraft. Let us stay with the left (upper) envelope of the band. The ultimate performance appears to be 1.2 × 10^6 passenger-km/hr. The following are the additional implications when one combines the information in Figures 4 and 5:

Figure 4 Growth of world air transport in million passenger-kilometres per hour, plotting $F/(1-F)$ as a function of time on a semi-log grid, where F is the fraction of the estimated saturation level K. In this way, results that would otherwise appear as S-shaped curves become straight lines, making them easier to interpret. *Source:* Reference [6]



- The performance of the present 747 is almost half-way to the 'ultimate' level. A stretched 747 (perhaps the planned 500 series) may be all that is needed. Certainly, this has serious implications for R&D decisions.
- The 'ultimate' market can be served by 170 stretched 747s or 340 planes of the present vintage, if the aircraft operate to capacity all the time. Of course, this is not feasible for many reasons. There are about 600 747s in service now, suggesting a 30% capacity utilization (assuming that 170 stretched 747s would be needed). We do not know what the ultimate capacity utilization should be. But it seems obvious that in the future, the need for additional production capacity will not be great. Yet at the present, both Japan and the EEC are trying hard to increase their penetration of the 747 market. Although they do not plan to build aircraft as large as the 747, they could increase the volatility and competition in the market by offering competing smaller aircraft.

Figure 5 Improvement of passenger aircraft performance (productivity) in thousand passenger-km/hr, plotting $F/(1-F)$ as a function of time on a semi-log grid, where F is the fraction of the estimated saturation level K. *Source:* Reference [6]



The above analysis is, by intention, grossly oversimplified. A more careful analysis would segregate the total market according to distances and the aircraft that serve these sectors. Yet it is not clear how a more disaggregated analysis would alter the basic conclusion that the industry as a whole may be moving into the state of overcapacity.

It is also interesting to note that ΔT for the evolution of technical performance is 33 years – not very different from that for the total market. Associated with the dynamic technical evolution of aircraft is cost improvement which has a significant effect on market growth. At the embryonic stage, the cost improvement is easy to achieve. The market grows rapidly because of demand elasticity. When a product moves toward the mature stage, improvement in technical performance becomes more difficult or costly, the learning effect on cost slows down and so does the market growth. It is therefore not surprising that ΔT for a purely technological attribute (performance) is not very different from the ΔT for a market attribute. The detailed reasons behind the actual closeness of these two numbers in the example should be the topic of further research. The fact that they are close implies that the total number of aircraft in service has been relatively stable, especially when compared with a factor-100 increase on all operations and aircraft productivity.

If one had to make a choice between different modes of transportation for investment purposes in the 1930s, the only information on air transport was the characteristics of the Douglas DC-3. Comparing the performance, cost and personal comfort of travelling by DC-3 versus travel by railroad, one might easily prefer to invest in the latter – if the relative rates of technical change were not considered. Fifty years later, there is no direct way to travel by rail from coast to coast in the USA. Looking at Figure 5, the reason for this is clear. The young aviation technology in the 1930s has improved its performance by more than a factor of 100. The already mature railroad technology showed little, if any, improvement. In fact, the total length of the main tracks and thus the effective size of the network decreased by about 30% since the 1930s. The lesson: neglecting the technology life-cycle phenomenon, and consequently also the growth potential of embryonic technologies, can lead to disastrous investment decisions.

3 Contingency planning: an example

In 1975, Marchetti [2] studied energy substitution processes (Figure 6) and predicted that after oil, natural gas may become the dominant energy supply in the world. His prediction was made at a time shortly after the oil embargo and the whole world was concerned with the depletion of two valuable energy resources: oil and natural gas. President Carter declared in 1976 that the energy problem was the moral equivalent to war. The Fuel Use Act was passed to forbid the use of natural gas in industrial boilers. The country adopted the energy policy of depending on nuclear energy and coal to become energy-independent.

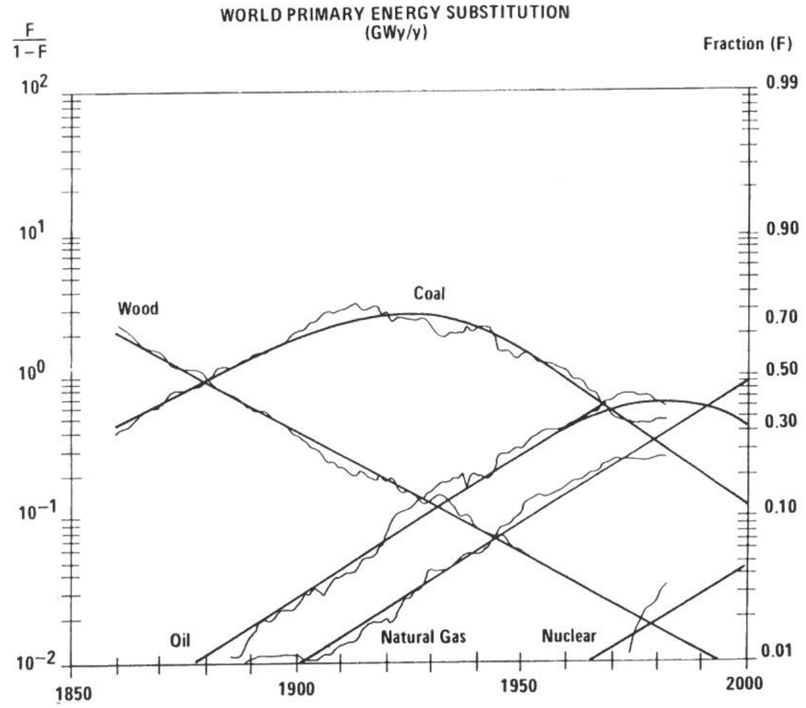
A massive energy R&D programme was introduced to develop the use of coal: coal gasification, coal liquefaction, fluidized-bed combustion, and a host of other technological options. Industries responded to this call for energy independence well; among them, the General Electric Co. (GE). It spent several billion dollars to acquire a major coal company – Utah International.

It was against this background that Marchetti was invited to present his prediction to GE's executive office. Half-way through his presentation, one of the senior vice presidents stormed out of the meeting, angrily stating: "I don't believe a word he said". One of the authors had a subsequent conversation with that senior vice president to point out that it is futile for business people to engage in a debate on which prediction is correct. It is an endless debate. The proper questions to ask are:

- If the prediction is correct, what might the consequences be to the General Electric Co.?
- If the potential consequences are severe enough, is a contingency plan (or insurance policy) justified?

The answer to the first question was obvious: GE's steam turbine business might be in serious trouble, since the bulk of it was in the large steam turbine sector which supplied machines to large nuclear and coal-fired plants. On the other hand, the stationary gas turbine business might grow. The answer to the second question was rather obvious too: GE should have acted to protect its stationary gas turbine business by investing in R&D and by developing a creative international strategy.

Figure 6 The history of global primary energy substitution from 1860 to 1983. F is the fractional market share of a given energy source in global primary energy consumption and data are shown plotting $F/1-F)$ as a function of time on a semi-log paper. In this way, straight lines show the S-shaped growth and decline in market shares. Coal and oil curves went through a saturation phase that joins S-shaped growth to S-shaped senescence due to the fact that in a multicomponent substitution process not all competitors can follow S-shaped growth and senescence paths at the same time, so that one competitor is saturating. Market shares of primary energy sources are projected through 2000 by making explicit assumptions about the market penetration rate of nuclear: a 1% market share in 1965 and a 5% share in 2000. *Source:* updated from Reference [2]



Whether that discussion had a deciding effect on GE's strategy, we will never know. In any event, GE did pursue gas turbine market leadership aggressively. In 1983, 15 years later, the large steam turbine business in the USA, for all practical purposes, collapsed. The gigantic plant in Schenectady had to depend mostly on spare parts business. At the same time, the gas turbine business prospered, not in the USA, but in international markets. GE's creative gas turbine strategy, the 'manufacturing associates' arrangement, propelled GE to be the unquestionable number one supplier in the world. The dollar volume ratio of gas turbine business to steam turbine business within GE reversed almost exactly from that of 10 years previously.

We do not suggest that GE's success in the intervening 10 years in the gas turbine business was due to smart contingency planning, because it was never considered as such within GE. We report this conversation, therefore, only for the purpose of illustrating the potential importance of contingency planning.

Ironically, GE's gas turbine business had a major set-back in late 1985 and 1986, due to the drop in oil prices. A significant fraction of GE's gas turbine business was in the mid-East. The drop in oil prices caused cancellations that were not expected. Should there not have been a contingency plan for low oil prices in GE's gas turbine division? The answer is (in retrospect): Yes. However, we suspect no such plan actually existed.

Let us now return to the aircraft example. Two questions that executives and planners in the aircraft industry might debate are:

- Are Figures 4 and 5 good forecasts for the total market?
- Is Figure 5 a reliable forecast for the performance of civil aircraft?

Based on previous arguments, we suggest that, instead, the proper questions to debate are:

- If Figures 4 and 5 are correct – knowing the behaviour of the industry in general – what is the likelihood that the industry as a whole will march into a situation of excess capacity?
- If that happens, what are the implications for market share, price level and profitability?
- Should the industry spend money on an aircraft that is more advanced than a stretched 747?

By more advanced aircraft, we mean having higher productivity than that of a stretched 747 (say, higher than the planned 500 series). This means either more passengers (perhaps more than 1000 passengers capacity), higher speed (supersonic or hypersonic), or both. Emergence of more advanced aircraft could imply a new growth curve that would eventually substitute current aircraft technologies with a promise of a much larger growth potential. This situation is similar to the choice between railroad and the DC-3 in the 1930s.

One of the authors of this paper published a paper in *Harvard Business Review* not long ago on R&D planning.[5] In it, he proposed the concept of 'robustness' for examining the value of an R&D programme against possible (even unlikely) environmental shocks. Contingency planning is a way to improve the robustness of a strategic plan. Technology life-cycle can be a very useful concept for that purpose.

In business, the challenge is always to develop viable management strategies in the face of imperfect information. The S-curve concept helps to reduce the imperfection.

4 Multiple S-curves and their implications

Now we examine a few examples where the evolution cannot be described by a single S-curve. These examples shed light on the question: Is the S-curve a reliable forecasting tool?

Figure 7 show the advances of capacity for the best aero-engines on the market. The fact that there are two parallel straight lines means:

- There are two S-curves (Figure 8), one sitting almost on top of the other, each describing the evolution of a technology: the bottom one for piston engines and the top one for jet engines.

Figure 7 Advances of capacity for the best aircraft engines on the market, shown as two S-shaped growth pulses by plotting $F/(1-F)$ as a function of time on a semi-log paper, where F is the fraction of the estimated saturation level K. The first pulse (left) shows piston aircraft engines and the second (right) the jet engines. *Source:* Reference [4]

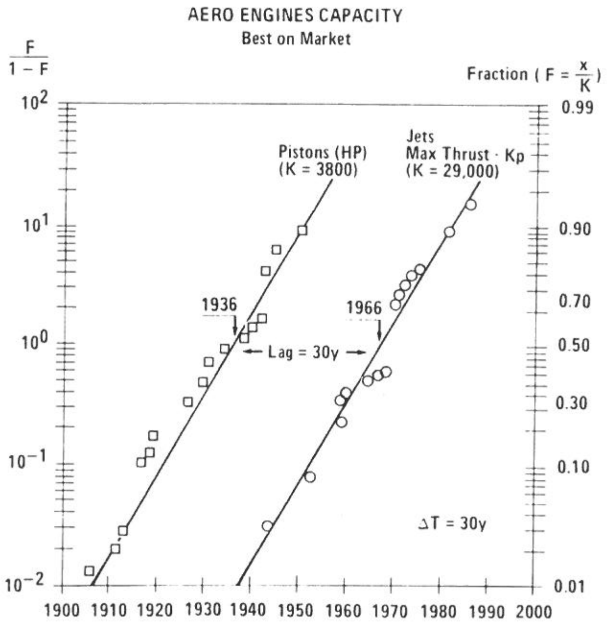
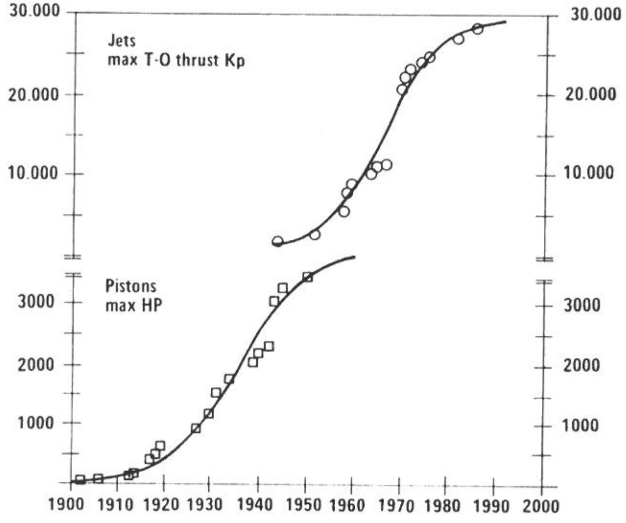


Figure 8 Advances of capacity for the best aircraft engines from Figure 7. The first (lower) S-shaped growth pulse shows the increase in horsepower (HP) of piston aircraft engines, while the second (upper) growth pulse shows the increase of take-off thrust (in Kp) of jet engines. *Source:* Reference [4]



- The rate of change of the technology, and the characteristic time ΔT is the same for both technologies, suggesting the existence of some social and economic environment common to both technologies. In this case: they serve common markets, namely civil and military aviation.

What useful implications can be extracted from Figure 7? If one believed in the predictive value of the logistic curve, say in the year 1930, one might have concluded that the largest piston engine would saturate with a thrust of about 3800 horsepower. Such a conclusion, by itself, would not have been too unreasonable. But if one used it in conjunction with multi-component substitution curves for all modes of transportation (Figure 9), one might have been led to a disastrous conclusion, based on the following logic.

The aviation market in 1940 was rapidly increasing (Figure 9), but the piston engine was nearing its ultimate technical performance. The 'obvious' strategy to capture greater market share is the learning-curve strategy. This strategy had not been formally articulated (as far as we know) by 1940, though T.P. Wright formulated in 1936 the so-called labour cost–quantity curve, on the basis of an analysis undertaken in 1922.[7] Actually, the Curtiss Company's price determinations for the decade after 1922 were based on the use of these curves, that subsequently became well known as learning curves. To exploit that strategy, one needs to have greater production capacity for piston engines. Following this strategy would have been disastrous because of the imminent appearance of a new technology: jet engines. The fact that saturation of piston engines was approaching in the 1940s while the total market was still growing should have alerted the planners to the possible emergence

Figure 9 The history of transport infrastructure substitution in the USA from 1830 to 1982. Market shares of transport infrastructures are projected through 2050. F is the fractional share of a given transport infrastructure length in total length of all transport networks. *Source:* Reference [6]

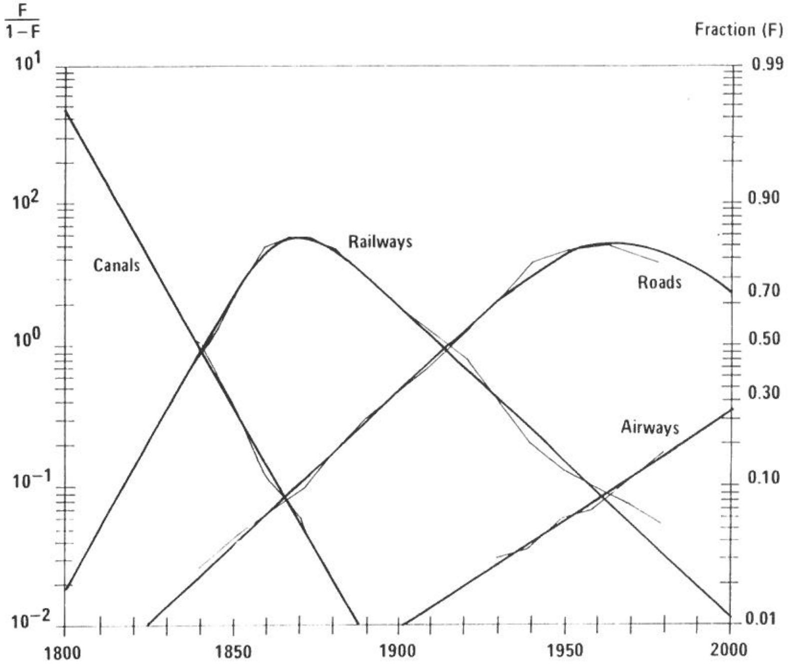
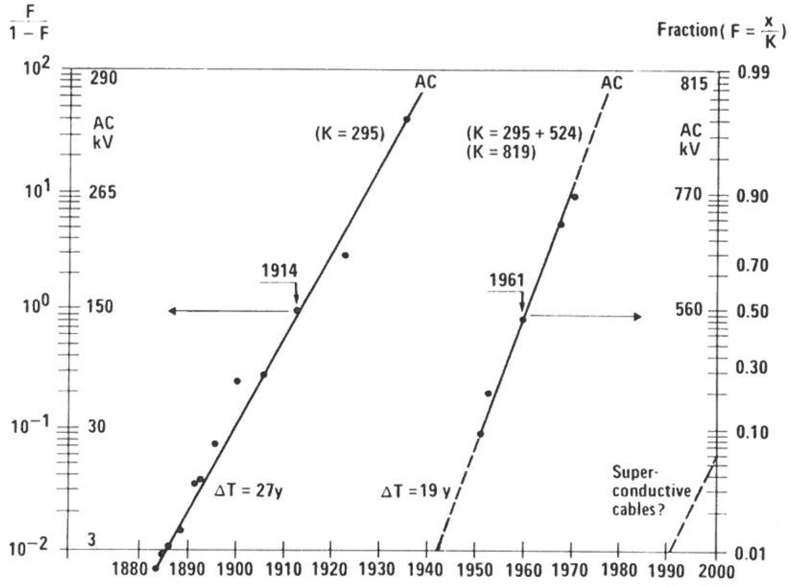


Figure 10 Evolution of transmission voltage, shown as two S-shaped growth pulses by plotting $F/(1-F)$ as a function of time on a semi-log paper, where F is the function of the estimated saturation level K. The first pulse (left) shows the voltage increase to $K = 295$ kV and the second (right) the increase to $K = 819$ kV. We have added a third, hypothetical increase in voltage that could be possible with the advent of superconductor cables. *Source:* Reference [4]



of new technologies. The job of the planner was made more difficult by combining the dynamic behaviour of both the market and the technology, but the risk of wrong decisions can be minimized.

A second example is shown in Figure 10, which shows the evolution of transmission voltages in electric power systems. Again, there are two straight lines, though with different slopes.

If a planner had studied the situation in the late 1940s, he would have seen a continuing growth of electricity demand (Figure 11), at an annual rate of 7% and a 'saturated' transmission voltage.[8] The obvious strategy would again be to exploit the learning curve. If this strategy was followed, it would have been disastrous.

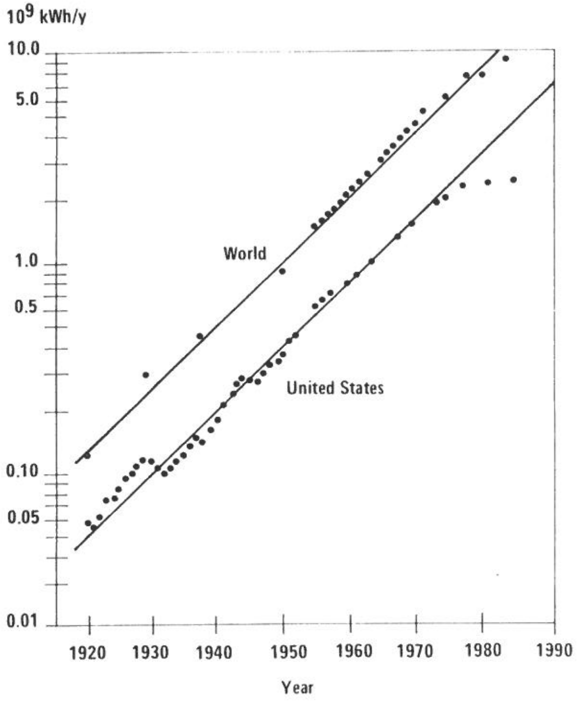
What actually happened? In the early 1950s, the electric utility industry discovered that by shifting a greater percentage of its capital resources into transmission *vis-à-vis* generation, the net saving, due to lower generation needs, is quite attractive from an overall viewpoint. This might well have occurred because of saturation in the rate of improvement of power generating technology. When this resource allocation strategy was discovered, an international competition on 'who builds the highest voltage first' began. This significantly altered the economic environment and probably was responsible for the shorter ΔT (19 years) for the second line.

It is interesting to note that the maximum voltage predicted by Figure 11, 819 kV, has not yet been exceeded. Some isolated attempts to develop voltages higher than 1000 kV have not yet led to commercial applications. There are indications in today's environment that power plants may change in the future from large to small, from centralized to dispersed. Thus, the need for higher transmission voltages may not appear for some time, although superconductive transmission may emerge as a new technology thereafter.

Two conclusions can be drawn from the previous examples:

- A single-attribute S-curve is not a reliable or useful forecasting tool (and may even be a misleading one). The most important reason is the possibility of a second wave, either due to new technology or due to a new economic environment.
- A multi-attribute approach to technology dynamics can be useful for business planning.

Figure 11 Generation of electric power over the past half century, for selected years worldwide and for the USA. The trend lines correspond to uniform growth at 7.2% per year (100% per decade). World electric power generation has been growing at about 8% per year. During the last decade both curves show signs of saturation implying an S-shaped growth process. *Source:* updated from Reference [8]



5 Conclusions

1 The S-curve offers a tool for recognizing the period when excess capacity and technology saturation may become probable. This should be factored in the for-

mulation of business strategies, e.g. the learning-curve strategy may cease to be feasible.

2 S-curves may not be reliable forecasting tools, but they can be very useful for contingency planning.

3 Saturation of a dominating technology in a growing market may signal the emergence of a new competitor or successor technology.

4 A single S-curve is not as useful, for planning purposes, as a set of S-curves dealing with different aspects of the same technology and market.

In short, S-curves can be useful, but we must learn how to use them intelligently.

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9 We will plot the S-curves on a semi-log paper. A simple S-curve has a saturation level K. For the variable x_i *(be it total market, cost, market share, etc.), we can express it as a fraction of the saturation level:* $f = x/K$. If $f/(1-f)$ is plotted as a function of time on semi-log paper, a perfect S-curve will appear as a straight line. Saturation level K is sometimes unknown, but it can be estimated from the data.

Technology offsets: structuring a new strategy for industrial benefits

Offsets technologiques: structuration d'une nouvelle stratégie pour profits industriels

Technologieableger: Der Aufbau einer neuen Strategie zum industriellen Nutzen

技術の相殺 — 産業的利益のための新しい戦略の構築

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Abstract: The changing structure of reciprocal trade practices or industrial benefits has received increased attention over the past five years by managers of advanced technology companies. In particular, technology offsets are being used by newly industrialized countries to forge a bold new trade strategy in order to become major players in this costly competitive game. The consequence of these compensatory arrangements has placed increased emphasis on developing strong linkages through licences, coproduction, turnkeys and marketing know-how. The principal focus of this paper is to examine technology offsets, a form of industrial benefits, in light of the dynamics of negotiating contracts from the international manager's perspective. In addition, an agenda for technology offset undertaking is examined in which influencing variables are separated in order to understand the competitive behaviour of the principal actors. The authors have researched and interviewed 25 high-technology companies which provide excellent case studies to support the theme of the paper.

Keywords: technology offsets, industrial benefits, offset management and strategy

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