83p

Applying the biological metaphor to technological innovation.

Businaro U.L.

Futures, December 1983, p. 463

A synthetic theory of evolution is taken as representing the metaphor for the process of innovation. The model is employed to highlight major characteristics of changes in technological innovation and in the time phasing of industrial inventions and innovations. Analysis at the level of the industrial sector is used as a heuristic example of the metaphor, with a focus on innovations in the car industry.

Forecasting future products is seen as related to materials requirements, primary human needs and the role of the service sectors.

83 p

APPLYING THE BIOLOGICAL EVOLUTION METAPHOR TO TECHNOLOGICAL INNOVATION

Ugo L. Businaro

A synthetic theory of evolution is taken as representing the metaphor for the process of innovation. The model is employed to highlight major characteristics of changes in technological innovation and in the time phasing of industrial inventions and innovations. Analysis at the level of the industrial sector is used as a heuristic example of the metaphor, with a focus on innovations in the car industry. Forecasting future products is seen as related to materials requirements, primary human needs and the role of the service sectors.

Keywords: industry; science and technology; systems analysis

THE USE OF expressions from the language of biology when dealing with innovation is not uncommon. Natural evolution was more explicitly used as a metaphor by Nelson and Winter, first in dealing with the economy and then to develop a model for technological innovation.[1]

The natural evolution metaphor might look quite simple to a non-specialist who would mainly refer to a simplified Darwinian two-stage process—mutation (invention) and selection (innovation).

Closer analysis reveals a much more complex and conflictual situation in the realm of biology, which might be of great value when seeking to draw comparisons with the variegated analysis attempted by students of the technological innovation process. Striking parallels between the two sets of literature have been discovered.[2]

The metaphor

When dealing with biological evolution one may refer, albeit somewhat simplistically, to three different points of view—that of the palaeontologist, of

The author is with the FIAT Company, Turin, Italy. This article is an edited version of a paper given to the international seminar on Innovation, Design and Long Cycles in Economic Development at the Royal College of Art, London, 14–15 April 1983.

0016-3287/83/060463-15$03.00

the biologist, and of the molecular biologist. The first, represented, for example, by Grassé,[3] deals with understanding and explaining the phyletic evolution of the biological world. The second point of view, eg that of Dobzhanski,[4] deals with the evolution of a single species through the study of populations. The third approach, eg in the work of Monod,[5] seeks to understand the basic principle of biological evolution at the level of biochemistry.

These various perspectives place emphasis on different aspects of biological evolution. This might explain why, 100 years after Darwin, there is still a serious debate among students of biological evolution, with each school aggressively defending its own theories. The palaeontologist tends to emphasize the finality of evolution, while the molecular biologist emphasizes mutation (by chance) and selection (survival of the fittest).

The search for a unifying theory has characterized the past half century of biological evolution research. We refer here to the 'synthetic theory'[6] as representing the metaphor for the innovation process. The basic ingredients of the metaphor are the following:

- a process for generating ideas or inventions characterized by creativity and chance;
- a 'storage container' where inventions can be accumulated;
- a 'duct with an on–off valve' which connects invention storage to the selection device;
- a 'selection machine' to test the inventions, accepting only those which are fitted to the 'environment'.

With respect to a simplistic 'change and necessity' theory, there are two major differences. First, the ultimate fate of an invention is not decided at the moment when it first appears, so future, more favourable conditions could govern the selection process. Second, the state of the valve (open or closed) is governed by a complex feedback mechanism that is dependent on past events. This is due to the architectural constraints imposed by the 'solution' already developed (the biological individual or the product and its related manufacturing process) that the invention aims at modifying.

These two ingredients in the model (storage and the go–no-go valve) are responsible for some of the most interesting features that appear to be characteristics of both biological evolution and technological innovation—the existence of a 'preferred path' of evolution (a chreod or necessary path according to Waddington[7]) and of different speeds of evolution in different times and conditions.

The existence of a different era of accelerated and large innovations in the period of phyletic change followed by a period of exploitation of the 'basic' invention is best expressed by Grassé.[8]

In studying Drosophila populations[9] genetic changes appear to diffuse in filling an ecological niche, with the characteristic features of a logistic curve.

Mutation in DNA cannot be fruitful unless in the cytoplasm the proper enzyme is available that can 'read' the new words formed in the genetic code. When, following a completely different chain of events at organic and glandular levels, new enzymes are produced, then a stored unused mutation in the DNA could produce sudden important changes.[10]

The Russian puppets model

Koestler presents his theory of the 'holon'[11] in a way reminiscent of Russian puppets. He uses the word *holon* to mean a unitarian and complex system. At a certain level of observation of the world, one can view it as a holon. At a more detailed level of analysis one sees a holon at each level of analysis. The same happens if one goes up in the level of aggregation. The resulting global image of the world is therefore that of an infinite set of holons, one included in the other. The dream of breaking down our view of the world into elementary components (the reductionist's approach) seems, at the least, impracticable.

Referring to biological evolution, the view put forward by Koestler seems to apply: at a certain level of aggregation (at the palaeontological, or biological, or molecular biological level), one can look at the observed data as manifesting systemic behavour. The fact that each holon shows the same basic dynamic characteristics, might simply be a 'topological' characteristic of open systems.[12]

We now consider to what extent the Russian puppets model also applies to technological innovation, a process that encompasses very different levels of world view—from fundamental science, to applied research, to development and industrialization. To emphasize a certain correspondence (although it is not an essential point) with the three levels of aggregation presented for the case of biological evolution, we refer here to three levels of aggregation when examining technological innovation:

- the epistemological perspective such as that of Kuhn;[13]
- the perspective of the diffusion of innovation, as typified recently by the work of Marchetti;[14]
- the macroeconomic viewpoint such as that of Freeman,[15] and Abernathy and Utterback[16] in the study of long-term innovation change in industrial sectors.

As we try to show, the theories put forward to explain the basic facts analysed in each of the three vantage points are consistent with the basic metaphor described above.

Popper's theory of conjectures and refutations[17] (focusing on the holon of the individual scientist) parallels that of a simple 'chance and necessity' Darwinism. Kuhn,[18] with his concept of 'normal' science, placed emphasis on the 'architectural' constraint of history which seems to force the search along preferred paths. We refer below to the contribution of Feyerabend.[19]

The success of 'substitution analysis',[20] when applied to so many different sets of data, can be interpreted with the same model used by biologists in studying the diffusion of a best fitted population in an ecologocial niche. The three-stage model[21] used to interpret the technological change of an industrial sector (from a state of flux when product innovation prevails in the search for a successful design, to a maturity phase where incremental process innovation prevails) looks very similar to Grassé's[22] model of phyletic evolution.

The catastrophe model

The dynamics of a closed system are governed by the increase of the entropy. Open systems on the other hand, in their input–output interaction with the environment, tend to increase the varieties of their configurations and their complexity to the point where through a crisis or a catastrophe a new systemic structure is produced (order from disorder).[23]

The simplistic model of an open system described above using the biological evolution metaphor, can explain the dynamics of the system between one crisis and another. The selection mechanism ensures that the system keeps itself in 'equilibrium' with the environment after it has adapted to it. The effect of the reservoir is a strategic one—in other words, being prepared for changes in the environment. The biologist, to underline these two abilities of a biological system, distinguishes between 'normalizing selection' (the tactical ability to maintain the system's aptness to the environment notwithstanding the push to change coming from mutations), from a 'directional or balancing selection' (the strategic ability to keep the system's fitness in line with the changing environment, taking advantage of the stored mutations).

This model, however, does not explain sudden 'catastrophic' changes. The literature of biological evolution can help further in pursuing the metaphor application to technological innovations. At the palaeontologist's level of aggregation, phyletic evolution has presented four or five big 'revolutionary' changes. In each one of these crises a 'mother form' appears from which various phyla develop. Some phyla go through a specialization process and evolution might come to an end, either with the species maintaining a static equilibrium with the environment, or with the disappearance of the species.[24] Other phyla maintain more archaic characteristics, develop less specialization and also take on new characteristics seemingly of no use for the species itself (eg mammalian characteristics in reptiles), up to the moment when they converge in a new 'mother form'.

Increasing complexity in body organization and in the level of brain development characterizes the changes from one stage of phyletic evolution to the other. 'Progress' in nature seems therefore to have a precise characterization: the ability to manage increasingly complex structures by means of an increasing ability to process information (higher mind).[25]

At the biologist's level of aggregation, the appearance of a new species (speciation) is the equivalent of crisis change. How may speciation be explained? Are new species generated by a continuous process of change (anagenesis) or by a sudden change process (cladogenesis)? Three of the mechanisms posited to explain cladogenesis[26] might be important for our metaphor:

- Isolation of the environment (the dumb-bell principle). A population of a given species living in an environment which separates from the rest (eg after a tectonic movement)—and stays thereafter completely isolated from other populations—might develop into a new species.
- Transplanting pregnant females into a new environment (the founder principle). Their progeny could develop into a population in which the selection of stored genetic changes fitted to the new environment might result in a new species.
- Hybridization among close species, living in overlapping ecological niches.

The first case refers to the effect of the construction of different environmental histories—open systems interaction; and the second case refers to exploitation of the potentiality for changes stored in the reservoir in case of a sudden environmental change. The third refers to interaction among separated open systems to form a new one.

It is interesting to use the metaphor to find analogies in epistemology. Feyerabend's[27] contribution to epistemology is that of revindicating the role of the 'anarchist' scientist who, by following an unconventional search path, produces new ideas (experimental data and theories). To do this he has to *isolate himself from the prevailing environment* of 'normal science' (to behave as an anarchist). The build-up of the new ideas together with the increasing inability of normal science to explain accumulated experimental data, might result in a new theory (a new Kuhnian paradigm).

An analogy with the founder principle (but also with the importance of carrying forward archaic characteristics in phyletic evolution to produce a new 'mother form'), might be found in the procedures by which a designer operates. In approaching a new problem to be solved, he first makes a perusal of past solutions to both similar and different problems.[28] Making old ideas work in a new set of specifications sometimes results in successful new products.[29] It is also interesting how often philosophers, in their search for truth, revisit ancient philosophical theories (eg revivals of Eleatic studies by neo-positivists) to find new starting points. With respect to the hybridization model, it is interesting to explore its relevance in the progress of science and technology through the overlapping and convergence of separate disciplines into new fields such as bio-engineering, physical chemistry, etc.

Long-term changes in technological innovation

It is naive for electrical engineers to state that complex systems demonstrate oscillating dynamic behaviour, because of the complexity of their feedback correlations and the imperfections of their 'control and instrumentation' system. Industrial dynamics[30] have helped to transfer this basic understanding to the economic and social systems. When trying to set up a simulation model of a complex system, the need for simplification compels one to distinguish between internal and exogenous variables, and to look for the determinants of changes.

Changing the way this subdivision is done in the model brings about differing explanations for the cause–effect relationships. The debate is clearly apparent when dealing with the issue of long-term economic change.[31] It is suggested here that any *complex open system* shows intrinsically a dynamic behaviour that goes through a series of expansions of a logistic type followed by catastrophic changes. The interactions between different complex systems (holons?), or, more simply, between a system and the 'rest of the world' (the environment), determine the timescale between one crisis and another. The Russian puppets model and the interactions *up and down* between the different holons could help to understand the appearance of micro- and macro-cycles and hypercycles.

It is not our intention to pursue this line of thought further. We simply point out that it is not strange at all, when one focuses the analysis on the technological system, to discover intrinsic sagging-type dynamics. Analysis of major invention–innovation data is consistent with the metaphor put forward at the beginning of this paper. The storage mechanism in particular is clearly evident.[32] That the interactions between different holons are important in setting the time constants of the global system, can be seen for instance in the analysis by Marchetti.[33]

The scarcity of data on technological inventions and innovations, and the ample margin of discretion in their classification, leave plenty of room for debate when trying to define quantitatively the characteristics of cycles (eg are waves of a constant length or not; how many cycles have there been since the beginning of the industrial revolution?).

To what extent does the metaphor that we are proposing help? We have already obtained hints on how the speciation metaphor can explain changes in the paradigms within the basic science holon. What about the interactions among the different holons internal to the innovation process (basic research, applied research, development)? Giarini and Loubergé[34] have proposed an interpretation of the past 200 years of economic development in terms of two major waves—the first is a technological wave based on the build-up and exploitation of empirical knowledge developed in the 18th century, and the second is a wave based on the *interaction* between technology and science starting in the last part of the 19th century.

Industrial sectors

One could interpret the second wave proposed by Giarini and Loubergé as a speciation deriving from the hybridization of overlapping 'species' (science and technology). For the heuristic use of our metaphor we propose a more disaggregated analysis, at the level of the industrial sector. At the beginning of the industrial revolution all industrial sectors were based on empirical knowledge and their development could be viewed on the basis of the invention–storage–selection model internal to the holon of development and industrialization. The development of modern mechanics and thermodynamics has certainly helped the development of technological innovation, but in a somewhat indirect way (a positivist philosophical posture, an understanding of the basic principles and constraints from science, etc).

The thermo-mechanical sectors have so far developed mainly on the basis of empirical knowledge. Other industrial sectors have instead developed following a different pattern, *viz* the 'science-based' industrial sectors (such as the electrical and chemical industries). Scientific knowledge developed first; the related industrial development can be seen as the exploitation of the niche opened up by the scientific discoveries.

The relationship between science and technological development has been very strict. The history of the development of large companies in the electrical sector, eg General Electric, or in the chemical sector, shows the pushing role of basic and applied research. The fact that these sectors were based on scientific knowledge had an important effect: their technological development 'path' could be forecasted following the scientific discoveries and progress. The similarity with the chreods of the biological metaphor is apparent. The 'ecological niches' of these sectors seem now to be well exploited, and several authors[35] point to the 'law of diminishing returns' of research in such fields.

The position and the role of research in the empirically based sectors are different. Applied research here has mainly had a 'service' role in solving problems posed by the practical development of the sector itself. Direct coupling with basic research has been scarce.[36] What will happen when the empirically based sectors 'encounter' the basic science, and scientific knowledge could then be used to design a product (predicting theoretically its detailed behaviour without having empirically to test prototypes)? This might be the beginning of a new chreod of development, a speciation by hybridization of different cultures. There are signs that this is becoming a reality for very complex products such as vehicle engines.

The reservoirs of basic and applied research—filled up with inventions that have led to innovations in other sectors—will be available to exploit the new innovation needs, as soon as the 'selection valve' on the ducts connecting them to the empirically based sectors opens. The limitations of the empirical approach for complex product design have until now enabled the attainment of only 'satisficing' design compromises. The scientific approach will enable real optimization in meeting design specifications and constraints. How far is today's 'good enough' car engine design (which developed through a century of empirically based invention and innovation) from tomorrow's optimal design (based on the possibility, for instance, of predicting on paper the distribution of flow fields and of materials composition in every part of a combustion chamber)?

While existing scientific-based industrial sectors are approaching the exhaustion of the exploitation of their respective chreods, the old, mature, empirically based sectors might be faced with a lengthy period of new development. The actual situation is more complicated because we are facing not only hybridization between empirically technological and basic knowledge, but also hybridization with 'horizontal' new technologies such as microelectronics and informatics.

The coarse picture of technological innovation that emerges above at an aggregated macroeconomic level is that of a superimposition of the somewhat separated development of two different classes of industrial sectors: one development started from the holon of industrialization, and the other from the holon of basic science. It might be interesting to speculate whether there has been a third chreod of development for new sectors starting within the holon of applied research.

Without going too far into this topic could one not look at the phenomenon of the large applied research projects started during world war 2 (radar, nuclear energy) and soon after (space) from this point of view? These projects certainly may have started because of existing consolidated scientific knowledge (successfully passing the selection test in the basic research holon) pointing to potential practical application (filling the applied research reservoir of inventions). The establishment of large projects has had the effect of opening the selection valve and providing resources to perform the selection operation itself. It can be viewed as a speciation emerging from a 'pregnant' applied research 'female' transplanted to a new environment (the resources made available by the big projects).

Will these new phyla given birth by the 'mother form' of applied research develop into successful new industrial sectors (species)? The fate of the nuclear industry is in doubt but space telecommunications, eg, seems here to stay.

Time phasing of industrial innovations

In another paper,[37] this author has used the biological innovation metaphor to illustrate how the relationships within an enterprise develop between R and D and other functions within a company, and whether a rational approach could be followed in the subdivision of the financial resources between the different investment needs.

In a large company, manufacturing, design and applied research can each be considered as a complex open system—separated organizationally and spatially from each other—displaying its own 'evolutionary' dynamics, with complex interactions among themselves and with the environment (see Figure 1 where the case of three interacting invention–selection systems is shown forming the innovation process, from basic to applied research, to development and industrialization).

The intrinsic 'time constant' is different for the different stages in the innovation chain. For instance, in the case of the car industry, the lifetime of an engine factory is of the order of 20–30 years, that of an assembly line is around ten years. The commercial lifetime of a new car model is around ten

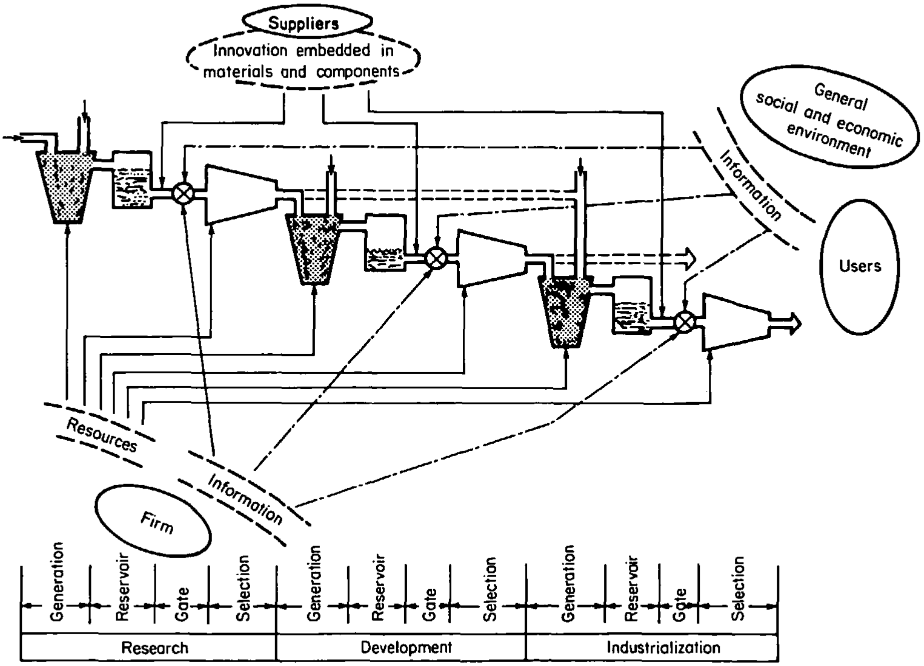

Figure 1. The inter-related open system of the company

years, with two to three major restylings during the model life. The time needed to design a new car, assuming that all the relevant technical and technological information is already available, is four to five years. Demonstrating that a new engine concept is feasible, or that new materials can be technically and economically introduced on cars, can range from a few years to 10–20 years. The difference in time constants and the uncertainties intrinsic to R and D projects show how important it is to have the reservoirs of invention in the development and industrialization system well filled at the moment when the decision is taken to proceed with a new product design and new capital equipment investments.

On the other hand, the successful completion of an applied research phase showing how to change innovatively a product component cannot be transferred before a decision is taken to change the product model or to renew the obsolete manufacturing equipment (the selection valve should be open).

According to our metaphor it is to be expected that the flux of actual innovation (the output at the end of the innovation chain) will display oscillatory behaviour. Do these oscillations have wave-like characteristics with constant periods? The theory of product life-cycle assumes that products, in a certain product class, have a distinct constant lifetime. In recent years, however, this theory has been much criticized, and only in special cases (a mature industry, a stable market) a periodicity is apparent (eg in the case of automobiles in the USA in the years 1950–60).

More common are non-periodic oscillations. The company management is directly responsible for setting the time of each innovation oscillation because of the decision to start a new product and/or to renovate the capital investment. The intensity of the innovation in the new product depends, however, less directly on the management itself, because of the effect of previous decisions on giving resources to research projects (opening the selection valves in the R and D system) and the availability of innovation proposals from outside the company (suppliers of materials and equipments), etc.

When aggregating individual companies in an industrial sector, and different sectors in the entire productive system, it seems difficult to accept that the aggregation of widely different unphased and unperiodic oscillations will lead to a periodic behaviour. Even the clustering of major innovation seems difficult to understand in terms of aggregating the microscopic behaviour of the different actors of the innovation process. The contradiction with the evidence of large innovation changes within an industrial sector (see eg Abernathy's study of the US car system[38]) might simply be another example of the reductionist approach in complex systems analysis being invalid (the system displays global behaviour that is different from that of the sum of its components).

Environmental change

The biological evolution metaphor, and especially the reference to speciation mechanisms, could help in understanding better how change in the environment could be related to a sudden burst of innovation.

Let us suppose that a major economic crisis is the equivalent of an environmental change in natural evolution. What happens at the micro-level of a company when a sustained crisis is occurring? Each individual company, because of the gloomy market forecast, will try to delay the introduction of new models and renewal of the manufacturing plants whose planned time of change falls within the period of economic crisis. Notwithstanding this, the old product has to sustain the competition which is becoming stronger due to market shrinkage. Company management is therefore looking for innovation which can reduce manufacturing costs and to some degree renovate the old product (a restyling or facelift?) at as low a cost as possible. The innovation, mainly at the component level, should be compatible with the existing product and the current manufacturing system.

Within these constraints, the management is ready to take higher risks, to some extent accepting not fully proven innovations. In the jargon of our metaphor, the selection valve is now open. During an extended crisis, therefore, the selection machine operates at the component level, and the entire industry structure has an opportunity to learn, directly in the field, how to make the best use of innovation. In other words the formal barrier between research and industrialization is raised and the two systems proceed together along the learning process.

When the economic crisis is over, the diffusion of the acquired learning, at the component level, within all the company functions, of how the innovative changes can be dealt with, will provide the starting point for innovative jumps, this time at the *system* level (both product and manufacturing being considered as a system). To give an example, the introduction of a microcomputer as a trip computer on cars, mainly as a way of giving a facelift to the old product, will introduce electronics to the *mechanical* world of car engineers and provide a degree of familiarity; this learning will thus provide the basis for a true integration of electronics and mechanics when designing new engines.

As another example, the introduction of automated computerized quality control stations at different points in car manufacturing lines might be accelerated, in a time of crisis, because they are compatible with existing manufacturing facilities, they increase quality, and reduce cost. The experience thus built up will enable, when a completely new plant is being designed, changes to be made in the entire systems philosophy interconnecting, via computer, all the automated quality control stations; with such automation feedback, signals may thus be obtained which will enable changes to be made in the process variables (for instance changing the dies or tools) in order to keep quality within prescribed ranges.

The future of the world of products

When analysing natural evolution, it is difficult to resist the temptation—following the apparent finality of the evolution itself—to forecast what will be the next step. Teilhard de Chardin[39] attempted this. The pervasive diffusion of information technology—with the exponential increase in the flow of communications, and the building of memories external to our brains—might be seen as a move in the direction of the development of the *nous*, forecasted by Teilhard de Chardin. Further, a recent book[40] suggests that increasing data available on the mental activity of different animals might point to the direction of evolution focused on developing the optimal brain.

The reason for mentioning Teilhard de Chardin and his epigons here—acknowledging their much more ambitious and far-reaching work—serves to raise the following question: is it possible, on the basis of the *process* of evolution (not its ends but its means), to forecast the lines of development of products made by man? Technological innovation (in its broadest meaning) is the process (the means) used to renovate the world of products. It might seem easier here, with respect to the natural evolution case, to accept that the end (the finality) of the progress in the world of products is clear, *viz* to satisfy, in an increasingly better way, human needs. But is it? How do human needs change in the light of the appearance of new products?

Fortunately, it is not necessary to examine the finality of product development. The general process itself by which an open system interacts with the environment seems to condemn it to progress in a certain direction, following a typical pattern. An open system that emerges renovated in its structure after a revolutionary change (a catastrophe) exploits the potential of its new structure (it fills its ecological niche), increasing its complexity (both internal to the system and in relation to the environment) to a point where it requires increased capability to deal with such complexity. A revolutionary change might then occur, which will change the systemic structure and the system's relationship with the environment.

The Grassé[41] definition of progress in phylogenetic natural evolution (increasing complexity, 'controlled' by an increased level of mental ability), could be translated as a metaphor to the world of products by substituting the notion of mental ability with 'information' or 'knowledge'. It is not difficult, when looking at human history, to trace the continuous increase in the knowledge needed to manufacture and/or use products. The simple case of the vase proves the point. In prehistoric times, clay and solar heat were used to make pottery. The amount of information needed to learn the manufacturing process was low. It was then learned how to make vases out of glass: the information needed to learn this process was much higher. Referring now to a vase made from thermoplastic material, a great amount of information has had to be accumulated (organic chemistry to develop new materials, manufacturing technology, etc) in the past two centuries to make this possible.

Luckily, one has not had to use all that accumulated information (studying chemistry, thermodynamics, control theory, etc) to make a plastic vase. The information has been aggregated in easy-to-use 'packages' (the thermoplastic grains, the extrusion press, etc) so that, because of this high degree of order,[42] it is very simple to transfer the required knowledge to the practical manufacture of plastic vases.

Forecasting product changes

The method we are suggesting here in trying to forecast revolutionary changes in our world of products (revolutions, which might be difficult to detect because they are masked by the continuous incremental innovation both in products and manufacturing process), is to look at the increasing degree of complexity (in different product sectors, and/or looking from the perspective of different societal functions), and ask oneself if in dealing with such complexity a new 'order' might not be needed and made possible because of a higher-level ability to aggregate and manage information. It is suggested here that the problem be examined from three vantage points: that of the *materials* needed to manufacture products, that of the *primary human needs* satisfied by the products, and that of the so-called *service sectors*.

Materials. The number of different materials available to build any kind of product has increased 'exponentially'. Even a talented mechanical engineer has difficulties in perceiving the relative advantages/disadvantages of a host of engineering plastics, for example. Different materials are first adopted and then discarded in new models of a product, to reappear (often together with a new manufacturing process) in later versions of the same product. The successful application of new materials in one industrial sector (eg carbon composites in aircraft) is pushing designers to look at the possibility of their use in completely different fields (eg electric motors, cars etc). The learning process for optimal use of new materials goes through a phase of trial and error, and it is very lengthy: it took more than 15 years from the first appearance of thermoplatics in car panel boards to its optimal use today (both from the point of view of design style, choice of materials, and manufacturing process).

The first wave of industrial revolution was dominated by steel as the base material for most industrial products. Since then, new materials have been added to the list, at an accelerated pace in the past half century thanks to developments in chemistry. Fibre composite materials, together with new process technology developed to increase the flexibility of application, might well become the new base materials. If so, the product design itself (and possibly the way products perform their basic functions) will be changed. Today's subdivisions between industrial sectors (primary materials producers, the materials processing industry, and the component and end-product manufacturers) will have to change in such a case.

The amount of information needed to design and manufacture products using composite materials at their optimum, is certainly greater than that for using steel. The problem (in our metaphor, the problem for progress) is to establish whether such increased information could be managed to simplify the entire process of designing, building and using products.

Primary needs. To oversimplify, one could say that products can be grouped according to the primary human functions they satisfy—the home, transport, food, etc. The primary needs, however, do interact among themselves, to a higher or lesser degree case by case. Product specifications should therefore take account of such interactions. The basic design of a product and the way it satisfies the basic need—and takes care of other needs—might, however, have remained unchanged over several decades or even centuries (even if the product and its manufacturing technology have undergone a continuous series of innovations).

In the meantime, from the first appearance of a product society might have changed greatly and hence the way the primary functions interact. Is the base design of the product (conceived years ago and at that time, hopefully, optimizing the satisfaction of human needs) still then the optimal response?

As an example, consider kitchenware. The number of products has increased enormously, and often they remain unused in the kitchen which has become increasingly small, especially in the dense urban areas. Patterns of food consumption are also changing with a growth in the variety of foods available (from all over the world), and the types of processing (raw, pre-cooked, frozen, etc). Today's consumer is confronted with many alternatives, from the traditional family recipe, to fast microwave cooking, to frozen TV dinners. Has the position not now become too complex and too great a contrast with the changes in other primary needs (home, leisure, etc)? A reappraisal of kitchenware goods to simplify (with a higher-level use of available information) the situation might be needed. This might signify quite a 'revolutionary' change in the product world.

As another example, in the same vein, take the interaction of the automobile with urban traffic. One solution proposed by transport planners years ago, but apparently with little or no success, was to induce a shift in the use of the different modes of transport, favouring the increased use of collective public transportation. The resistance of car drivers to abandoning their habits, notwithstanding the increasing complexity and reduced efficiency of modern driving (slower average speeds, parking problems, etc) should point to a new direction, which might lead to a 'revolutionary product change'. Here again the answer might lay in making use of higher-level information management, thanks to the information technology revolution. The new car of the future will then be one having the capability of interacting actively with a computerized traffic control system, not only to optimize the operation of traffic lights, but also to change modes of driving (to an automatic mode) on certain properly instrumented lanes.

It might be too limited, though, to look at 'revolutionary changes' in automobiles by considering merely the interaction with urban traffic. The interaction with parking, for instance, as well a with other short- and long-distance transport needs are important, and, taken together, might lead to a complete redesign of transport means and infrastructures. In this specific case I am not indicating a 'hard change'. The constraints derived from historical developments so far (with all the patterns of 'hard' investment already made) preclude such a 'hard' change.

Hopefully, smarter use of 'soft' technology at the car design stage (for instance the length of a car, better matching requirements for parking and car transport by rail) and for improved use of existing infrastructure ('intelligent' traffic lights, instrumented lanes, etc), might achieve a lot. In the end, a big revolutionary change (a simpler way of managing a dense and highly mobile society) might result. Nature, to change from primates to man, did not rebuild the body, but simply added a small cortex to the brain!

Services. The third case derives from the service sectors. An increasing share of the active population is working in the tertiary sector, and social scientists have for several years claimed that we are shifting to a post-industrial society. This does not mean, however, that less and less hard products will be produced, substituted by soft products or services.

A recent study by Gershuny[43] is illuminating in this respect. While the level of service activities is increasing, this merely means that the hard products we buy have a higher content of service activities in their added value. While industries are buying more and more industrial services the reverse seems to be the case for personal services. If one looks at the way that personal services are performed one can detect a trend of increasing complexity and reduced efficiency (school, health, social services). Gershuny suggests that new hard products are emerging that, together with the availability of an increased amount of free time (reduced working hours), heighten the possibility of substituting personal services that were previously bought with do-it-yourself work. Examples range from the substitution of barber services with the safety razor, to magnetic tape substituting for university lessons (eg the case of the UK Open University), to using family computer terminals and special detectors for medical check-ups as substitutes for doctor's visits (at least for a first screening and for minor illnesses).

Enough has been said in the past few years on the effects of the informatics revolution. It is suggested here that the revolutionary effects of information technology, which are still to be seen, will come about because of the increased complexity of our society's 'open system', due to the very success of the latest wave of development (an affluent society, increased social security and social equality, worldwide person-to-person communicatons and interactions). This increased complexity is displaying—firstly in the social services—a *decrease* in efficiency. No matter how popular a conservative political approach might become (dreaming of going back to the 'good old days' when society was less affluent and less complicated), the *process* whereby there is progress in the open system will derive from using at a 'higher level of intelligence' the information technology available, from simplifying the use of complex knowledge (by packaging it in a way different from today), and from recuperating a greater role for individuals, possibly beginning in the nature of the service products themselves.

Notes and references

1. R. R. Nelson and S. G. Winter, "In search of a useful theory of innovation", *Research Policy, 6,* 1977, page 36.
2. U. L. Businaro, "Comparing natural evolution and technological innovation" (FIAT Research Center, 1982, Internal report).
3. P. P. Grassé, *L'Evolution du Vivant, Matériaux pour une Nouvelle Théorie Transformiste* (Albin Michel, Paris, 1973).
4. F. Dobzhanski, *Genetics of the Evolutionary Process* (Columbia University Press, New York, 1970).
5. J. Monod, *Le Hasard et la Nécessité* (Editions du Seuil, Paris, 1970).
6. E. Mayr, *Animal Species and Evolution* (Harvard University Press, Cambridge, MA, 1963).
7. C. H. Waddington, "Stabilisation in systems: chreods and epigenetic landscapes", *Futures, 9* (2), April 1977, pages 139–146.
8. Grassé, *op cit*, ref 3.
9. Dobzhanski, *op cit*, ref 4.
10. Monod, *op cit*, ref 5.
11. A. Koestler, *Janus—Equisse d'un Système* (French translation) (Calmann-Levy, Paris, 1979).
12. See J. L. Le Moigne, *La Théorie du Système Général* (Presses Universitaires de France, Paris, 1977), for an analysis of the evolution of 'open systems'.
13. T. S. Kuhn, *The Structure of Scientific Revolutions* (The University Press, Chicago, 1962).
14. C. Marchetti, "Invention et innovation: les cycles revisités", *Futuribles*, March 1982, page 43.

15. C. Freeman, *The Economics of Industrial Innovation* (Penguin, London, 1974).
16. J. M. Utterback and W J. Abernathy, "A dynamic model of process and product innovation", *Omega, 3* (6), 1975, page 639.
17. K. R. Popper, "The Logic of Scientific Discovery" (1934).
18. Kuhn, *op cit,* ref 13.
19. P. K. Feyerabend, *Against Method, Outline of an Anarchist Theory of Knowledge* (New Left Books, London, 1975).
20. Marchetti, *op cit,* ref 14.
21. Utterback and Abernathy, *op cit,* ref 16.
22. Grassé, *op cit,* ref 3.
23. J. Prigogine and J. Stengers, *La Nouvelle Alliance, Métamorphose de la Science* (Gallimard, Paris, 1979).
24. J. L. Heim, *700000 Siècles d'Histoire Humaine* (Eyrolles, Paris, 1979).
25. Grassé, *op cit,* ref 3.
26. M. J. White, "Speciation: is it a real problem?", *Scientia,* 1981, page 455.
27. Feyerabend, *op cit,* ref 19.
28. J. C. Jones, *Design Methods: Seeds of Human Futures* (J. Wiley and Sons, New York, 1980).
29. As a marginal note, the reader is referred to the discussions among students of the design process to discover reference to Popper's 'conjectures and refutations' theory, to the historical cycle theory of philosophers such as Vico, and others: see R. Jacques, J. A. Powell (eds), *Design: Science: Method* (Westbury House, Guildford, 1981).
30. J. Forrester, *Industrial Dynamics* (McGraw Hill, New York, 1966).
31. Special issues on Long Waves, *Futures, 13* (4), August 1981, and *13* (5), October 1981.
32. See Figure 18 in A. K. Graham and P. M. Singe, "A long wave hypothesis of innovation", *Technological Forecasting and Social Change, 17,* 1980, page 283.
33. Marchetti, *op cit,* ref 14.
34. O. Giarini and H. Loubergé, *La Civilisation Technicienne à la Dérive* (Dernod, Paris, 1979).
35. *Ibid.*
36. When criticizing, as several people do, the unsatisfactory links between industries and universities, one should also distinguish between empirically based sectors and scientifically based sectors.
37. U. L. Businaro, "R and D investments and business cycles; development of the corporate strategy", EIRMA Annual Conference, Paris, 1982.
38. W. J. Abernathy, *The Productivity Dilemma, Roadblock to Innovation in the Automobile Industry* (Johns Hopkins University Press, Baltimore, 1975).
39. P. Teilhard de Chardin, *Le Phénomène Humain* (Editions du Seuil, Paris, 1955).
40. R. and B. Chauvin, *Le Modèle Animal* (Hachette, Paris, 1982).
41. Grassé, *op cit,* ref 3.
42. See the paper by H. A. Simon, "The architecture of the complexity", in H. A. Simon, *The Sciences of the Artificial* (MIT Press, Cambridge, MA, 1969), for the importance of the ability of complex systems to decompose themselves into quasi-independent subsystems.
43. J. C. Gershuny, "Social innovation: change in the mode of provision of services", *Futures,* December 1982, page 426.

AUTOMOBILE USAGE IN A FUTURE INFORMATION SOCIETY

Ove Svidén

The information society provides a challenge for the future of the automobile. This article, based on a two-year Swedish study as part of the MIT Future of the Automobile Programme, used four scenarios against which to predict the future of the car in Sweden. It concludes that, overall, information technologies will not substitute for travel, only for the information carried on paper; rather, future moves towards increasingly dispersed living will keep car usage high.

Keywords: automobiles; information society; Sweden

THIS article is based on a Swedish project study which is part of the Future of the Automobile Programme initiated at Massachusetts Institute of Technology in 1980.[1] Entitled "Automobile Usage in a Future Information Society", the Swedish study was performed at the Institute of Technology, Department of Management and Economics at the University of Linköping. The study was financed by a number of government agencies concerned with road and traffic administration and technical development.

The purpose of the study, and of this article, is to investigate the effects of improved information technologies on automobile technology and usage, with Sweden being chosen as the main example. Scenario scenes for the years 1990, 2000, 2010 and 2040 indicate some of the structural changes necessary for an industrial society to evolve into a mature information society. The scenario is used as a base for a quantitative estimate of travel demand and automobile usage in Sweden in the future, with 1980 as a reference year. Some of the results of this futures study are intended as input to the Swedish government's long range planning.

Cars and the future

The future post-industrial society is an information society and its evolution implies major structural changes.[2] It will influence the way we live, work,

Ove Svidén is the manager of energy forecasting with Volvo, Sweden. He is currently involved with the Future of the Automobile Programme at Linköping as a part-time PhD student and can be contacted at Sandtorspgatan 8, S–582 63 Linköping, Sweden.