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The Vain Search for Alternatives: Closure Processes in Internal-Combustion Engine Design, 1960-1990

Andreas Knie

Background

On the occasion of last years (NSU/Wankel-Engine) Tokyo Motor Show MAZDA presented the worlds first rotary engine driven by hydrogen. This engine is part of the "Concept Car," a car which is equipped with sophisticated technology and which meets the standards of California State's strict exhaust regulations.

It was another world premier when a MAZDA car came out as the winner of last years car race "24 hours of LeMans" in France. Such successful race cars as the Mercedes Silver Arrow, Jaguars, and Porsches were beaten by a car equipped with a rotary engine.

It seems as if a promising future lies ahead of the rotary engine. Its efficiency has been proven for over ten years in the MAZDA "RX-7" serial car. Hence, the MAZDA company can build upon a decade's worth of experience for its future development.

Of course, this success did not arrive all by itself. Although it obviously was not Japanese engineers doing a better job than their colleagues in the US or in Europe. Technological novelties, however, if they are to

successfully compete with established technologies, are in need of an uncompromising promotion by industry.

Introduction

For a number of years now, social science has been addressing more intensively the problems of technological development. In particular it has investigated the contextual ambience of new technologies. While processing and sifting the empirical material, social scientists always sought to disassociate themselves from the traditional historiography of technology and its emphasis on engineering work. Instead of focusing on the ingenious personality of the inventor who, inspired by flashes of inspiration, determines the course of technological development, the sociologists attached great importance to defining the emergence and development of technologies as a process embedded in institutional and organizational contexts. Although sociological research thereby drew attention to the "societal" and "cultural" character of the generation process, a strange preference for anonymous structures and processes remained. While men were still identified as individual or collective actors, their scope for action remained bound to rigid systems of order to which were frequently attributed an evolutionary logic, exhibiting an intrinsic dynamic of its own. The social sciences preserved a preference for extensive, depersonalized, but stringent patterns of interpretation which frequently claimed to be globally valid. Faced with the fragmentation and insecurity that can be perceived in all spheres of life, the social sciences developed an affinity for theories which try to

capture societal phenomena by means of models borrowed from the physical sciences. In doing so, the antiquated and dust-covered, rigorous causal relations are merely replaced by notions like self-organization or self-reproduction—according to the motto that what is true for microorganisms cannot be false for the description of complex social processes. In addition, the increasing replacement of physics by biology as the "model discipline" of comprehensive scientific theory formation has resulted in the adoption of models from the theory of evolution. As in George Basalla's interpretation of technological development:

The history of technology is filled with examples of machines slowly changing over time and replacing older models, of vestigial structures remaining as parts of mechanisms long after they had lost their original functions, and of machines engaged in a struggle for survival...¹

The emergence of new technologies is here understood as the result of a metamechanism which asserts itself independently of the volition of single actors, so to speak behind their back. The human factor—*per se* a basic object of the social sciences—is distilled away and evaporates into a depersonalized superstructure.

Undoubtedly, it is mainly thanks to sociological research that the possibilities and limits of human action are being analyzed under structural conditions. A search for regularities is definitely among the main

¹ G. Bassala, *The Evolution of Technology* (Cambridge, 1988 (1990)), p. 16.

tasks of sociology.² But "pattern recognition" should not lead to a de-subjectified process schema in which human actors degenerate into executive organs of anonymous powers. With the construction of order, reference is made to the preconditions of human action; organizational and institutional contexts indicate scopes of action and define types of action. Nonetheless, a proper dynamic of social practice has to take into account that structural boundaries are frequently being violated and that new societal realities are being created beyond objectively given conditions.

If confining itself to the macrolevel and assembling empirical building blocks into a closed order, sociological research fails to gain insight into those processes which on the microlevel constitute themselves as violations of the limits of given routines of action, thereby molding reality. Even when considering supposedly inconspicuous stages of technological development and incremental enhancements, it becomes apparent that, in the defining phase of a performance specification, every step in the materialization of technologies has to be understood as a controversial practice. External

² Cf. P. Feyerabend, "Wissenschaft ist keine Monokultur. Plädoyer gegen eine verordnete Rationalität," in *taz*, *Word Media* Nr. 3 (24th Dec., 1991), pp. 60-61; B. Joerges, "Soziologie und Maschinerie," in P. Weingart (ed.), *Technik als sozialer Prozeß* (Frankfurt, 1989), pp. 44-89; W. Rammert, "Technisierung und Medien," in *ibid.*, pp. 178; W. Rammert, "Vom Umgang der Soziologen mit der Technik," *Soziologische Revue*, 4 (1987), pp. 44-55; M. Dierkes, "Technische Entwicklung als sozialer Prozeß," *Naturwissenschaften*, 77 (1990), pp. 214-220; M. Hård, "Beyond Harmony and Consensus: A Social Conflict Approach to Technology," *Science Technology, and Human Values* (to be published in 1993).

requirements cannot be translated straightforwardly into technical solutions, but can only materialize as a compromise that is subsequently subjected to evaluation. The process of selection, so heavily stressed by theory of evolution as the motor of development, is based on the selection of solutions which are, primarily, optimized with regard to function. However, constructions of such a quality do not emerge out of the blue. In order to be able to convert the formulation of a solution into a functionally optimized artifact, organizational preconditions have to be met. Thus, what will prevail as a technical solution also depends on the formation of sufficient defining power which can guarantee the necessary evolutionary space for new solutions. "*Fahnenträger*" must push for novelties and stand up for them without any ifs and buts; "promoters" must provide the necessary resources and defend the project against the resistance of representatives of prevailing standards, until their functionality as a generally accepted solution has been "societally hardened."³ In the present paper, this thesis will be unfolded by using as an example the problems encountered in pushing through alternative prime movers for automobiles; however, first some fundamental ideas concerning the social basis of new technology will be presented.

³ Cf. A. Berthoin-Antal, *Corporate Social Performance: Rediscovering Actors in Their Organizational Contexts* (Frankfurt, 1992); A. Ginsberg and E. Abrahamson, "Champions of Change and Strategic Shifts: The Role of Internal and External Change Advocates," *Journal of Management Studies*, 28 (1991), pp. 173-190.

Technological Voluntarism?

When sociologists began to use the label "technology as a societal process" or, as is done here, make the success of technology formation dependent on the existence of sufficient defining power, engineers frequently accused them of abandoning "technological determinism" too vehemently. In the technicians' view, the social scientists appeared to make everything seem technically feasible, if only societal powers were configured accordingly. This argument also reflected the—definitely justified—criticism to the effect that sociological research only insufficiently treated concrete problems of everyday design practice. Moreover, in many instances only analogies from research in the physical sciences were formed, thus purporting the idea that scientific theory formation could be assimilated with the design of technical devices.⁴

The subject matter of the work of technicians, engineers, designers—in brief, of all those working in the field of technology—is the construction of machinery. In this work, the material characteristics of the machines are only of secondary importance. What is really essential is their functional character. Machines are employed to execute well-defined repetitive operations within given limits as frequently as desired, to a large extent independently of place and time, and in a reliable and predictable manner. To achieve this goal, complex requirements and demands must first be redefined in terms of unequivocal

⁴ Cf., e.g., R. Laudan (ed.), *The Nature of Technological Knowledge* (Dordrecht, 1984).

purposes and then disassembled into an algorithm which may serve as the foundation for a mechanical process.⁵ This unequivocal formulation of purposes constrains designers to assure a high degree of consistency, since the result of their work can be evaluated immediately in terms of the predefined goals. In order to avoid functional deficiencies, the engineer's work has a steadfast, almost conservative character. By its very nature, engineering is fundamentalist. Once a mechanical structure has stabilized, engineers will defend it—or at least its basic functions—as long as possible against all demands for modification. Every such demand for functional change, be it only minimal, threatens to disrupt the intrinsic structure. Conversely, every demand for new structures will threaten the functionality of the machine. Even the tiniest changes can, by a kind of domino effect, be a big threat. "When change is not necessary, it is necessary not to change," is a motto which sums up this attitude.⁶

In established markets of technology and in the framework of well-defined branch structures, it is apparent that competing companies possess a common frame of reference for ideas and actions which allows them to come to a fundamental understanding. In addition, conventions relate to technological fundamentals, an inventory of design-related and functional principles which are codified and stabilized

⁵ Cf. A. Bammé et al., *Maschinen-Menschen, Mensch-Maschinen* (Reinbek, 1983), pp. 108ff.

⁶ M. Bentele, *Engine Revolutions* (Warrendale, 1991), p. 198; M. Hård, *Technology in Flux: Local Practices and Global Patterns in the Development of the Diesel Engine*, WZB FS II 92-103 (Berlin, 1992).

as "ruling standards." Such an achievement in the way of common understanding permits both users and producers to rely on the functionality and operational reliability of a basic inventory of knowledge and experience. This implies that the risk that goes with new developments is minimized, and preconditions for a highly selective evolutionary performance are created without constantly putting into question fundamental decisions. "Ruling standards" comprise universally accepted and, thus, validated function and design principles which all manufacturers in a given market segment recognize and use as a kind of "grammar" for technological action and which, thus, is laid down as rules. These standards can then be discerned and described as "the common practice" of a field of engineering—for instance, in the automobile industry being represented in the form of the reciprocating internal-combustion engine as a means for propelling cars.

However, this does not imply that all technological solutions are identical. The global principles are translated into concrete designs on the level of "local practices," whereby the inventory of knowledge and experience defined as the "ruling standard" furnishes the elements from which every company can select some and combine them in a specific way. It is only in the framework of "local practice" that new elements of knowledge and experience can be generated—elements which, having initially been supported by just one company, can gain permanent stability when being codified, through the process of inter-branch communication, as the generally recognized "ruling standard." On the basis of shared engineering foundations, a company is highly motivated—for the

purpose of competition—to design certain particular elements unique to its "local practice" and, for the purpose of staying on the technological front, being able to exploit it for as long a period as possible. However, this special accentuation can only materialize into economic competitive advantage and high technological reputation if competitors accept the new conditions as guidelines and are prepared to copy them. "Success is when your product gets copied," as the manager of a development department once put it.

This mutual agreement about the fundamental principles and shared definitions of a type of machinery also leads to the creation of corridors for further development. After the establishment of a "ruling standard" not all the options are open any more.

On the one hand, this implies the creation of structures which facilitate technological action under given cognitive, societal, and economic conditions. On the other hand, it implies the danger of a "technological fix:"⁷ in the interest of the longest possible preservation of stable basic machine functions, a situation may emerge when the goal definition and the use of resources no longer match. No longer are problems defined first and possible technical solutions later investigated, but the existing mechanical solutions determine the future design paths.

The example of automobile drive concepts may serve to illustrate this point: even though car technology with its characteristic structure was molded by the specific conditions which existed at the turn of the century, these basic mechanical functions

⁷ L. Winner, *Autonomous Technology* (Cambridge, 1977).

could be cultivated in a linear process of updating by the use of new materials, electronic control engineering, and new manufacturing methods so that remarkable performances could be achieved. Nevertheless, the fundamental design-related decisions which were dictated by the conditions that prevailed at the time when that technology emerged were maintained. In particular, fluid hydrocarbons—a mobile energy storage which was quite well adapted to the purposes then pursued and which was suited to internal combustion, not only on the ground of its high mass- and volume-specific energy content, but also as an easily evaporated fuel—no longer meet today's generally altered technological preconditions for the provision of mobility, given its principally limited availability, but, above all, its high capacity for environmental pollution. However, in an effort to justify the future utilization of the reciprocating internal-combustion engine which derives its technological superiority only from the use of gasoline or diesel oil, legislators and manufacturers perpetuate requirements which since long have been overtaken by reality. A leading car designer describes such a status-quo-oriented user perspective as follows:

Since filling up is always a nuisance and particularly so in its present form, one tank filling should be sufficient for at least 600 kilometers. Given their superior characteristics (energy density per unit of mass or volume, ease of handling, good

storing properties, quick filling), fuels will also in future be hydrocarbons.⁸

In this context, one should not forget that today two thirds of all car rides cover distances of less than 10 km.⁹ A search for new approaches which in the future would assure the necessary technical preconditions for providing mobility does not seem any more, in the literal sense of the word, to be "conceivable" independently of existing solutions. Moreover, it frequently happens that the performance demands cannot be straightforwardly translated into the algorithmic forms required for machines to work. This point, too, may be exemplified by referring to the car engine: users expect that, regardless of time and place, whether in summer or winter, at home or at a holiday resort, it immediately starts and is ready for operation. Within the limits of its lifetime, the engine is supposed to work and to cover at least 100,000 kilometers. The engine must be suited for cruises on highways as well as for short rides downtown, i.e. the engine is expected to be able to transmit its driving power onto the wheels already at low speeds while providing sufficient acceleration and power for take-over maneuvers, all that with a minimum of noise emission. It goes without saying that not only fuel consumption, but also pollutant outlet should be kept at a minimum. However, on the basis of the reciprocating internal-combustion principle which is

⁸ H.J. Förster, "Das Automobil am Anfang seines zweiten Jahrhunderts" (1988), in H.J. Förster, *Technik für den Menschen. Aus den Erfahrungen eines Ingenieurs* (w/o place and year), p. 134.

⁹ D. Seifried, *Gute Argumente: Verkehr* (München, 1990), pp. 27-28.

globally accepted for automobile engines, i.e. belonging to the "ruling standard," these varied requirements cannot be met. The desire for high final velocity is hardly reconcilable with the need for high torque at lower speeds. Multiple-valve technology, which these days is coming into fashion, improves the filling ratio and, thus, combustion, reduces specific fuel consumption and somewhat improves pollutant outlet, but all this only at higher speeds which can hardly be applied any more. To the contrary, during everyday usage these sophisticated design features not only bring about higher friction losses and costs, but also inferior combustion. The utilization of technologies for exhaust-gas reduction results in a higher car weight and, thus, causes an increase in fuel consumption.

It is true that, once agreement about certain basic functions has been reached, a limited set of elements can be chosen for use, so that in the interest of the designers a structured search for a solution is assured, but, with regard to mechanical realization the multiple demands put on engine technology can only result in a compromise. Thus, design results are subjected to assessment and have to be defined as a complete unit, have to be made accepted in a given shape, and have to be defended against other lines of compromise.

Now, solutions in the form of mechanical systems can be negotiated and outlined in the laboratory; however, there remains the problem that the negotiated line of compromise cannot be straightforwardly translated into a mechanical system which assures a maximally trouble-free execution of the desired operations. This "process of inscription" constitutes itself as a process of "liquid" knowledge being poured step by step and on the basis of evolving

capabilities into "hardened" mechanical systems. Thus, new mechanical configurations are temporarily dependent on external back-up, i.e. on the compensation of functional deficiencies through manual support. In order to achieve the goal of optimal functionality, one not only has to provide the necessary resources. It also takes a sufficient amount of power in order to protect, defend and define as potentially functional those emerging solutions which, when compared to established technology, still work rather poorly. Advantages designed into new machinery do not straightforwardly function as criteria for success or acceptance, but these can only be established by an appropriate policy of protection.

Thus, as far as the basic problem of materialization and the qualitative formation of technical devices are concerned, their design is closely interrelated with societal processes: the agreement reached on a common inventory of functional material elements, components of know-how, and procedural pathways, as well as on the processes of negotiating the determination of a compromise line in defining a design, are as elementary to "technological development" as the existence of sufficient defining power which is necessary for providing room for development. The generation of new technologies has to be understood as a project which has to be actively initiated and politically secured.

When analyzing technological development taking place in established markets, the formative phase can be considered as a "process of closure and consolidation" of newly generated knowledge and experience which are only brought to successful conclusion when a new technological solution becomes

the "ruling standard." New solutions and procedural methods are thereby globally recognized as the "legitimate" repertory of knowledge and experience, and they are, as "common practice," part of the process of coming to an understanding which occurs on an inter-company level, and, thus, are available to every company for application in "local practice."

Three phases can be distinguished:

- "Penetration" into existing structures of knowledge and power that are defended against attack from outside. The eliminating power of the binding and stabilizing forces of the current "ruling standard" must be partially neutralized, resources have to be mobilized, and precautions have to be taken in order to develop the "defining power" necessary for securing rooms for development.
- "Closure and consolidation:" newly acquired knowledge is inscribed into mechanical systems and stabilized, and agreement is reached on a structural materialization which is no longer open to choice or change.
- "Institutionalization:" newly developed elements or configurations are societally "hardened" in the context of formation of a "local practice" by being codified as "ruling standard" and, thus, transformed into generally accepted and applied rules.¹⁰

¹⁰ This concept sees itself in the tradition of socioconstructivist approaches, cf. H.T. Engelhardt and A.L. Caplan (eds.), *Scientific Controversies. Case Studies in the Resolution and Closure of Disputes in Science and Technology* (Cambridge, 1987) and K. Knorr-Cetina, *Die Fabrikation von Erkenntnis* (Frankfurt, 1984).

The Future of Alternative Drive Concepts

When from this viewpoint genetic processes are seen as political projects, the question for the chance of success of a so-called alternative prime mover concept can no longer be understood as a technical problem only. In order to successfully pursue future goals, new organizational conditions for R&D have to be created. This is particularly obvious considering the extensive goals which the automobile industry has set itself, i.e. not only to be able to operate a medium-range car on 3 liters of fuel per 100 km by the turn of the millennium, but also

to dispense gradually with fossil fuels from the same time on and be able to convert part of the available solar energy, e.g. through photovoltaic, wind- or water-driven equipment into electric energy or hydrogen.¹¹

These alternative concepts - which are extensively debated by the general public - are widely considered to comprise structural designs and shapes which depart from the classical line of the four-stroke internal-combustion engine burning hydrocarbons in an otto or diesel cycle. Apart from electrotraction, these alternatives include the Stirling engine, the gas turbine, the composite engine, as well as efforts to run conventional piston engines on different fuels, e.g. hydrogen or alcohol. At first sight, the German automobile industry gives the impression of being forcefully engaged in developing concepts of this kind.

¹¹ R.v. Basshuysen, "Herausforderung der Zukunft," *Automobiltechnische Zeitschrift*, 93 (1991), p. 1.

On the other hand, the experts in the field agree that a short-term application of such concepts is out of question, all the more so as engineers presume that there is still a substantial potential for the further development of conventional otto or diesel engines.

However, on closer examination it becomes obvious that thus far no organizational measures have been taken which could assure the future materialization of these new drive concepts. In order to justify the use of existing drive systems also for meeting future requirements, it is only necessary to choose the premises skillfully. Here is an example: The Volkswagen Corporation was planning to develop, with financial aids from the Science and Research Department of Berlin's local government as well as from the Federal Ministry of Research and Technology, an advanced compact car which was meant to answer the economic and ecological requirements of the 1990s. For the selection of appropriate drive systems, Volkswagen fell back upon an internal study which had been concluded in 1976, and took from it the following recommendation:

At the present state of the art, only displacement engines with internal cyclic combustion can meet the requirements which have to be exacted from a compact-car engine.

The unconventional options, engines with continuous internal combustion (axial-piston engine) and those with continuous external combustion (Stirling engine) which for a long time have been an alternative to the existing piston engine, were disregarded because

in view of their present state of development it seems doubtful whether at the end of the 1980s they will be ready for series production, as the participating experts said in 1988.

Thus, the conventional reciprocating engine with crank gear represents the most promising system for a combustion engine for car traction.¹²

By using time horizons in a very instrumental way, a very demanding project resulted in a very conventional concept. A point in time is set by which the development of a solution for a drive system which answers higher environmental standards should be finished. Thereafter, unconventional solutions are passed in review, the options are compared to existing technologies, and the experts arrive at the conclusion that it is much more likely that at that preset date conventional techniques will show a developmental advantage and will be available for series production. This elimination process being concluded, time horizons surreptitiously can be extended again. Even at the beginning of the 1990s, the Eco-Polo is far from being manufactured in series. In this way, however, the developmental advantage of conventional systems is cemented, and in doing so the greater experience with existing drive concepts is used to justify their very continuation. Outwardly, the process of selection and closure can be represented as a rational decision,

¹² B. Wiedemann, M. Willmann, and W. Scher, "Öko-Polo-Antriebskonzept," in: *VDI-Fahrzeugtechnik: Die Zukunft des Dieselmotors* (Düsseldorf, 1988), p. 137ff.

political considerations being skillfully concealed behind the formulation of the premises.

On the whole, when compared to the conditions of the outgoing 19th century, chances for such a fundamental change to the range of technological solutions seem to have decreased. Automobile manufacturers have tied up huge amounts of capital in manufacturing equipment. On a world-wide scale, the engineering sciences has accepted stable border conditions in teaching and research which are a prerequisite for high productivity and the generation of knowledge which at any time can be assimilated into the existing stock of know-how; to renounce these stable border conditions would mean to render useless a costly infrastructure of industrial instrumentation.

There are no powerful actors that could promote the new concepts, create margins for their development and also defend them against the prevalent opinion. As long as these preconditions are not met, no new technological solution will be able to establish itself.

Those who plead for turning away from the piston engine, the main technological elements of which can be traced back to the 19th century, and advocate the use of alternative systems, must have the will to act accordingly and must take the necessary precautions. It certainly is futile to expect that at some indefinite point in time new solutions will prevail by virtue of sheer technological superiority. A rational superiority which is inherent to a certain technology is not sent from heaven, but, as a German engineer once put it, "it needs somebody who believes in it!"

Yamamoto, head of the Rotary-Engine developing MAZDA company put it into the following words when he gave a lecture in Detroit in 1983:

New ideas, even technological ones, mean crossing established frontiers. The paths are uncharted. And the snipers keep you in the sight of their barrels even while maintaining themselves safely at a distance. We used science and experimentation to cross that frontier. But we learned that without enthusiasm and untiring devotion, we could never have defied those seemingly impossible challenges. Defiance of the old, and essential quality of innovative ideas, is necessary to bring on the new.

Mercedes Benz and Audi had originally developed the concept of a rotary engine in the 60s and early 70s in Germany. Their car, the "NSU Ro80," featuring the rotary engine, was also manufactured in series. Back then they considered technical and economic problems too heavy to continue and after the first generation of engineers had retired the new concept was lacking a sponsor in German industry. This is one reason why these companies are not going to profit from this late triumph of the rotary engine.