Society in the Making: The Study of Technology as a Tool for Sociological Analysis

Michel Callon

Social scientists, whether they are historians, sociologists, or economists, have long attempted to explain the scope, effects, and conditions of the development of technology. They consider technology a specific object that presents a whole range of problems that these experts have tried to solve using a series of different methods available to the social sciences.[1] But at no point have they judged that the study of technology itself can be transformed into a sociological tool of analysis. The thesis to be developed here proposes that this sort of reversal of perspective is both possible and desirable. Not only would it enlarge the methodological range of the social sciences but it would also facilitate the understanding of technological development. To bring this reversal about, I show that engineers who elaborate a new technology as well as all those who participate at one time or another in its design, development, and diffusion constantly construct hypotheses and forms of argument that pull these participants into the field of sociological analysis. Whether they want to or not, they are transformed into sociologists, or what I call engineer-sociologists.

Seeing the process of technological innovation and the role played by engineers in this way defies certain accepted ideas. By taking this perspective I am not simply repeating the already countless criticisms of the notion of innovation as a linear process. This notion describes technological development as a succession of steps from the birth of an idea (invention) to its commercialization (innovation) by way of its development. Everyone now recognizes that the to and fro's or coupling processes that continuously occur between technology and the market are extremely important.[2] Nor in this chapter do I challenge the notion that claims that the role and importance of financial backing or organizational structure varies considerably between periods of elaboration and development of an innovation.[3] What I am questioning here is the claim that it is possible to distinguish during the process of innovation phases or activities that are distinctly technical or scientific from others that are guided by an economic or commercial logic. For example, it is often believed that at the beginning of the process of innovation the problems to be solved are basically technical and that economic, social, political, or indeed cultural considerations come into play only at a later stage.[4] However, more and more studies are showing that this distinction is never as clear-cut. This is particularly true in the case of radical innovations: Right from the start, technical, scientific, social, economic, or political considerations have been inextricably bound up into an organic whole.[5] Such heterogeneity and complexity, which everyone agrees is present at the end of the process, are not progressively introduced along the way. They are present from the beginning. Sociological, technoscientific, and economic analyses are permanently interwoven in a seamless web (Hughes 1983). Using the case study of an innovation, I show how it is possible to use this characteristic in order to transform the study of technology into a tool for sociological analysis; this leads to a new interpretation of the dynamics of technology.

Engineer-Sociologists

To illustrate the capacity of engineers to act as sociologists (or historians or economists), I describe certain aspects of the development of what was intended to be a major innovation: the introduction of an electric car (VEL) in France.[6]

This project was first presented by a group of engineers working for EDF (Electricité de France)[7] in the early 1970s. They outlined the project in a series of technical publications and in applications for funding to government agencies.[8] It is by no means easy to create a new market of this sort in a society organized entirely around the traditional motorcar. The project conjectured not only that the technoscientific problems could be overcome but also that French social structures would change radically.

EDF's engineers presented a plan for the VEL that determined not only the precise characteristics of the vehicle it wished to promote but also the social universe in which the vehicle would function. We will see that in addition to their technical know-how the engineers of EDF used skills more commonly found in social scientists. They resembled their illustrious predecessors from the Renaissance who had deftly played on several registers at the same time (Gille 1978). Like Edison almost a hundred years ago, they continuously mixed technical and social sciences.[9]

First, the EDF defined a certain history by depicting a society of urban post-industrial consumers who were grappling with new social movements. The motorcar occupied a position that was highly exposed, for it formed part of a world that was under attack. Thus it served as a point of departure for the construction of far-reaching and radical demands that would lead to a future that could be discerned only with difficulty. The internal combustion engine is the offspring of an industrial civilization that is behind us. The Carnot cycle and its deplorable by-products were stigmatized in order to demonstrate the necessity for other forms of energy conversion. On the one hand, the motor vehicle was considered responsible for the air pollution and noise that plagues our cities. On the other hand, it was irretrievably linked to a consumer society in which the private car constituted a primordial element of status. However, electric propulsion would render the car commonplace by decreasing its performance and reducing it to a simple, useful object. The electric car could lead to a new era in public transport in the hands of new social groups that were struggling to improve conditions in the city by means of science and technology. The goal would be to put science and technology at the service of the user and to do away with social categories that attempted to distinguish themselves by their styles of consumption. The EDF based this vision on an evaluation of the trajectories of development open to different types of electrochemical batteries.[10] First, public transport could be equipped with improved lead accumulators. Then accumulators and fuel cells could open up the larger market of private transport by enabling the VEL to reach speeds of up to 90 km/h, on the condition that safe catalysts cheaper than platinum could be developed (cheaper but poisonous catalysts had already been found).

By predicting the disappearance of the internal combustion engine as a result of the rise of electrochemical generators and by ignoring traditional consumers so as to better satisfy users who had new demands, the EDF not only defined a social and technological history but also identified the manufacturers that would be responsible for the construction of the new VEL. The CGE (Compagnie Générale d'Electricité) would be asked to develop the electric motor, the second generation of batteries, and to perfect the lead accumulators that would be used in the first generation of the VEL. Renault would mobilize its expertise in the production of traditional automobiles in order to assemble the chassis and make the car bodies. The government would also be enlisted: Such and such a ministry would subsidize those municipalities interested in electric traction. The list went on: Companies that ran urban transport systems were to be put together with research centers, scientists, etc. The EDF defined the roles, and attempted to enroll other entities into them. It also bound the functions of these roles together by building a world in which everything had its own place.

Up to this point the entities are those familiar to the sociologist. There are consumers, social movements, and ministries. But it would be wrong to limit the inventory. There are also accumulators, fuel cells, electrodes, electrons, catalysts, and electrolytes, for, if the electrons did not play their part or if the catalysts became contaminated, the result would be no less disastrous than if the users rejected the new vehicle, the new regulations were not enforced, or Renault stubbornly decided to develop the R5. In the world defined and built by the EDF, at least three new and essential entities must be added: zinc/air accumulators, lead accumulators, and fuel cells with their associated elements (catalysts, electrons, etc.).

The EDF engineers determined not only the repertoire of entities that they enlisted and the histories in which they would take part but also their relative size. For EDF's engineers Renault would no longer be a powerful company seeking to be once more the largest European car manufacturer. Indeed, it would never regain that status. Rather, it was reduced to the level of a modest entity that intervened in the assembly of the VEL. The same is true of the old status groups that would give way to new social movements and their new demands.

The ingredients of the VEL are the electrons that jump effortlessly between electrodes; the consumers who reject the symbol of the motorcar and who are ready to invest in public transport; the Ministry of the Quality of Life, which imposes regulations about the level of acceptable noise pollution; Renault, which accepts that it will be turned into a manufacturer of car bodies; lead accumulators, whose performance has been improved; and post-industrial society, which is on its way. None of these ingredients can be placed in a hierarchy or distinguished according to its nature. The activist in favor of public transport is just as important as a lead accumulator, which can be recharged several hundred times.

This case shows that the engineers left no stone unturned. They went from electrochemistry to political science without transition. The analysis of French society that they proposed was both remarkably incisive and fully elaborated. Five years after the "great cultural revolution" of May 1968[11] and one year before the first oil crisis, they outlined the course of an evolutionary movement that would propel French society from the industrial to the post-industrial age. This change was to occur through pressure from new social movements and with the expected help of electrons.[12]

The sociologist who studies the VEL project cannot but be struck by the similarity between the "sociological" arguments developed by the engineers at EDF and the analyses proposed at the same time by one of the most respected French sociologists, A. Touraine. This similarity, which I come back to shortly, obviously suggests a question: Could not social sciences in some way or another make use of the astonishing faculty engineers possess for conceiving and testing sociological analyses at the same time as they develop their technical devices? It is to answer this question, which supposes that it is possible to compare the sociology of engineers with professional sociology, that I now present the analyses proposed by Touraine and the controversies to which they gave rise.

Sociology and the Problem of Consumption

Where was French society really going in 1973? And, in particular, what destiny lay in store for the traditional motorcar? The engineers at EDF asked themselves these sorts of question, and they responded to them by conceiving of the VEL project. They were not alone in asking these questions. Sociologists too were trying to answer them, and the analyses they elaborated display great diversity. Several schools confronted each other. For my purposes I need to retain only the opposition between Touraine (1973, 1979) and Bourdieu (1979; Bourdieu and Darbel 1966; Bourdieu and Passeron 1970). These two gave radically different interpretations of the dynamics of consumption.

Touraine is part of a sociological tradition that emphasizes the role of class conflict in making society function and in producing its history. Unlike Marxists, he believes that the central conflict of Western society is no longer the struggle between the working class and the bourgeoisie. Technological development has brought new factors into play. On one side now there are large concerns (big corporations, research and development agencies) that orient scientific research as well as define and control the application of technology. On the other side we find the consumer, whose needs and aspirations are manipulated by the technocrats who run the large concerns. This conflict explains the birth of social movements that challenge (either through categorical demands or through calls for a move "back to basics") the power of the technocracy or its orientations for social and economic development. These movements are relatively widespread and ephemeral. Sociologists must learn to decipher their demands and technocrats must take them into consideration if they wish to safeguard the legitimacy of their choices and decisions. This new type of class conflict defines what Touraine calls post-industrial society.

Bourdieu's vision of society can be arrayed point for point against Touraine's. For Bourdieu, society is not organized around a primordial confrontation between ruling classes and classes that are ruled, fighting for control of technological development. The confrontation is fragmented between various specialist spheres (the field of politics, the field of science, the field of consumption, etc.) that maintain mutual relationships of exchange and subordination. Each field is the site of strategic confrontations between social agents who fight to occupy positions of power. But these different fields, which in their multiplicity embrace the diversity of social practice and express increasing differentiation of societies, are caught in a group logic that lends cohesion to society. This unification is organized around a dominant cultural model, that of the upper classes, in relation to which the other social classes define and orient themselves. Whatever particular field is considered, these classes are in constant competition in order to delineate their differences and to vie for positions on a scale of status. This competition is nowhere more apparent and nowhere more lively than in the field of consumption. The reader will recognize here the essential elements of the theory of social stratification, in which distinction, differentiation, and mobility play an essential role.

Beyond the classical opposition they display between a sociology of social class and a sociology of stratification, Touraine and Bourdieu share the feature that they place the question of consumption at the center of their analyses. Touraine does so in order to show that consumption is largely manipulated by industry and the great technological agencies, Bourdieu to establish its irreducible autonomy. Touraine sees in the definition of demand or need the site of the emergence of new class conflicts, whereas Bourdieu affirms that goods and services, whatever their intrinsic characteristics, are ineluctably reinscribed by consumers into the logic of social distinction.

Although they attribute to consumption the same strategic value, these two analytic schemas lead to two radically different interpretations of its evolution. The automobile and its future provide particularly salient illustrations of this evolution.

If one has a stake in the coming of a post-industrial society, the traditional motorcar is doomed to lose ground because it is an integral part of a social system that is disappearing; it stands as both the symbol and cornerstone of that system. Social movements that diminish the importance of and criticize the use of the automobile anticipate and express the necessity of this evolution. In the Tourainian schema the technocrats/decision makers design products to meet these demands in order to use them for support: This double game, whereby popular protest is used by technocrats to serve their own ends, is the driving force of history. The appearance of a new technology, such as the VEL, is thus much more likely because it introduces a rupture in industrial society and is supported at the same time by social movements and the technocracy.

In Bourdieu's perspective the future of the automobile is inscribed in a different logic. The total banalization of an object of consumption, which plays a central role in struggles for distinction, seems highly improbable. Social movements that protest against the symbol Automobile are without doubt quite right to see in it one of the cornerstones of our societies; but instead of believing in their capacity to create a new era, we should learn the lesson it teaches them against their will. The automobile is at the nerve center of society, so socially embedded that it can be modified only with great care. It must undergo evolution, but this is not purely and simply a case of making it disappear so that it can be replaced with a radically new technology; the only realistic strategy is to transform it gradually through progressive introduction of technical improvements enabling it to respond to new user demands. The best answer that can be given to social movements is to introduce yet more differentiation, not make a tabula rasa of the past.

Who Is Right?

What, in 1970, was the future of the automobile in French society? This question was at the centre of the VEL project as it was developed by the engineers at EDF. Furthermore, it is a question that should not have been ignored by sociologists, because, as I have just shown, consumption and its evolution occupied a central place in the theoretical apparatus they had elaborated.

In fact, sociologists were little concerned with the EDF adventure and abstained from establishing some link between their theories and this astonishing story that was unfolding before their eyes. A story so much the more astonishing because, as we will see, the engineers at EDF were to become rapidly engaged in a controversy in which their Tourainian sociology would set itself against the sociology à la Bourdieu employed by the engineers at Renault. The controversy was, however, of a different sort, for success or failure was to be measured in terms of shares of the market.

EDF's engineers did not have to defend their ideas in an academic arena. Any brilliance or originality in the analysis they developed was of little import. For them the analysis was a question of life and death because the economic future of their project was at stake. No more sophisticated arguments and theorizing! What mattered was to be right: to be able to prove by the very success of their innovation that French society was evolving in the way they claimed it was, borne along by the aspirations of protest movements on which they in turn hoped to lean for further support. The rest was of no account. In short, if an engineer-sociologist is to be proved right he or she has to create a new market; success is measured by the amount of profit gained. This, in all its simplicity and toughness, is the test of truth.

For three years the engineers of EDF believed that they were right. Nobody dared interrupt their discourse. Car manufacturers, with Renault in the forefront, kept quiet, terrorized by the future promised them. In order to hold their own, they started to work feverishly on the VEL project. They knew little or nothing about electrochemistry and did not know how to tackle the EDF forecasts that cheap high-performance fuel cells would be available by the end of the 1980s, thus opening up the vast market of private transport. To counter their handicap, they signed contracts with specialized research laboratories in order to acquire the knowledge and expertise they lacked. To begin with, the electrochemists confirmed the optimistic predictions made by EDF engineers. How then could anybody resist a movement that allied consumer aspirations, the wishes of the authorities, and available scientific resources (or rather resources thought to be available in the not-too-distant future)? Nothing could stand in the way of this tidal wave. In addition to these existing forces, another event occurred to weaken still further the position of the traditional motor car: the sudden increase in oil prices, making cars much more expensive to run.

Slowly but surely the tide in favor of the VEL and its society was beginning to turn, or, to use the terms so aptly coined by Hughes (1983), reverse salients began to appear. Things began to go wrong for the EDF engineers. Resistance, of the kind so neatly described by Castoriadis to define reality,[13] got underway. As in guerrilla warfare, it started up spontaneously and unexpectedly in several places. Fairly quickly, the catalysts refused to play their part in the scenario prepared by EDF: Although cheap (unlike platinum), the catalysts had the unfortunate tendency of quickly becoming contaminated, rendering the fuel cell unusable. The mass market suddenly disappeared like a mirage. The VEL, recognized EDF's engineers, needed batteries whose performance was sufficient for the average user, and this sort of battery might be too expensive to produce for a long time to come. In addition, Renault challenged the future of other electrochemical generators identified by EDF. For example, Renault showed that the zinc/air accumulators lauded by EDF's engineers were actually a shaky venture elaborated by a handful of researchers at CGE[14] who were pushing the program without being sure that it was realistic. Furthermore, argued Renault engineers, if zinc/air accumulators were to be used in the VEL, this would presuppose the setting up of a vast network of service stations throughout the country whereby the used electrolyte might be changed periodically. Which industrial groups, they asked, would dare to challenge the all-powerful oil consortiums on their own ground? In contrast to the optimistic view of technological innovation taken by EDF, Renault engineers painted a gloomy picture of uncertain strategies and rival industrial groups with conflicting interests.

The Renault engineers did not stop there. They took their criticism further by showing that what EDF detected as signs of the coming of a post-industrial age was in fact only minor technical difficulties in the current age. According to them, the criticism leveled at the traditional motor car did not change the equilibrium of existing social forces, nor was it a sign of a demand for a new mode of development. It merely expressed temporary and local dissatisfaction with the car industry's lack of dynamism and the poor state of public transport. Pollution could easily be reduced and the reorganization of public transport in cities could be improved, in particular, by using more comfortable and higher-performance buses. They argued that in the space of three years protest movements had quieted down, especially those that had been most virulent in speaking out against the automobile society. Recession was looming large and talk was more of reindustrialization than of post-industrial society.

So it was the Renault engineers, in alliance with the contaminating catalysts and aided by the increasing weakness of the protest movements, who completely rehabilitated the traditional motorcar, although the motorcar underwent some subtle changes in the process (it polluted less, used less petrol, cost less to manufacture, etc.). At the same time, they reconstructed French society (present and future) in a different way. This time it was the EDF engineers' turn to remain silent. They had completely lost their position of strength. In the space of a few months the VEL had become a fiction that no one could believe in any longer. The proclaimed revolution had failed to materialize. EDF's engineers had lost. Their "failure" may turn out to be short-lived, for nobody knows what the future holds. But in the 1980s, contrary to what the EDF engineers confidently predicted, French society has reaffirmed the traditional motor with its attendant struggle for status, and there is no market for the VEL.

This was a remarkable controversy. The engineer-sociologists of EDF were matched by Renault's engineer-sociologists, who developed a sociology that in its arguments and its analyses was close to Bourdieu's. EDF against Renault is, on another stage and with different stakes and new rules, Touraine against Bourdieu.

The failure of the VEL can legitimately be ignored by sociologists. They have a perfect right to want their analyses judged elsewhere than in the economic sphere. This attitude, as defensible as it might be, seems to me only half convincing. Given the similarity of the controversies, should not sociologists take an interest in the engineer-sociologists, not to take them as models but in order to enrich their own analyses and to diversify their own methods of investigation?

To go along this path, we must leave behind the radical difference that separates sociologists and engineer-sociologists. Sociologists, when they develop, as Bourdieu and Touraine did, analyses that are opposed to each other point for point, can coexist without problems, just as in those preparadigmatic situations so well described by Kuhn (1970). For engineer-sociologists this sort of ambiguous situation did not make any sense. Either the VEL would find a market and eliminate competing techniques, or it would become a fiction without a future, thus leaving the road free for the traditional automobile. Both the VEL and the traditional motorcar could not be developed at the same time for the same purpose.

In order to transform the study of technologies into a tool of sociological analysis, I find it appropriate to answer this question: What is the particular faculty that engineers have (which sociologists in this case lack) of being able to evaluate the comparative merits of contradictory sociological interpretations? In order to answer this question, I briefly consider the notion of the actor network, which allows the characterization of the original contribution of the engineer-sociologists: the idea of heterogeneous associations.

Actor Networks

As has been noted in the EDF-Renault controversy, the engineers' projects had mixed and associated heterogeneous elements whose identity and mutual relations were problematic. For example, electrons, batteries, social movements, industrial firms, and ministries had been linked together. The success of the construction was measured by the solidity and longevity of the heterogeneous associations that were proposed by the engineers.[15] For them, it was not simply a matter of supporting a biased interpretation of French society and consumer tastes. They were attempting to link together fuel cells, electric vehicles, and consumers who were to accept using the VEL as a simple means of transportation despite its rather mediocre performance. The proposed associations, and by consequence the project itself, would hold together only if the different entities concerned (electrons, catalysts, industrial firms, consumers) accepted the roles that were assigned to them. To describe these heterogeneous associations and the mechanisms of their transformation or consolidation, I introduce the notion of an actor network.

The actor network is reducible neither to an actor alone nor to a network. Like networks it is composed of a series of heterogeneous elements, animate and inanimate, that have been linked to one another for a certain period of time (Schwartz Cowan, this volume). The actor network can thus be distinguished from the traditional actors of sociology, a category generally excluding any nonhuman component and whose internal structure is rarely assimilated to that of a network. But the actor network should not, on the other hand, be confused with a network linking in some predictable fashion elements that are perfectly well defined and stable, for the entities it is composed of, whether natural or social, could at any moment redefine their identity and mutual relationships in some new way and bring new elements into the network. An actor network is simultaneously an actor whose activity is networking heterogeneous elements and a network that is able to redefine and transform what it is made of. I show in the case of the VEL that this particular dynamic can be explained by two mechanisms: simplification and juxtaposition.

Simplification is the first element necessary in the organization of heterogeneous associations. In theory reality is infinite. In practice actors limit their associations to a series of discrete entities whose characteristics or attributes are well defined. The notion of simplification is used to account for this reduction of an infinitely complex world.[16]

For example, towns consist of more than public transport, the wish to preserve town centers, and the town councils composed of their spokespeople. They differ from one another with respect to population, history, and geographical location. They conceal a hidden life in which anonymous destinies interact. So far as the EDF engineers were concerned, however, towns could be reduced to city councils whose task is the development of a transport system that does not increase the level of pollution.

EDF's engineers did not need to know more. This definition would remain realistic so long as the simplification on which it was based was maintained. In other words, such simplifications will be maintained so long as other entities do not appear that render the world more complex by stigmatizing the reality proposed by them as an impoverished betrayal: The town council is not representative; living conditions in different neighborhoods cannot be reduced to those in the town center; and the system of public transport is but one aspect of a larger urban structure. The same was true for fuel cells. If the catalysts and electrolytes that were trusted became contaminated or destabilized, the fuel cell, which it was hoped would power the VEL, would become appallingly complex. Instead of being easily mastered, fuel cells were transformed into an apparatus whose ever-increasing elements turned out to be beyond control. A "black box" whose operation had been reduced to a few well-defined parameters gave way to a swarm of new actors: scientists and engineers who claimed to hold the key to the functioning of the fuel cell, hydrogen atoms that refused to be trapped by the cheaper catalysts, third world countries that raised the price of precious metals, etc.[17]

Behind each associated entity there hides another set of entities that it more or less effectively draws together. We cannot see or know them before they are unmasked. Hydrogen fuel cells and zinc/air accumulators were two of the elements that made up the world built by EDF's engineers; however, the controversies that developed in their name rapidly divided them into a series of other elements (much as a watch is dismantled by a jeweler to find out what is wrong with it). Thus simplification is never guaranteed. It must always be tested. The catalyst gave way and the fuel cell broke down, thus causing the downfall of the EDF. As for the catalysts, the electrolytes can be decomposed into a series of constituent elements: the electrons in the platinum and the migrating ions. These elements are revealed only if they are brought into a controversy, that is, into a trial of strength in which the entity is under suspicion. Of course, what there is to say about fuel cells, catalysts, and electrons is also true of city councils or administrations. In the project of the EDF engineers, the city was reduced to the city-council-that-wants-to-preserve-the-city-center-at-all-costs. But to preserve its integrity, the city council must stabilize the elements that hold it together: the middle class electorate that trusts it, the pedestrian precinct that pushes the flow of traffic to the edge of the town center, the urban spread, and the system of public transport that enables the inhabitants of the suburbs to come and do their shopping in the town center.

Such a simplified entity exists only in context, that is, in juxtaposition to other entities to which it is linked. Fuel cells, Renault as a car body builder for the VEL, and users who no longer consider the car to be a status symbol are all interrelated. Remove one of these elements and the whole structure shifts and changes. The set of postulated associations is the context that gives each entity its significance and defines its limitations. It does this by associating the entity with others that exist within a network. There is thus a double process: simplification and juxtaposition. The simplifications are only possible if elements are juxtaposed in a network of relations, but the juxtaposition of elements conversely requires that they be simplified.

These juxtapositions define the conditions of operation for the engineers' construction. In fact, it is from these juxtapositions that the associations draw their coherence, consistency, and structure of relationships that exists between the components that comprise it. If they were not placed in a network, these elements would be doomed. These relationships, which define the contribution of each element as well as the solidity of the construction as a whole, are varied. One must abandon the conventional sociological analysis that tries to adopt the easy solution of limiting relationships to a restricted range of sociological categories. Of course, there may be exchange relationships (the user exchanges money for a VEL), subcontractual relationships (the CGE works for EDF), power relationships (EDF brings Renault to its knees), or relationships of domination. But often the relationships between entities overflow simultaneously into all these categories, and some escape completely from the vocabulary of sociology or economics. How can one describe the relationships between fuel cells and the electric motor in terms other than those of electric currents or electromagnetic forces? Not only are the associations composed of heterogeneous elements but their relationships are also heterogeneous. Whatever their nature, what counts is that they render a sequence of events predictable and stable. Hydrogen feeds the fuel cells that power the motor that ensures the performance of the VEL for which the users are willing to pay a certain price. Each element is part of a chain that guarantees the proper functioning of the object. It can be compared to a black box that contains a network of black boxes that depend on one another both for their proper functioning as individuals and for the proper functioning of the whole. What would the battery be without hydrogen? What would become of consumers without their VELs?

Therefore the operations that lead to changes in the composition and functioning of an actor network are extremely complex. The extent to which an entity is susceptible to modification is a function of the way in which the entity in question summarizes and simplifies one network on behalf of another. If we wish to construct a graphical representation of a network by using sequences of points and lines, we must view each point as a network that in turn is a series of points held in place by their own relationships. The networks lend each other their force. The simplifications that make up the actor network are a powerful means of action because each entity summons or enlists a cascade of other entities. Fuel cells mobilize catalysts, electrons, and ions, which all work for the fuel cell. This, in turn, works for the VEL and the EDF actor network. Through these successive simplifications (which are never as apparent as when they fail) electrons, specialists at Renault, the middle class electorate, and researchers at the CGE have all been enlisted and mobilized. EDF's engineers see and know only fuel cells, accumulators, city council spokespeople, and the public transport authorities. But each of these entities enrolls a mass of silent others from which it draws its strength and credibility. Entities are strong because each entity gathers others. The strength of EDF and the durability of the VEL were built by means of these simplified and mobilized entities. Thus a network is durable not only because of the durability of the bonds between the points (whether these bonds concern interests or electrolytic forces) but also because each of its points constitutes a durable and simplified network. It is this phenomenon that explains the conditions that lead to the transformation of actor networks. It is possible to modify the performance of fuel cells to account for the new demands of users only if the catalysts or electron spin states can be modified in order to increase, for example, the power and longevity of the fuel cell. Each modification thus affects not only the elements of the actor network and their relationships but also the networks simplified by each of these elements. An actor network is a network of simplified entities that in turn are other networks.

Transformation thus depends on testing the resistance of the different elements that constitute our actor network.[18] Is it easier to change the expectations of the users, the demands of the municipalities, the interests of Renault, or the longevity of platinum? This is a practical question that is answered through the continual adjustments that are also negotiated changes. To adapt the VEL by changing this or that aspect of its performance is to act on the actor network, and its success thus depends on the capacity to test certain resistances to their limits, whether these spring from social groups, cash flow, or electrodes to be improved.

An actor network, such as the one described in this chapter, can in turn be simplified. The solidity of the whole results from an architecture in which every point is at the intersection of two networks: one that it simplifies and another that simplifies it. It can be mobilized in other actor networks. For example, the VEL can be linked to the TGV (high-speed train) or to the Airbus, thus forming a part of a new French transport policy. Although simplified into a point and displaced in this manner, it is still composed of associated entities, and although these entities are susceptible to being molded or shaped, they in turn may transform the actor network of which they form a part.

The actor network describes the dynamics of society in terms totally different from those usually used by sociologists. If car users reject the VEL and maintain their preferences for different types of the traditional motorcar, this is for a whole series of reasons, one of which is the problem of the catalysts that turn poisonous. It is these heterogeneous associations that sociologists are unable to take into account and yet that are responsible for the success of a particular actor network. The post-industrial society that Touraine believes is coming depends in this particular case not only on the capacity of new protest movements to influence the choices of technocrats but also on the way in which the catalysts in the fuel cells behave. Tourainian sociological theory, as with most other sociological theories, remains a clever and sometimes perspicacious construction; but it is bound to remain hypothetical and speculative because it simplifies social reality by excluding from the associations it considers all those entities—electrons, catalysts—that go to explain the coevolution of society and its artifacts. This criticism applies equally well to Bourdieu's interpretation of society. Although his theory happens to work better (explaining the success of the Renault actor network), this is pure luck, for in his explanation of car users' preferences he omits most of the elements that make up and influence these preferences. Although Bourdieu happens to be right and Touraine wrong, this is quite by chance. Although Renault turns out to be right, this is because the heterogeneous associations proposed by the EDF engineers disintegrate one by one: the discovery of a cheap catalyst as a substitute for platinum might have proved Bourdieu wrong and rehabilitated Touraine's sociological theory after all.

A New Methodological Tool

In what way could the analyses and the experiments developed by the engineer-sociologists be useful to sociology?

It was in order to answer this question that I introduced the idea of the actor network, which allows us to measure the distance between the heterogeneous and "impure" sociology of the engineers and the "pure" and homogeneous sociology of the sociologists. In the one case sociological and technical considerations are inextricably linked; in the other they are rigorously dissociated. If EDF and Renault sociology cannot be compared with that of Bourdieu and Touraine it is because its success depends not only on the behavior of traditional social actors but equally on that of catalysts or zinc/air batteries.

One can choose to be satisfied with this declaration and maintain the splendid isolation of academic sociology by underlining the radical difference between it and that of the engineer-sociologists. I would like to suggest now that this defensive position, which seeks to safeguard the orthodoxy, cost what may, is not the only possible one. According to whether one is more or less disposed to transform sociology itself, other more or less radical choices can be envisaged. They all lead to a transformation of the study of technology into an instrument of sociological analysis.

First of all, and this does not in the least imperil sociology, it is possible to use the controversies in which the engineer-sociologists are engaged as particularly powerful tools of investigation. To learn about society, sociologists employ tools that have been developed and tested over years: surveys, interviews, opinion polls, participant observations, statistical analyses, and so on. Another way of learning about society, as shown in this chapter, is to follow innovators in their investigations and projects. This method is particularly effective in cases in which, because they are working on radical innovations, engineers are forced to develop explicit sociological theories. In such cases this method enables sociologists to explore large sections of society (peering over the engineer's shoulder, so to speak). It is in this way that any sociologist, whether or not he or she knows anything about Touraine, could have found in the analyses of the engineer-sociologists of EDF valuable aids to the development of an analysis of the role of social movements in the evolution of consumption.

The study of engineer-sociologists can furnish more than a simple source of inspiration. In effect, the sociology developed by the engineer-sociologists is concretely evaluated in terms of market share, rate of expansion, or profit rate. With the failure of the VEL, EDF's theories about French society and its future collapsed (although perhaps only provisionally). The sociologist has here a powerful tool for evaluating different sociological frameworks of analysis. Engineer-sociologists, then, work for the good of sociology. The sociologists can rest content with following the engineer-sociologists, picking up their analyses and examining the way in which they are refuted or validated by the success or failure of the technical apparatus the engineer-sociologists have helped to bring into being. The results of the test may not necessarily be wholly positive or wholly negative. The case under discussion happens to show a complete reversal of fortune. But in other situations engineers may arrive at a compromise solution and progressively change their sociological interpretations, that is, their associations, and consequently change the shape of the technological devices they develop. In any event sociologists who study engineers shaping technologies have a chance to evaluate the validity of certain interpretations and to follow their successive adaptations in the light of the resistance they encounter.

But the sociologists, if they want, can be still more audacious, can display an audacity equal to that of the engineer-sociologists. They can, and this is the path I urge them to envisage, put into question the very nature of sociological analysis itself. From this point of view the study of technology can play a critical role. Instead of being someone whose ideas and experiments can be turned to the advantage of the sociologist, the engineer-sociologist becomes the model to which the sociologist turns for inspiration. The notion of the actor network then becomes central, for it recognizes the particular sociological style of the engineer-sociologist. To transform academic sociology into a sociology capable of following technology throughout its elaboration means recognizing that its proper object of study is neither society itself nor so-called social relationships but the very actor networks that simultaneously give rise to society and to technology.

As I have noted, the functioning of what I propose to call actor networks is not adequately described by the usual frameworks of sociological analysis. In short, not only does the repertoire of associated entities extend beyond that generally accepted in social science but also the composition of this repertoire does not obey any definitive rules. How can the social elements be isolated when an actor network associates the spin of an electron directly with user satisfaction? How can any interpretation of social interaction be established when actor networks constantly attempt to transform the identities and sizes of actors as well as their interrelationships? The fact that actor networks constantly create new combinations of entities renders this task even more difficult. The notion of actor network is developed in order to handle these difficulties. This notion makes it possible to abandon the constricting framework of sociological analysis with its pre-established social categories and its rigid social/natural divide. It furnishes sociological analysis with a new analytic basis that at a stroke gains access to the same room to maneuver and the same freedom as engineers themselves employ.

Dedicated to understanding the working of actor networks, whose analysis is still to be done, sociology will henceforth find itself on new terrain: that of society in the making. It will also progress resolutely along the path opened by Hughes in his different studies (1983 and this volume) consecrated to technological systems. If, however, we prefer the idea of actor network to that of system, it is essentially for two reasons.

First, the engineers involved in the design and development of a technological system, particularly when radical innovations are involved, must permanently combine scientific and technical analyses with sociological analyses: The proposed associations are heterogeneous from the start of the process. The concept of actor network can be used to explain both the first stages of the invention and the gradual institutionalization of the market sometimes created as a result without distinguishing between successive phases. It is applicable to the whole process because it encompasses and describes not only alliances and interactions that occur at a given time but also any changes and developments that occur subsequently. Certain simplifications become impossible to implement; associations are no longer taken for granted. The actor network is modified under the influence of the forces it seeks, although not always successfully, to enroll; but its structure remains that of an actor network whose development can be traced and followed. The concept enables sociologists to describe given heterogeneous associations in a dynamic way and to follow, too, the passage from one configuration to another.

This leads to the second point I would like to mention, if only briefly. The systems concept presupposes that a distinction can be made between the system itself and its environment. In particular, certain changes can, and sometimes must, be imputed to outside factors. The actor-network concept has the advantage of avoiding this type of problem and the many difficult questions of methodology it raises. For example, how do we define the limits of a system and explain concretely the influence of the environment? To answer such questions precisely, we must develop a formal science of systems, thus possibly depriving the analysis of all its descriptive and explanatory value. Hughes manages to avoid this pitfall by using the systems concept in a pragmatic way.[19] By stressing continually all the connections linking the "inside" and "outside" of the system, he comes close to the actor-network concept. By abandoning the concept of system for that of actor network, I believe we are taking Hughes's analysis—neatly summed up in the ambivalent title of his book, *Networks of Power*—a step further.

Notes

I especially thank Ruth Schwartz Cowan and Gerard de Vries for their sharp criticism, which I have probably failed, most of the time, to answer.

1. For an overview of social studies of technology, see MacKenzie and Wajcman (1985).

2. Several studies have been made to clarify the respective roles played by science, technology, and the market in the beginning and development of an innovation. Put in these terms, the question does not have a general answer. The first reason for this is that it is difficult to draw an indisputable boundary between science and technology. The sociology of science of the last ten years has shown empirically that it is impossible to give a general definition of scientific activity (Knorr-Cetina and Mulkay 1983) and has contested the idea of a noncontroversial distinction between science and technology (Callon 1981b). In addition, for a given innovation it is quite often impossible to outline a genealogy in which scientific and technological contributions that are linked to an innovation can be unquestionably separated. This is what two studies—HINDSIGHT (Sherwin and Isenson 1967) and TRACES (Illinois Institute of Technology, 1968)—have shown.

Anyway, it is difficult to distinguish market influences from those of science and technology. This is the conclusion of C. Freeman after having reviewed literature pertaining to this question. Following Mowery and Rosenberg (1979), his critique of two models, "technological push" and "demand pull," led him to propose the notion of "coupling," which leaves all possibilities of interaction open and recognizes that uncertainties in the market and sciences are the very motor of innovation. "The fascination of innovation lies in the fact that both the market and the technology are continually changing. Consequently there is a kaleidoscopic succession of new possible combinations emerging" (Freeman 1982, p. 111). Or "the test of successful entrepreneurship and good management is the capacity to link together these technical and market possibilities by combining the two flows of information" (Freeman 1982, p. 111). Freeman correctly notes that "the notion of 'perfect' knowledge of the technology or of the market is utterly remote from the reality of innovation, as in the notion of equilibrium" (1982, p. 111). It is because the innovation is caught between two series of uncertainties, the first concerning the market and the state of society and the second related to the state of knowledge, that it is impossible to describe it other than as an interactive process (Nelson and Winter 1977). Moreover, this point is confirmed by authors such as Peters and Austin (1985) when they seek to identify the organizational forms that favor innovation. Leaning on numerous case studies, they show that innovation is always a compromise that results from a long series of trials, which are at the same time technical and socioeconomic. Hughes (this volume) develops this argument in detail. See also Kidder (1982), Jewkes et al. (1969), and Callon and Latour (1986).

3. For this point, see the revealing studies of C. Freeman (1982) concerning research and development of synthetic materials and electronics.

4. This hypothesis is often formed by those who are interested in radical innovations. For two examples of this perspective in the fields of economics and history, see two excellent books: Mensch (1979) and Constant (1980).

5. Concerning this point, see the enlightening demonstration provided by Hughes (1983). The cases studies by Bijker and Pinch (1984; also Bijker, this volume), using the notion of interpretative flexibility, also show the impossibility of separating the definition of technical problems from the socioeconomic context to which the inventors associate them. See also Callon (1986).

6. As Woolgar has shown (this volume), engineers are not content with just analyzing the society around them. They do not hesitate, if need be, to play the psychologist and propose interpretations of the cognitive capacities of humans.

7. The EDF is a public company that has a monopoly on the production and distribution of electricity. It devotes a large part of its budget to research in the development of uses for electricity.

8. To study this project, I was able to consult all the archives of different ministries that at one time or another supported the VEL financially. Several interviews were carried out with the different protagonists.

9. This has been analyzed well by Hughes (1983), who shows how Edison conceived the incandescent lamp.

10. In this text the term "battery" is used as a generic term to cover all portable chemical devices for generating electricity.

11. For two contradictory analyses of the May 1968 movement, see Aron (1968) and Touraine (1968).

12. These unforeseen alliances between human beings and animate or inanimate nonhumans have been analyzed in detail by Latour (1984) and Callon (1986).

13. Castoriadis asserts that technology creates what nature is not capable of achieving. How does technology succeed? It succeeds by playing with the differences of resistances that exist within the environment that it uses and transforms, for this environment does not resist in any way and it does not resist stubbornly. Reality is not static because it consists of interstices that permit it to move, gather, alter, and divide; thus there is room to "make." Whether it concerns outside nature, the neighboring tribe, or bodies of people, resistance is regulated. It contains lines of force, veins, and partially systematic progressions. "Technology thus brings about the division of the world into the following two fundamental regions, which render it human: those elements which resist in all cases and those elements which (at a given stage of their history) resist only in a certain fashion" (Castoriadis 1968). I do not need to be so extreme; I have only to establish a general map of the differentiated resistances that are met by the actors (Latour 1984; Callon and Latour 1981).

14. CGE is a company that specializes in electrotechnology.

15. Concerning the definition and the use of the notion of heterogeneous engineering, see Law (this volume). See also the case of Draper Laboratories studied by MacKenzie (this volume).

16. There is an analogy here with scientific theory. As Hesse (1974) has so persuasively argued, description always entails loss of information and simplification. For a full development of this argument, see Law and Lodge (1984).

17. On the notion of black boxing as a form of simplification, see Callon (1981a) and Law (1985).

18. For a detailed empirical study of the mechanisms of the transformation of an actor network, see Law (1984b).

19. Concerning Hughes's pragmatism in his use of the notion of systems, see the excellent review of *Networks of Power* by Barnes (1984).