Six Principles for the Interdisciplinary Analysis of Technology

John Law

I Introduction

If one thing is clear from recent technological disasters, mishaps and failures — Three Mile Island, Chernobyl, Challenger, the Herald of Free Enterprise and the Nimrod early warning aircraft are just a few that come to mind — it is that technical failure is more than technical: typically if the nuts and bolts have gone wrong then so, too, have the social relations. But many are prepared to concede that technology has a human dimension so what are we to make of this commonplace? The question I want to consider is precisely *bow* that human dimension should be conceived. Is the human best seen as an appendage which surrounds, makes use of, or subverts technology? Or is it something that penetrates right through technology and helps to constitute it in the first place?

I am one of those who takes the latter view and it is this that I shall be exploring in what follows. However there are many who prefer the former position. Thus, some argue that technology *per se* is inherently dominator. Marcuse's (1968) position is well known and is, perhaps, not so distant from that of Weber. Though the way in which this argument is constructed varies, it lends itself to a dichotomy in which an (evil) technology resides on the one side and the (good) social on the other. However, another much more common and politically influential school of thought complements the first. Again it erects a dichotomy between the technical and the social, though this time the polarities are reversed. It is the technical that is good, and the social that is evil. Here it is assumed that when social factors *do* indeed impinge upon the technical they do so in a way that tends to undermine the inherent quality of the latter. The internal logic of technology is subverted and failure results.

The discursive logic of this second 'optimistic' conception of technology has been explored for cases of failure by such authors as Charles Perrow (1984) and Brian Wynne (1987).[1] They find that it is usually people rather than nuts and bolts that are blamed when things go wrong. Thus sometimes it is the designers who are thought to be at fault. To take a case that has, precisely, to do with nuts and bolts — that of the Kansas City Hyatt Regency Hotel disaster in which two walkways crashed down upon dancers in the lobby below — this occurred, or so the inquiry suggested, because engineers failed to see that a change in design would lead to unacceptable strain on a particular bolt.' On other occasions the design may be held to be beyond reproach, but failure is attributed to the actions of operators who override safety systems that have been built into the structure. The Chernobyl disaster has been explained in this way[3], as was the accident between New York and Washington in 1986 in which the Metroliner ploughed into three linked Conrail locomotives with considerable loss of life. Again, less proximate blame may be allocated to management for failing to ensure that proper procedures are followed (the Challenger disaster) or imposing unreasonable pressures upon subordinates (the Herald of Free Enterprise and the Challenger disaster again).[4] The failure of technical systems in the official and public views is thus more often than not put down to human inadequacy — people's failures to live up to a perfect (?) world of technology. It is almost, as Brian Wynne (1987) has indicated, as if there were collusion between technologists and their publics to protect the purity of the image of technology.

The recognition that "to engineer is human" (to use Petroski's felicitous phrase) thus in practice meets with some resistance. Engineers, it is conceded, may be human, but engineering itself is not, at least if the engineers are doing their jobs properly. The idea is that engineering in its sinews is something different, and it is all the more difficult to resist this idea because it is built right into our language. Thus while it is true that there is a handful of cumbersome and relatively new locutions (one thinks of `sociotechnical systems' or 'actor-networks') which try to bring the social and the technical together, we find that we are pushed, by our language, into talking about the 'technical', the 'social', the 'economic' and the 'scientific' as if these were all different in quality. If we want to communicate at all we are more or less bound to adopt a version of this dividing vocabulary. Our everyday usages thus conform to the experience of both the pessimists and the optimists — that despite the possibility of mutual interference or interaction technology is different in kind from the social.'

If there is a difficulty about talking of the `sociotechnicar in everyday talk, or in the language of the public inquiry into disaster, we are, unfortunately, no closer to solving the problem in the social study of technology. There are a number of reasons for this. One, quite simply, has to do with disciplinary vested interests. We tend to assume that those explanatory features of a phenomenon that we have been trained to treat with are, indeed, the most significant features of that phenomenon. In addition, however, perhaps because our academic perceptions relate too closely to classic common sense, we have not generally succeeded in breaking away from the standard, dichotornising vocabulary. We are good at looking at little bits of the phenomena that confront us, but bad at getting a grasp of the whole picture. In particular, we are often very poor in sensing the way in

which the technical and the social interpenetrate one another, and seek, instead, to treat these as if they were two separate types of phenomena which at best display a range of interconnections.

This point can be developed in a number of ways, of which I will mention just two. First, as a community of scholars we tend to shy away *either* from the content of technology, or, contrariwise, to become so concerned about it that we lose sight of its 'social context'. The historians are, perhaps, better at avoiding this particular fork than the rest of us[6], though there are plenty of antiquarian histories of artefacts which take the latter route and do scant justice to the social relations in which the technologies in question developed. By contrast, sociologists, economists, and political scientists tend towards the former route and deal scantily with technical content.' Frequently, indeed, the later is avowedly 'black boxed' while the authors seek to display the explanatory relevance of their disicplinary models — models that can be applied with little alteration to diverse subject-matters. The argument in favour of this kind of work is that it demonstrates the power of general theory: it shows that social variables drive technical change, or (in its other version) that technical variables drive social change. The argument against it — and one which I find much more persuasive — is that it makes use of what the historian, Svante Lindqvist, has described as 'Sauerkraut' theory — that is theory which, while equally at home explaining the production of Sauerkraut and (say) boatbuilding (or, for that matter, class relations or gender inequality), thereby fails to explain the specificity of any of these activities. Our problem, then, seems to be that as a community we find it quite difficult to sustain a reasonable level of attention to both the technical and the social. More often we concentrate excessively on either one or the other.

My second point is related to the first. It is the fact that when we start by privileging a particular, discipline-based, model of the relationship between the social and the technical we tend to work on the assumption that the explanatory variables identified in that model display *stability* with respect to that which has to be explained. This assumption — which may be perfectly permissible under certain empirical circumstances — rests upon another: namely that the phenomenon that has to be explained is unlikely to influence that which is used to explain it. Again, as a suggestion about the way in which things work under certain circumstances this is far from obnoxious. But when it is raised, as is sometimes the case, to the status of a general principle, it is much more questionable. Thus if the technical is thought to be *inherently* dominatory in character then this is held to exert a broadly consistent influence on the social that surrounds it. It shapes the social but cannot, in turn, be influenced by the latter. Contrariwise, in the parts of sociology which I know best, the opposite assumption is made (though it is seldom articulated as a general principle): certain relatively stable background social interests are thought to operate to explain such changing foreground phenomena as instances of technological innovation. The assumption is thus that the background phenomena are not themselves susceptible to change. Here it is the social that is black boxed, while the arrow of causality drives in the opposite direction — from the social to the technical. In this perspective devices become a passive end product: like the modelling clay of a child they display plasticity in the form of a set of social thumbprints.

Thus, though there are some exceptions to which I shall return below, overall it seems to me that the social analysis of technology breaks down in much the same way as everyday vocabulary and official discourse: it proves difficult to concentrate evenhandedly on both the technical and social; it proves close to impossible to deal with these in a way that avoids the assumption that they are different in kind and have therefore to be treated in quite different ways; and it turns out to be difficult to resist the temptation of assuming that there is a small class of relatively stable variables — whether these are social or technical depends upon the writer in question — which is able to explain everything that might reasonably be of interest about the phenomenon in question.

2 Six Principles of Sociotechnical Analysis

How, then, can we escape from our vocabulary, from the platonising ideals of official discourse, and from the disciplinary blinkers which we bring to the social analysis of technology? How can we put a more satisfactory picture of technology in place — one that does not bleach out the way in which the social and the technical interpenetrate one another? And how can we attempt this while, at the same time, avoiding a wishy-washy eclecticism? The answer, of course, is that we cannot hope to do all these things in one fell swoop. Nevertheless we are, by now, in a position to sketch out the elements of a possible response, one that draws upon a range of work in the history, sociology, politics and economics of technology.' This approach, which is magnificently exemplified in Thomas Hughes' (1983) *Networks of Power,* rests upon an old sociological and anthropological principle: that is, when in doubt it is often best to follow the actors and see what it is that they actually do, how it is they do it, and how it is they interpret what it is that they have done. Applied to the case of technology it turns out that this principle tends to dissolve the disciplinary distinctions that I have been complaining about in favour of categories and elements devised by the actors themselves. In short, it erodes the 'technology', 'society' fragmentation that structures so much thinking about technology and replaces it with something that is much richer.

Let me start, then, by considering the following phenomenon: thorough analy

ses of technological failure, though they tend to attribute blame for failure to designers, operators, or managers, also typically move towards an analysis of technology as a *system* — and not simply a technical, but rather a sociotechnical system.[9] Links, relationships, interactions — some social, some technical, many of a hybrid character — are *seen* to have interacted to generate failure. This is well illustrated by the Challenger disaster report, but it can also be seen elsewhere — for instance in the (happily non-catastrophic) failure of the British Advanced Passenger Train. I shall draw, here, upon a recent study (Potter: 1987) of this ill-fated venture in order to illustrate my argument.

The proximate causes of this particular failure lay in specific technical breakdowns. Thus the clearance for the low speed brakes led on some occasions to wheel overheating, while high speed brake failure led to axle failure on at least one occasion. Again, the tilt mechanisms for the passenger coaches were not entirely reliable and also offered a jerky ride until they were attached to sensors in the preceding coach. Had problems of this kind not occurred then the public trials of the train would have been a success rather than a failure. As it was, there were ignominious and widely publicized breakdowns during those.

However, Potter's analysis does not stop with a catalogue of the simple technical problems. He also talks of problems of manufacture. Thus it has been argued that this arose because the train incorporated new, aircraft-derived, technologies which required standards of tolerance that were difficult to achieve in a traditional craft-oriented industry such as British Rail, and it has also been suggested that there was tension between the team responsible for the APT and the more evolutionary-minded Traction and Rolling Stock Design Department which had other priorities and tried to impede the development of the APT. Other commentators have argued that internal reorganizations combined with changing markets also contributed to failure. Whatever the facts of this particular case, the more it is considered the more difficult it is to write a purely technical account of the failure of the project. The object, in the form of the train, embodied decisions made by engineers and designers, and failure reflected an interaction between those decisions and the circumstances (some social some technical) in which that object was deployed. Let us, then, make explicit a first principle for the social analysis of technology. I will call this the *heterogeneity principle* which states that *all technologies are heterogeneous in character*.

So far, so good. We have turned an object into a set of objects that is both technical and social. There are relationships between the efficiency of hydrokinetic brakes and speed. There are (human) calculations about the relations between the weight of unsprung bogies and track wear. There are (further human) calculations about the degree of cant deficiency acceptable to passengers. There are reactions by the inner ears of the passengers to the operation of the tilting mechanisms. And there are rivalries between groups of experts at Derby, market projections by British rail economists, and desperate attempts by engineers to keep the prototype running in bitterly cold winter weather. Here, then we have a jumble of heterogeneous bits and pieces. But it is more than a jumble. Rather it is a structured *network* of elements, or relationships between sociotechnical elements. Thus, though it is *possible* to treat the train as a unitary object, detach it from its environment", and write a purely technical history of it, this makes precious little sense. This, then, is a second principle which I shall call the *network principle.* It states that *all technologies are networks of elements* or, if this is prefered, *all technologies are constituted by sets of relations.*

However, the story of the Advanced Passenger Train also points us in the direction of a third principle. Note, first, that the train was not ultimately a success. The APT was not put into production, and though some of its technology was incorporated in the High Speed Train which followed it, this was an evolutionary development in the British Rail tradition. There is no need to detail the various failures in the APT program again. What does, however, bear repeating is the fact that these failures were not exclusively technical in character. Though some of them were technical, some were social and many more were socio-technical. If the directors of the project were to make sure that the project was successful — that the train was actually adopted for general use by British Rail — they had to ensure that the technical, social, economic and political elements in the network that made up the project *all* played the roles that had been designated for them. From the hydrokinetic brakes through to the British Rail Board — all of these were necessary if the APT was to be adopted for general service. We are used, I think, to the idea that the technologist is an engineer — someone who juxtaposes technical bits and pieces and persuades them to play their designated roles in order to create a working artefact. However, we are not yet used to the fact that she is also, and just as much, a social engineer. That is, she not only fits technical but also social (and economic, and political — how tiresome this vocabulary is!) bits and pieces together into networks of interacting roles. Let us, therefore, try to avoid this fragmenting vocabulary by noting a third principle, *the principle of sociotechnical engineering.* This states that *all technologies are the product of heterogeneous, or sociotechnical, engineering."* It follows, of course, that technologies extend far beyond objects into the physical and social relations which interweave with those objects. It also follows that the object is no longer treated as an object. Rather it is subset of the sociotechnical relations that have been pieced together by the heterogeneous engineer.

Now note that these pieces, these relations, are not necessarily pre-constituted. The sociotechnical engineer is not like a shopper in a supermarket where all the possible bits and pieces have already been assembled and it is merely a question

of selecting those that are needed. Rather, she has the much more hazardous and exciting job of dreaming many of them up, of sorting out how it is that they relate to one another, of selecting between designs, of machining them to shape, of fitting them together with other equally novel social and technical objects, and so persuading them to act in quite novel ways. Thus in the case of the APT many of the components that went to make up the new train were not ready-made in the stores in Derby. Rather, they were invented by the designers and were specially built in the machine shops: lightweight bogies, tilting mechanisms, high speed brakes. But the innovations were not simply technical. The composition and organization of the team that brought the train into being was unusual. The task of introducing the train into experimental service required that it be carefully inserted into tight railway timetables that were not adapted to trains that ran at 260 kph. The concept of maximum 'commercial' speed was created to relate demand elasticity to costs. And so on. This, then, is a fourth analytical principle, that of *object malleability:* namely that *all technologies involve the creation and juxtaposition of partially new sociotechnical entities."* The task of the sociotechnical engineer is the difficult one of creating something that is new by selecting and reshaping existing materials: by inserting these into relationships where they have no choice but to play the roles that have been allocated to them.

This process of selecting, shaping, and inserting is full of pitfalls. Regrettably, this is admirably illustrated by the case of the APT. In the network of roles and relations that constituted the object there was always something that was falling out of role. Consider, for instance, a single instance — a derailment that took place at 200 kph (first role failure). When the train stopped it was found that a wheel set had collapsed (second role failure) because a ring of bolts had fractured (third role failure). The fracture had taken place because they had not been tightened (fourth role failure). Potter does not say why the bolts were not tightened, but such an inquiry would, presumably, take us to further role failures in the form of inadequate tools, time, training, supervision, or task specification. One failure, then, led to another, and another, and another. By contrast, a successful technology is one in which it proves possible not only to define the important roles, but also to ensure that the sociotechnical objects that are designated to play these actually do so *and thus keep each other in line.* The heterogeneous engineer is therefore someone who works with more or less obdurate materials in the attempt to create networks and relations that force these to play their designated roles. This fifth principle, that of *strategy as juxtaposition,* once again applies indifferently to the social and the technical. It states that *all technologies may be treated as sets of more or less successful methods for juxtaposing and hence enrolling* raw *materials."*

The fifth principle has a number of implications. One of these is that the extent to which the strategies for sociotechnical engineering are strongly determined by the environment in which the system-builder finds herself is an empirical matter rather than something that can be determined a priori. Evolutionary models of technical change, and particularly those that attend primarily to 'internal' technical development, are thus of limited prospective explanatory value." A second implication, and one that is more important in the present context, is that under some circumstances sets of sociotechnical relations may be put in place that ultimately acquire a degree of solidity that is independent of the continuing work of the heterogeneous engineer. Many devices are of this kind. A working train is one that does not fail in service. The bits and pieces — social and technical — which make it and its environment up thus form a network of self-sustaining roles which successfully hold each other in place. To be sure, such 'going concerns' will never, or almost never, be purely technical in character — many of the roles will be social or sociotechnical involving, for instance, driving, maintenance and accountancy skills. In addition, successful objects are almost never free-standing. As I indicated earlier, objects form part of a broader web of interrelated roles which extend beyond the object itself. Nevertheless, there is a difference between a technology, such as the APT, which depends upon continued non-routine intervention in order to keep it on the rails, and one, like the French Train a Grande Vitesse, which forms a routinized network which sustains itself more or less independently from those who conceived it. This, then, is the sixth principle — that of *technology as a going concern.*[15] It states that *successful technologies are usually those that form a routinely self-sustaining structure of heterogeneous roles.*

This principle is important for a variety of reasons. However, at present I want to point to just one of these. This is that it makes it possible to distinguish, analytically, between *project failure* on the one hand, and *catastrophic break-down* on the other. Project failure results from the inability of sociotechnical engineers to create a routinely self-sustaining heterogeneous structure that is independent of their continual intervention and modification. Examples of project failures include the APT, the Nimrod early warning aircraft, the TSR2 project (Law: 198713), the early eighteenth century introduction of steam power into the Dannemora mines in Sweden (Lindqvist: 1984), attempts at rural electrification in Africa (Akrich: 1986) and the program to convert urban transport in France from petrol to electric traction (Callon: 1986b). Project failures are described in a variety of ways — but at the level which I am talking there is no analytical distinction between what the weapons procurement specialists call 'programmatic failure' and what development experts call 'failed technology transfer'. The dynamics in both cases are the same, and reflect an

inability to create an independent self-sustaining network of sociotechnical roles.

Such project failures may, however be distinguished from catastrophic break-down. The latter occurs within sociotechnical networks that have been estab-lished as going concerns. That is, it occurs within what have become routineley self-sustaining structures which are substantially independent of the intervention of those who brought them into being. The network explanation of catastrophic breakdown is clear. It takes place because one or more components that make up the network fall out of role and are thus unable to play their part in keeping other their neighbours in place. As a result, the consequences of that failure are not contained but move rapidly through the network destroying it as they go. Chernobyl, Challenger, the Herald of Free Enterprise, the Comet 1 aircraft, the Hindenburg, the Titanic — any classic failure will serve as an example of catastrophic breakdown."

3 Methods and Centres of Sociotechnical Control

The problem for the sociotechnical engineer is simply described in the network terms that I have been advocating. It is that of creating a heterogeneous network that is freestanding with respect to its designer. In short, it is to create a sociotechnology that works and regulates itself. In this section I want to consider the *methods* and *materials* that are available for this task by returning, once again, to the case of the APT and considering the kinds of methods used by the British Rail engineers at Derby as they sought to design and build their train. First, of course, they were sociotechnically skilled. They knew how to select, assimilate and manipulate relevant data in order to arrive at possible solutions to technical problems. But they also knew how to manage one another and had more or less successful strategies for overcoming the various resistances that they encountered from colleagues in other departments as they went about their work. In short, they had some skill — it turned out not enough — at what is sometimes called bureaucratic politics. The first class of methods for sociotech-nical engineering thus take the form of individual skills. If we wanted to express this in a Foucauldian way, we might say that we were dealing, here, with the attributes of disciplined bodies.

However, such bodily sociotechnical skills do not exhaust the methods and materials available to heterogeneous engineers!' In addition, they make use of what I will call *material intermediaries.* Thus, the engineers in Derby dealt endlessly with documents. They read journals, they collected data, they made notes, they roughed out designs, they wrote reports, they issued instructions and blueprints — the list of documents which they handled was very long. Indeed it is difficult to imagine working on any large scale project without documents of one kind or another being used for most purposes in place of personal surveillance or verbal reports or instructions. Imagine the chaos that would have ensued if the British Rail engineers had been required to deal with all their staff each day in person. And, in so far as the reports they received were trustworthy, and their instructions were obeyed, they were accordingly able to operate upon materials and people that were physically and socially removed from Derby. Documents, then, constitute an important class of forms which act as intermediaries between the sociotechnical engineer on the one hand and that which she is seeking to design, build and render autonomous on the other.

However, documents are not the only form taken by material intermediaries. In addition, they come in the shape of a range of devices. Though Potter does not write much about these we can imagine the types of instruments and tools that were in use at Derby. There must have been computers, pocket calculators, slide rules, lathes, drills, micrometers, thermometers and voltmeters, and complex objects such as telephone systems, wind tunnels, and rail cars which automatically record the alignment of the track over which they are run. Of course, the notion that devices are crucial in extending muscle-power is an old one in the history of technology. This, however, is a somewhat restricted way of understanding their importance because devices not only have the potential to work upon aspects of their social and technical environments. In addition, they are crucial in helping those who have them at their disposal to detect and control phenomena which would otherwise be invisible. Again, then, it is difficult to imagine being involved in any large scale project without a range of devices that operate in place of personal surveillance on the one hand, or personal intervention on the other. Like documents, devices represent an important class of intermediaries, a form of (sometimes) enforceable two-way communication, between the heterogeneous engineer, and the sociotechnical world that she is seeking to modify and build.

Disciplined skills, documents and devices may be combined in many ways.' For instance, they may be used to generate such combinations as administrative bureaucracies, design shops and laboratories. Overall, however, when they are used successfully, they have the effect of creating major asymmetries between those who have them at their disposal and those who do not. This is because they tend to bring centres and peripheries into being. Thus there are some actors — social and technical alike — who find that their actions are increasingly subject to control: they find themselves at the receiving end of sets of instructions, the deployment of devices, and drilled people. At the same time they find that their behaviour is being monitored and reported back to those who deployed the material forms of control. They find, that is, that they are being pushed into

forms and shapes that will contribute to or form part of novel combinations — the forbears of new sociotechnical going concerns.

If the deployment of disciplined skills, documents and devices tends to reduce the freedom of those on the periphery while increasing their visibility, then it has something like the opposite effect on those at the centre. This expresses itself in a number of ways. First, of course, in the paradigm case the centre knows all about the periphery as a result of the operation of intermediaries and the production of documents. This increases its ability to intervene in ways that are optimal. Second, however, this ability is increased by the fact that the reports which document the state of the sociotechnical system are subject to further comparison and analysis. Thus centres typically work with techniques that allow different parts of the network under construction to be related together and modelled. For instance, in the case of the APT project, there were expressions which related such variables as curve radius, cant, centrifugal force, speed and cant deficiency to passenger comfort. This capacity to juxtapose representations of different parts of the network makes it possible to undertake quick experiments that would be unacceptable or downright impossible in real life. This in turn makes it possible to accumulate experience and make mistakes that are neither expensive nor consequential. It makes it possible to sort through a wide range of combinations of heterogeneous bits and pieces in order to turn up particular arrays that may be expected to hold together by themselves when they are put into place. It grants, in other words, a degree of autonomy to the engineer — a limited time and a limited place in which she may try out a range of possible sociotechnical worlds before trying to put any of them in place.

4 Conclusion

In this paper I have tried to do four things. First, I have argued that technology is essentially heterogeneous. I have suggested that it runs together the technical, the economic, the political, the social and the natural — and I have suggested that we would do well to lever ourselves out of our customary disciplinary modes of analysis if we want to understand and control that heterogeneity. Second, I have sketched out six principles for the analysis of sociotechnical systems — principles that are, I hope, blind to conventional disciplinary distinctions. Third, using these principles I have identified two modes of sociotechnical failure. On the one hand I have talked of project failure which occurs when it proves impossible for the heterogeneous engineer to put a network of roles in place that is self sustaining and does not require her intervention. On the other hand I have characterized catastrophic breakdown as that which occurs when a routinely self-sustaining network of roles, a going concern, suddenly loses its structure because a vital element falls out of role and no longer keeps its neighbours in place. Finally, I have considered some of the methods and materials that are available to the heterogeneous engineer as she seeks to build a network whose parts will display the desired autonomy of the sociotechnical going concern. There is, of course, much more to be said about all these questions. In particular, I have not even attempted to talk about the way in which sociotechnical going concerns reproduce their structure and autonomy.' This in turn means that I have not touched upon a vitally important issue: that of the difference between centrally conceived networks like the APT, and those that arise out of negotiation between a range of participants, but which lack an overall focus of design or control — such as the linked electric power systems described by Hughes. I want to end, however, with another thought. I have suggested that when the sociotechnical engineer deploys materials and methods of surveillance and control she creates for herself a space and a time where she has relative autonomy. Inside that space and within that time she may build and test future social and technical worlds without being supervised from outside. This is by no means a new idea. Thus Bruno Latour (1984) makes essentially the same point about Pasteur and his laboratory: science, he says, may be seen as politics by other means. He asks us to imagine how foolish scientists would look if, like politicians, they only ever had one chance to solve a problem, and they had to make all their mistakes in public.

However, although I think that Latour is essentially correct I believe that the differences between the autonomy of the technologist and the politician are not as great as he suggests. Thus the autonomy of the engineer (and, for that matter the scientist) is never complete. As she deploys the materials that keep outsiders in their place and so creates a space and time of relative autonomy she enters into implicit contracts with those outsiders. They will keep away, but only if she fulfils her part of the bargain: that she will produce a working prototype of the APT on the due date; that she will arrange for appropriate workshop facilities to be made available; that she will ensure that the tilt mechanism does not jam or cause the passengers to feel queasy — and all the rest of it. The point I want to emphasize, then, is that autonomy is never absolute but only relative?' It may be built up, and it may be undermined. Indeed, I believe that the trajectory of project failure often takes the form of a progressive loss of autonomy and freedom from surveillance', while the most successful politicians are precisely those who are able to conceal their mistakes from public gaze by creating a space and a time where they may experiment in relative peace.

However, if the differences between the technologist and the politician are those of quantity rather than quality and engineering is always *both* social *and* technical in character, then we are faced with a cruel dilemma. Do we wish to

grant those who refashion society and its artefacts the space and time to commit their mistakes in private? Do we wish, in other words, to give them the opportunity to make both more satisfactory devices and devise more effective means of social control? Or are we prepared to accept technical inefficiencies, accidents and breakdowns as the price of greater social autonomy? Or, perhaps, to avoid developing certain technologies at all?' Perhaps there is no single answer to these questions and they have to be answered case by case. One thing, however, is clear. Though technology *per se* is not dominatory, neither is it ever socially neutral. In the end I believe that the clearest justification for a non-disciplinary study of technology is not that it will help to make technology more efficient, though it seems likely that it will help to do this. It is rather that it will make it easier for us to see what we are doing to ourselves and our children, and so debate the desirability of the futures that confront us.

Notes

1 See also Hughes (1987).
2 For details see Petroski: 1985, pp 85ff.
3 See, for instance, Edmonds: 1986.
4 On the Challenger disaster, *see Report of the Presidential Commission on the Space Shuttle Challenger Accident* (1986). For speculation on the causes of the capsizing of the Herald of Free Enterprise, see Brown et al. (1987).
5 Even those who are neither optimists nor pessimists typically assume such a distinction — witness such phrases as -the social impact of the computer. (Law and Whittaker: 1986) — which make computers sound as if they were projectiles from outer space.
6 For examples of historical work which combine 'context' and 'content' see Constant (1980), Hughes (1983) and Lindqvist (1984).
7 There are, of course, a number of honourable though mostly recent exceptions. For a cross-section of these, and a useful commentary, see MacKenzie and Wajcman (1985). See also Bijker, Hughes and Pinch (1987).
8 See, for instance, Akrich (1986), Bijker (1987), Bijker and Pinch (1984), Bowker (1987a), (1987b), Callon (19866), (1987), Callon and Latour (1981), Callon and Law (1987), Constant (1980), Coutouzis and Latour (1986), Elzen (1986), Gerson and Star (1986), Hughes (1983), (1986), Latour (1987), Law (1986c), (1987a), (19876), Law and Whittaker (1986), MacKenzie (1984), (1987), Rip (1986), Wynne (1987).
9 In what follows I will concentrate on failure. This reflects a second sociological principle which states that failures tend to uncover material and expose relationships that would never otherwise have seen the light of day. However, in principle success can also be studied in the same way.

Consider as an example, Hughes' (1983) work on electrical systems, and my own study of the Portuguese expansion (Law: 1987a).

10 This has now been done. It is to be found in the Railway Museum at York. But it is no longer a working train!

11 For the related notion of the engineer-sociologist see Callon (1987); for the concept of heterogeneous engineering see Law (1987a).

12 Except in the most unusual circumstances, there is novelty even in quite routine situations. The role played by an element is defined both by its neighbours and those elements that it draws upon which are invisible to the sociotechnical engineer. It is very rare that both sets of relations are unchanged. Note, also, that it is the invisibility of further elements that constitutes the element in question as a unity rather than as a set of relations itself.

13 Such strategies, and the designs which form their blueprints, are sometimes referred to as translations. See Callon and Law (1987) and Callon (1986b).

14 This claim is important because it suggests that evolutionary or trajectory models of technological change are likely to be applicable only retrospectively in the form of glosses which normalize sets of choices which were not necessarily obvious at the time when they were made. For models of this kind see Dosi (1982) and Nelson and Winter (1982). In the specific context of evolutionary modelling I am saying, then, that the sociotechnical engineer has some degree of *choke* over the environment to which she wishes to adapt her strategies, but that this choice tends to disappear in those studies — such as Potter's — which are organized around distinctions between evolutionary and revolutionary technological innovation. For further discussion of this point see Callon and Law (1987).

15 I draw the notion of 'going concern' from the writing of Everett Hughes (1971). For a recent application of this notion to scientific theory *see* Star (1987).

16 Though I have been talking here about technology, it should *be* noted that this mode of analysis is applicable to non-technological failures and breakdowns.

17 If they did there would be little to choose between entrepreneurs on the one hand, and my two-year-old son on the other. In fact it is easy to argue that we are all sociotechnical engineers — see, for instance, Law (1986b) where I analyse laboratory work in this mode. For the original version of the argument about intermediate forms that I am about to develop, see Callon and Latour (1981).

18 For an extended discussion of the interaction between documents, devices and drilled people and their contribution to sociotechnical control see Law (1986c).

19 In fact they do this in ways that are not dissimilar to the methods by which projects are put in place.

20 For this point forcibly and elegantly expressed in a language of sovereignty, see Gerson (1975). Note also Callon and Law (1987) where the concept of 'negotiation space' does the same work.

21 This is certainly true for the APT, as it was for the TSR2 project.

22 For these issues, subtly debated, see Winner (1977) and Winner (1980).

References

Madelaine Akrich (1986), *Analyse des Facteurs Socio-Culturels a Prendre en Compte dans la* Planification *Energetique dans les Pays en Developpement,* Paris, Ecole Nationale Superieure des Mines de Paris, mimeo.

Wiebe Bijker (1987), "The Social Construction of Bakelite: Towards a Theory of Invention", forthcoming in Bijker, Hughes and Pinch (1987).

Wiebe Bijker and Trevor Pinch (1984), "The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology Might Benefit Each Other", *Social Studies of Science,* 399-441.

Wiebe Bijker, Thomas P. Hughes and Trevor Pinch (eds.) (1987), *The Social Construction of Technological Systems, New Directions in the Social Studies of Technology,* Cambridge, Mass., M.I.T. Press.

Geof Bowker (1987a), 'A Well Ordered Reality: Aspects of the Development of Schlumberger, 1920-1939", *Social Studies of Science,* forthcoming.

Geof Bowker (19876), "Science, Society and the Missing Link: the Sociology of the C.S.I.", this volume.

Kevin Brown, Hazey Duffy and Michael Cassell (1987), "Government Orders Emergency Checks on Ferry Doors", *Financial Times,* Tuesday 10th March, page 1.

Michel Callon (1986a), "Some Elements of a Sociology of Translation: Domestication of the Scallops and Fishermen of St. Brieuc Bay", pages 197-219 in Law (1986a).

Michel Callon (1986b), "The Sociology of an Actor-Network: the Case of the Electric Vehicle", pages 19-34 in Callon Law and Rip (1986).

Michel Callon (1987), "Society in the Making: the Study of Technology as a Tool for Sociological Analysis", in Bijker, Hughes and Pinch (1987).

Michel Callon and Bruno Latour (1981), "Unscrewing the Big Leviathan: How Actors Macrostructure Reality and Sociologists Help them do so", pages 277-303 in Knorr-Cetina and Cicourel (1981).

Michel Callon and John Law (1987), "On the Construction of Sociotechnical Networks: Context and Content Revisited", *Knowledge and Society,* forthcoming.

Michel Callon, John Law and Arie Rip (eds.) (1986), *Mapping the Dynamics of Science and Technology: Sociology of Science in the Real World,* London, Macmillan.

Edward W. Constant 11 (1980), *The Origins of the Turbojet Revolution,* London and Baltimore, John Hopkins University Press.

Mickes Coutouzis and Bruno Latour (1986), "Le Village Solaire de Frangocastello: vers une Ethnographic des Techniques Contemporaines", *L'Annee Sociologique,* 36, 113-167.

Giovanni Dosi (1982), 'Technological Paradigms and Technological Trajectories", *Research Policy,* 11, 147-162.

John Edmonds (1986), "Counting the Cost of Nuclear Complacency", *The Independent,* Thursday 4th December, page 14.

Brian Elliott (ed.) (1987), *Technology and Social Change,* Edinburgh, Edinburgh University Press, forthcoming.

Boelie Elzen (1986), "Two Ultracentrifuges: a Comparative Study of the Social Construction of Artefacts", *Social Studies of Science,* 16, 621-662.

Elihu M. Gerson (1975), "On Quality of Life", *American Sociological Review,* 41, 793-806.

Elihu M. Gerson and Susan Leigh Star (1986), "Analyzing Due Process in the Workplace', *ACM Transactions on Office Information Systems,* forthcoming.

Everett C. Hughes (1971a), "Going Concerns: the Study of American Institutions", pages 52-64 in Hughes (1971b).

Everett C. Hughes (1971b), *The Sociological* Eye*: Selected Paperes on Institutions and Race,* Chicago, Aldine Atherton.

Thomas P. Hughes (1983), *Networks of Power: Electrification in Western Society, 1880-1930,* Baltimore, John Hopkins University Press.

Thomas P. Hughes (1986), "The Seamless Web: Technology, Science, Etcetera, Etcetera", *Social Studies of Science,* 16, 281-292.

Thomas P. Hughes (1987), "Inventing Controls for Large Systems", this volume.

Karin D. Knorr-Cetina and Aaron V. Cicourel (eds.) (1981), *Advances in Social Theory and Methodology: Toward an* Integration *of Micro and Macro-Sociologies,* London, Routledge and Kegan Paul.

Karin D. Knorr-Cetina and Michael Mulkay (eds.) (1983), *Science Observed: Perspectives on the Social Study of Science,* London and Beverly Mills, Sage.

Bruno Latour (1983), "Give Me a Laboratory and I Will Raise the World", pages 141-170 in Knorr-Cetina and Mulkay (1983).

Bruno Latour (1987), *Science in Action: How to Follow Scientists and Engineers Through Society,* Milton Keynes, Open University Press.

John Law (1986a), *Power,* Action *and Belief: a New Sociology* of *Knowledge?* Sociological Review Monograph 32, London, Routledge and Kegan Paul.

John Law (19866), "On Power and its Tactics: a View from the Sociology of Science", *Sociological Review,* 34, 1-37.

John Law (1986c), „On the Methods of Long Distance Control: Vessels, Navigation, and the Portuguese Route to India", pages 231-260 in Law (1986a).

John Law (1987a), "On the Social Explanation of Technical Change: the Case of the Portuguese Maritime Expansion", *Technology and Culture,* forthcoming.

John Law (19876), "The Anatomy of a Sociotechnical Struggle: the Design of the TSR2", forthcoming in Elliott (1987).

John Law and John Whittaker (1986), "On the Malleability of People and Computers: Why the PC is not a Projectile", *SIGIOS Bulletin,* 7, 2-3, 21-32.

Svante Lindqvist (1984), *Technology on Trial: the Introduction of Steam Power Technology into Sweden,* Stockholm, Almqvist and Wiksell International.

Donald MacKenzie (1984), "Marx and the Machine", *Technology and Culture,* 25, 473-502.

Donald MacKenzie (1987), "Missile Accuracy - a Case Study in the Social Processes of Technological Change", forthcoming in Bijker, Hughes and Pinch (1987).

Donald MacKenzie and Judy Wajcman (eds.) (1985), *Th Social Shaping of Technology: How the Refrigerator got its Hum,* Milton Keynes, Open University Press.

Herbert Marcuse (1968), One Dimensional Man, London, Sphere.

Richard R. Nelson and Sidney G. Winter (1982), *An Evolutionary Theory of Economic Change,* Cambridge, Mass., Belknap, Harvard.

Charles Perrow (1984), *Normal Accidents: Living With High Risk Technologies,* New York, Basic Books.

Henry Petroski (1985), *To* Engineer *is Human: the Role of Failure in Successful Design,* London, Macmillan.

Stephen Potter (1987), *On the Right Lines? The Limits of Technological Innovation,* London, Frances Pinter.

Report of the *Presidential Commission on the Space Shuttle Challenger Accident* (1986), Washington D.C.

Arie Rip (1986), "Controversies as Informal Technology Assessment", *Knowledge: Creation, Diffusion, Utilization,* 8, 349-371.

Susan Leigh Star (1987), *Regions of the Mind: British Brain Research,* /870-1906, forthcoming, Palo Alto, Stanford University Press.

Laurent Thevenot (1984), "Rules and Innovations: Investments in Form", *Social Science Innovation,* 23, 1-45.

Langdon Winner (1977), *Autonomous Technology: Technics-out-of-Control as a Theme in Political Thought,* Cambridge, Mass., M.I.T. Press.

Langdon Winner (1980), "Do Artefacts Have Politics?", *Daede/us,* 109, 121-136.

Brian Wynne (1987), "Unruly Technology: Two Faces of Expert Judgement and Public Understanding", Lancaster, University of Lancaster, mimeo.

Acknowledgements

This work arises out of long term collaboration with Michel Callon, Elihu Gerson, Bruno Latour and Leigh Star. I am deeply grateful to them for their support and encouragement, as I am to Thomas Hughes and the Technische Hochschule Darmstadt, for the invitation which led to the preparation of this paper.