Preface to Second Edition

Engineering design concerns us all. It affects our everyday lives and increasingly affects the future of life on this planet. The time has gone when design engineers were told what was required and did their best to come up with something that worked. Competition is fierce, markets are international, and the consequences of poor design are felt globally. There is strong pressure for shorter project timescales and higher quality design at lower cost. Designs must work, they must be culturally and politically acceptable, and they must be safe, reliable and environmentally sound. A failure in any one of these aspects can result in bankruptcy or disaster, and to avoid such debilitating situations the design engineer needs the genuine support of all parties involved: management; marketing; manufacturing; customers and users. It is no longer acceptable for design engineers to work in isolation from everyone else, and it is no longer acceptable for everyone else to plead ignorance of the design engineer's work. We are all involved with design and we all have a responsibility to make sure that design is done in the best possible way.

So what is the role of a design engineer? A design engineer is presented with a technical problem or need, and the ultimate aim is the conversion of this into the information from which something can be manufactured at high enough quality and low enough cost to overcome the problem or to meet the need. This may sound simple, but in fact so many factors influence the situation that it is often difficult for one person to understand the problem fully, let alone produce solutions that meet everyone's expectations. Design is a team activity. Communication and information exchange are critical.

The manager responsible for engineering design must understand the problem or need in its overall context, must be able to build up a strong working team within that context, and must be able to steer the project through the design process to the point where manufacture is in progress. From then on there is a reduced, but important, responsibility to monitor the performance of the design in practice and ensure that it continues to satisfy customer and user needs throughout its life. Feedback of performance information is essential for future development.

It is not possible to cope with all the issues using an "inventor" approach to design, neither is it necessary. We now know enough about the design process, the working of teams, and the communication of information to be able to tackle a design project in a systematic and confident manner. The rapid advances in computing and communication technology during the decade since the first edition of this book was published have enabled the implementation of approaches to engineering design that have long since been developed, but which have lacked the practical means for delivery. The use of Web-based design aids and geographically dispersed design teams has become a reality, and it is now possible to work in ways that would not have been considered a few years ago. There is little excuse for poor design.

This book brings together some guidelines for the management of engineering design projects within a Web-based framework that encourages a systematic approach to design. It is based on the results of experience in industry combined with the results of academic design research, and it includes a unique series of checklists and work sheets for direct application on projects. The checklists pose a structured set of questions for the design manager to use during each phase of the design process, and the work sheets provide a means for summarizing the project status at any particular time. They can be used before or during design review meetings to highlight action items and, when collected together, they form a historical record of project progress.

Many people offered suggestions and encouragement during the original development of this book, but there are two in particular whose invaluable help must be especially acknowledged. Firstly there was Ken Wallace, Professor of Engineering Design at Cambridge University in the UK. It was Ken who, in the early 1980s, translated the systematic engineering design approach as presented by Professor Pahl and Professor Beitz in Germany. This has become our cornerstone for both design teaching and design practice. Secondly there was Tom Zabinski, of the Graphics Communication Department at Triodyne Inc. in the USA. It was Tom who spent many long hours making the complicated diagrams more understandable to the reader and laying out the checklists and work sheets in a practicable form, which ultimately could be converted to a Web-based system.

We selected the Life chair, designed by Formway in New Zealand but manufactured and marketed by Knoll in the USA, to provide a working example of successful product design. The help of both companies is gratefully acknowledged, and in particular the enthusiastic involvement of Jon Prince, Design Team Leader for the chair project. We would also like to thank Katherine Vyver and Andrea Roberts from Formway Design for providing final images and proofreading sections of the text. A detailed review of the project was undertaken, and its history was reconstructed chronologically by questioning according to the checklists. The checklists were used in the same order as presented in this book, and the corresponding work sheets were filled out as the reconstruction took place. The result was a set of completed work sheets that have been used as examples in sequence throughout this book.

The Triodyne Safety Information Center provided help with the research on standards and codes, and a set of five reference papers written by Triodyne staff laid a foundation for the text. The help of Marna Sanders is acknowledged in bringing together current information with regard to the sourcing of relevant standards and codes for engineering design. Using the Triodyne facilities, she was able to compile a useful bibliography on standardization and a compre-

hensive international list of Website addresses for obtaining standards and codes.

There are now many helpful books available on the management of projects, on the engineering design process, product design, concurrent engineering and specific design techniques. However, when it actually comes to managing an engineering design project within a company, circumstances often make it difficult to apply all but the simplest techniques. There are some subtle day-to-day issues that are time consuming, frustrating and difficult to handle, yet which have not been addressed adequately in the literature. They are sometimes referred to as the "hidden costs of design." What has been attempted here is to present a systematic and practical approach to handling such issues by considering first the context within which the design work will take place, then the nature of the project, the design team and the available tools, and then each phase of the design process itself. As the book is intended to complement texts on project management, design methods, and specific areas of design, references are given and further reading suggestions are provided in the Bibliography. The underlying idea is to help the design manager operate effectively and efficiently by integrating multidisciplinary viewpoints and coordinating the design process at every level within a company. If it helps to improve the quality of our engineering design for the future then it will have done its job.

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April 2004

Chapter 2
The Project Context

2.1 Engineering Projects

Projects are a common denominator in engineering. During any engineering project, the design activities and the development of the designed system must be monitored. Every project is different, though certain types of project may have comparable features. What makes each project unique is the *context* in which it takes place. It is worth trying to map out the project context right at the start, and to be able to see the overall picture from different *viewpoints* and at different *levels of resolution*. Then we can choose particular levels of resolution, and look at the project from specific viewpoints. In this book we will be concentrating on the *engineering design* viewpoint.

2.2 Engineering Design in the Project Context

At the *project* level of resolution, typical phases of the work and the typical inputs and outputs may be represented as shown in Figure 2.1.

The project takes place within some kind of management system within an organization, generally a *company*. Typically, the company receives revenue from products being bought by customers in the *market*. A product is used by a user until its operational life is over. Customers and users are not necessarily the same, and often have different needs to be satisfied by the product. Once a product is established in the market, the revenue generated from it, less costs, provides the company with an operating profit until competition, demand, or new ideas makes it imperative for the expensive business of developing a new product by means of an engineering project. Naturally, it is in the interest of the

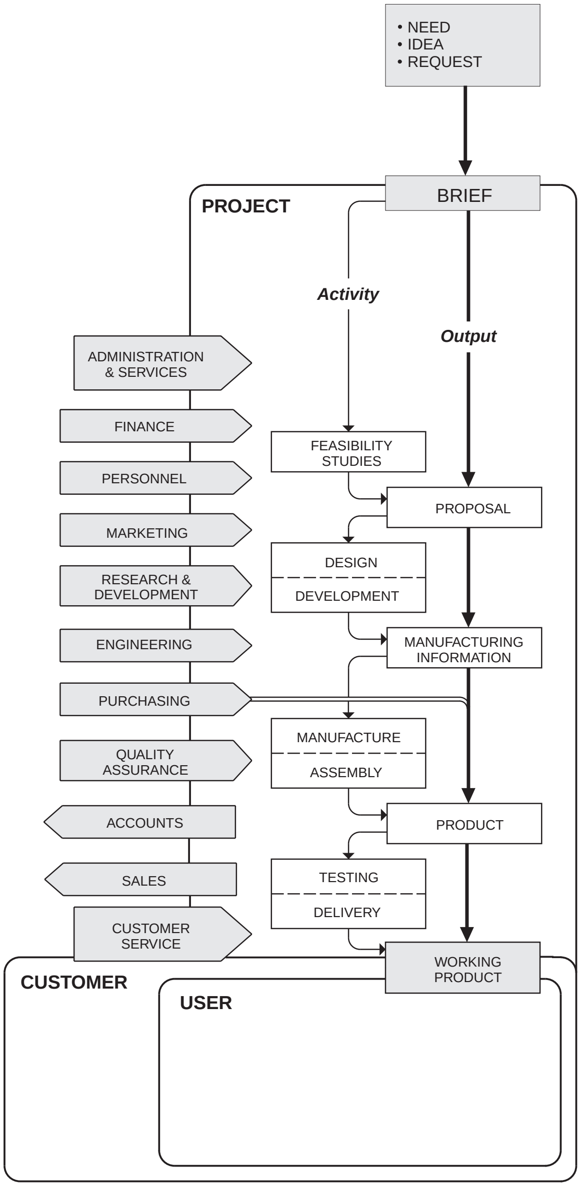

Figure 2.1. Typical inputs to and outputs from an engineering project

company to minimize the cost, time, and risk involved in such a project. For example, Japanese companies have developed what may be termed "incremental design," where new components or sub-assemblies are systematically introduced into an existing product to the point where there is almost a metamorphosis into an overall new and proven design. The "economic loop" within a particular market, as shown in Figure 2.2, may be used to identify and encourage the use of such approaches.

Each market exists within what might be termed an outer *environment*, which strongly influences what happens within the company, and hence what happens within a particular project. Figure 2.3 shows how we can now visualize a project, with its management, within a particular company, within a particular market, within the environment. Feeding into each project through individuals or groups are resources from the environment, the market, and the company. Customers, and thereby users, purchase products, generating revenue through exchange processes.

Within such a context we are concerned here with the *engineering* input to the project, as distinct from marketing, quality assurance, finance, or any of the other complementary inputs. By highlighting the engineering input, with both the design and production processes displayed as sub-sets within the project, the phases of the engineering design process may be visualized in terms of team activities and outputs, set in context with production, as part of a project within a company, within a market, within the external environment, as shown in Figure 2.4. This diagram is intended to function like the street map of a city. Although it may seem complicated at first glance, in just the same way as a street map it takes little time to become familiar with viewing it as a whole and then windowing in on the details as needs be.

The design process is often considered to be an iterative decision-making process. Although this is not a very accurate description of what actually occurs in practice, it is certain that without decisions there can be no progress through the steps and it emphasizes that management involvement (as a catalytic resource) is a crucial aspect of engineering design. Typical iterations in the process are represented in Figure 2.4 by the feedback loops. The transformation from "abstract ideas" to "concrete products" during the course of the design process is shown by changes in line-style around the loop as the information flow changes first to document flow then finally to material flow when manufacture starts. Thus, from the *engineering design viewpoint*, at this *personal* or design-team *personnel* level of resolution, the phases of the engineering design process may be simply described as follows:

1. Through *task clarification* activities the problem is defined.
   Output is a design specification.
2. Through *conceptual design* activities the solutions are generated, selected, and evaluated.
   Output is a concept.
3. Through *embodiment design* activities the concept is developed.
   Output is a final layout.
4. Through *detail design* activities every component is fixed in shape and form.
   Output is manufacturing information.

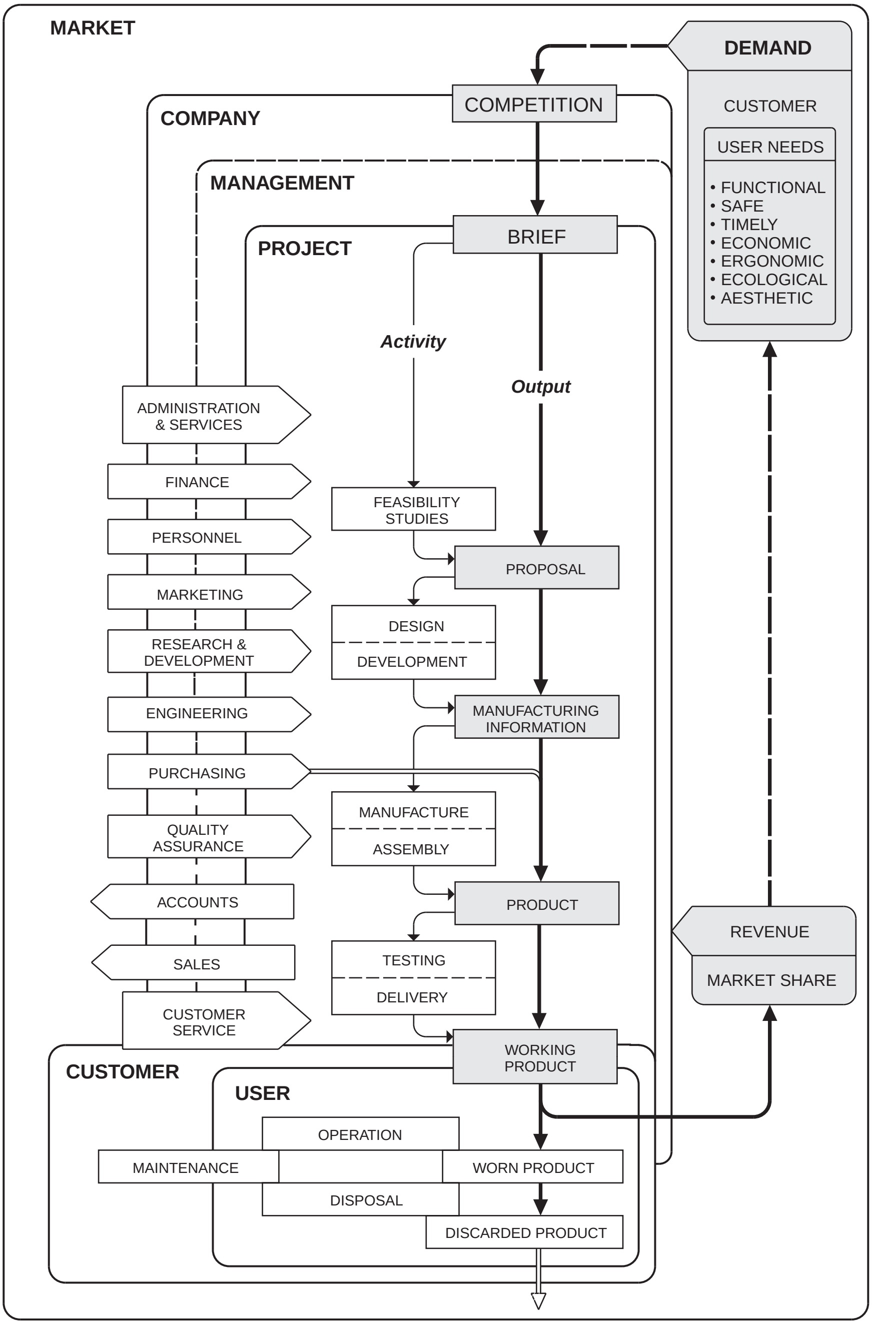

Figure 2.2. Economic loop for a typical project

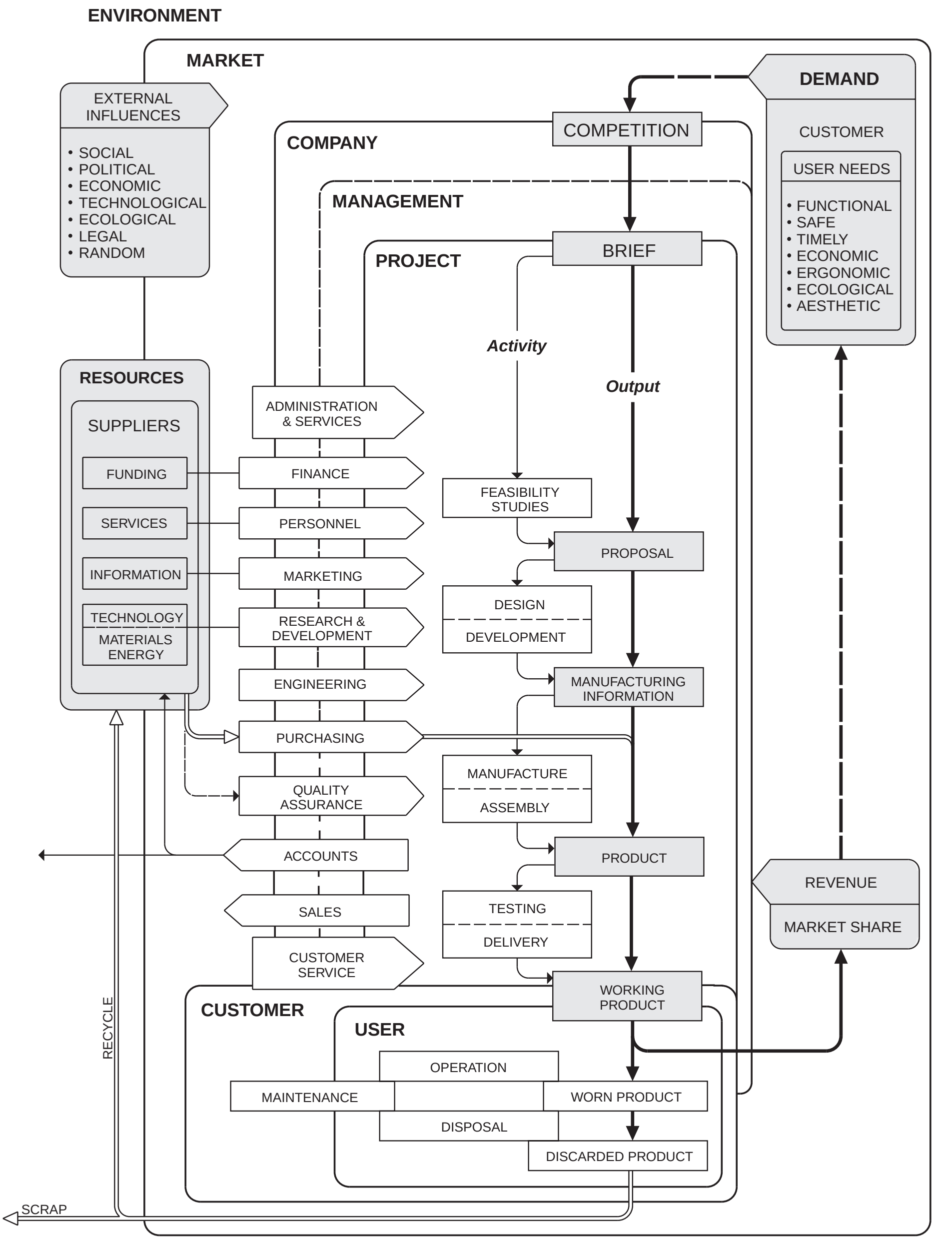

Figure 2.3. Project set in context

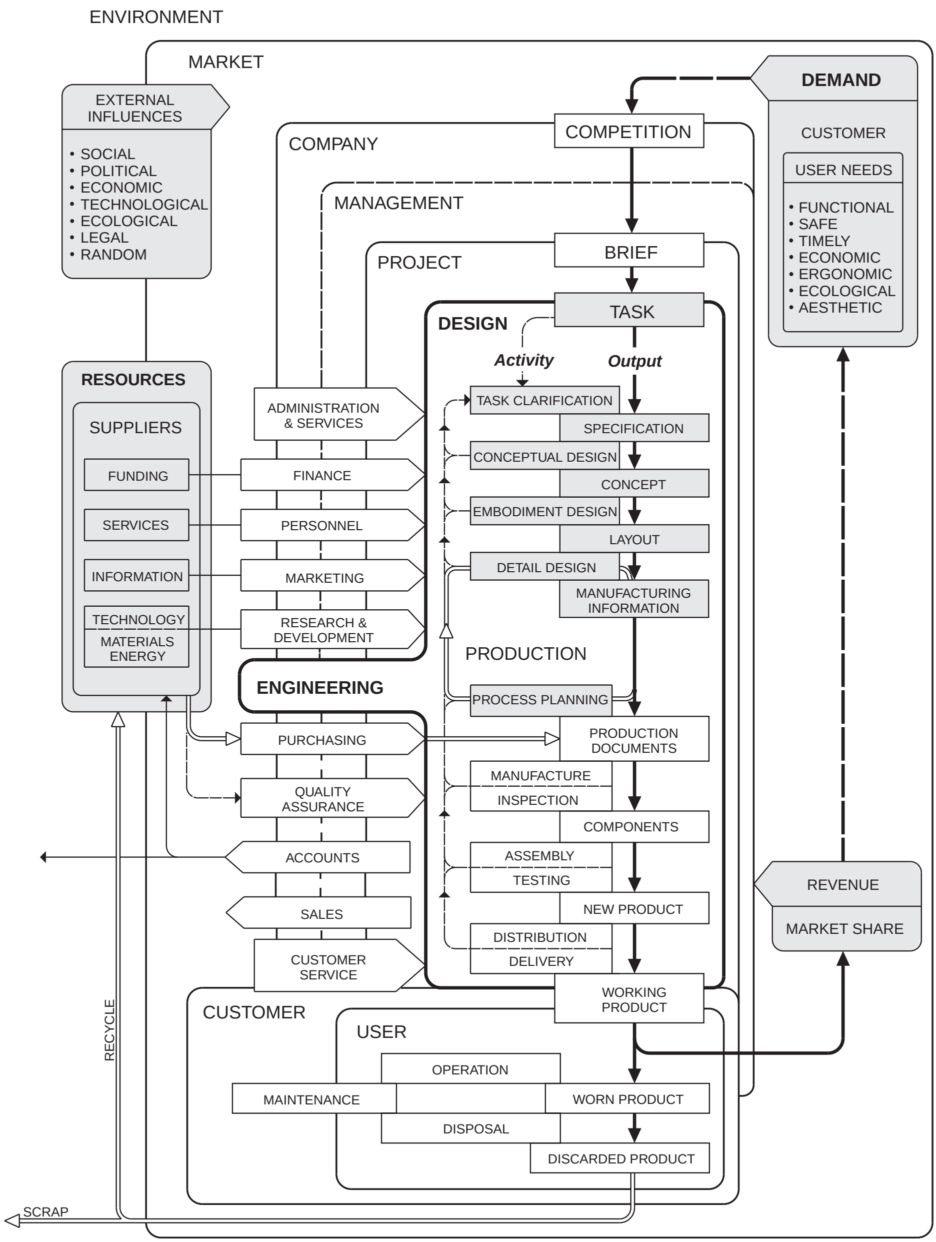

Figure 2.4. Engineering design process set in context within project

This conceptual model or map is useful in visualizing how the activities of design are influenced by numerous factors acting at different levels of resolution, and it is readily adapted to different project situations. For example, if a large company holds a monopoly in the market then the "company" may be regarded as equivalent to the "market." This is represented on the model by "windowing-out" the "Company" box to become coincident with the "Market" box while leaving everything else the same. The economic "loop" for the project then lies wholly within the overall company.

Having set engineering design in a general context, we can also window in on just the design process, as shown in Figure 2.5.

By "windowing in" and "windowing out" from one resolution level to the next, it is possible to concentrate effectively on the detail while keeping the wider context in mind, a crucial aspect of managing engineering design.

2.3 The Effect of Influences

One of the most frustrating things about being a design engineer or design manager is the way projects are manipulated by those who have very little to do with the design process itself. One minute everything is extremely urgent and the next minute the project is no longer required or the money has run out. More and more influences affect the course of design projects. It is necessary for the design manager to be aware of the impact of various influences and also to exercise some control over those that can be controlled while compensating for those that cannot, in the best interests of the customer, the project, and the design team.

Influences have been defined, for example by Lawrence and Lee (1984), as "people or things having power," with power as "the ability to affect outcomes." The engineering design process, as a goal-orientated process, cannot be effective unless the balance of power favors the attainment of project goals as distinct from goals at other resolution levels. A disgruntled project manager once said that his upper management had come out with an edict that project managers must become more "goal-orientated." And he had. His goal was to build up enough Frequent Flyer miles on company business to get a free round-the-world ticket!

Influences may range from being strongly positive towards the attainment of project goals, through neutral, to strongly negative. Also, they may be almost constant in effect, such as the pay scales for staff, or they may be highly variable, such as the degree of commitment to the project from an undecided management. At each resolution level there is a mixture of slowly changing "structure-orientated" influences, such as corporate organization, and continuously changing "process-orientated" influences, such as "enthusiasm" and "involvement." Though it may not be possible to define such influences as constants and variables in a quantitative way, it is certainly possible to identify

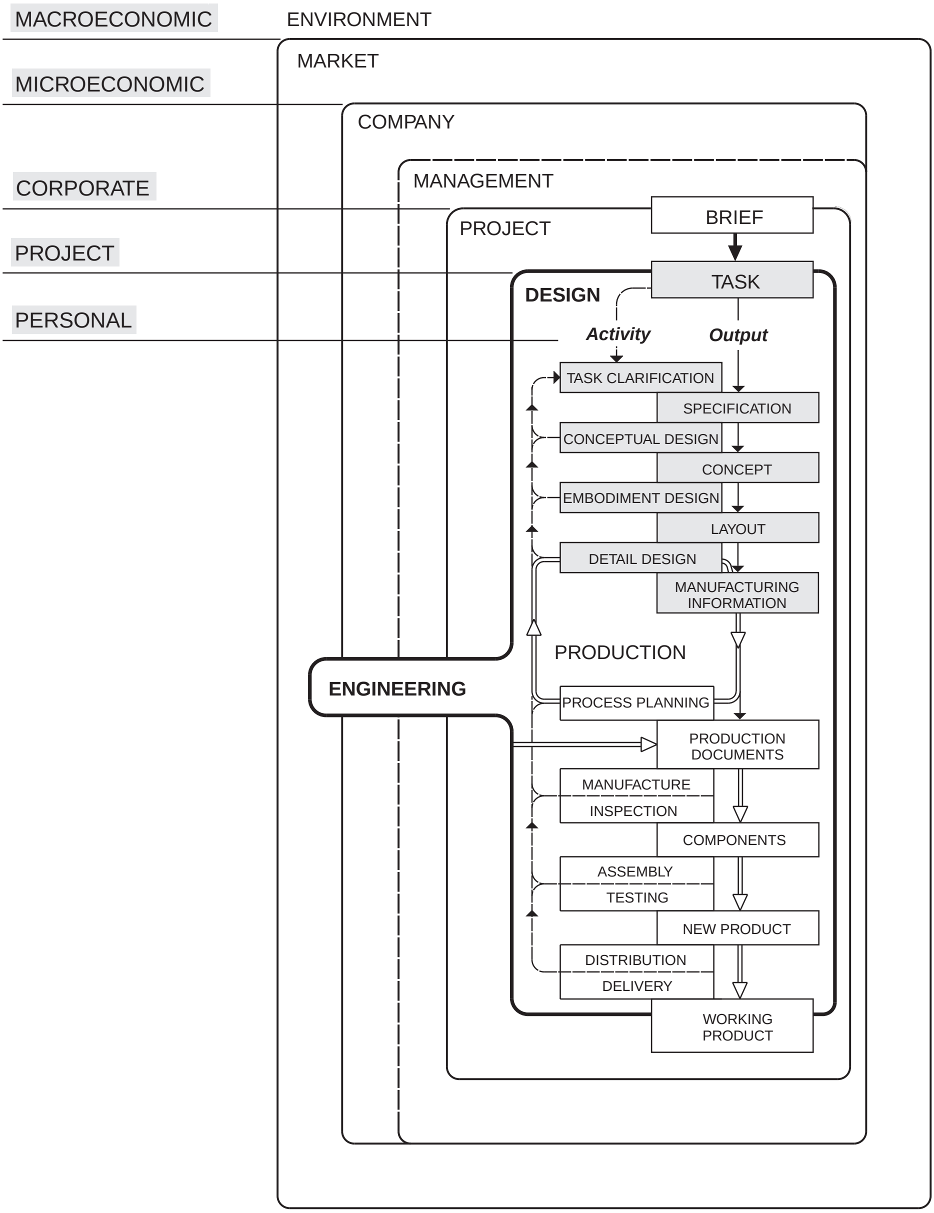

Figure 2.5. Levels of resolution related to engineering design process

categories of influence and contributing factors within each category, with subjective assessments of their observed impact.

During the 1970s, the Hughes Aircraft Company (1978) did a 5-year study in the USA on improving research and development productivity. This resulted in a practical set of checklists and guidelines for the compensatory control of influences. The engineering design process is analogous to the research and development process, and a study was carried out to identify a similar comprehensive set of influences specific to the engineering design process (Hales, 1987). The results of this design research have now been converted into a Web-based checklist and work sheet form to help the manager identify key influences in a particular design situation, then to monitor and deal with them in a somewhat systematic and controlled fashion.

2.4 Influences at the Macroeconomic Level

2.4.1 Cultural, Scientific, and Random

Design deals with the future and therefore is highly susceptible to cultural, scientific, and random influences. The factors contributing to these influences vary from country to country and from culture to culture in complex ways, as discussed in *The Seven Cultures of Capitalism* by Hampden-Turner and Trompenaars (1993). Important contributing factors within the category of cultural influence are social issues, the political climate, the economic situation, and legal requirements. These may be stable at a particular time and therefore have little effect on a project, but they can also change rapidly and leave the manager in an untenable position. For example, in 2001, the aftermath of the 11 September terrorist attacks in the USA had an immediate negative influence on many projects within the aviation industry. Social and political relations between American and Middle Eastern cultures were affected and the consequent slowdown in travel and tourism put the future of prominent airlines in question. Such influences are beyond the control of the project manager, but their effect may often be anticipated and compensating plans made accordingly. A manager of projects servicing the once stable aviation industry may now need to develop a contingency plan for alternative markets should the targeted market experience an unexpected downturn.

Scientific influences include the effects of technological developments and increasing concern with ecological effects in the environment. These are continually changing, and they will always have an important influence on the design process. Consider, for example, the effect of the first electronic wrist watches on the traditional Swiss watch-making industry, or the effect of recycling efforts on the design of aluminum cans for drinks. Technological developments tend to go in cycles and to follow "S-curves," as illustrated by the slide rule and electronic calculator example in Figure 2.6. The slide rule was developed to a highly sophisticated level by the end, and the very first electronic cal-

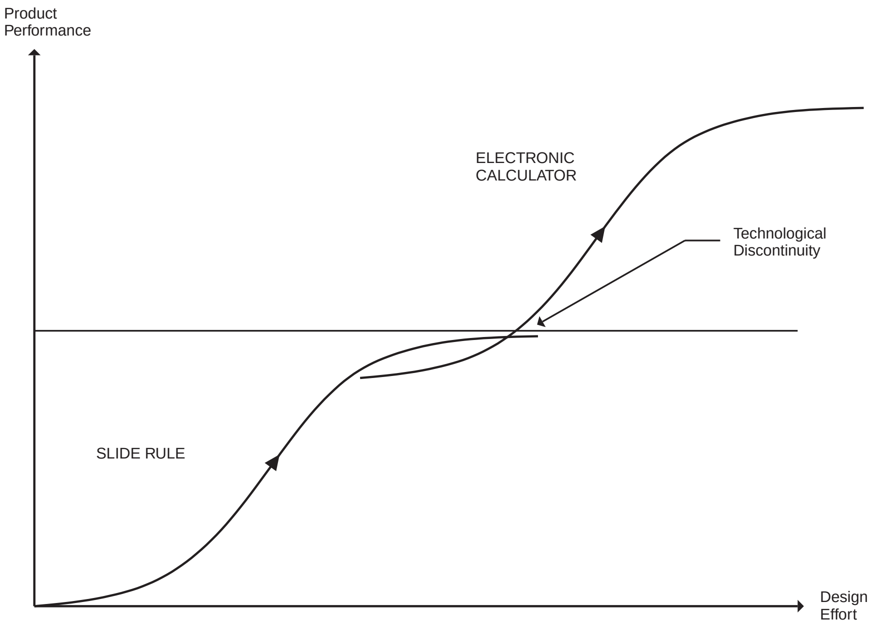

Figure 2.6. Technological cycles (S-curves)

culators were no match for the best slide rules. However, within a short time the capabilities of the calculator far surpassed that of the slide rule and the price of calculators steadily fell to the point where the slide rule became extinct. By the use of trend studies, expert opinions, and other means of technological forecasting, it is possible to predict some developments that might affect the project, but the design manager must always be on the lookout for that new idea which might wipe out the whole project at one blow. The notion of using "appropriate technology" (Schumacher, 1973) for the particular situation is also important. It is all very well developing a complex mechatronic water spray device using ultrasonic misters and oscillator circuits to keep vegetables fresh in supermarkets, but why do that when a system of simple valves and timers is just as effective? One such mechatronic system was so difficult to clean that it never was cleaned, with the result that bacteria in the mist caused an outbreak of Legionnaires' disease, followed by costly lawsuits. There is also the notion of "intermediate technology" (Intermediate Technology Development Group, 2003), where the level of technology used in a design is matched specifically to the capabilities and available resources of the users. An example would be the design of water turbines for small-capacity, low-head hydroelectric power-generation using only flat steel sheets (Giddens, 2003). Very little power-generating capacity is sacrificed by using flat blade geometry instead of curved blades, but there is an enormous advantage for poor communities attempting to develop self-sufficiency for the future, as the machines can be manufactured on site by local people, using local materials and simple tools.

Random influences are not controllable, but the effect of them on the project can be minimized by anticipation. They include the effect of "luck" and "chance," and a useful approach is to try and maximize the benefits of good luck while minimizing the effects of bad luck. For example, a design team may suddenly be offered the services of a highly skilled person, laid off from another project. It is not so easy to absorb additional people suddenly into a team, no matter how good the person is, but if the manager has thought about such a possibility ahead of time then advantage can be taken of such a situation. Similarly, if a key member of a design team becomes ill or leaves for some reason then it can devastate a project, but if contingency plans have been made ahead of time then the effect can be minimized. For example, it may be necessary to hire a replacement person under contract, and if such a person had been identified beforehand then it would shorten the disruption time.

Example: Gasifier Test Rig

At the start of this project, the political and economic forces in the UK favored development of coal gasification as an alternative energy source, and within the company there was emphasis on coal gasification research. This emphasis faded during the course of the project due to changes in Government policy for the purchase of natural gas from Europe, at prices making the use of synthetic natural gas (SNG) uneconomic well into the future. By comparison with these political and economic influences, the social, technological, ecological, and legal influences were insignificant. However, if construction of the rig had gone ahead as originally planned then the balance of external influences would have changed. For example, the immediate area around the company's property was being rapidly developed from a run-down industrial zone to an "up-market" residential zone, and there was increasing pressure on the company to ensure that it released no pollutants. The gasifier test rig would generate a small volume of hydrogen sulfide and, despite inclusion of an efficient gas scrubber in the system design, additional precautions for operation under emergency conditions were being discussed.

Random influences affected the project in many small ways. An example was the chance interchange between the contract design engineer and a company director for SNG production. Despite his lack of support for the gasifier test-rig project, the director said that he had passed the reactor assembly drawing on to one of his senior engineers who had commented favorably on a number of technical features. This gave some welcome encouragement in month 26, just as a final push on embodiment design was beginning. Bad luck also took its toll. The most significant event was the hospitalization of the contract design engineer due to peritonitis in month 16, just at the end of the conceptual design phase when the A-Form (cost justification) was to be submitted.

2.5 Influences at the Microeconomic Level

2.5.1 Market, Resource Availability, and Customers

The purpose of design is to address some kind of need, and unless it is clear what this need is, where it has come from, and the likelihood of it continuing as a need, the design manager runs the risk of designing something nobody wants or designing something to meet the wrong need. It is important to get as much information as possible about the market influences before the project starts, and also to monitor them closely during the course of the project in case things change.

Obviously, the outcome of a design project is bleak unless the market exists for the new product, or one can be generated through demonstration of the superiority of the product over existing equivalents. How to create successful products is an issue that has been analyzed by researchers such as Cagan and Vogel (2002), whose resulting simple approach for developing "breakthrough" new products has proven effective in practice. Only under exceptional circumstances, such as legislation mandating use of the product, will a mediocre design survive in the now highly competitive world markets. Even then it is likely to be rapidly superseded by improved designs developed by other companies. *Product planning* is, therefore, important: the systematic search for promising product ideas, together with their selection and development. Figure 2.7 is an attempt to show the project context from the *marketing* point of view, as distinct from the engineering design point of view. Marketing involves, for example, market analysis, discovery of new ideas, selection of appropriate product ideas, and the definition of particular products. It is essential that the design team draw in the expertise of the marketing staff right at the beginning of the project, to ensure that the technologically marvellous project will not turn out to be a financial disaster. Honest communication is absolutely essential. It is no use the marketing staff promising more from a product than is realistically possible, or the design team promising the product within unrealistic times or costs. There has to be a build up of mutual trust based on appreciation and understanding of the different points of view.

Resources are often a sore point between design teams and management. One reason for this can be seen in the familiar graph of a typical product life cycle, as shown in Figure 2.8. Design work is always a heavy cost item for a company, and it directly affects the cash flow in a negative way. It is quite possible to imagine the feelings of management towards a design team following the cash flow curve in Figure 2.8 as more and more money is spent with apparently little to show for it. This is most unfortunate, because without high-quality design a company is doomed, and cutting back on the resources of a design team is one sure way to achieve poor-quality design. Assuming that a project has been approved as viable, the design manager then has a major role to play in negotiating to get the best possible resources for the design team. By this is

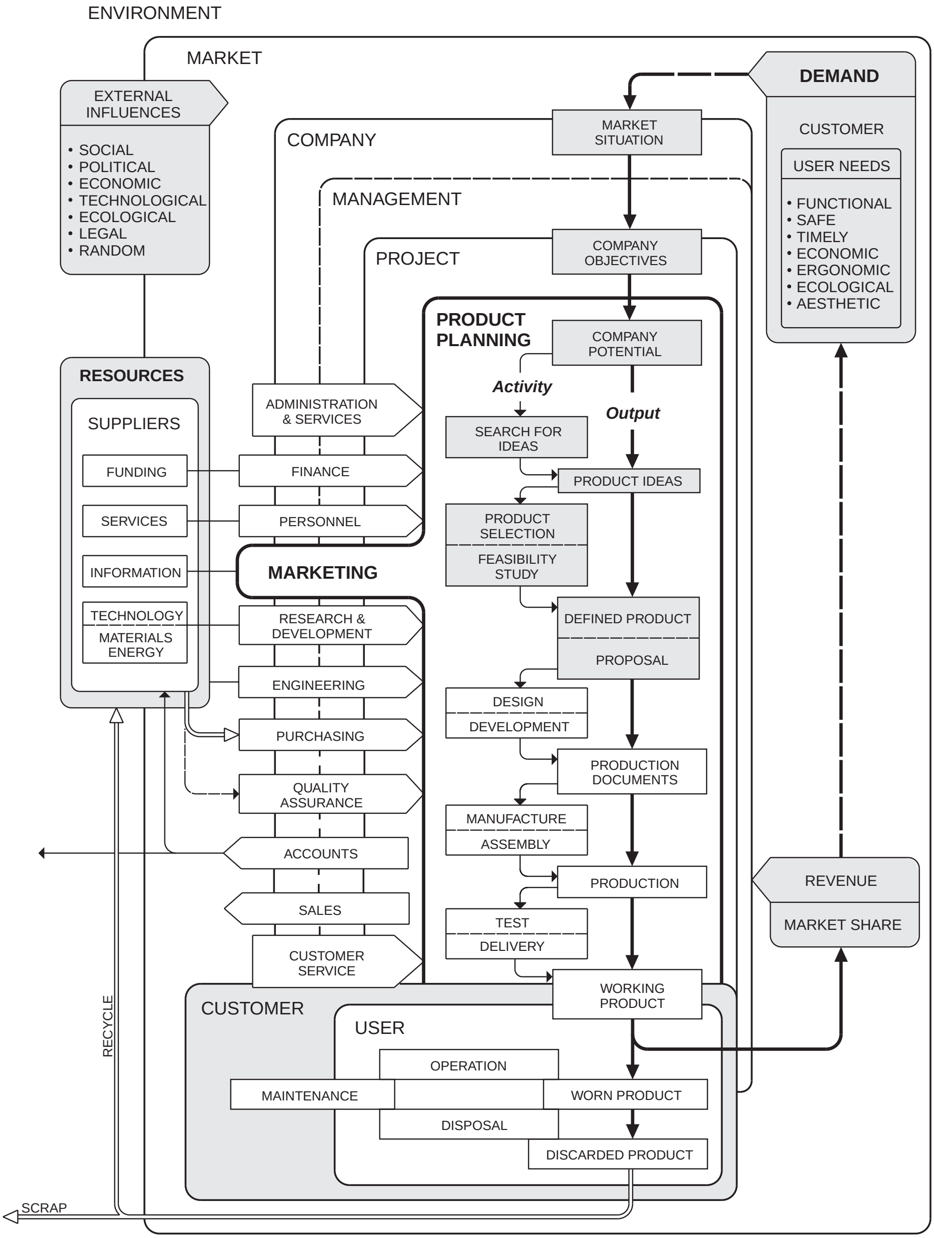

Figure 2.7. Marketing set in project context

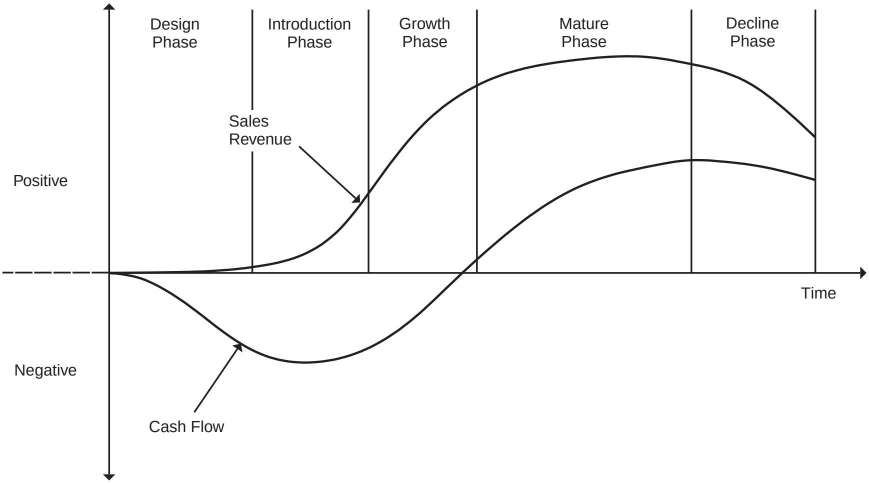

Figure 2.8. Project life cycle

meant the best possible people, the best possible funding, the best possible information, the best possible technology, the best possible working environment, and the best possible support all round. If, for *any* reason, the design manager fails to negotiate sufficient resources for the project then it will almost certainly cause the project to fail, though this may not become apparent until it is too late for recovery. The design team will lose heart and have difficulty maintaining respect for its leader. "Guesstimates" will be offered in place of calculations, sketches in place of drawings, sick time in place of overtime. Corporate management will demand results, requests for additional time will be met by extremely loud voices (America) or extremely quiet voices (Europe), and discussions over design issues will give way to recriminations over time and money. Most design managers have probably been through this sort of troublesome experience and come out of it wondering why they put so much effort into something that nobody seems to want in the end. Sooner or later one gets a feeling of frustration, and the thought of a becoming a sales manager seems rather attractive, with a company car and an air of breezy confidence at the positive end of the cash flow curve.

However, if the design manager instills a systematic approach into the design process then it will be found to have great advantages when it comes to the matter of resources. Corporate management will be more directly involved with the project, as the design process will be more visible, there will be tangible output to share and discuss during each phase, and the design manager will gain additional respect and goodwill from the professionalism demonstrated. Resource needs can be more precisely defined, problem areas identified sooner, and the whole design process managed in a less volatile manner.

Example: Gasifier Test Rig

Sufficient resources were available for the design effort, except for the lack of a qualified detail designer and a problem in obtaining field data on actual gasifier operating conditions. Unlike the control system design, where it was up to the project team to secure the services of a design engineer, detail design was under the control of a Services Group, and the recruiting of individuals for this was outside the control of the project team. When the time came for detail drawings to be done, no qualified person was available to do the work. What is more, it took a further 6 months to attract a suitable person and this caused a severe discontinuity in the project effort. The project had not been funded for construction, so the project team had little control over the situation. With regard to information needed on gasifier operating conditions, there was strict confidentiality on such information within the company. It was taken to such lengths that the rotational speed of a major component, essential for calculating the specimen movement in the rig, was wrong by a factor of 4 when told to the contract design engineer. The point here is not only that the contract design engineer wasted design effort because of wrong information, but also that this information was being used by permanent company staff in the absence of anything better.

2.5.2 Customers and Users

Ultimately, a product or technical system will be bought by someone and used by someone, and it is the perception of the value and the appeal to both customer and user that will largely determine the success or otherwise of the initial design. Therefore, it is an obvious first step to try and find out what the customer would like, but in practice this is not so easy. Customers often do not know what they want, and what they say they want is not always what they actually want. There is also often a difference between the real needs of customers and users. For example, carpet cleaning equipment may be purchased by a customer, Rent-a-Tool, but used by individuals who hire equipment from Rent-a-Tool. The rental company may look for particular features in the design, such as low cost or maintenance, in order to maximize the rental income, whereas the user is likely to be looking at it from quite another point of view, such as portability. The insurance company for Rent-a-Tool, on the other hand, is perhaps concerned about safety problems with the design from a liability point of view. Unless the design team is able to foresee how the design will be perceived by all the different parties involved in its use, and indeed what kind of *foreseeable misuse* it will be subjected to, there are likely to be many problems with the equipment during its life.

Another factor that influences design acceptability by customers and users is their continually changing expectations. Nowadays, pleasing the customer means aiming at a moving target. For example, sophisticated electronic calculators used to be something one would gather information about and have demonstrations on before getting close to a final selection. Now they are assumed to be bubble-pack items in a supermarket. Environmental and safety issues have become more and more important in design, and this trend is likely to continue, especially as the legal ramifications of noncompliance are enormous.

Example: Bicycle

On 30 January 1991, a woman in Wisconsin, USA, was paralyzed from a brain injury in a fall from a bicycle. Before trial her attorney negotiated a combined settlement of $7 million from the manufacturer, the importer, and the distributor. The lightweight, 15-speed bicycle was made in Taiwan, imported into America, and was given to the family as a gift when they bought a home entertainment center from the distributor company. The parents had given it to their only son, who then used it for the next 2 years. On the day of the accident the mother was riding this bicycle for the first time, as hers had a puncture. She fell off only a few blocks from her house, while going down a slight incline on a town street. People directly behind her and one person directly across the street witnessed what happened. Inspections of the bicycle after the accident revealed that the front forks of the bicycle were bent forward from their designed position, changing its steering characteristics. Although it was never established through evidence how the forks had become bent forward, and it was never proven that the bent forks were the cause of the accident, the design and manufacture of the bicycle was blamed for the whole affair. The manufacturer did not have sufficient records to prove that the bicycle met the agreed specifications. In addition, the importer and retailer were held to a higher standard of care than usual because they had copied a decal from another bicycle and put it on this one, in an attempt to promote it as competition caliber. The decal included the words: "CR-1010 Competition High-tension Steel." In engineering terms this means nothing, but it was held to convey a misleading message.

2.6 Influences at the Corporate Level

Although it is clear that the structure of a company and the way it works, or *organizational behavior*, has a great influence on engineering design projects, it is by no means clear what exactly the influencing factors are. Opinions and terminology in the management literature vary widely from author to author. Not only this, but the engineering design process is all but ignored in organization theories, though the production process is occasionally mentioned. Up to now the design manager has been left to develop effective management approaches alone.

By drawing from a wide variety of sources and gradually refining the huge number of influencing factors suggested in the literature, it has been possible to identify a condensed set of factors proven to be of importance with regard to engineering design. To make the list more manageable it can be broken down into small groups based, for example, on the "McKinsey 7-S Framework" described by Peters and Waterman (1982): corporate structure, systems, and strategy; shared values; and management style, skill, and staff. These groups form a sufficiently coherent set to be of use to us in assessing the effects of the organization on a particular design project. The condensed set of factors is discussed in the rest of this section.

2.6.1 Corporate Structure, Systems, and Strategy

There is a big difference between doing a design project within a large company spanning several countries and doing the same project in a small, perhaps family-run, firm. The large company is likely to have a wealth of resources in the way of facilities, specialists, and information. However, the access may be so cumbersome that the design engineer ignores it all and starts from scratch, getting information as if it has never been done before. It is common to find that an engineer on one side of the office does not know what others are doing on the other side of the same office. On the other hand, the small company is likely to be "lean" and close-knit but may lack the resources needed for a particular design project. The design manager in the large company might need to work towards better communication, whereas the design manager in the small company might need to find outside help to boost the necessary resources. By and large, in either type of organization, the more control the design team has over its own affairs the more likely it is to generate the enthusiasm, involvement, and tenacity to see the project through, but the team requires positive and continual encouragement from the upper management.

The way a company is organized may not be at all conducive to efficient or effective design, especially in the area of accounting. Design is such a wide-ranging activity that normal cost accounting systems and the thinking behind them often seem unable to cope. A simple example concerns telephones. Design engineers need to gather in a huge amount of information very quickly from all sorts of peculiar sources, and need to stay in close touch with many people. Effective design management would suggest assigning a direct-line telephone to each design engineer without restrictions or operator barriers. When cost accounting prevails it seems that the guard at the gate gets a direct dialling telephone for security purposes, but the design engineers have to plod through the operator from a shared telephone. The guard at the gate can phone day or night, but the design engineer has to call within operator hours. It is this kind of thinking that restricts design work and makes it almost impossible for a design team to compete internationally. A design engineer might need to be in the library one minute, calling Australia the next, making something out of a piece of wire the next, calculating something the next and negotiating for something the next. This is the essence of design, and anything put in its way is a barrier requiring extra time, energy, and money to get removed. Consider the thinking about books. A book may be cheaper than a good lunch and a lot more useful, yet the buying of a book often requires special management approval. Another example is the way time is accounted for. From the design manager's point of view the one tangible thing that can be measured is actual hours of work, and it then does not matter whether it is done in the middle of the night or at work on Monday. However, if the accounting system is based on days of work in an average week with certain average hours per day and a short day on Friday then you can either forget about doing design or forget about effective cost control. Design cannot be done in average days.

Example: Gasifier Test Rig

The project manager's monthly cost sheets were in terms of people rather than projects, and in terms of 1/10th days rather than hours. The measurement of project effort in 1/10th days would have been virtually impossible from a design research viewpoint, especially with Fridays having shorter hours than other days. Although an attempt was made to flag all the costs and effort attributed to the gasifier test rig by means of an extra digit on the job number, this digit was not recognized by the computerized accounting system. The project manager was surprised at the small number of total hours (2368) recorded by the participant observer: "It had seemed to be more than that," but an approximate check through the manager's cost sheets confirmed that the total project effort was about 1.5 "man-years".

Corporate management tends to consider pay scales and employee benefits as a "package," and perhaps this is the best approach for most employees. However, there are complications with regard to design. It may be true to say that the higher the pay scale the more motivated the design team is likely to be, but the matter of benefits is a problem. For example, flexi-time may be fine for certain types of employment but it needs to be carefully thought out with regard to design. If half the design team comes in early and leaves early while the other half does the reverse, then it is soon found almost impossible to get the whole team together at one time for some solid work output. Of course, the idea of giving design engineers more freedom is excellent, but unless those design engineers have the project as their first priority then this personal benefit is very much to the detriment of the project. Similarly with holidays: we would all like the luxury of long vacations, but unless there is some control over when they can be taken then the project can suffer greatly.

Example: Gasifier Test Rig

Both the pay and the benefits offered by the company were considered good by most team members, and in the case of one or two they were the main reasons for them staying in their jobs. From the gasifier test-rig viewpoint, however, the influence of pay was quite different from the influence of benefits. Whereas the level of pay was observed to act as an incentive, particularly with the contract staff, the benefits in the form of vacation time, holidays, "sick time," "flexi-time," and personal freedom were observed to cause unpredictable disruptions in project progress. The type of problem this caused within the project team is illustrated by a notebook entry on 9 April: "Holiday schedule: J__ in until 19th, then away 1 or 2 weeks; R__ in until Easter; F__ away 16–27 April and again 13 May to 23 June; H__ away 2 weeks after next week; Easter Holiday 20–23 April; Bank Holidays 7 & 28 May."

2.6.2 Shared Values

In a sense, all this comes back to the attitude and approach of the corporate management. If the management make their objectives clear, make it clear what risks are being taken, make it clear that they are committed to the project, and transfuse their enthusiasm through active involvement, then the design engineers are likely to respond in a positive fashion and not take personal advantage of benefits to the detriment of the project. The design manager is caught in between, and must see things from both points of view so as to motivate everyone in the direction most beneficial to the project. This is easier said than done in an economic climate where trust in management has gone, and loyalty is history. How is a design manager supposed to remain enthusiastic at a project level when the corporate executives may, at any time, uproot not only their traditional manufacturing facilities, but also their design capability, and move it all from country to country in their continual quest for cost reduction?

2.6.3 Management Style, Skills, and Staff

In a simplistic way, we can look at the extremes of management style as follows:

- Autocratic – what the boss says goes.
- Benevolent – what the team says goes.
- Consultative – what the boss says goes, after others have been heard.
- Participative – what the boss and team say together goes.

There are advantages and disadvantages with each of these extremes, and it depends on what type of project is being carried out as to which style, or mixture of styles, is likely to be the most appropriate. It took an autocratic style to produce the Sony Walkman; it took a combined participative and consultative style to produce the Life chair. For any particular project, a design manager has to assess whether the degree of design-team freedom and the degree of design-team participation is appropriate, and what to do about it if it is not.

Example: Gasifier Test Rig

Of the four styles (autocratic, benevolent, consultative, and participative), the benevolent style was most in evidence. It was observed at all levels of management. Concern for an employee's personal problems and health sometimes took precedence over concern for the project, and personal vacations could be scheduled at any time. "Flexi-time" gave additional personal freedom, and the working atmosphere was generally relaxed. Thus, the predominantly "benevolent" style of management tended to favor the team members at the expense of the project, and this acted as a negative influence as far as project progress was concerned.

The design team has a tough job to do and it needs the support of quality management, *i.e.* management with the skills to ensure that things are planned out, coordinated properly, and with adequate resources available at the right time. There has to be keen interest in the project and an element of the "project champion" present to boost confidence in the project on behalf of the project team. A design team is expected to be *effective* (doing the right things) and *efficient* (doing things right), but to accomplish this the team needs managers who can communicate well, who have good judgment, who are motivated themselves, and who have sufficient confidence in themselves to guide the team all the way from design specification to working product.

Example: Gasifier Test Rig

The 5-month period of indecision regarding funding of the project would suggest that, at the time, the corporate strategy on coal gasification research was not clear, at least not to those responsible for approving funding for the gasifier test rig. It also indicated a reluctance to take risks. To proceed with the detail design work but not the application for construction was a way of "hedging one's bets." These were important factors, as a slightly clearer strategy might have forced the decision against the project much earlier, and a slightly less cautious approach certainly would have favored construction. In the literature, "innovation" (implementation of a design or new ideas) is seen as an important influencing factor at the corporate level. The gasifier test rig was regarded as "novel" in design, but until it was built and operating it could not demonstrate "innovation"; so, although this contributing factor was considered important, the project data could provide no evidence for this. It would seem that innovation and risk taking are interdependent: had the more risky decision to build the rig been taken, and had the rig performed as expected, then it is likely that the project would have been seen as innovative. Another factor often stressed in the literature is corporate "involvement." For this project, such corporate involvement (*i.e.* higher level than project management) was intermittent, and it was either at the request of the project team or as a result of a chance interchange. No unsolicited corporate involvement was observed; and, as far as the project team was concerned, this was seen to indicate a lack of commitment towards the project, acting as a negative influence.

2.7 Design Context Checklist and Work Sheet

To assist the design manager in building up a picture of the context within which a design project will, or is, taking place, the *Design Context Checklist* shown in Figure 2.9 has been developed, together with the associated *Design Context Work Sheet* shown in Figure 2.10. These are provided as electronic files

DESIGN CONTEXT CHECKLIST

LEVEL	INFLUENCES	CONTRIBUTING FACTORS	SOME QUESTIONS TO ASK: EFFECTS ON PROJECT?
MACRO-ECONOMIC	CULTURAL SCIENTIFIC RANDOM	Social issues Political climate Economic situation Legal requirements Technological advances Ecological concerns Luck/chance	Effects of social change? Effect of politics? Effect of economic situation? Regulations, codes, standards, liability? Changes in technology? Environmental problems? Effect of luck/chance?
MICRO-ECONOMIC	MARKET	Demand Competition Financial risk	Demand for product? Competition for product? Effects of success or failure?
	RESOURCE AVAILABILITY	Human services Capital finance Information for design Appropriate technology Appropriate materials Appropriate energy	Right people available? Enough money for job? Enough design information? Do we have the technology? Access to materials? Power/fuel supplies adequate?
	CUSTOMER	Understanding of need Urgency of need Expectations Involvement	Is it clear what customer needs? Is there time to do the job? Expectations realistic? Customer helpful in design?
CORPORATE	CORPORATE STRUCTURE	Span of company Size of company Type of project control	Effect of company span on project? Effect of company size on project? Adequate project independence?
	CORPORATE SYSTEMS	Help getting information Quality of work environment Pay scales and benefits	Information easily obtained? Work environment good? Effect of these on project?
	CORPORATE STRATEGY	Clarity of objectives Level of risk taking/innovation	Does company know what it is doing? Is management strong/innovative?
	SHARED VALUES	Degree of commitment Degree of involvement Degree of project enthusiasm	Management commitment adequate? Management involvement adequate? Management enthusiasm adequate?
	MANAGEMENT STYLE	Degree of staff freedom Degree of staff participation	Is staff encouraged to be creative? Is staff involved in management?
	MANAGEMENT SKILL	Quality of planning/coordination Quality of communication Effectiveness of project support Effectiveness of resource use	Are the management plans realistic? Is communication effective? Is there a "project champion"? Are resources used effectively?
	MANAGEMENT STAFF	Number of staff involved Quality of judgment Degree of motivation/morale Degree of confidence	Is there enough input from staff? Is good judgment exercised? Sufficient motivation/morale? Is confidence high?

Figure 2.9. Design context checklist

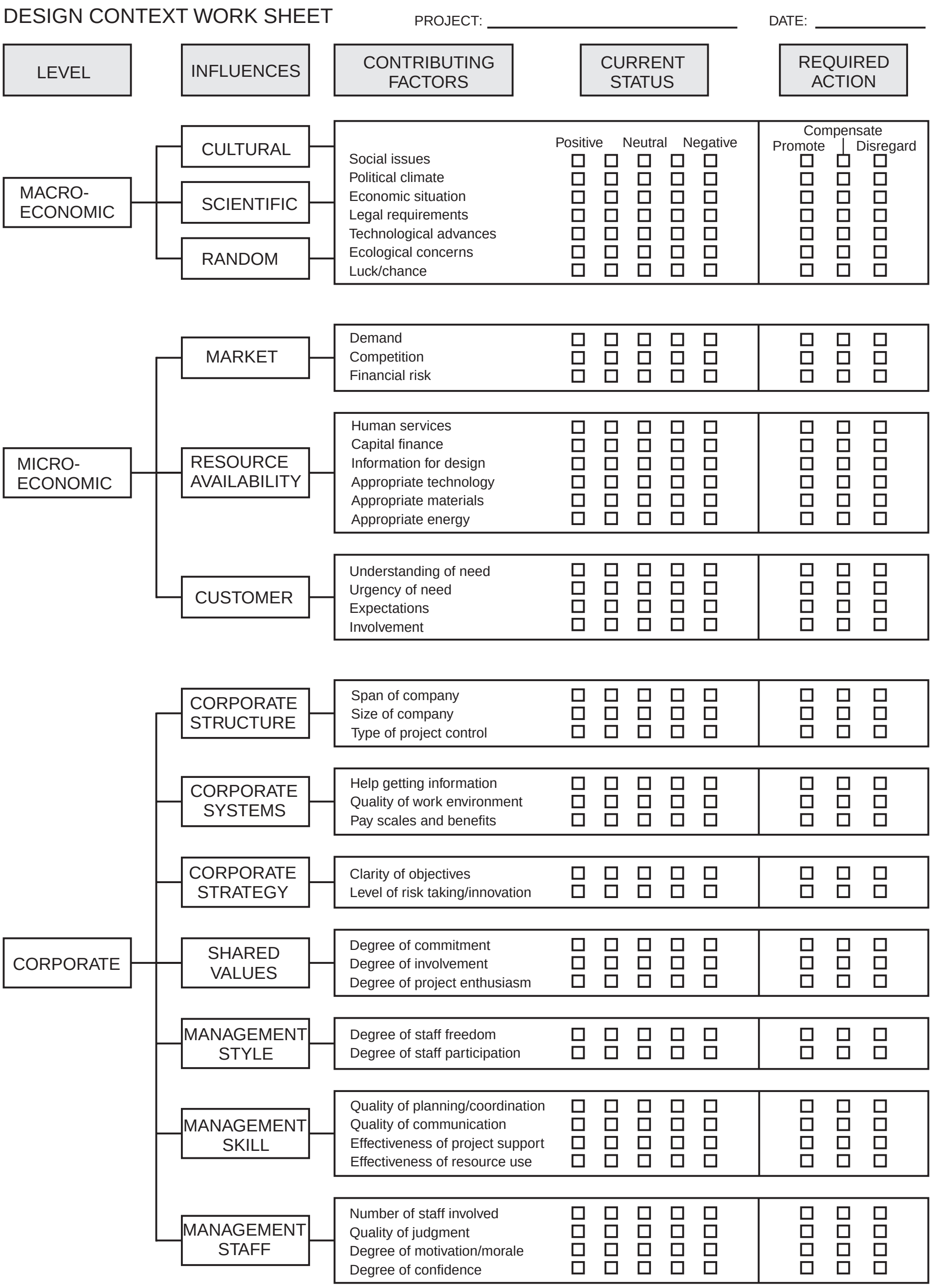

Figure 2.10. Design context work sheet

on the CD accompanying the book, for Web-based use within geographically dispersed design teams. The checklist provides a list of questions to ask oneself, the design team, upper management, or others, and the work sheet provides a series of answer boxes to fill out. Both the checklist and work sheet are broken down by level of resolution, area of influence, and contributing factor. The work sheet has an assessment column for recording whether the influence factor is considered negative or positive with regard to the project, and how strongly. Then there is an action item column for the design manager to decide whether to try to control or manipulate the influence, compensate for it, or simply monitor it and hope for the best.

The completed work sheet becomes a status report on the key influences impinging on the project at that time, as shown by the example in Figure 2.11 based on the reconstruction of the Formway Life chair project. Influences at the *macroeconomic level* shaped the design intent for the Life chair. With reference to Figure 2.11, contributing factors were as follows:

1. *Social issues* and *technological advances* were closely linked and positively influenced the chair project. The team predicted areas of likely social change due to technological advances in office working environments and the need to accommodate users working "away from the office."
2. *Legal requirements* were considered to have a positive influence on the project. The majority of competitor products did not meet the ergonomic needs of the end user; hence, when public perception of the health and safety risks reaches a sufficient level of intensity, this is likely to be reflected in legislation. A change in health and safety legislation would favor products with superior ergonomics. Legal requirements were made a high priority ("promote" on work sheet) and ergonomics became a primary driver in the design of the chair.
3. The *political climate* could be either strongly positive or strongly negative and was considered unpredictable by the design team. The status needed constant monitoring and was compensated for by obtaining resources from suppliers in different political climates.
4. The *economic situation* was positive because the weak New Zealand dollar at the time generally favored export goods.
5. *Ecological concerns* were seen as having a positive influence on the project. A focus on environmentally sound principles builds on New Zealand's "clean green" image and, if promoted, would give the product a competitive advantage from both a customer and legal perspective.
6. The effect of *luck and chance*, due to the detailed brief and meticulous project planning, was considered as neutral by the design team. They did, however, promote this effect, *e.g.* by taking advantage of opportunities to use new technology.

Influences on the project at the *microeconomic level* led to the development of the primary market goals for the Formway Life chair project. Significant influences (Figure 2.11) were as follows:

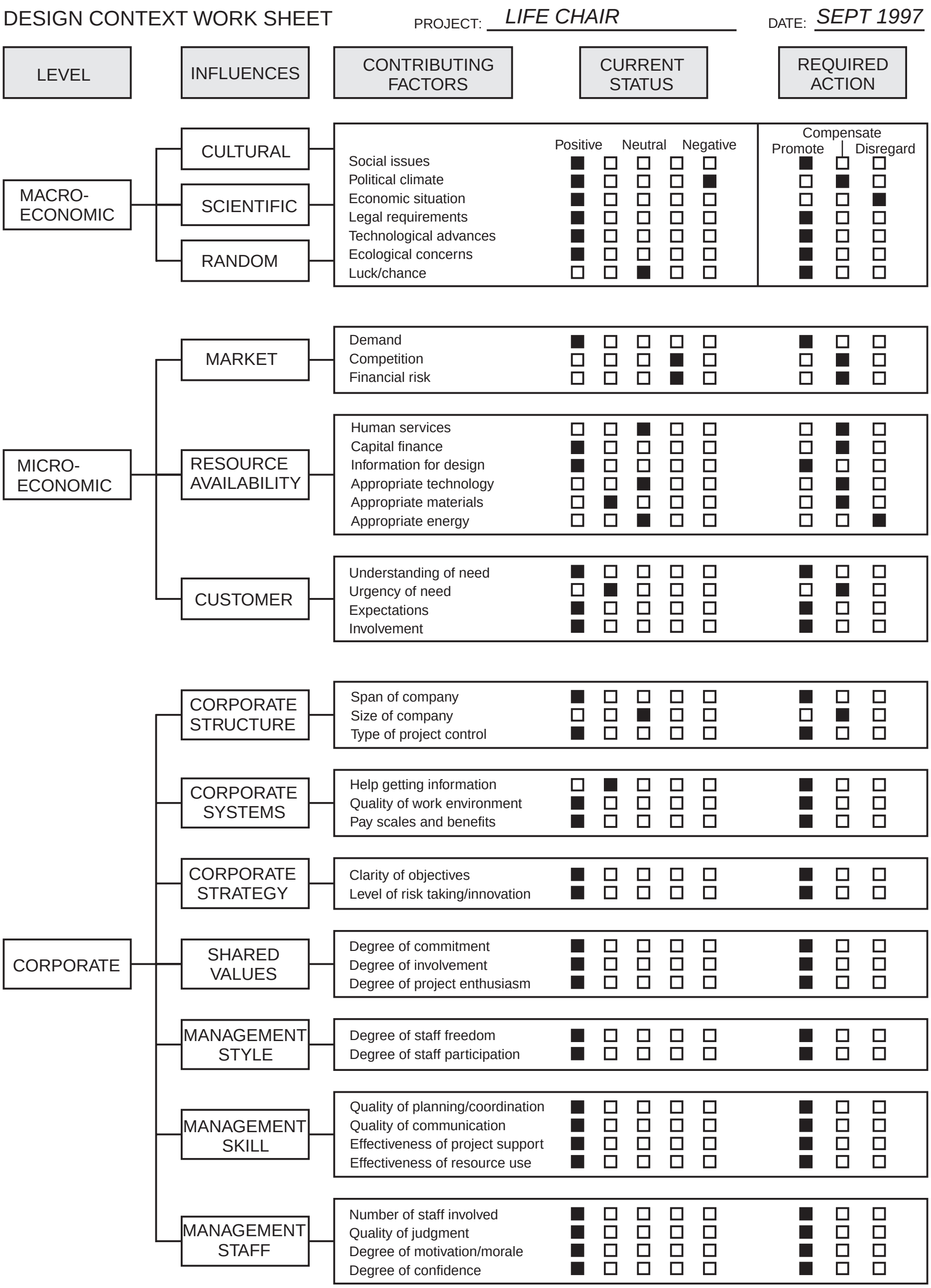

Figure 2.11. Example of design context work sheet

1. The *market influence* was considered positive because the demand for a cost-competitive ergonomic chair was identified as a likely continuing market requirement. Market research identified a promising opportunity for a chair that was both value for money and had superior ergonomics.
2. There was strong *competition* in the market. Despite the positive market influence, the influence of competition was negative because, as the Life chair was being developed, competitors were also evolving better products and patenting ideas that impinged on Life's competitive advantage in the market.
3. The *financial risk* of developing the chair was seen to have a negative impact on the market influence. Formway's manufacturing facility was too small to manufacture and distribute this product internationally. This factor was compensated for by the smaller New Zealand company (Formway Design Studio) licensing their design at the working prototype stage to a much larger American company (Knoll Inc.) for the detail design, manufacture, and distribution phases.
4. *Human services*, *appropriate technology*, and *access to materials* were considered, overall, to have a neutral influence. On the one hand, there were positive influences, such as: the design team were very experienced furniture manufacturers; they had up-to-date appropriate technology; they had access to and experience with materials for manufacturing office furniture. On the other hand, there were negative influences due to the effect of novelty. Compensation for these factors was made by contracting external help, such as staff training, engineering analysis (*e.g.* three-dimensional (3D) scanning), specialist engineering machinery (*e.g.* rapid prototyping), and advice on the use of new materials.
5. *Capital finance* was strongly in the design team's favor during the task clarification, conceptual design, and embodiment design phases. A realistic budget was set aside for the design phase; however, the detailed design phase capital finance was compensated for by the collaborative partnership with Knoll Inc.
6. *Information for design* was considered a positive influence. The team members were able to use whatever means possible to gather design information, *e.g.* team members had the opportunity to visit international trade fairs.
7. The *customer* was considered to have a positive influence on the project. The customer's *needs* were clear and their *involvement* in user trials was likely to be effective in prototype assessment.
8. The customer's *expectations* were high; however, this had a positive influence because it was perceived that these expectations could be easily met.
9. *Urgency of the need* was considered neutral. The design team were given sufficient time to complete the task within the company; however, this was offset by the constant threat of a competitor in the market introducing a new product or patenting new ideas first.

Influences at the *corporate level* provided critical guidance and support for the design team. Contributing factors (Figure 2.11) were as follows:

1. The *corporate structure* had a significant influence on team dynamics. Formway Design Studio is a small company with around 15 designers. The design team operates out of a single office alongside two other small project teams. In this case, the *span of the company* resulted in a close-knit group, which positively influenced communication between team members. On the other hand, the *size of the company* had a negative influence in terms of obtaining resources; this was compensated for by building collaborative relationships with companies who had specialist skills and specialist equipment.
2. The *corporate structure* allowed the design team adequate independence, and hence control, over their project working. This *type of project control* promoted a level of freedom that encouraged initiative in daily project working.
3. *Corporate systems* allowed designers unrestricted access to all available communication tools and, when necessary, *help in getting information* was compensated for by employing external consultants.
4. The design team worked in an open office with team members grouped according to specific design activities; the office was fitted with high-quality furniture throughout and there were areas set aside for social interaction. This promoted a fun *work environment* with good communication (and healthy banter) within the team, but there were also quiet areas where individuals and small groups could work uninterrupted. A communal project work area was established for this particular project so that team members could exchange ideas using a white board, post design information on a notice board, or hold project meetings.
5. *Pay scales and benefits* were considered to be at a good level, and designers were permitted to work flexible hours; however, time was scheduled where all team members or specific groups were required to be available in the design office at one time.
6. The *corporate strategy* was transparent to the design team; hence, management's *objectives* were *clear*, and this had a positive influence on the project.
7. The company's management had considerable experience in supporting the development of office furniture, and this supported the high *level of risk and innovation* required to evolve a new chair concept.
8. There was a strong sense of *shared values* between management and the design team. The *degree of commitment* by management in providing the necessary resources strongly favored this project. In fact, this was considered by the team to be almost to the detriment of other internal projects.
9. Representatives from *management were involved* in all critical project decisions, and there was considered to be a high level of *project enthusiasm* by management; these factors had a strong positive influence on the design team.

10. *Management style* was predominantly *participative*, where representatives from management and the team members had an equal say in deciding the direction of the project. This kept the project on track while generating a sense of ownership that led to an enthusiastic design team with the tenacity required to accomplish project milestones.
11. Team members were allowed 1 day per week of absolute *freedom* to pursue their own project ideas. This encouraged creativity and, although team members were not required to direct this free time towards any particular project, their enthusiasm for the Life chair concept was evident, in that they generally elected to spend their free time pursuing ideas for the chair. The team was also encouraged to "get out of the office" and try new environments for stimulating ideas. For example, the team would often pack up a portable white board, some good food, and drinks and go to a local boat club for brainstorming sessions.
12. Management's *planning/coordination* was detailed and was perceived as realistic by the design team. When goals were not found to be realistic, the management then showed understanding in its approach to the negotiations for revised realistic goals.
13. *Communication* between management and the design team was effective due to: the availability of management (on site with an open-door policy); a management team that was considered approachable by design team members; management being proactive in informing and involving the team in decisions that had a bearing on their project working.
14. The *effectiveness of project support* had a positive influence due to two of the company directors being considered as part of the design team and "project champions" at the management level.
15. *Resources were used effectively* by management to progress the project, and this had a positive effect on the project.
16. The *number of staff involved* was a positive factor. Together with the design team, representatives from marketing, finance, and production were all considered as stakeholders in signing off at project milestones. The inclusion of all the stakeholders ensured that good judgment was exercised in guiding the project to obtain successful outcomes.
17. The *degree of motivation and morale* had a strongly positive influence on the project. This was due to the positive attitude of management, commending the team for good work and showing their appreciation by celebrating achievements.
18. Management understood the strengths and weaknesses of the design team and, hence, was able to demonstrate a high *level of confidence* in the project team.

In looking at the context work sheet, it is not hard to see why this project was successful. The team used the macroeconomic influences in a positive way; this promotes a final product that is likely to be stable in its intended market. At the microeconomic level, the market opportunity was defined, the resources availability established, and it was shown that the needs of the customer could be met. At the corporate level, the design team and the management team worked together to achieve a common overall objective.

The completed work sheet can be referred to in progress or review meetings, used for discussion purposes, and updated at regular intervals. It provides the design manager with a simple way of keeping some measure of control over difficult issues in a systematic fashion and recording what the thinking was at the time. The Web-based format provides easy future reference and helps in compiling company design histories.

2.8 Tips for Management

- Design projects take place within a specific context.
- Mapping the context helps in visualizing the "big picture."
- Keep the big picture in mind, then "window" in and out on details.
- Five levels of resolution provide a useful framework for the context:
  - Macroeconomic level – environment external to the market.
  - Microeconomic level – market within which the company is operating.
  - Corporate level – company within which the project takes place.
  - Project level – project with engineering design input.
  - Personal level – individual/team inputs to design process.
- Identify and understand the different viewpoints at different levels of resolution.
- Design projects involve team activities, team outputs, and contextual influences.
- Activities and outputs of the engineering design process may be phased as follows:
  - Task clarification activities result in a design specification.
  - Conceptual design activities result in a design concept.
  - Embodiment design activities result in a design layout.
  - Detail design activities result in manufacturing information.
- Use the checklist to help identify key influences.
- Explore the influences on the engineering design process at each level of resolution.
- Summarize the positive and negative aspects on the work sheet.
- Take appropriate action and review on a regular basis.