ELECTRONICS PRODUCT DESIGN BEST PRACTICE - - AN INTERNATIONAL PERSPECTIVE

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INTRODUCTION

The Electronics Designers' Toolbox (EDT) Project is a 3 year UK Government- funded research project, through the ACME Directorate of the Science and Engineering Research Council, the objective of which is to develop a functional specification of a next- generation electronics designers' toolbox. The research has modelled the electronics product design process in a manner which considerably enhances earlier attempts[1,2] at understanding the process of product design. In particular, it extends BS7000: Guide to Managing Product Design by specifying, in greater detail than the more generic British Standard is able to, the activities and tasks necessary for effective design management and actual design of an *electronics* product.

In addition, the understanding of computer- support requirements for advanced electronics product design, gained through development of the design process model, has enabled the authors to begin the development of a functional specification for a next- generation "Electronics Designers' Toolbox" for electronics product design. Although it is not our intention to describe this aspect of our research in detail in this paper, it is sufficient to mention that the functional specification will enable electronics design automation (EDA) vendors to specify the precise functionality of advanced design toolsets. EDA tool users will be able to use an appropriately edited process model to identify the nature and number of design tasks currently being undertaken, as well as to pinpoint their future design task requirements. Once the design tasks have been identified, the design process model will provide toolset users with the means of determining requirements for both EDA tool performance and integration as well as for appropriate product design infrastructures.

In order to establish a base line for this work, the authors have identified current technical approaches to electronics product design, as well as to the management of the design- to- manufacture cycle, through a series of in- depth interviews with senior design and production staff at eighteen UK and continental European electronics manufacturing firms. Similar case study visits were undertaken by the authors to eight leading U.S., Japanese and Korean electronics companies and research institutes.

Study Tour Rationale

The project team's earlier research visits[3] had confirmed the view that there were no UK electronics manufacturers able to demonstrate world leadership in both product design and manufacture. Companies were discovered, however, which exhibited *aspects* of "World Class" capability in this field. Hence it was feared that, unless the research team was able to visit acknowledged leaders in the electronics field, we would be forced to work to an inadequate model of electronics manufacture and that, as a consequence, the functional specification for a next generation electronics designers' toolbox we produced would ultimately be of little value to the UK electronics industry.

In order to understand the functional requirements of next generation electronics design automation (EDA) tools, the authors used the study tour to collect data on current design practice, design methodologies and EDA tools used by acknowledged electronics sector market leaders in the United States, Japan and Korea. The companies and research organisations visited are described in outline below.

The remainder of this paper will discuss the research methodology used to carry out the research and will present details of a number of the most significant international case study findings, highlighting differences in both the technological and managerial approaches to electronics product design adopted by the companies visited. The paper will highlight examples of new knowledge discovered through the research visits and will conclude by presenting a number of practical ways in which Western electronics firms, by learning from international "best practice," can effect major improvements in their design- to- product capabilities.

OUTLINE DESCRIPTIONS OF CASE STUDY COMPANIES

The United States

Data General - - Boston. Data General (DG) in Boston is primarily concerned with electronics design. In fact, design is regarded as so central to corporate survival that it is resourced at over 10% gross annual turnover. In addition, the R&D function is given preferential treatment with staff enjoying better salaries and working conditions. Fabrication of the company's products is carried out away from Boston at sites both within the United States and in Japan. The Boston site employs some 9,300 staff, of whom 300 are engineering staff.

DG products compete on two main dimensions: time- to- market and hardware processing speed. The company currently has two strategic product lines, the Eclipse (proprietary architecture) and the AViiON (Open Systems) product ranges. They currently have about a one year cycle time on

Eclipse developments and nine months on their AViiON open systems.

MIT Computer Architectures Group - - Boston. The MIT Computer Architectures Group is involved in a number of research projects, some of which are funded through the U.S. Department of Defence. The projects include the "J- machine" project investigating fine grain parallelism using around 1000 nodes in a three- dimensional mesh (a $1 million U.S. DOD contract), a shared memory 64- 256 node machine and a high speed routing chip using 50- 100Mhz channels.

It was discovered that the MIT group was not using any advanced tools or techniques for either hardware or software design.

Hewlett Packard Printed Circuit Division - - Palo Alto. With an annual turnover of $140 million, the Hewlett Packard (HP) Printed Circuit Division is the third largest fabricator of Printed Circuit Boards (PCBs) in United States. The division has four plants world wide, two of which (in Japan and Mexico) are joint- venture companies.

USAF - - Sacramento. The USAF at Sacramento designs radar, air traffic control and weather forecasting equipment, UHF radio and electronic warfare systems. They also maintain existing equipment and reverse engineer obsolete equipment. This USAF site uses traditional manual methods for design and engineering staff have only recently taken delivery of their first integrated CAD system.

Japan

Toshiba - - Fuchu Works. Toshiba's Fuchu Works employs a total of 7,500 staff, of which 4,200 are full- time employees. Of the full- time employees, 20% are used to develop software for mid- range and process control computers, 15% develop microcomputer software, 20% are systems engineers (software and hardware) and 20% are hardware engineers. The remainder perform Quality Assurance functions. The plant makes a 15% contribution to Toshiba Group sales, and has had a recent growth rate of between 13% - 15% per annum.

The main products produced by Toshiba's Fuchu Works can be grouped into four areas: information processing and control systems, energy systems, industrial equipment and printed wiring boards and hybrid functional circuits.

Toshiba - - Ome Works. Toshiba's Ome Works employs a total of 3,700 staff, of which 1,400 are engineers. 700 engineers work in manufacturing control, 400 are part time employees and the remainder are contracted into the plant from subsidiary companies and from software engineering companies. The Ome plant has two of its own subsidiaries, Toshiba Computer Engineering Corporation (300 engineers) and Toshiba Software Engineering Corporation (300 engineers), bringing the total of engineers employed to 2,000.

The main products produced by Toshiba's Ome Works can be grouped into two areas: information processing and control systems and software.

Sony Semiconductor Division - - Atsugi Technology Centre. The Atsugi Technology Centre of Sony's Semiconductor Division employs 1,700 staff, not including those in sales and marketing, out of a total 7,000 employees in the company's entire semiconductor group. The Division's annual turnover is currently around £700 million and is derived from sales of such products asASICs for audio and visual products, as well as for computer peripherals, CCD image sensors, SRAMs, single chip MPUs and Gallium Arsenide (GA) lasers.

The Atsugi facility carries out R&D into, and design of, leading- edge LSI devices. They design and fabricate more than 100 new semiconductors each year, of which 20% are totally new.

Fujitsu Mainframe Division - - Kawasaki. The Fujitsu Mainframe Division is part of the company's Information processing Group. The Division is engaged in the design and manufacture of Supercomputers (VP2000 Series), Mainframe Computers (M Series) and the new Fault Tolerant Communications Control Processor (SURE2000). The latter is a completely non- stop system, even when changes are required to hardware or software.

In fiscal 1990, Fujitsu's Information Processing Group spent (excluding software) some 7% of net sales on R&D. Much of this expenditure went on the development of 0.5 micron integrated circuit technology.

Korea

Samsung Corporate Profile. The Samsung Corporation is estimated by Fortune Magazine to be the 15th largest company in the world outside the United States. The company is heavily involved in the development of semiconductors, communications equipment, computers (joint ventures with Hewlett Packard), as well as aerospace and defence products. It is also a major provider of insurance and leisure facilities, both within Korea and elsewhere in the world.

Samsung supports four electronics institutes and a CAE Centre. Nevertheless, while the company invests some 8% of turnover in electronics research it is instructive to note that Samsung derives only 40% of its revenue from manufacturing, of which only 25% comes from its electronics interests.

The research team visited Samsung's colour TV and VTR Divisions at Suwon City, as well as the company's ASIC Research Centre in Seoul.

RESEARCH METHODOLOGY

All the research data was collected through a lengthy semi-structured interview, on many occasions lasting for up to two days, at each of the design sites visited. The interviews were usually conducted by two members of the research team who questioned groups of design and production managers and staff. The authors were able to interview a considerable number of very senior design, R&D and executive staff managers, particularly in Japan and Korea. In addition to these interviews, the overseas visits included demonstrations of design tools, which sparked discussion regarding their effectiveness and future development directions, as well as guided visits around production facilities.

In order to gain an in- depth understanding of how each currently develops its electronics products, a question set was developed which was continuously refined as the case study visits progressed. Interviewees were all questioned on organisation strategy, the position of design within that strategy and the organisation's overall approach to product development. Such insight could only be gained by talking to Board- level personnel, including the Managing Directors, of the various companies. Particular emphasis was also placed on establishing the methods used to control the product design process.

Interviewees were also asked, where relevant, to reveal details of their manufacturing methods, quality programmes, information storage and distribution methods as well as their approaches to customer and supplier development. During the discussions, some 200 questions were posed to the interviewees. The answers to these questions, which were grouped under the general headings **Corporate Strategy**, **Electronics Design** and **Electronics Manufacture**, provided a significant input to the development of the authors' design process model as well as their functional specification of a next generation designers' toolbox for electronics design.

KEY ISSUES IN ELECTRONICS DESIGN

Despite the obvious constraints involved in conducting the kind of semi- structured interviews described above, the researchers were able to gather a considerable amount of highly relevant data, particularly in the United States and Japan. The UK/European case study data have since been analysed in light of the results of the US/Far East visits, and a number of key issues emerged which will be discussed under the following headings:

- *Design Process Management*
- *Design- for- manufacture*
- *Concurrent Engineering*

Design Process Management

It has generally been thought, certainly within Western electronics companies, that product design is a creative activity which cannot be managed. It is the authors' view, however, that design is a goal- directed, problem- solving process which **must** be managed since new product development in the modern competitive context can no longer be undertaken successfully using the previously tolerated, essentially haphazard approaches. It is vital, therefore, that senior executives of electronics companies drive the product development process, including its design aspects, and that they ensure the process is effectively managed.

Indeed, this was one of the key lessons to emerge from the authors' visits to Japanese electronics companies. At Fujitsu's Mainframe Division in Kawasaki, for example, an annual business plan is developed by key engineers who understand the impact the product will have on the company's competitive fortunes. The plan, which is made in consultation with senior management, considers such issues as market trends and the need for the product and product development policy. It lists new products to be developed in that fiscal year, highlighting factors such as product performance, cost and the development schedule. Quality aspects are defined separately.

This strategy document is translated into detailed operational requirements appropriate for each level in the organisational hierarchy, the end result being that each department, section and team has its own business plan for that year. Each operational unit is then allowed considerable freedom, in line with Fujitsu's bottom- up culture which seeks to provide a free atmosphere for engineers to manage their own work and to achieve the goals set out in the company's business plan. To keep on target, each operational unit has regular discussions on a daily and weekly basis. The entire product development group meets monthly to review progress.

During the design of large mainframe computer systems, for example, Fujitsu's project managers define system performance requirements down to LSI level. Once partitioning of tasks has been undertaken by experienced engineers, who specify precise targets for each task, engineers are then free to implement the design in any manner they choose. Support for this part of the design process may be sought through consultation with colleagues as well as through open access interrogation of Fujitsu's engineering database. Information concerning LSI use/implementation methods is freely circulated among engineers, both verbally and by memo, and tight communication links are maintained between CAD development engineers, technology development engineers and systems design engineers. Formal information exchange takes place between hardware and software development engineers, often through small group meetings, especially when new system functions and architectures are being defined.

As part of the overall product planning to production process, quality, product life cycle and design- for- manufacture knowledge are communicated back from production. Subcontractors, who contribute significantly to Fujitsu's product development success, are taught how to use new technology, for example, and how to reduce costs.

Low staff turnover. While this design management approach superficially may appear to be unexceptional, it is important to point out that a key factor enabling the Fujitsu Mainframe Division to disseminate its detailed business plans in this manner is its low (<2%) engineering staff turnover. The lifetime employment system adopted by the larger Japanese corporations makes it possible for firms to trust their employees with even the most confidential information, secure in the knowledge that it is unlikely to be "leaked" to competitors. Low staff turnover can increase company effectiveness in a number of other ways, not least because it is possible for those firms to retain hard won engineering experience, which is not usually recorded either in a computer database or on paper within the company.

In this context, all three Japanese electronics companies visited train staff using on- the- job- training (OJT) systems which rely heavily on the availability of experienced engineering staff to teach preferred engineering techniques to novice engineers, and to pass on design process knowledge. At Fujitsu Mainframe Division, for example, it is estimated to take one year of OJT to turn a graduate recruit into a proficient designer, despite the fact that Japanese engineering undergraduates are not taught how to use CAD/CAE systems at university. However, despite the fact that the company's design review process is based upon previous development experience, with the list of items being reviewed expanded each time they go through the process, it is worth noting that Fujitsu Mainframe Division has not yet succeeded in incorporating their own design process knowledge into its engineering design tools.

Similarly, Toshiba places heavy emphasis on educating, training and nurturing its key people and, as part of that process, the company organises conferences for technology executives during which they discuss issues like "the use of computers in factories." Such conferences also provide attendees with important opportunities for "jinmyaku" or networking with colleagues. One result of this internal technology transfer process has been that Toshiba is now selling an air conditioning system using twin fan inverters originally developed in its heavy electronics business. The company also has an organised approach to learning from mistakes, both its own and those of its competitors, and to applying the lessons learned.

In marked contrast to Japanese practice in this area, our research indicates that a 10% - 20% annual engineering staff turnover is considered an acceptable, even desirable means for Western firms to enhance their design engineering capabilities. In such circumstances, long- term corporate interests may be sacrificed to human resource policies which favour piecemeal skills acquisition, in spite of the fact that the design and manufacture of increasingly complex electronics products places a premium on retaining design knowledge and wisdom within the company.

Indeed, a comparison of Japanese OJT and design apprenticeship techniques with UK, European and US practice in this field highlights the fact that the Japanese generally adopt a longer- term view even of personnel recruitment than do their Western competitors. It has been reported elsewhere[4] that Japanese companies have twice as many staff engaged in human resource management as their Western counterparts. They are tasked with training, recruitment of new employees in schools and universities and with facilitating change within the companies themselves.

Design- for- manufacture (DFM)

DFM at Hewlett Packard. While the case studies indicated that many UK and European firms are good at parts and materials selection, they tend to be poor at understanding effect of early parts and materials selection upon final manufacturing costs and constraints. In contrast, the authors discovered at least one US electronics manufacturer which demonstrated a well developed understanding of these issues. In order to maintain competitiveness in world markets, Hewlett Packard (HP) has had to develop a detailed understanding of the relationship between design and manufacturing.

The company has developed its own printed circuit board (PCB) design support tool, known as the Board Construction Advisor (BCA), which uses an expert system approach to automate the calculation of yields from early stages in the design process. An important consequence of HPs use of the BCA tool has been the removal of product cost ownership from the domain of production engineering. That responsibility now correctly resides within the design group.

The tool incorporates knowledge derived from PCB yield curve measurements taken over a number of years. Its effectiveness also stems from the company's detailed knowledge of PCB circuit performance, design density, thermal properties, complexity, assembly, test repair, field support and relative cost, data for which have been systematically extracted from CAM databases of actual designs. Based upon an in- house design- for- manufacture manual containing, among other relevant information, design equations relating to such factors as electrical performance and PCB impedances, the BCA tool makes it possible for HP engineers to predict PCB yields and costs from as early as two months into a project.

During conceptual design, the BCA tool can advise engineers regarding the impact of size, density and technology on yield and performance. Later on in the product development path, as the design is refined in its detail prior to prototype construction, the BCA (given appropriate circuit netlists) can provide an extremely accurate picture of fabrication costs and process yields resulting from specified electrical capacitance, resistance and impedance goals.

Concurrent engineering (CE)

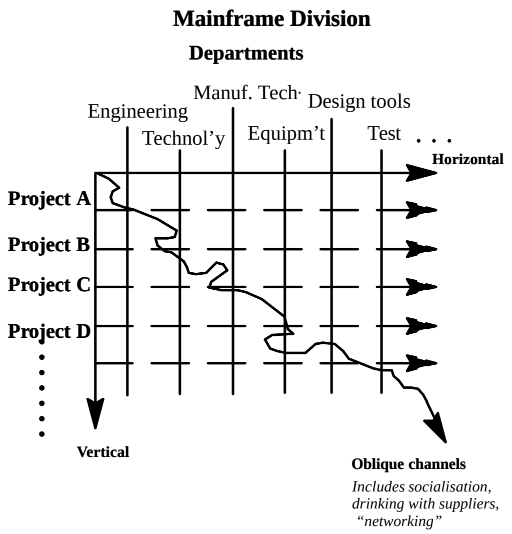
The UK and European companies visited during the research are engaged in the development of only a very small number of entirely new products each year. Since most of their design activities are concerned with making incremental improvements to existing product lines it is perhaps not surprising that we found only one company which had successfully adopted the CE approach. The remainder were aware of the need to eliminate the traditional sequential approach to product development[5], the end result of which is a design thrown "over-the- wall" to production, but each had to a greater or lesser degree failed to put the necessary procedures in place. The larger the company, the greater the difficulty.

Design for Test (DFT), Design for Manufacture (DFM), Design for Assembly (DFA) are all techniques used, and applied, in various sectors of electronics production engineering in both the UK and the United States. However, few design engineers interviewed in these countries appeared interested in the issues which lie behind such concepts, and even fewer realised that it should be their concern. Further, design appeared to be compartmentalised in many UK, US and Korean companies, with industrial design, product function design and product assembly and test design being done by different groups of people in different parts of a company, with little routine communication between them. In Japan, on the other hand, the case study companies routinely marshal whatever resources are required to accomplish a particular product development goal and, in so doing, place great emphasis on effective communication, both horizontally between small development teams and vertically with regard to strategic product planning.

Fujitsu Mainframe Division's overall approach to managing its product development activities emphasises the management of projects, *not* departments. In any event, for Japanese companies the concept of the *department* has much “fuzzier” connotations than is traditionally the case in the West. Personal roles also tend to be ambiguous. For example, even though a person may be an engineer, he may act as a manager. On the other hand, since the head of the group is only regarded as a symbol, the manager may be technically inferior to many of the people on his team. In such circumstances, choosing the right “head” is a key consideration since the leader’s most important role is considered to be the synchronisation and harmonisation of his staff. Any manager who is weak technically will be provided with the necessary assistance he or she requires.

Project management at Fujitsu is accomplished using matrix structures with the vertical structure comprising Division, Departments, Sections and Teams. Projects cut horizontally through this structure, utilising personnel across departments as necessary. As Figure 1 below illustrates, each manager manages his own organisation, and many jobs are related to the different projects which are managed across that organisation. The engineering department has overall control in a horizontal direction while the organisation, which may be involved in several different projects, occupies the vertical dimension.

Fig 1: Project Management at Fujitsu



“Oblique” communication channels, such as socialising with ones former workmates from another department or going out drinking with suppliers, are considered an important mechanism both for gathering new product ideas and for maintaining the harmony of the product development team. It is taken for granted that the achievement of high quality products and timely delivery to customers can only be achieved using multi- disciplinary teams. At Sony’s Semiconductor Division, too, little distinction is made between the various functional responsibilities in a project. They simply organise and coordinate the people and resources required to achieve a particular target.

Overall control of Fujitsu Mainframe Division’s entire portfolio of development projects is accomplished by its several engineering departments, with each engineering department involved in one or two large projects. However, while the manager in charge of the Mainframe Division is kept informed of progress of all ongoing projects, the managers of each engineering department retain effective day- to- day control of the projects. The effectiveness of this approach is demonstrated by the fact that, to date, the company has experienced no significant product failures and, in the period 1990 - 1991, it reports that 97% of all mainframe deliveries were on time.

To conclude this paper, a number of practical ways in which Western electronics firms, by learning from international “best practice,” can significantly improve their design- to- product capabilities will now be presented. The “best practice” lessons have been grouped under three headings, namely **Design methodology**, **Design culture** and **Design automation systems**.

LEARNING FROM INTERNATIONAL BEST PRACTICE

Design methodology

Our case study research has highlighted a patchy appreciation, by many Western companies, of the importance of company- wide design procedures and methodologies. While the Japanese companies visited were particularly effective in organising their design efforts and in developing design methodologies, only a few Western companies appeared to assign any significance to the establishment of corporate design methodologies. In fact, the predominant UK view appeared to be that product design is a “black art” and should be left alone.

With regard to design methodology, we believe that firms should recognise the importance of classifying design projects according to the amount of engineering risk involved, or according to their degree of difficulty. The adoption of such an approach by one UK company would have helped it avoid major cost and time overruns on the development of a strategic product aimed at “leapfrogging” the competition. The problems were caused by a failure to recognise that a considerable amount of R & D work would be required, in addition to the normal product development activities.

The research has also highlighted the importance of ensuring that company design procedures are known and documented, and that their application is reinforced both through technology and through the “social system” of the company.

Design culture

The Japanese company visits left us with the view that design must be regarded as a strategic corporate activity, that full automation of the design process should be the eventual goal and that product design *can* be effectively managed and controlled. It was quite clear, too, that Japanese electronics companies do far more designing than their Western counterparts and have highly developed technological and product engineering infrastructures which operate like learning social systems. The more they design, the better they get.

This culture of design appears to alter the way in which Japanese companies consider electronics product design and manufacture. One Japanese company has found that excellence in design has enabled it to take control of its manufacturing operations to such an extent that the company is now free to invest heavily in engineering support for the earlier phases of design.

A number of the Japanese companies visited have both a top down and a bottom up approach to project initiation. They encourage their (predominantly young) designers to design products they themselves would like to own and, partly as a result of this trend, the focus of their design effort is increasingly becoming concerned with the social and lifestyle context within which the products are being used. The visits also revealed that Japanese electronics firms spend more time developing their product specifications and designing out problems than is customary in the West.

In addition, all engineers in the companies visited have free access to corporate information, including secret information. The lifetime employment system these firms operate means very few employees ever leave, and there is little danger of such information "leaking" to competitors. Such practices differ markedly from those encountered in the West, and particularly in the UK where many engineers are denied access even to component cost information.

Given the complexity of modern electronics products, it is also vital that engineering knowledge and "wisdom" should be retained within the company, in a form which is easy to access and utilise.

Design automation systems

The Japanese companies also provided some insight into future directions for design automation systems, particularly with regard to the manner in which they have developed their own electronics design toolsets, but also through their efforts at integrating commercially available design software into their design processes. The companies have each had vigorous in-house CAD/CAM/CAE/CIM development programmes in place for a number of years, and they have been using this work to extend the boundaries of engineering design. By this we mean that they are moving away from a narrow, merely technological focus in design and are increasingly venturing into design management, the development of design infrastructures, design-for-manufacture and even into aesthetics and lifestyle design.

The design automation systems used in all the Japanese companies demonstrated a degree of integration with other computer-aided aspects of their operations not witnessed elsewhere in the world. In particular, their toolsets are strongly integrated backwards into manufacture and, additionally, considerable efforts have been made to effect parallel integration of the various design functions with costing, quality, industrial design and management systems. Where gaps are uncovered between the toolsets themselves, Japanese design engineers -- many of whom also have software engineering skills -- are encouraged to write their own "bridging" software.

CONCLUSION

It must be emphasised that the conclusions which the authors have drawn from their data relate only to the the results of their case study visits. Although they have attempted to research a good cross-section of the international electronics industry, extrapolation from these results must be undertaken with care.

Our studies have allowed us to investigate design practice and design CAD tool usage in a number of companies around the world. Although the human potential we have observed in each company has been roughly similar, the evidence of good design practice has varied. Many of the UK companies appeared to be preoccupied with getting production perfect, to the detriment of design. Their efforts were considerably hampered, too, by ongoing "civil wars" between the design and production engineering functions.

On the other hand, leading Japanese companies are clearly aware of the wider impact of design on product competitiveness and the authors observed a consistent approach to company management of product design in the companies they visited. It is our view that the leadership shown by the senior staff in these companies has facilitated the development of policies, procedures and practices, without which their design engineers would be unable to continually improve both the quality of their products and the design process itself.

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[5] See [3] above.