Design for Manufacturing and Assembly

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Concepts, architectures and implementation

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Owen Molloy dedicates this book to his wife Rosaleen, for her patience and support.

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Steven Tilley would like to dedicate the book to his parents for giving him the opportunity to work in the fascinating world of technology.

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Ernie Warman wishes to dedicate this book to his family for their patience and to the memory of Jozeph Hatvaney for inspiring him.

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About the Authors

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Owen Molloy is a Senior Software Engineer with Nortel in Galway, Ireland. Previously he worked as project manager in the area of Concurrent Engineering at the CIM Research Unit, Galway, Ireland, where he managed a number of Irish and European industrial research projects in Concurrent Engineering and Design for Manufacturing and Assembly. These included the BRITE EuRam DEFMAT (Design for Manufacturing Architecture and Tool Suite) project, which led to the production of this book. Previously he worked as a software engineer for Dassault Systemes, France, working in the area of CAD Interfacing. He obtained his PhD in Industrial Engineering from University College, Galway in 1995. He holds an MEngSc degree in Electronic Engineering from University College, Dublin.

Steven Tilley

Steven Tilley (1964) finished his degree in Mechanical Engineering at the Katholieke Universiteit Leuven (Belgium) in 1988 on the off-line programming of robots. Since 1988 he has been a research engineer with WTCM, the research centre of the metal working industry in Belgium. In the period 1988-1990 he was involved in several national and European projects in the area of Process Planning for sheet-metal products : PRESS, BRITE 2406. In the period 1990-1995 he was involved in Design For X projects: Design to Cost for sheet-metal, IDAM (Integrated Design for Assembly and Manufacturing), BRITE DEFMAT (Design for Manufacturing and Assembly Architecture) (4661) and Esprit CONSENS (CONcurrent Simultaneous ENgineering System) (6896). Since 1995 he has been involved in the development of new design and process planning methods for sheet-metal products and production methods, specifically the design and implementation of software tools for the selection of tools on punching machines and the sequencing and quality assurance on bending machines.

Ernie Warman

Ernie Warman initially trained in the Automotive Industry at F.Perkins Ltd., after which he graduated in Production Engineering and Mechanical Engineering. Following completion of his Ph.D, he was promoted to be totally responsible for the technical computing and automation strategy of the Perkins Engines Group (10,000 employees) and relating this strategy to the overall requirements of Massey Ferguson (the parent company). He co-founded Productivity International in Dallas Texas, where work was undertaken for major corporations in introducing new design and manufacturing technologies and the required organisational changes. Following this he joined Inbucon Consultants as a Senior Associate where he established their presence in computer aided design and integrated manufacturing. He then founded K.Four Ltd. and a wide range of work relating to design, manufacturing and organisational impact has been undertaken for leading companies. He acts as a project reviewer for many EEC projects, Euromanagement consultant for DG XXIII of the EC, and reviewer for ACME directorate of the SERC on design and manufacturing research projects. Dr Warman has published over 60 papers and is on the editorial board of Computers and Industry and has extensive professional activities with the various engineering bodies of which he is a member. He is a member of I.Mech.E., I.Manf.E., I.E.E., B.C.S., and A.C.M. He is a recipient of the IFIP Silver Core award.

Preface

In today's economic environment, companies must produce greater product variety, at lower cost, all within a reduced product life-cycle, in order to compete and survive. In order to achieve these goals, a Concurrent Engineering approach to the design process must be adopted, where concurrent consideration of life-cycle constraints leads to a 'right first time' approach to product design. Central to the Concurrent Engineering philosophy, and in many cases the main realisation of it, is Design For Manufacture and Assembly (DFM/A). It is to DFM/A that companies most often look for immediate benefits of an integrated approach to product and process design.

To reap the full rewards of DFM/A, companies should be able to assess their products with respect to their own manufacturing processes and equipment. Further considerations include the ability to analyse product designs against various process and equipment combinations, to assess cost and manufacturing lead time considerations. Overall a DFM/A system needs to answer manufacturing cost as well as design functionality questions and give these constraints their proper "importance" weightings. A move to a state of "reasoning with knowledge" can be argued to be the best approach for these DFM/A traits. The knowledge-based approach enables, for example, a repeated cycle of process selection, cost estimation and design evaluation. This move is all the more justified since the advent of computer technology which offers fast, efficient processing of knowledge and data as well as a platform for a direct link between knowledge-based systems and CAD systems.

Effective DFM/A must take place through feedback to the design domain. Introducing multiple DFM/A criteria into the design process raises numerous issues, such as how to incorporate DFM/A considerations into design without seriously retarding the design process. It will also be more difficult to optimise a design with respect to many (often conflicting) criteria, and to weigh these criteria against each other. If DFM/A is to be automated it must be possible to relate particular DFM/A criteria to particular design entities, even from the conceptual design stage. It should also be possible to filter the DFM/A analysis to coincide with a company's design review process, so that the appropriate analyses are carried out at each review stage. This would ensure completeness as well as accountability.

There is a need for new architectures for DFM/A systems which capitalise on the latest software and knowledge based techniques to deliver the DFM/A systems of tomorrow. Such architectures must be based upon complete understanding of the issues involved in integrating the design and manufacturing domains.

This book provides a comprehensive view of the capabilities of advanced DFM/A systems based on an advanced generic DFM/A systems architecture. It addresses the potential for improvement of currently available DFM/A solutions and points the way forward through adoption of a comprehensive architecture based approach to the design of DFM/A systems.

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1. Design For Manufacture and Assembly Concepts

There are a number of major pressures currently making themselves felt in manufacturing industry, coming both from customers and the business environment.

Globalisation of the marketplace (Browne, 1992), due to such factors as accessibility of markets and improvements in transport, is forcing manufacturers to operate in the context of global standards. Great emphasis is placed on becoming *world class*. In order to become more competitive a common strategic priority is to develop integrated engineering and manufacturing systems that address shorter product development cycles, increased product quality and reduced product cost. There is a shift from mass production towards make-to-order and ultimately one-of-a-kind production, with emphasis being placed on product range, variation, customisation, quality and cost.

There is a growing tendency towards the "Extended Enterprise" (Browne, 1992), where different enterprises supply expertise and capability in different areas (e.g. design, manufacturing, distribution, marketing) and co-operate to exploit a business (product) opportunity. This creates a need for new organisational structures and tools to support multi-functional design incorporating a life-cycle view throughout the design process.

Environmentally benign production has become a key issue, from the legislative, business and customer points of view. Recyclability and environmental costing are now important design issues. According to Tipnis (1993, 1994), a new paradigm *"Green Products plus lean Production equals Sustainable Growth"* has emerged to which responsible companies must respond to compete and survive. Issues such as Design for Recycling and the environment must be studied in the context of the changing value-chain and the extended enterprise, and its effect on competitivity.

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The trend towards reduced manufacturing product life, coupled with extended field life has been noted by Tomiyama (1992). Tomiyama argues that current mass-production methods are not sustainable on a global scale, and proposes a post mass-production era based on modular products with long life-cycles, which may be upgraded as well as individual components recycled. Such trends (which are already visible in the personal computer market) place greater pressure on manufacturers to plan for product life-cycle phases such as disassembly, modularity, compatibility between product versions, and indeed disposal.

With the moves towards recycling in recent years (witness the German automotive industry's push towards totally recyclable cars), Design For Disassembly is becoming a major influence on certain products (Boothroyd, 1992). Weule (1993) reports on the Daimler-Benz group's method of life-cycle analysis, whose principle is to measure the impact on the ecosystem of all aspects of the product life-cycle. The increases in the rate of scrapped products, stemming partly from better distribution, cheaper products, and shorter lifetimes, have also meant the tightening of regulations regarding the recyclability of products. Emerging policies reported by Jovane (1993) include:

1. incentives for manufacturers who use recycled materials when these are not the most economic choice
2. taxes on the use of virgin materials, as well as deposit fees to be returned when these materials are to be recycled
3. systems to measure recyclability of products, so that manufacturers could be penalised if they do not meet specific recyclability standards.

These multiple criteria of life-cycle analysis (e.g. manufacture, test, maintenance, environment, recycling) may be grouped under the term Design For X (DFX). DFX incorporates the manufacturing and assembly criteria for design, as well as beyond to the rest of the product life-cycle.

Such pressures as noted above have raised the need to adopt a life-cycle view of products through all design stages. This life-cycle view is commonly called Concurrent Engineering (CE) or Simultaneous Engineering (SE). Of course CE means different things to different people - strategy, philosophy, methodologies. For example, Canty (1987), provides a very broad strategy statement from Digital

Equipment Corporation: "CE is both a philosophy and an environment. As a philosophy, CE is based on each individual's recognition of his/her own responsibility for the quality of the product. As an environment it is based on the parallel design of the product and the processes that affect throughout its life-cycle" (Figure 1.1). Through addressing life-cycle issues earlier in the design process, it is intended to gain cost and time-to-market benefits (Figure 1.2). Other commentators such as the UK CE industrial forum, and Eversheim and Gross (1990), give more focused definitions of CE, which accentuate the need to produce better products faster and cheaper, using parallel task processing to shorten time to market.

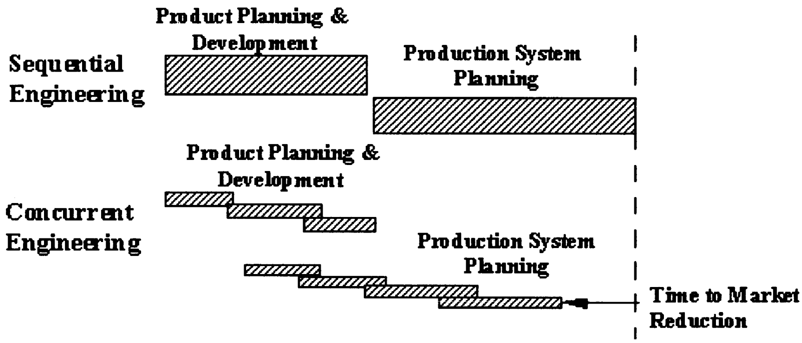

Figure 1.1 *Early Life-Cycle Planning Through Concurrent Engineering*

What is clear is that design of products and their associated processes must happen concurrently in order to reap the greatest benefits from taking the life-cycle view of the product.

In itself, the term "Concurrent Engineering" places no limits on the number of possible interpretations, and is really an aspiration: to appraise and design all aspects of a product and its life-cycle concurrently in order to reach a solution satisfying all these aspects and their inter-relationships; a very broad brief, if it is to be fully embraced.

The USA Defence Advanced Research Projects Agency (DARPA) Initiative in CE (DICE) states (DARPA, 1990): "CE is a systematic approach to the integrated, concurrent design of products and their related processes, including their manufacture and support. This approach is intended to cause the developers, from the outset, to consider all elements of the product life-cycle from conception through disposal, including quality, cost, schedule and user requirements".

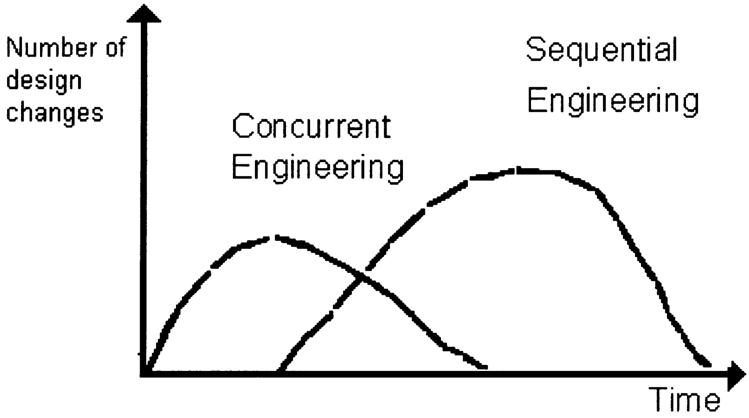

Figure 1.2 *Early CE Means Fewer Late Design Changes*

DARPA also concluded (Reddy *et al.*, 1992) that "..advanced computer software to assist a human team in considering all aspects of a product, including manufacture and logistical support, concurrently from the outset, is essential for the development of high-quality products in the shortest possible time at affordable costs". The mission of the DICE initiative (Engines, 1989) is to create an open computer-assisted CE environment, consisting of:

1. a shared information model that captures complete descriptions of the product or system and all associated process activities and organisational activities
2. a global object framework that enables the use of the shared information model by a network of co-operating computer-based clients
3. services, methods, tools and advisors that assist concept evaluation, analysis and intelligent decision making.

The stated aim of DICE is to emulate, for large organisations, the tiger-team approach to CE, which is successful for small groups. Indeed CE is fundamentally about taking a team approach to product development, and the necessary organisational and cultural adaptations must be understood before supporting technology can be introduced. The problem of migration from a sequential development environment to the implementation of CE architectures is the subject of considerable research (e.g. Singh (1992), Bradley and Molloy (1995)). The adaptation of Business Process Redesign (BPR) tools to develop CE strategies may in future help in this migration.

In 1990 Japan initiated the IMS (Intelligent Manufacturing Systems) international collaborative project with the US, Europe, Australia and Canada. Prompted by population trends leading to fewer people entering manufacturing, Japan identified the need for R&D in the areas of integration, production technology and systems. The unity of design and manufacturing is explicitly recognised in the IMS proposal.

1.1 Implementation of Concurrent Engineering

The implementation of CE may be approached in a number of complementary ways, such as:

1. integration and optimisation of product and process design
2. organisational changes to promote parallel product and production planning
3. the adoption of a team approach to product development
4. technological approaches to improvement of communications and data sharing facilities.

In practice, companies and individuals tend to tackle CE from particular perspectives, employing a variety of methodologies used either by multidisciplinary product development teams or by individuals. These techniques range from generic methodologies such as Design For Manufacture / Assembly (DMF/A) guidelines, Failure Modes and Effects Analysis (FMEA) and Quality Function Deployment (QFD) to specific company guidelines and tools. Because Concurrent Engineering implies interaction between functions, personnel and departments which hitherto tended to be more isolated, improved communication procedures and computer-based tools must be provided to enable CE to take place. Implementation of CE may necessitate new organisational structures, special training, investment in IT tools to support team design and information management for CE.

The approach to DFM/A proposed in this book is to provide fast, company-specific support to the resolution of the conflicting requirements imposed by manufacturing and assembly during the different stages of design, while minimising the dilution of design requirements imposed by such additional analysis methods. However the inherent advantage of addressing DFX constraints earlier rather than later in the design process cannot be understated. Wallace and Suh (1993) have developed a computer program to derive design strategies for products based on customer requirements. The basic principles used here could be taken a step further by integrating a number of analysis tools (such as QFD, FMEA, DFM/A) through a common product model, as proposed by Molloy (1995). His prototype system (Figure 1.3) demonstrated the use of an expert systems-based approach to a CE design system allowing the concurrent resolution of both customer and manufacturing constraints. As noted by Ishii *et al.* (1993a), DFX goals are going to conflict, requiring human intervention to weigh out the various options.

Effective DFX must take place through feedback to the design domain. Introducing multiple DFX criteria into the design process raises numerous issues, such as how to incorporate DFX considerations into design without seriously retarding the design process. It will also be more difficult to optimise a design with respect to many (often conflicting) criteria, and to weigh these criteria against each other. If DFX is to be automated it must be possible to relate particular DFX criteria to particular design entities, even from the conceptual design stage. It should also be possible to filter the DFX analysis to coincide with a company's design review process, so that the appropriate analyses are carried out at each review stage, perhaps using hypermedia solutions to present relevant information to designers (Spath, 1994). This would ensure completeness as well as accountability.

DFX analysis of a product may take place on several levels. Alting and Jorgensen (1993) point out that environmental screening of a product may take place on the four levels of:

1) product function,
2) product structure,
3) product life-cycle and
4) product components,