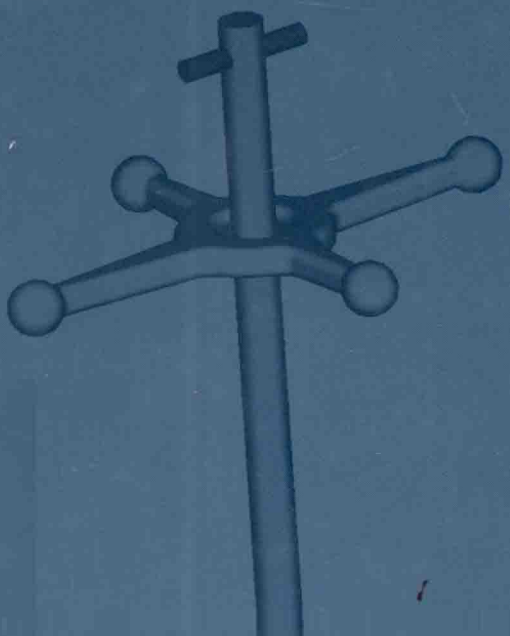
Second Edition

Integrated Product and Process Design and Development

The Product Realization Process



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Dedication

To

June Coleman Magrab

Preface — Second Edition

Since the first edition of this book appeared more than a decade ago, the product realization process has undergone a number of significant changes due, in large part, to globally competitive corporations that are producing innovative, visually appealing, quality products within shorter and shorter development times.

This second edition reflects these advances while still meeting the goal of the first edition: to present a thorough treatment of the modern tools used in the integrated product realization process. The book presents a coherent and detailed introduction to the creation of high quality products by using an integrated approach to the product realization process. It emphasizes the role of the customer and how one translates customer needs into product requirements and specifications. It provides methods that can be used to perform product cost analyses and gives numerous suggestions on how to generate and evaluate product concepts that will satisfy the customers' needs. It then introduces several important product development steps that are usually considered simultaneously: materials and manufacturing processes selection and assembly procedures. It then considers the impact that life-cycle goals, environmental aspects, and safety requirements have on the product's outcome. Lastly, the design of experiments and the six sigma philosophy are briefly introduced as one means of attaining quality.

The book provides numerous figures and tables to illustrate the various ideas, concepts, and methods presented, and two book-long examples provide the reader with a realistic sense of how a product's creation progresses through its various stages. It will be found that the book contains a large amount of specific information that normally appears in many separate sources.

To capture the newer aspects of the product realization process, the author was fortunate to have had three of his colleagues help him enhance the original material. Dr. Satyandra K. Gupta read the entire manuscript, made numerous suggestions for improvements, and added new material on in-mold assembly, layered manufacturing, and bio-inspired concept generation. Dr. Peter Sandborn completely rewrote Chapter 3, "Product Cost Analysis." This chapter now explains how one computes manufacturing cost, costs of ownership, and life-cycle costs of products and systems, and how these costs can influence a design team's decision-making process. Dr. F. Patrick McCluskey extensively revised Chapter 8, "Material Selection," and added new sections on such modern materials as engineered plastics, ceramics, composites, and smart materials. In addition, the first chapter has been rewritten to reflect the advances that have been made during the last decade and to place the product realization process in its new context. The section on concept generation has been expanded to include bio-inspired concept generation and TRIZ.

The book can be used as a single, comprehensive source on the integrated product realization method. The material has been used successfully in the Department of Mechanical Engineering at the University of Maryland at the senior level for a decade. Since many companies are now expecting newly graduated engineers to have the capabilities, approaches, and skills associated with the approach presented in this book, it should prove useful to both beginning and experienced engineers who may need to learn more about the modern approach to the product realization process. The integrated product realization method has applicability in the development of

mechanical and electromechanical products; aircraft systems and subsystems; electronic packaging and fabrication; building design and construction; and in the development and procurement of military hardware.

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F. Patrick McCluskey
Peter A. Sandborn
College Park, Maryland

Preface—First Edition

The product realization process during the last decade has undergone a number of very important changes, many of them brought about by the increasing international competition based on quality, cost, and time-to-market. The material in this book presents the development of the integrated product and process design and development (IP^2D^2) team method, which has been successfully used to conceptualize, design, and rapidly produce competitively-priced quality products. The IP^2D^2 descriptor was selected to indicate, in the broadest sense, the overlapping, interacting, and iterative nature of all of the aspects that impact the product realization process. The method is a continuous process whereby a product's cost, performance and features, value, and time-to-market lead to a company's increased profitability and market share.

The new paradigm for the IP^2D^2 team approach is to consider a very broad set of requirements, objectives, and constraints in a more or less overlapping manner prior to the start of the detailed design process. This approach to the product creation process is one in which the evaluation and selection of the final candidate solution are made from a comprehensive list of alternatives that initially appear to satisfy a set of functional requirements and their constraints. Hence, the goal of the book is to create an attitude toward design that encourages creativity and innovation, while considering as an integral, and equally important part of the product development process, the more or less simultaneous consideration of customer requirements and satisfaction, quality, reliability, manufacturing methods and material selection, assembly, cost, the environment, scheduling, and so on. The book also demonstrates the need for the members of an IP^2D^2 team to represent many different types of knowledge and company constituencies; from business, marketing, purchasing, and service to design, materials, manufacturing, and production.

The book details the means of implementing an integrated approach to the product realization process, and contains a large amount of specific information that is normally widely scattered throughout many sources. It emphasizes customer satisfaction and its relationship to the product's definition, and presents and illustrates proven methods that have been used successfully to create products. The book give numerous figures and tables to illustrate the various ideas, concepts, and methods presented, and includes two book-long examples to provide the reader with a realistic sense of how a product's creation progresses through its various stages. It is felt that these two examples will greatly enhance the understanding of the various stages of the IP^2D^2 process. However, to gain the most benefit from the process described in this book, one should participate in the process.

There is a catch-22 situation in trying to convey the integrated nature of the new product realization process. The IP^2D^2 method is more or less a simultaneous and iterative one; however, when one introduces the method, it must be done sequentially. Therefore, when introducing the method, the way it is learned and the way it is applied in practice after it has been learned will differ in this regard. That is, the steps that are learned in a sequential manner will be applied in an overlapping and iterative manner, and with differing time scales. The method described here contains all the components as presently applied; however, different organizations tend to apply them to differing degrees depending on their products and on their policies.

The material in this book is arranged in the following manner. The first three chapters introduce the IP^2D^2 method in context with its evolution to its present form, define quality and show how it now is one of the driving forces in product development, outline the goals and methods that have been successfully used to realize a product; explain what the IP^2D^2 method is and the order in which its tasks are usually implemented; and, lastly, identify the factors that influence a product's cost.

Chapters 4 to 6 give specific procedures that an IP^2D^2 team can use to obtain customer needs, convert these needs into a multilevel set of functional requirements for the product, and generate and evaluate numerous candidate solutions and embodiments to arrive at a product that satisfies the customer.

Chapters 7 to 10 present the most important aspects of design for X, that is, a design process that produces products that maximize the individual desirable product characteristics—the Xs. Chapters 7 to 9 cover assembly methods, materials selection, and manufacturing processes, three very important aspects of the product development cycle that affect the product's cost, time-to-market, producibility, plant productivity, and product reliability. Chapter 10 presents numerous specific suggestions on how the IP^2D^2 team can satisfy several manufacturing, marketing, social, life-cycle, and environmental requirements, which sometimes place conflicting constraints on the product.

The last chapter, Chapter 11, introduces a very powerful statistical technique that can be used to improve a product and the processes that make it.

The book can be used as a single, comprehensive source on the IP^2D^2 method. The material has been used successfully in the Department of Mechanical Engineering at the University of Maryland at the junior and senior levels and at the graduate level. Since many companies are now expecting newly graduated engineers to have the capabilities, approaches, and skills associated with the approach presented in this book, it should prove useful to both beginning and experienced engineers who may need to learn more about the modern approach to the product realization process. The IP^2D^2 method has applicability in the development of mechanical and electromechanical products, aircraft systems and subsystems, electronic packaging, building design and construction, and in the development and procurement of military hardware.

The author was very fortunate during the generation of the final manuscript to have many of his colleagues from the Mechanical Engineering Department at the University of Maryland at College Park provide considerable input that led to many improvements. Drs. George Dieter and Shapour Azarm read the entire manuscript and provided numerous suggestions and insights. Dr. MarjorieAnn Natishan was very helpful with the material appearing in Chapters 8 and 9. Most of the material in these two chapters was taken from a portion of the master's thesis of Arun Kunchithapatham, who integrated, under the author's direction, this material into a computer tool called the Design Advisor. Drs. Ioannis Minis and Guang Ming Zhang read Chapter 11, and Dr. Minis provided its example #4. In addition, Dr. Minis also made substantial contributions to Section 10.10. Dr. Zhang also provided a large amount of feedback from the use of the final manuscript in his fall 1996 junior course, Product Engineering and Manufacturing. Melvin Dedicatoria did the vast majority of the drawings.

The two book-long problems, the drywall taping system and the steel frame joining tool, are a synthesis of the final results of semester-long projects submitted by the students from the author's fall 1994 and fall 1996 graduate class, Design for Manufacture, respectively. The data used in examples #1 and #3 in Chapter 11 were obtained from the reports submitted by the students in the author's graduate course Advanced Engineering Statistics. The material in Table 6.5 is a synthesis of the results submitted by the students in a two-semester senior course, Integrated Product and Process Development, taught by Dr. David Holloway during 1995–96.

Support to produce many aspects of this book was provided by a very generous grant from the Westinghouse Foundation, and by an ARPA/NSF Technology Reinvestment Project award titled "Preparing Engineers for Manufacturing in the 21st Century," of which the author was director.

Authors

Edward B. Magrab is emeritus professor, Department of Mechanical Engineering, College of Engineering, University of Maryland at College Park and former director of the Manufacturing Program in the College's Engineering Research Center. He has done research in the integration of design and manufacturing. Prior to joining the University of Maryland he held several supervisory positions in the Center for Manufacturing Engineering at the National Institute of Standards of Technology (NIST) over a 12-year period, including head of the Robot Metrology Group and manager of the vertical machining work station in their Automated Manufacturing Research Facility. Dr. Magrab went to NIST after spending 9 years on the faculty in the Department of Mechanical Engineering at Catholic University of America in Washington, DC. Dr. Magrab has written seven books and numerous journal articles, and holds one patent. He is a life fellow of the American Society of Mechanical Engineers and a registered professional engineer in Maryland.

Satyandra K. Gupta is a professor in the Mechanical Engineering Department and the Institute for Systems Research at the University of Maryland. He is interested in developing computational foundations for next-generation computer-aided design and manufacturing systems. His research projects include generative process planning for machining, automated manufacturability analysis, automated generation of redesign suggestions, generative process planning for sheet metal bending, automated tool design for sheet metal bending, assembly planning and simulation, extraction of lumped parameter simulation models for microelectromechanical systems, distributed design and manufacturing for solid freeform fabrication, 3D shape search, reverse engineering, and automated design of multistage and multipiece molds. He has authored or coauthored more than 150 articles in journals, conference proceedings, and book chapters. He is a member of American Society of Mechanical Engineers (ASME), Society of Manufacturing Engineers (SME), and Society of Automotive Engineers (SAE). He has served as an associate editor for the *IEEE Transactions on Automation Science and Engineering* and the ASME *Journal of Computing and Information Science in Engineering.* He has also served on the program committees for the Geometric Modeling and Processing Conference, Computer Aided Design Conference, Product Lifecycle Management Conference, CAD and Graphics Conference, and ACM Solid and Physical Modeling Conference.

F. Patrick McCluskey is an associate professor of mechanical engineering at the University of Maryland, College Park, and a member of the CALCE Center. He has published extensively in the area of materials and materials processing for microelectronics, microsystems (MEMS), and their packaging. He is the coauthor of three books and numerous book chapters, including the book *Electronic Packaging Materials and Their Properties.* He has also served as general or technical chairman for numerous conferences in this area and is an associate editor of the *IEEE Transactions on Components and Packaging Technologies.* He is coordinator for the undergraduate Engineering Materials and Manufacturing Processes and Mechanical Design of Electronic Systems courses. He received his Ph.D. in materials science and engineering from Lehigh University.

Peter A. Sandborn is a professor in the Mechanical Engineering Department and the Research Director in the CALCE Electronic Products and Systems Center (EPSC) at the University of Maryland at College Park. His research interests include technology tradeoff analysis, system life cycle economics, technology obsolescence, and virtual qualification of systems. Prior to joining the University of Maryland, he was a founder and chief technical officer of Savantage, Austin,

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Contents