Computer Integrated Manufacturing

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COMPUTER INTEGRATED MANUFACTURING

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Foreword

The reader of Computer Integrated Manufacturing will soon discover that this book is not just a pre-digested compilation of quotes from other works of its kind or claims from sales brochures. Although a manual on this subject has been needed for some time, I have not seen another, nor any group of papers, which serves an equal purpose. This is a text for the understanding, introduction, and implementation of a modern manufacturing system and it is obviously written against a background of personal knowledge of manufacturing functions extending from the shop floor to the president's chair.

Dr. Harrington has gained national and international recognition as an authority in his field during a long career with Arthur D. Little, Inc. My professional acquaintanceship with him goes back many years, and I can think of few people better qualified to present the subject of this book. I believe he succeeds in helping to remove much of the confusion that surrounds computer usage in manufacturing and clearly distinguishes the skills and knowledge corporate management needs to acquire before sound policy decisions can be made concerning computer integrated manufacturing.

Computer integrated manufacturing does not mean the automated factory. Manufacturing technology and management has been marked by a number of historical developments which stand out as milestones in industrial evolution. Dr. Harrington sees the inevitable development of computer integrated manufacturing as just such a milestone. No company has so far developed such a system to its optimum mode, but some have gone a long way toward it and many are moving in the same direction. I agree with the author's view that the manufacturing companies which will survive in the coming decade are those that are now giving serious attention to what their competition is doing and to what they themselves should be doing in this field.

There will be some experts who will disagree with the author in some details or concepts presented, due, in part, to the inevitable myopic view each of us tends to take when attempting to apply a written instruction to our own unique application. These should take care to read the whole book and they will find Dr. Harrington has supplied alternatives to match the exceptions. Beginners, on the

other hand, may find it necessary to do some technical "digging" just to bring themselves to a level where they can appreciate the true expertise and vision contained in this work.

Between these two extremes is an enormous body of engineers and managers who are trying to understand and bring some order to a technology progressing and expanding so rapidly that it has long since outpaced its own vocabulary. This book is not addressed discretely to any one of the three groups but is a comprehensive work, valuable to all, which covers the philosophy, the economics, and the techniques of the state of the art and extends into a forecast of even greater things to come.

The book's unique characteristic, which will greatly enhance the understanding of its readers, is the way in which it breaks down complex manufacturing systems into basic elements. It then traces control factors from design to shipped product, including feedback for management information and strategy and for on-line process control. Digital data thus becomes useful information throughout the manufacturing cycle and the book becomes an explanation of a computerized, integrated system which is applicable to almost any discrete manufacturing, although it is illustrated as applied to the metalworking field.

The reader will do well to refer frequently to the glossary of terms appended. Some of these are recently coined, some have different nuances within the art, and some can be quite ambiguous when used across disciplinary lines. Current standardization efforts may accept or change many of the terms used but, for the purposes of this book, Dr. Harrington has most ably defined them in context and is consistent in their use.

As technology advances and new knowledge is gained, it may be appropriate to amend or update this book. When and if that project is undertaken, it will be found that the approach is still valid. I feel it will be many years before the book is out-of-date. I can recommend it without reservation to all manufacturing personnel.

Edward E. Miller, President
Numerical Control Society

Preface

I remember watching the first numerically controlled milling machine producing three-dimensional contoured surfaces at a demonstration in the Servomechanisms Laboratory at MIT in 1952. The basic metal-cutting machine tool and its cutter were familiar enough, but the electronic control system was strange and puzzling. How, I wondered, could such complexity and the cost of it be justified in industry? Others were puzzled too. It was not until 1955 that the first commercially built machines found applications in the aerospace industry.

In the short period of seventeen years since then, a wide range of advanced NC machines and equipment has been developed from these specialized beginnings. The range covers a full spectrum of metal-cutting operations, and also includes machines used in associated manufacturing areas such as NC inspection equipment.

The year 1967 saw the beginnings of another line of development. Conventional punched paper NC tapes required at each machine could be replaced by direct control from a central computer and the data could remain stored in the computer where it had been generated. But if the computer could instruct one machine tool, it could instruct many with little additional effort. Direct Numerical Control came into being just in time to meet the recession of 1969 to 1971; fortunately, it survived and is now doing well. The electronic link between machine and computer turned out to be versatile beyond all expectations. It carried reports of status back to the computer as readily as it carried instructions to the machine. Again, the horizon had broadened considerably.

Concurrently, the development of computer aids to other manufacturing processes began to move forward. Computer aided design, numerically controlled inspection and equipment assembly, computerized test gear, and computer controlled materials-handling and storage systems all vied for center-stage attention. Someone coined the terms Computer Aided Design and Computer Aided Manufacturing, terms which have been reduced to the acronym CAD-CAM in our haste to keep up with the virtually explosive progress of the technology.

There is no valid evidence that computer aided manufacturing is limited in its application to the metalworking field. Many other industries have applied it successfully. I believe that this fact is significant. I also believe that there is a basic structure of manufacturing which is invariant regardless of which end products are being manufactured or from what materials. Therefore, the lessons learned in the metalworking field should be transferrable to other fields.

This common substrate of manufacturing is rarely discussed except in connection with some specific product or industry. In fact, it is hard to find concise terminology which does not carry strong connotations of one industry or another. I have tried to solve this problem by setting forth the basic structure of manufacturing and then resorting to the metalworking field for detailed discussions of the state of the art. Those engaged in non-metalworking fields will see the relationship to their own industry and can translate accordingly.

There is another common ground underlying this subject. Management of either machines or men involves the exchange of instructions or reports and the medium of this exchange is usually electronic equipment. Data processing—most of it in digital form—is universally present in all the subdivisions of the manufacturing art. Thus a further thread of commonality is introduced.

I believe that manufacturing management systems must parallel the basic structure of manufacturing itself. We will do well if we tailor the control to that which is being controlled. Therefore, the better we understand the basic structure, the better we can design the control mechanisms. While the details of manufacturing technology are in a state of rapid evolution, the basic structure of manufacturing is not, and it is important to design the management control systems on this already developed base.

This book is dedicated to understanding manufacturing at three levels: the basic structure, the current state of the art of control and its direction of evolution, and as much of the future as can be reasonably discerned. This book is aimed at those men in industry who are responsible for production, on time and on budget, of goods which can compete successfully in the marketplace. It is they who must decide:

- What product will be made, with what tools, and at what cost
- What plant, equipment, and staff will be required
- How they are to be managed.

Their responsibilities pyramid when a necessary change in the controls may mean a complete change in staff, equipment, and even the design of the product. Today, all signs point toward the adoption of computer integrated manufacturing technology. But such a decision is several orders of magnitude more complicated than the decisions managers make daily in following the familiar procedures of the past. Truly, they have a tiger by the tail.

This book should also be of help to the many people who are students:

Acknowledgements

A great many people have contributed to the task of preparing this book for publication and I would like to acknowledge their interest and cooperation. Because the scope of the subject matter is so great, and no one man could claim to be an authority in all its ramifications, I have sought help from many sources.

I would never have started the project had it not been for the gentle persistence of Mr. Graham Garratt of Industrial Press Inc. He saw the need for such a book and asked me to undertake the task at the suggestion of Dr. Louis Rader, Chairman, Department of Electrical Engineering, and Professor of Business Administration at the University of Virginia. Mr. Garratt's guidance and counsel contributed greatly to getting the text balanced and in shape for publication.

Portions of the text have been drawn from talks which I have presented to professional society meetings in the recent past, amplified and adapted to this format. In particular, pages 27 through 32 of Chapter 3, "The Basic Structure–Compartmentation and Fragmentation of Management," are reproduced by kind permission of the Society of Manufacturing Engineers from a report prepared for SME by Arthur D. Little, Inc., entitled, "The Manufacturing Engineer, Today and Tomorrow."

Professor Merrill Ebner, Chairman, Manufacturing Engineering Department, Boston University, read the manuscript in draft form and I would like to thank him for the constructive suggestions he made. Mr. John Randall, then President of Kearney & Trecker Corp. and now an independent consultant to senior corporate managers, also read and commented upon the manuscript.

I have drawn additional help from other sources too numerous to mention–articles in the technical journals, papers presented to professional society meetings, contacts made during my consultant work, and materials made available by manufacturers. I must gratefully acknowledge the contribution of all these sources to whatever excellence this book may have; if there are errors, they are mine.

Finally, I thank my wife Alene for her approval of the undertaking, and her patience and tolerance during its execution.

- Those who are unfamiliar with the CAD-CAM technology, but who feel they cannot remain uninformed
- Those who are not directly involved with computer aided manufacturing but who want to be able to work intelligently with their peers who are so involved
- Those who are looking forward to a career in manufacturing.

One of the problems inherent in such a text is writing, editing, and publishing the manuscript before the state-of-the-art sections are out of date and the forecasts have already become realities. I wrote this text to express my thesis and then checked it against the most recent technical literature. There will, of course, be developments that will surface in the near future, but they will have to be covered in a later edition. We cannot afford to wait longer. If this snapshot appears to be blurred in spots, remember, the subject was in motion.

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Part I

Manufacturing

1

Introduction

We are at one of the major milestones in the evolution of manufacturing technology and manufacturing management. The arts of control and communication in the 1980s will be substantially different from their counterparts of the 1960s. It is important to understand the changes taking place now in order to take the fullest possible advantage of the benefits which may result.

We also seem to be at a turning point. The whole direction of technology and management is changing. For a century, machinery has become more and more automated and, hence, more and more specialized. A gear-generating machine produces precision gears and does so virtually unattended. But it makes only one class of gears. For more than a century, the management of production has become more and more compartmentalized, more and more specialized.

It now seems apparent that things are about to change - not incrementally, but radically. Fractionated management skills are being reintegrated and the new managers with their broader perspectives are directly controlling versatile machines capable of manufacturing diversified and customized products. The total manufacturing effort is being reintegrated into a responsive directable entity. It is a giant step and a step in a new direction.

This radical change in direction is a result of the coinciding of many small advances in the state of the art. Taken individually, each advance is an incremental improvement in one field. Taken collectively, when the fields are contiguous, the result is more than just the sum of the parts. All the tumblers in the lock are falling into place; the door is swinging open. It is one of those rare moments in time when all of a compatible and connected set of conditions has been achieved.

Those conditions were not achieved simultaneously but close enough in time and interrelationship to be discernible as a set. The span of time may have been five years, so that this radical change has not been readily perceived by industry. In fact, it takes careful observation to be aware of the opportunity. A few are already aware, and it is the purpose of this book to share that perception with others. What are the pieces of this puzzle? It's a long list. We have: