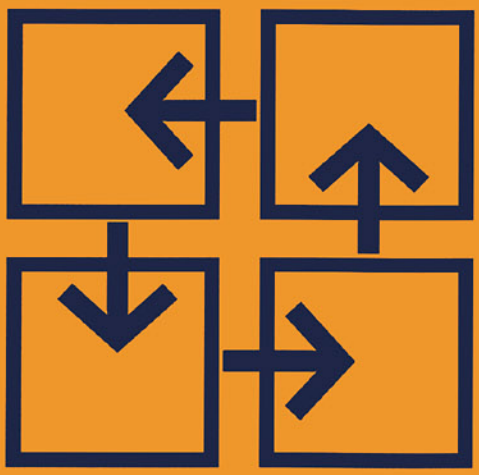
Handbook of Manufacturing and Supply Systems Design

from strategy formulation to system operation

Bin Wu



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To my dear wife Sharon
and my beloved Daniel and Christopher

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Preface

This is my third book in the area. With its publication, I feel that I have finally completed a trilogy on the design and operation of manufacturing and supply (MS) systems. Looking into the engineering domain of industrial and manufacturing systems, one cannot fail to notice its multidisciplinary nature. There are numerous philosophies, various approaches and techniques. Its path is paved with buzzwords. It has long been a desire of mine to be able to present a more coherent and scientific view of the area to which I have devoted my professional life.

For my part, I have always restrained myself from using too many buzzwords that happen to be the flavor of the day. This, I adhere to both in my research and in my writing. Fashions will come and go, but only sound scientific principles stand up to the test of time. That is the reason why I have attempted to follow a consistent theme throughout this trilogy of three books. The theme originates from a few words: *systems concepts, systems methods* and *systems approach*. This theme, in my opinion, provides one of the most important ways of thinking in the field. It is the basis upon which many of the so-called "philosophies" should be explained and assessed. Any sound and workable approaches must have an underlying framework that follows key systems principles. In this field, systems thinking—in terms of a set of systems concepts and prerequisites for the system's effective operation—is what provides the *necessary* conditions for any logical approach. This is my philosophy of the fundamental approach as adopted in the trilogy.

The aim of the books is to provide a comprehensive coverage of the field. Together, they serve to: (1) set systems thinking into the context of MS systems management; (2) provide a theoretical framework into which various concepts and techniques fit logically, hence illustrating *what* functions are involved, *where* they belong and *how* they can be applied; (3) present a self-contained workbook to help put the framework and techniques into practice. Accordingly, the three books cover different aspects of the subject area independently, yet their contents are complementary in a logical way.

Manufacturing Systems Design and Analysis (Wu 1994) sets systems thinking into the context of the area of manufacturing systems design. It discusses the general systems concepts and techniques, and relates these to the manufacturing domain by demonstrating the systems aspects of a manufacturing operation. In addition, it presents a structured approach for the modeling, design and evaluation of modern manufacturing systems. In essence, this book provides the systems background of the trilogy. It helps the reader to understand the structure and operation of a manufacturing organization through a systems perspective, and it shows how to use systems methods and tools to describe, analyze and design a manufacturing system in a structured way.

Manufacturing and Supply Systems Management: A Unified Framework of Systems Design and Operation (Wu 2000) provides a theoretical framework of the trilogy. Based on an extensive analysis of the available methodologies and techniques, plus results gathered through field research, it presents a unified framework of *manufacturing and supply systems management* (MSM). MSM is defined as a domain involving the activities necessary for the design, regulation and optimization of an MS system as it progresses through its life cycle. This book provides an extensive literature survey of the key topics involved in the field, and carries out an in-depth analysis of the application and future requirements of the relevant techniques. In particular, it specifies the key functional areas, outlines the contents and relationships within them, and then combines these into a closed-loop to provide the basis for an integrated management system.

Finally, this current text is all about practicality. Based on the MSM conceptual structure, this self-contained handbook guides the reader through the complete cycle of MS strategic analysis, MS system design, management of system implementation, and system operations monitoring. The structure and contents of this handbook are designed with the following in mind:

- *From the research perspective*. Many researchers involved in MS systems design and operation should find the structure of the MSM framework relevant, because it provides a logical basis for the development of consistent procedures and parameters. While researching individual methods, such a framework can help the researcher keep a systems perspective of the problem domain, and apply the resultant tools more effectively.
- *From a teaching and learning perspective*. The MSM framework will help develop a coherent view of the subject area, and aid in the understanding of how the individual concepts and techniques fit into the overall picture. The task-centered way in which the individual topics are presented will be a useful feature for lecture and tutorial preparation. The workbook itself is ideally suited for students undertaking MSM-related projects.
- *From an industrial perspective*. Industry-based professionals may utilize the workbook to plan, coordinate and execute their MSM activities in a strategically driven way. Also, the workbook is designed to assist with institutionalizing the processes dealing with system design and improvement in a company. Such an in-built ability will help a company to cope with its changing environment and demands, which is becoming increasingly crucial for the success of an MS organization.

I hope that, together, these three texts will further enhance the establishment of *manufacturing and supply systems engineering* as a scientific discipline. I can honestly say that I wish someone else had written such a trilogy, for that would have made my own life as a teacher and researcher in industrial engineering much easier!

In association with my professional activities, I have been very fortunate to receive tremendous help from a large number of people to whom I am indebted. I would like to thank a group of most highly respected colleagues: Professor R.Wild of Henley Management College, Professor J.Powell of the University of Salford, Professor

D.J.Williams of Bespak Europe Inc., Professor A.K.Kochhar of Aston University, Professor D.Price of Bradford University, Professor R.J.Paul of Brunel University, UK; Professor T.J.Black of Auburn University and Professor A.Kusiak of the University of Iowa. I also wish to thank my former colleagues at Cranfield University, England, where I spent a number of very enjoyable and fruitful years.

I am particularly grateful to my colleagues in the Department of Industrial and Manufacturing Systems Engineering, University of Missouri (MU): Professors Cerry Klein, Thomas J.Crowe, Alec C.Chang, James S.Noble, Luis G.Occeña, Wooseung Jang and Jose Zayas-Castro; and Sally Schwartz and Nancy Burke. I thank them for accepting me as a colleague, for giving me the opportunity to work with a wonderful team, and for all the help that they have given as I adjust to academic life in America. I also need to thank them for their imaginative nickname for me—it is indeed great to be the *Wu at MU*.

Special thanks are due to my wife Sharon for painstakingly checking the manuscript, and for professionally converting the entire text to, alas, American English! Having studied, lived and worked in Britain for over twenty years, it took this American to force me to "agree" that the British cannot spell English properly. Of course, any errors and omissions that the reader may find in the book are entirely my own.

Finally, to Daniel and Christopher, I wish to repeat what I said in the preface of my last book: I love you guys—so very, very much!

B.Wu

Columbia-Missouri. 2001

CHAPTER ONE
A Unified Framework of Manufacturing and Supply Systems Management

1.1 INTRODUCTION

The economic and social significance of manufacturing industries has long been established: it is mainly through their activities that real wealth is created. There is little doubt that manufacturing industry will continue to play a vital role. The experiences of the manufacturing industry in the last decades of the twentieth century have provided a strong indication that the companies in the new millennium will face some new challenges.

In order to help manufacturing industries tackle the issues, a substantial amount of research has been carried out in relevant areas such as manufacturing and supply strategy analysis, and manufacturing and supply system design. Consequently, structured approaches, tools, and techniques have been developed. These have resulted in a better understanding of the processes and tasks in their individual areas. When it comes to the actual application, however, there is still a gap between theory and practice. For example, companies often still deal with their system design problems in a fire-fighting manner, due to a number of reasons identified previously. One of these appears to be a general lack of guidelines linking strategy and system design activities. Another reason appears to be the inadequate monitoring of current manufacturing system status. Without a reasonable estimate of the current status of the system in terms of its level of achievement and its position along its system life-cycle, it is difficult for the company to decide when it is necessary to initiate a new round of strategy analysis/system design activities. Also, there is a lack of integrated computer-aided tools in the area.

The issues above highlight the need for a more comprehensive framework to help companies manage their manufacturing system through the life cycles. Factories of the future will not only need manufacturing information systems to plan and control the operation of their existing manufacturing structures, but also methodologies and tools to help restructure their manufacturing and supply (MS) systems themselves. To face this challenge, the author has previously proposed a unified framework which aims to set systems thinking into the context of manufacturing and supply systems management. *Manufacturing and supply systems management* (MSM) here is defined as a functional domain that involves the major activities, such as design, implementation, operations and monitoring, etc., that are needed to regulate and optimize a manufacturing system as it

progresses through its life cycle. The aim is to achieve understanding of the MSM domain, and to provide a basis for identifying a set of consistent parameters and logical procedures, so that effective mechanisms and tools can be developed to help a company's future MSM activities. Detailed discussion of this framework can be found in: *Manufacturing and Supply Systems Management: A Unified Framework of System design and Operation,* (B.Wu, Springer, 2000, London). This framework provides an MSM process reference architecture that is structured to follow the fundamental systems engineering and problem-solving principles, as well as a system reference architecture which covers the systems structure and sub-structures of an MS system. These together provide the basis for the structure of this handbook of integrated design and operation of MS systems.

This handbook has two distinctive features: it adopts a systems approach to follow through the complete cycle of MS strategic analysis, MS system design, and MS operations; and it presents MSM procedures in a task-centered and self-contained way in order to guide the user step-by-step through this cycle. Together, the MSM framework and its task-centered workbook help set systems practice into the context of MS system design and operation. They present an integrated MS systems management framework, logically incorporating the principles and key techniques from a number of relevant areas, including:

- systems concepts and systems engineering,
- systems structure and systems perspective of MS operations,
- strategic planning and objectives formulation,
- system design methodology and techniques,
- project and change management, and
- system performance monitoring.

Following the key principles of systems theory and techniques, the remainder of this chapter provides an overview of the conceptual structure of the MSM framework which identifies the main functional areas, specifies their generic functionality and contents, and logically integrates them into a closed-loop to provide the basis for effective systems management. The task-centered workbook will be presented in the subsequent chapters of the book. Issues related to the framework's institutionalization within an MS organization will also be discussed.

1.2 BACKGROUND AND KEY ISSUES

The last two decades of the twentieth century have seen a new approach to manufacturing. The new demands from the customers and the market have resulted in a reduction in product life-cycles, and hence the need to reduce the time-to-market period for new product development. In addition, it is no longer possible to merely exist and compete at a local level. Competition is seen to exist on a global scale, with world class

standards being set in many areas.

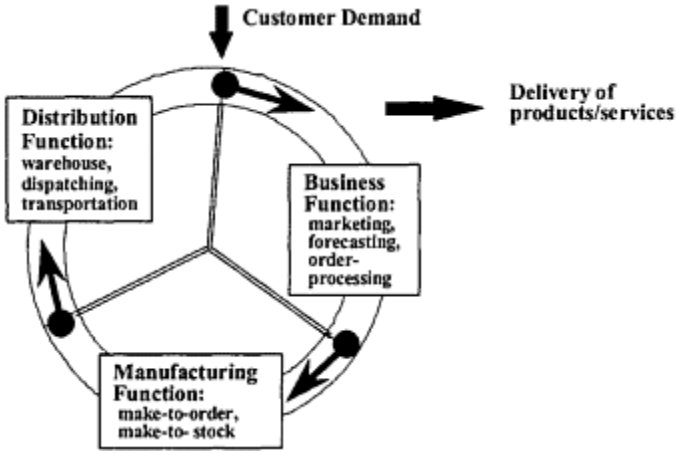

Figure 1.1 Three main functions contributing to MS performance

For many decades, manufacturing and other system functions, such as marketing and distribution, have been treated as separate activities in a manufacturing organization. They may no longer be treated in such a way: in today's global setting, the success of a manufacturing organization can only be achieved with the optimization of the manufacturing and other functions in logical association with one another.

For instance, the importance of transportation/distribution within the manufacturing domain is highlighted in Figure 1.1. This shows that, from a customer's point of view, there are three main functions contributing to a company's delivery performance. This makes it quite clear why companies are increasingly using their supply chains as competitive weapons. Hence, logistics and manufacturing are linked together in an organization's overall manufacturing and supply operation, frequently making the structure of the organization a distributed one involving manufacturing/supply units at different sites and geographical locations (Figure 1.2).

Optimization of the complete manufacturing and supply cycle has increasingly become an essential determinant to gaining a competitive advantage. However, current techniques of manufacturing strategy formulation and system design seem to have concentrated mainly on the issues related to manufacturing activities alone, without much consideration being directed to their subsequent operations. It is evident that many companies have found this restricting, and have begun to ask for ways to consider these relevant activities and treat them as an integral part of the complete cycle. For many manufacturing companies, reaction to market and business conditions suggests the requirement for a step change followed by continuous improvement. This in itself is likely to be continuous, needing steps or sprints in performance to be achieved

periodically, with incremental changes occurring in between. Consequently, MS system design (MSD) projects are being carried out much more frequently than before. Similar to what is known as a *product life cycle*, a manufacturing and supply system also possesses a life cycle, going through a series of stages as shown in Figure 1.3. As shown, greenfield type system design projects are required when a completely new system is introduced, designed, and implemented to satisfy a new set of manufacturing requirements. The subsequent system design activities, brought about by continuous improvement initiatives and projects responding to new market requirements, can be referred to as *continuous improvement* or *brownfield* type projects. In both cases, it is generally necessary to carry out a redesign project, requiring the utilization of existing resources, and being subject to constraints related to the existing system. This concept of *MS system life cycle* provides an insight into the reason why today's manufacturing organizations have to become more lean and agile.

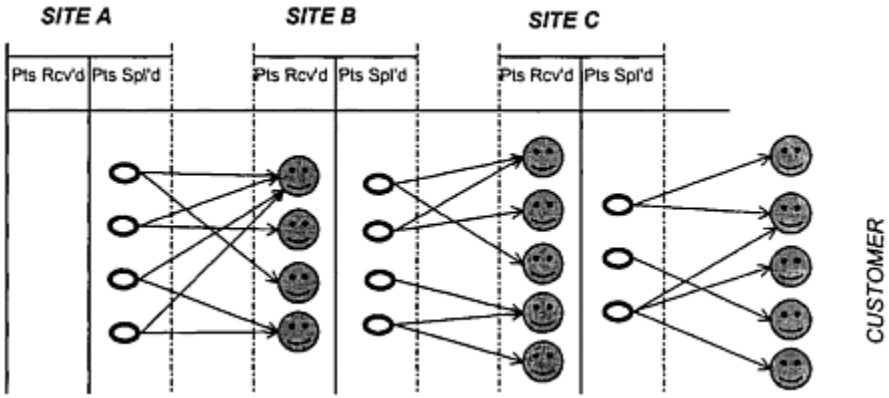

Figure 1.2 Structure of a distributed MS operation

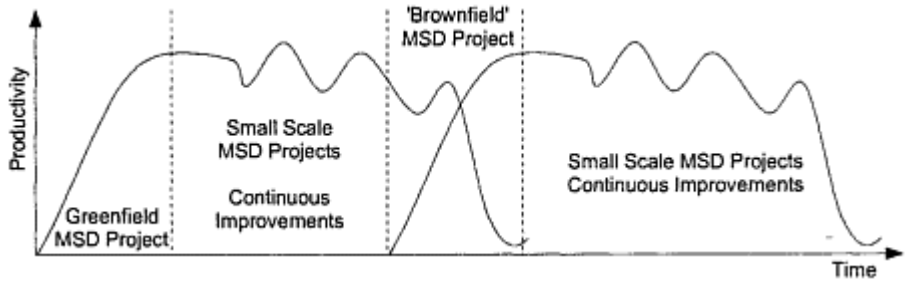

Figure 1.3 MS system life cycle

In reality, every case is different. Companies commence system design projects from

different perspectives. Not only are the markets different in many cases, but each enterprise possesses a unique history, a unique organizational culture and state, and a specific strategic direction. Other factors, such as the combination of time, resources, and financial constraints are also specific to individual companies. Therefore, a design process should be adapted to suit the particular case, requiring an appropriate means of guiding the organization through the relevant design tasks. Such an approach would need to consider the entire design process from the setting of objectives to the detailed design stages and the specification of implementation activities. Based on an extensive analysis of the relevant literature and results from practical cases, a number of separate, yet interdependent, key issues in the area can be summarized as follows:

- *System design methodologies.* There are several problems regarding the use of manufacturing system design methodologies: (1) Awareness—the actual application of methodologies in practice; (2) Planning—the requirement to encourage coherence in the tasks undertaken from project initiation through to implementation; (3) Documentation—the recording, manipulation and retrieval of design data such as design notes, assumptions made and their justifications, etc.; (4) Implementation—failures in system design projects are often related to inadequate organizational and operational planning and/or faulty execution of the implementation process. The primary areas of concern include the lead-times of projects, decision making, and the insufficient coordination of tasks.
- *Manufacturing strategy analysis/formulation.* A few relevant issues in this area are: (1) *Manufacturing strategy formulation*—this covers the strategy content and process. There is substantial agreement concerning the decision categories or manufacturing policy areas to be addressed within a manufacturing strategy; (2) *Interdependency between strategic policy areas*—the decisions made for the manufacturing policy areas are interdependent. The policies and ensuing system design activities can logically link functions to strategy, or can involve more complex multiple links between functions; (3) *Audit approaches*—these allow a systematic involvement of key personnel, and allow both data and judgments to be recorded and revisited.
- *Strategy/system design interface.* Strategy formulation can highlight both strategic improvements and operational improvements that can be achieved through system design activities. The planning and formulation of a design project should be assisted by strategic plans, by identifying *cause and effect* relationships between strategy and operations. The plans derived from the manufacturing strategy should concern the definition of implementation requirements for the manufacturing policies, the definition of the basic manufacturing systems and procedures, the definition of manufacturing controls, the selection of operations critical to manufacturing success, and the definition and formulation of performance measures and review procedures. However, the process of strategy formulation and its subsequent derivation into the specification of action plans is currently considered to be mainly creative. A significant feature resulting from this fact is that the action plans are often not sufficiently detailed to aid implementation. Since strategy development is an iterative process, it should be useful to consider iterations across the strategy/system interface

throughout the system design project, though particularly at the early stages. These iterations may also feed back to the top level corporate and business strategies where necessary. Strategy/system design interface can be viewed as being a complementary task to that of strategy planning and specifies how the strategy is to be executed, the resources required and the performance measures to be applied. It can therefore be considered to occupy the phase of the interface that concerns the development of action plans. In a tactical sense, these plans represent individual system design projects.

- *Systems status monitoring.* This area raises issues about strategy/system implementation, and how to judge the success/effectiveness of a project. A problem has been observed with respect to knowing where to start a system design project. The reason appears to be the lack of an online monitor of current system status within the MSM context. It must be realized that, in order to effectively support a strategy, the development and implementation of the necessary system and operations are a continuous process. Once a new system is implemented, its performance needs to be regularly monitored to assess its fitness-for-purpose, so that the original strategic goals are achieved.

1.3 SYSTEMS APPROACH TO MS MANAGEMENT

In order to deal with the complexity involved, the systems approach to the design and operation of modern MS system, as presented in one of the author's previous books on the subject (Wu, 1994, *Manufacturing System design and Analysis,* 2nd Edition, Chapman and Hall, London) has become more relevant than ever. The structure of the proposed MSM framework closely follows the systems principles and the prerequisite conditions for effective system construction and operation. It essentially supports a structured mechanism for the provision and execution of relevant MSM methodologies, and the communication of system designs.

1.3.1 Key Systems Requirements

Amongst the various concepts as presented in the above mentioned text, of particular interest are a prototype system model and its set of conditions necessary for the effective operation and control of manufacturing organizations. As far as the development of the MSM framework is concerned, the following are especially relevant: (1) *Coherent organizational and operational strategies*. The objectives adopted at various levels of the system must be in line with the overall business aims. Therefore, regardless of the type of system design projects concerned, their activities should be strategically driven so that they are carried out following a coherent frame of objectives to guarantee the system's fitness-for-purpose; (2) *Adequate system structure*. In order to achieve the first goal, a hierarchy of closed-loop control mechanisms must be implemented which corresponds to the hierarchy of manufacturing and supply functions. Hence, three fundamental system

functions must be properly designed and implemented at each level along the hierarchy—objective setting, operational and performance monitoring; (3) *Adequate measurement of the processes.* To facilitate an effective control, it is necessary to be able to measure relevant process parameters in an adequate manner, highlighting the need for the current system performance to be adequately estimated for the subsequent decision-making within the MSM loop; (4) *Awareness of environmental influences.* Sufficient consideration must continuously be given to environmental factors, including changes in customer requirements, technological development, competitors/partners' level of achievement, and changes in government regulations and economical climate. If one relates these well-proven systems principles to the area of MS management, it becomes apparent that a few key elements should be logically incorporated into an overall framework, so as to provide a logical and practical MSM management approach.

1.3.2 Overview of MSM Framework Structure

As shown in Figure 1.4, the MSM framework should consist of three main functional areas: manufacturing and supply strategy analysis (MSA), manufacturing and supply system design (MSD), and manufacturing and supply operations management (MSO). Generally speaking, the nature of MSA approaches can be summarized as a method of helping a company analyze its products, market, and operations to identify areas of concern, and then setting objectives for improvement. However, the implementation of strategic initiatives will rely on the management of change through MSD projects. The general aim of an MSD project can therefore be defined as the determination of the best structure of a manufacturing and supply system in order to provide the capability needed to support strategic objectives. This must be achieved within the resource and other constraints. An MSD procedure is usually based upon a general model of a problem solving cycle, as exemplified by the MSD methodology outlined previously by the author. In addition, the complete MSM cycle should also include the aspects of manufacturing and supply to plan, monitor, and control the production processes once the system is implemented and in operation. Therefore, the MSO area largely reflects the planning and control activities normally associated with an manufacturing resource planning (MRP)/enterprise resource planning (ERP).

The systems thinking in the management of manufacturing and supply requires the development of a set of coherent strategic objectives and goals. The message bears repetition: a hierarchy of compatible system structures should support this hierarchy of objectives. Failure to deploy such an approach will tend to produce solutions/systems that may be technically good but not necessarily good for the business as a whole, due to a lack of context and coherence. In close relations to the MSA function, therefore, a core area involving costing, quality assurance and performance measurement is specified. Its role is to provide a coherent means of establishing goals and objectives, and evaluating the output from various functions in a way that is consistent with the overall strategic aims.