高等院校机械工程·工业工程系列教材

System Modeling and Simulation
With Witness
系统建模与仿真

Fang Shui-liang
方水良 编著

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图书在版编目(CIP)数据

系统建模与仿真＝System Modeling and Simulation with Witness：英文／方水良编著．—杭州：浙江大学出版社，2007.8
(高等院校机械工程、工业工程系列教材／唐任仲主编)
ISBN 978-7-308-05480-5

Ⅰ.系... Ⅱ.方... Ⅲ.①系统建模—高等学校—教材—英文②系统仿真—高等学校—教材—英文 Ⅳ.N945.12
TP391.9

中国版本图书馆 CIP 数据核字(2007)第131924号

系统建模与仿真
System Modeling and Simulation with Witness
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责任编辑　张　明
封面设计　刘依群
出版发行　浙江大学出版社
(杭州天目山路148号　邮政编码310028)
(E-mail：zupress@mail.hz.zj.cn)
(网址：http://www.zjupress.com)
排　　版　浙江大学出版社电脑排版中心
印　　刷　德清县第二印刷厂
开　　本　787mm×1092mm　1/16
印　　张　15.5
字　　数　397千字
版 印 次　2007年8月第1版　2007年8月第1次印刷
印　　数　0001—2500
书　　号　ISBN 978-7-308-05480-5
定　　价　28.00元

浙江大学出版社发行部邮购电话　(0571)88072522

Preface

Computer simulation is a discipline of designing a model of an actual or theoretical physical system, executing experiments on the computer, analyzing the simulated outputs, and optimizing the system. It is a powerful tool that is often applied to the design and analysis and optimization of complex systems.

This book aims to give a fundamental knowledge about the system concepts, system modeling methodology, and computer simulation technology. The main contents of the book are about the technology and application of the Witness simulation software of the Lanner Groups. The ACD (Activity Cycle Diagram) based system analysis and modeling, and the computerized modeling with the Witness' Elements, Rules, Actions, etc., are discussed. Some examples have presented and explained in order to make the contents more understandable.

This manuscript is firstly prepared in 2005. After two years' teaching in the Industrial Engineering classes of Zhejiang University, several thorough modifications have been made and this is the third version.

This book is hoped useful for the Chinese universities to have a bilingual course about the System Modeling and Simulation, and also useful for the users of the Witness software.

Contents

Chapter 1 Introduction to System, Modeling and Simulation

1.1 System

Generally speaking, a system is a set of interrelated components working together to fulfill some common objective or purpose. Each component is an operating part of the system with certain inputs and outputs.

System is a flexible concept: any system can be divided into several smaller systems (sub-systems), and also, any system should be a sub-system of a larger system. As shown in Figure 1.1, a machine is a mechanical or mechatronical system, which can fulfill the operations for parts; a workshop is a larger system, which is composed of various kinds of machines and materials handling devices, and it can manufacture various kinds of parts for different products; and also a factory is a much larger system, which may be composed of different workshops and many other departments such as design department and sales department, etc.

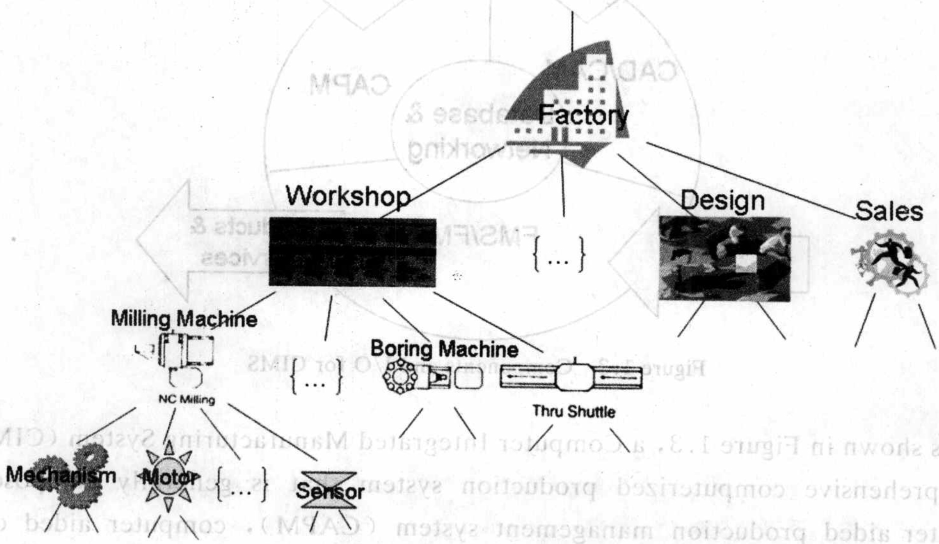

Figure 1.1 Hierarchical Factory Architecture

A Flexible Manufacturing System (FMS) is an advanced manufacturing system, widely used to manufacture a family of similar parts with great flexibility and high performance. As shown in Figure 1.2, a FMS generally consists of a numerically controlled machining system, an automatic tooling system; a material handling system, a load/unload station, a pallet system, an automatic storage and retrieve system (AS/RS), and a comprehensive computerized control system, etc.

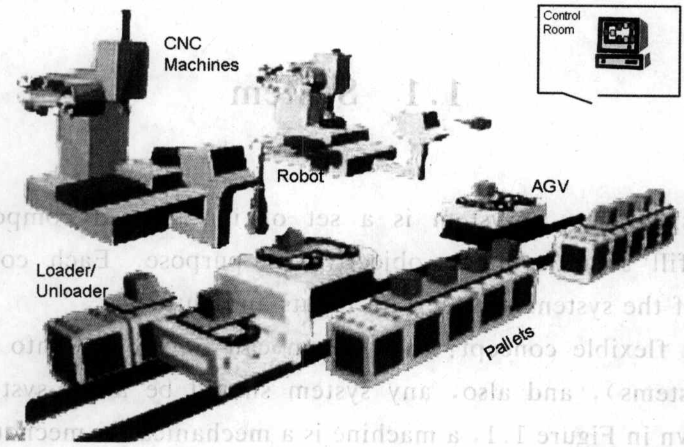

Figure 1.2 FMS Systems

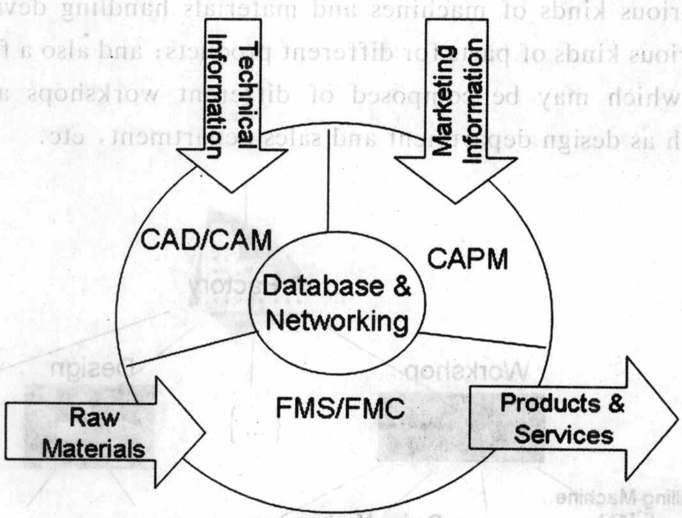

Figure 1.3 Components and I/O for CIMS

As shown in Figure 1.3, a Computer Integrated Manufacturing System (CIMS) is a comprehensive computerized production system that is generally composed of computer aided production management system (CAPM), computer aided design system (CAD), computer aided manufacturing system (CAM), and flexible manufacturing cell/system (FMC/FMS), and some support systems such as database and networking system, etc. It gets from outside the CIMS the technical and the marketing information, and transfers the raw materials into products with high quality and short time.

As shown in Figure 1.4, a hub or focal company will select many suppliers to supply raw materials and various kinds of parts for them to manufacture and assembly the final products, and also must locate many distributors to sell their products to the final customers. The company should try to optimize their whole supply and distribution networks.

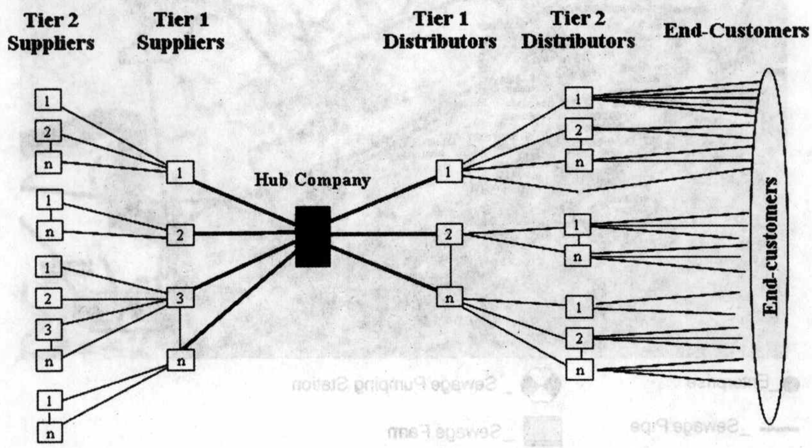

Figure 1.4 Supply and Distribution Networks of a Hub Company

A bank branch on the side of certain community is a service system, which may include different kinds of customers, some clerks, and facilities like teller windows, automated teller machines (ATMs), loan desks, and safety deposit boxes. By the study of the distribution of the customers and the service times of the clerks, etc, the branch manager can determine the right numbers of clerks arranged to satisfy the customers. However, in the scope of a whole city, the headquarter manager must consider all the bank branches as a larger service system, and he should study to determine the total numbers of the branches and their locations, so as to serve the customers of the whole city efficiently.

A waste waters collection and processing system is planned to collect and process the sewage produced by some enterprises, as shown in Figure 1.5. The system is composed of a lot of enterprises located over a field, a group of sewage pipes and some sewage pumping stations for the collection of the sewage coming out from all the enterprises, and certainly several sewage processing factories for the sewage processing. The purpose of the system study is to optimize the numbers and locations of all the enterprises, pumping stations and sewage processing factories.

The other system examples are:

- A field-service system for appliances or office equipments, with potential customers scattered across a geographic area, service technicians with

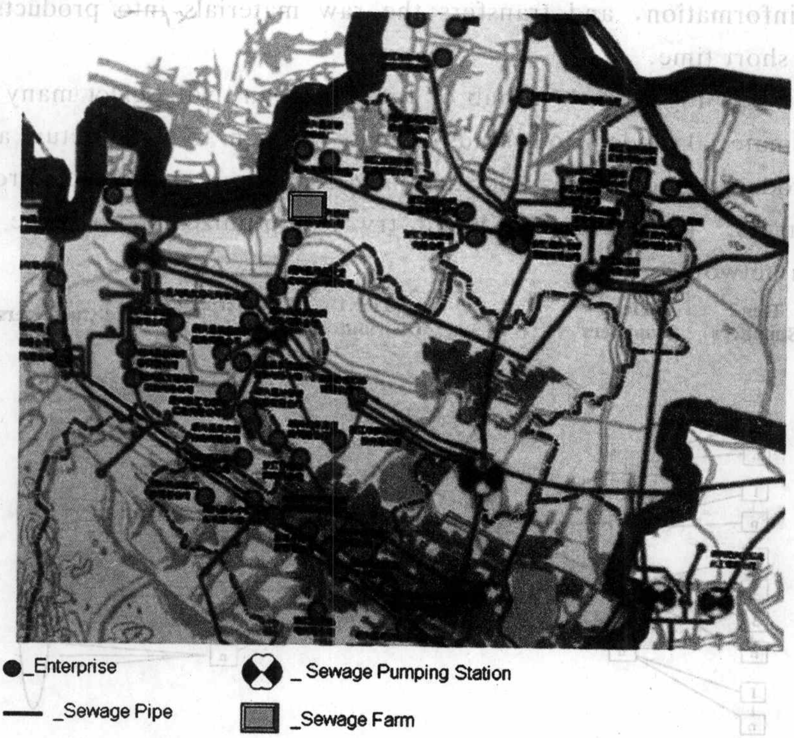

Figure 1.5 Sewage Collection and Processing System

different qualifications, trucks with different parts and tools, and a central depot and dispatch center.

- A chemical products plant with storage tanks, pipelines, reactor vessels, and railway tanker cars with which to ship the finished products.
- An emergency facility in a hospital, including doctors and nurses, rooms, equipments, supplies, and patient transportations.
- A computer network with servers, hubs, switches, cables, terminals, disk drivers, tape drivers, printers, operators, etc.
- A supermarket with goods, shelves, carts, storages, inventory, checkouts, clerks, and customers.
- An automatic milking turntable system, as shown in Figure 1.6.

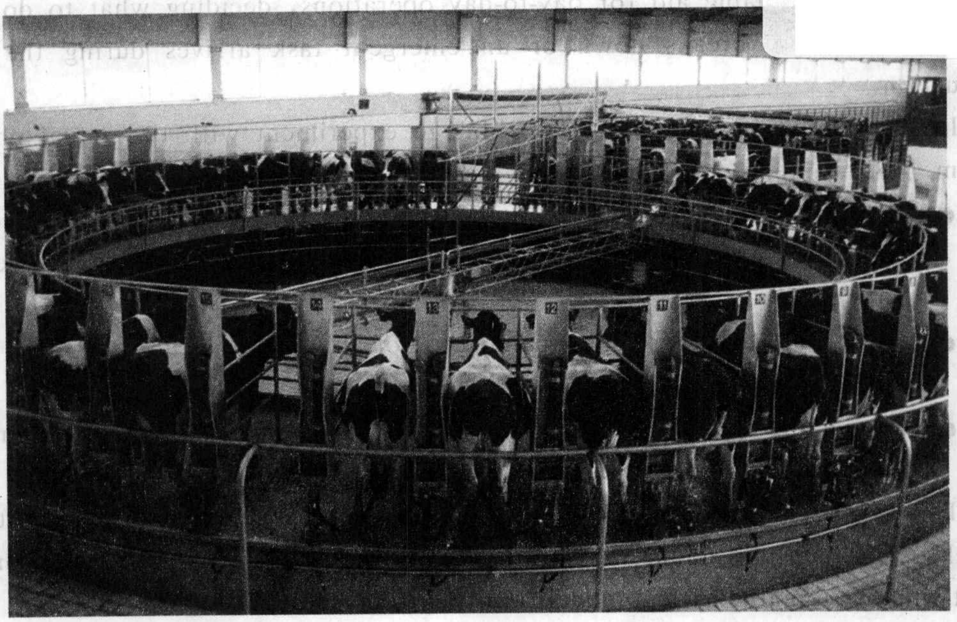

Figure 1.6 Automatic Milking Turntable System

Among the various kinds of systems, each can be classified into:

- Natural systems or artificial systems;
- Social systems or engineering systems;
- Conceptual or physical systems;
- Static or dynamic systems;
- Discrete or continuous systems;
- Discrete-time or discrete-event systems;
- Deterministic or stochastic systems
- Open-loop or closed-loop systems;
- And so on...

For any systems, they have common fundamental characteristics of:

- Aggregation: the set of components composing a system;
- Correlation: each components have relationships with each others;
- Objective: the system must have an explicit objective or purpose;
- Alterability: a system often includes material, energy, and information, a function of the system is the alteration for them;
- Integrality: the set of all the components constituting the system always has more characteristics or functions than what any of its subsets can exhibit.

People often study a system to measure and to improve its performance, or design it if it is to-be constructed. Also, the managers or controllers of a system might like to have a readily available aid for day-to-day operations, deciding what to do if an important machine breaks down or an emergent task arrives during the daily production.

In some situations, it does be possible to experiment with the actual physical system. For example:

- A supermarket manager might try different policies for inventory control and checkout personal assignment to see what combinations seem to be most profitable.
- An airport could test the expanded use of automated check-in passage to see if this speeds up the check-in.
- A computer facility can experiment with different network layouts and job priorities to see how they affect machines utilization.

This approach certainly has its advantages. If experimenting directly with the actual system then it's unquestionably looking at the right thing, without worrying about whether a mathematical model faithfully represents the right system.

However, in practice, sometimes it's impossible (or shouldn't) to experiment with the real systems. Some reasons are:

- The results of the experiment may be unpredictable and/or dangerous to the system or to the persons who operate it, for example the nuclear power plant.
- In many instances a real dynamic system would not allow precise replication, but for system investigation, one should experiment any times with the same situation. For example, it would be hard (really impossible) to run a bank twice to see the effects on the customers waiting times when opening or closing a nearby bank branch.
- Time scale of the real system may be too long (e.g. evolution of a galaxy), or too short (e.g. impact between vehicles) for convenient experimentation.

In many cases, it's just too difficult, costly or downright impossible to do physical studies on the real systems:

- A new system may require design decisions to be made prior to construction of the system.
- It might be very costly to change an experimental layout of an existing factory. Experiments may unacceptably disrupt the operational requirements of the system.
- Trying a new check-in procedure at an airport might initially cause a lot of people to miss their flights if there are unforeseen problems with the new procedure.

In these situations, it's necessary to build a system model to serve as a stand-in for studying and ask relative questions about what would happen in the system if one does this or that. Nobody gets hurt, and the freedom to try wide-ranging ideas with the model could uncover attractive alternatives that might not have been able to try with the real system.

1.2 System Modeling

To study and optimize a system, one should firstly set up the model of the system, especially for a large and complex system. A model is a simplified description or representation of the real system with abstract features of the system relative to the objectives being analyzed. The system model should contain sufficient details for the functionality of the system to be understood, but exclude unnecessary complexity that clouds understanding. So, it is important to define the system under consideration of objectives by specifying its boundaries or scope, the composing components and their relations, and the system's inputs and outputs, etc., as shown in Figure 1.7.

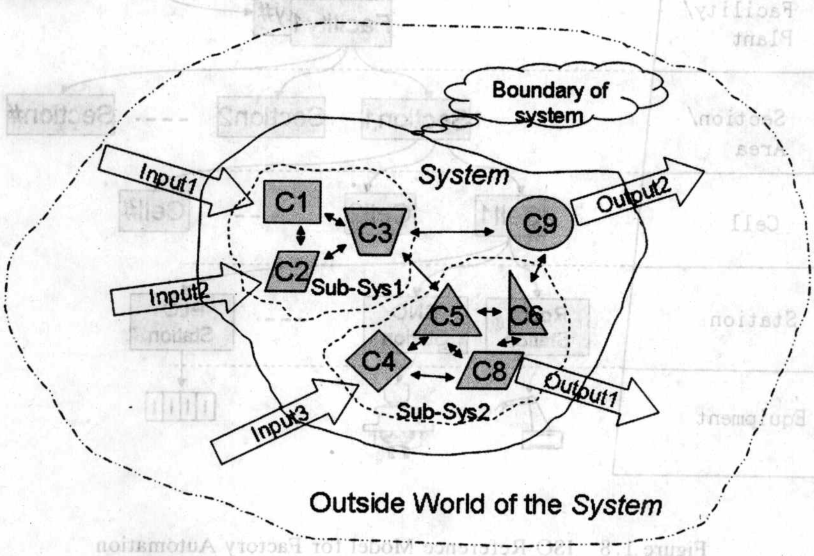

Figure 1.7 System Boundary and System Inputs and Outputs

System modeling is very dependent on the purpose of the study. The purpose of a model is an important aspect of model formulation and must be discussed and agreed before a model of the system can be constructed. For example, a company may be wishing to expand production capability for a particular product. To do this, they will need to purchase one or more additional machines. There is a choice between a high throughput and also high cost machine, or a low throughput but low cost machine.

The purpose of the study may be to ascertain the number of machines of each type that would be needed to achieve target production. The model is then constructed in a form that will enable the correct decision to be made.

For the understanding and study of some large and complex systems, one should divide the system into different sub-systems carefully and rationally, either in horizontal or vertical directions, or in different views. For example, as for the complex computer-integrated manufacturing system, or factory automation system, the International Standard Organization (ISO) has proposed a six-level reference model for them, as shown in Figure 1.8. In this model, the highest level is Enterprise, and then Facility (Plant), Section (Area), Cell, Station, and the lowest level is Equipment. The interfaces between the conjoint levels are also defined in the hierarchical model.

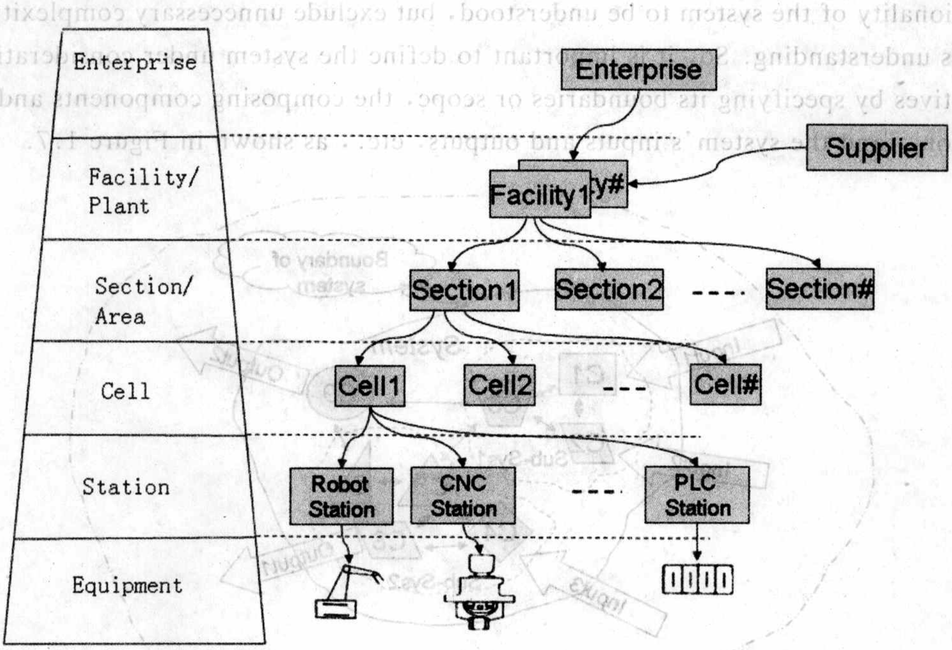

Figure 1.8 ISO Reference Model for Factory Automation

Also in the beginning of 80's last century, the National Bureau of Standards (NBS), now the National Institute of Standards and Technology (NIST) of the USA set up an Automated Manufacturing Research Facility (AMRF) for the R&D of CIMS technologies and system. They have proposed a hierarchical control structure for CIMS, as shown in Figure 1.9. In this model, a CIMS has divided into five layers: Factory (Facility), Shop, Cell, Workstation, and Equipment, and the relations between each layer are also defined.