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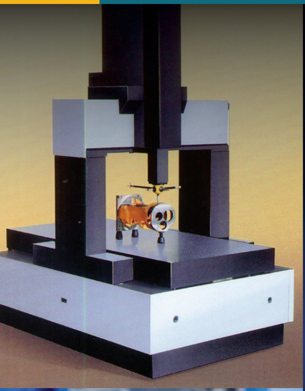

Resources Utilization and Productivity Enhancement Case Studies

Anil Mital
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Dedication

To Mrs. Chetna Mital, MD, and Ms. Priya Pennathur, PhD, and all those in the forefront of the fight against global warming.

Abstract

This book presents examples of engineering applications; particularly Industrial Engineering applications. Six distinct cases are included. The applications range from product design to quality control. The emphasis is on developing methodologies that can enhance utilization of resources. Case studies are important in demonstrating the use of engineering design principles and methodologies. The published literature, however, shows a paucity of cases that may be used for teaching and learning purposes. The reasons for a dearth of published case studies are many, including the propriety nature of problems and confidentiality of data. Such issues are further aggravated as many companies are self-insured and are reluctant to share information with outsiders.

Keywords

Resource utilization, Maintenance, product design, Disassembly, Standardization, Demand variability, Allocation of resources, Productivity

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Preface

Case studies are important in demonstrating the use of engineering design principles and methodologies. Engineering educators generally agree that case studies form an important link in reinforcing the learning process by showing how real-world problems can be solved using engineering fundamentals. And yet, the published literature shows a paucity of cases that may be used for teaching and learning purposes. The reasons for a dearth of published case studies are many, including the propriety nature of problems and confidentiality of data. Such issues are further aggravated as many companies are self-insured and are reluctant to share information with outsiders.

This book represents a small effort, to bring to light examples of engineering applications, particularly, industrial engineering applications. Six distinct cases are included. The applications range from product design to quality control. The emphasis is on developing methodologies that can enhance utilization of resources.

The first case presents and demonstrates the application of a methodology for designing products for maintainability. In the second case, the same authors describe a methodology for disassembling products so as to maximize the utilization of resources by enhancing reuse, recycling, and remanufacturing of components. In the third chapter, Hagiwara proposes a database system for standardizing maintenance information. The fourth chapter deals with optimizing the allocation of nursing resources in hospitals that have a mix of patients. It is well-known that shelf space in retail business is a premium resource. In chapter 5, Lee et al. demonstrate how, as a resource, the shelf space can be managed effectively. Finally, in Chapter 6, issues of productivity enhancement in environments that are constrained by the availability of resources, are dealt. Collectively, all these six cases should provide the reader with a diverse menu of methodologies and applications.

This book is a subset of the original publication, *Industrial Resource Utilization and Productivity: Understanding the Linkages*, from Momentum Press (ISBN 978-1-60650-130-6; year 2010). The original publication has additional details of the cases included here. Interested readers may refer to it should they wish for further details. Nevertheless, cases included here would not leave one with the impression of any omissions. Additionally, there are eight more chapters that will enhance readers' experience and knowledge pertaining to applications of engineering principles and methodologies to practical problems.

Finally, we wish to acknowledge our contributors for their time and effort in putting their works in the format of cases, and our publisher, Mr. Joel Stein, for the foresight to have this book compiled in the form of a case studies collection.

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CHAPTER 1

The Case for Simplifying the Maintenance Process through Product Design

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Preamble

The industrial revolution was made possible primarily through the development and evolution of a wide variety of machines. These range from mechanical equipments at one end of the spectrum to intelligent equipments at the other end. Machines characteristically are comprised of moving parts (especially those machines that use mechanical power) and use friction to perform work. Friction leads to wear and tear of mating surfaces. The phenomenon of wear and fatigue (wear that occurs over an extended period of time) eventually leads to equipment failure.

Machine failure can have catastrophic consequences in a manufacturing environment. When machines are unable to function, they have to be either repaired or replaced. Both options are resource intensive, not to mention the amount of downtime that adversely affects production output. Machines need to be maintained under two main scenarios. The first scenario involves preventive maintenance wherein industrial equipment that is in sound shape is maintained to prevent catastrophic failure in the future. The second scenario involves response to catastrophic failure and is referred to as repair.

Another problem associated with ill-maintained machines is the quality of products that can be manufactured. Poor quality output can erode not only a company's bottom line but also have more far-reaching consequences. An example of such a consequence is the erosion of public image and customer base that can be traced directly to low quality items. If customers are consistently disappointed, they will eventually turn to competitors, and at its worst, this damage can be irreversible. Thus, the importance of well-maintained manufacturing equipments cannot be overemphasized.

In spite of the obvious importance of maintaining industrial equipment, equipment design tends to considerably lag behind industry needs. This implies that every time a machine needs to be maintained (repaired or maintained on a preventive basis), the amount of downtime necessitated is often quite large. The same can be said of resources necessary to affect maintenance. Highly skilled labor is required to affect maintenance over long periods of time. The solution to this problem can only be achieved by designing machines in such a way that they are easy to maintain. Thus, maintainability needs to be incorporated into equipment architecture at the design stage itself, the implication being that different parts of a machine that require frequent maintenance be easy to access, reach, and manipulate. This would considerably shorten the amount of time necessary to perform any routine maintenance operation. Repair can be characterized as a specialized maintenance operation. It is often the result of a catastrophic failure in one or several components that renders a machine inoperable. Thus, to return it to its proper working condition, the component in question needs to be replaced or repaired in some way. Once again, this implies maintainability of the component.

According to the department of defense, maintainability is "a characteristic of design and installation that is expressed as the probability that an item will conform to specified conditions within a given period of time when maintenance action is performed in accordance with prescribed procedures and resources (Harring and Greenman, 1965)." Designing equipment for maintenance has been practiced more as an art than as a science. It has evolved to a greater extent as a result of common sense than by means of scientific investigation. Maintenance is perhaps the most expensive of all human–machine systems. The following reasons are responsible for this fact:

- Given the proliferation of different types of products and systems, there has been an ever increasing need to perform different kinds of maintenance operations.
- The cost of human labor has increased consistently. An estimation of the cost of human labor is extremely important since maintenance is perhaps the only field of operation that relies solely on human capital and human skill.

A methodology to enhance maintainability of equipment is presented in the next section of this chapter. It is further corroborated by a case study that serves to underline the practical importance and applicability of the methodology.

A DfX-Based Design for Maintenance Methodology

In this methodology, the most common and widely used maintenance operations are recorded and described in complete detail. Every maintenance operation is then subdivided into basic elemental tasks. Only a small fraction of all the tasks in the entire maintenance operation are actually responsible for performing effective maintenance. The remaining tasks constitute such actions as reaching for tools, grasping tools, and cleaning components prior to maintenance.

Incorporating Human Factors into the Methodology

Maintenance workers in most cases need to adopt a particular posture and expend a requisite amount of energy so as to accomplish a particular maintenance task. There are several postures such as bending, squatting, and so on which are most uncomfortable. An effective design methodology needs to take into account the different postures adopted by workers when performing maintenance tasks.

Format of the Design for Maintenance Index

The index under consideration consists of three distinct sections. The first section is comprised of premaintenance actions such as slackening, tightening, and so on. The second section of the index focuses on evaluating design variables directly affecting the actual maintenance processes such as lubrication, fitting, replacement, and so on. The third section takes into account all allowances that play a role in all maintenance operations. Human factor allowances have also been incorporated into the methodology as described above. These include allowances for postural requirements, manpower requirements, visual fatigue, and so on.

Developing a Numeric Index to Evaluate Ease of Maintenance

Most maintenance operations are comprised of three major tasks, namely: Disassembly, Maintenance, and (Re)assembly. Products that can do away with the need to disassemble a product prior to maintenance are often the easiest to maintain. An abridged version of a time-based numeric index for accessibility of joints and grooves has been presented in Table 1.1. A score of 73 TMU was assigned to this task, which corresponded to time duration of approximately 2 seconds.

Maintenance operations are largely performed by people and often require the adoption of unnatural postures. This component of the index addresses the human factors aspect of the operation. A table of percentage multipliers for motions allowances is presented in Table 1.2.

The methodology for enhancing the disassemblability of a product is presented in Figure 1.1 by means of a decision-making flowchart.

Table 1.1 Numeric scores for accessibility of joints and grooves for the maintainability index

<table>
<tr><td rowspan="6">Accessibility of joints/ grooves</td><td rowspan="3">Dimensions</td><td rowspan="3">Length, breadth, depth, radius, angle made with surface</td><td>1</td><td>Shallow and broad fastener recesses, large and readily visible slot/recess in case of snap fits</td></tr>
<tr><td>1.6</td><td>Deep and narrow fastener recesses, obscure slot/recess in case of snap fits</td></tr>
<tr><td>2</td><td>Very deep and very narrow fastener recesses, slot for prying open snap fits difficult to locate</td></tr>
<tr><td rowspan="3">Location</td><td>On plane surface</td><td>1</td><td>Groove location allows easy access</td></tr>
<tr><td>On angular surface</td><td>1.6</td><td>Groove location is difficult to access; some manipulation required</td></tr>
<tr><td>In a slot</td><td>2</td><td>Groove location very difficult to access</td></tr>
</table>

Table 1.2 Percentage multipliers for motions allowance during maintenance

Motions allowances	Percentage multipliers (%)
Normal motions	0
Limited motions	5
Awkward motions	5
Motions with confined limbs	10
Motions with confined body	10

A numeric index for assembly is presented in Table 1.3. Table 1.4 presents a similar index for an actual maintenance operation such as lubrication.

Case Study Illustrating Practicality of the Approach

This section presents a case study to illustrate the lubrication process of a handheld drill rotor. A list of individual component for the drill is presented in Table 1.5.

The process illustrating the maintenance operation is presented in Table 1.6.

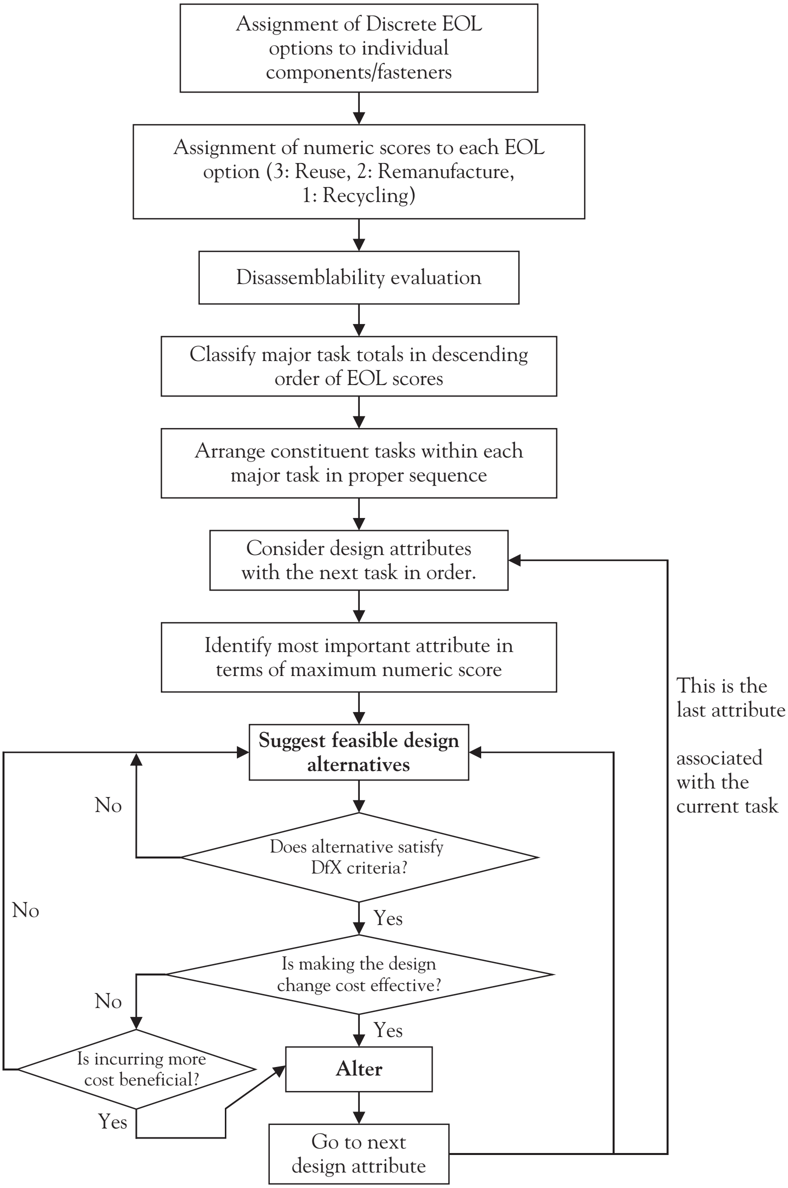

Figure 1.1 Disassembly of components using the MTM-based methodology

Table 1.3 Numeric index for assembly force during (re)assembly post maintenance

Design attribute	Design feature	Design parameters	Score	Interpretation
Assembly force	Straight line motion without exertion of pressure	Push operations by hand	0.5	Little effort required
			1	Moderate effort required
			2	Large amount of effort required
	Straight line and twisting motion without pressure	Twisting and push operations by hand	1	Little effort required
			2	Moderate effort required
			4	Large amount of effort required

Table 1.4 Numeric index for lubrication

Lubrication	Design feature	Score	Interpretation
• Lubrication with brush • With oil can • With grease gun • Hand packing • Through access point • Through adapter	Lubrication between mating surfaces to minimize friction and prevent material loss	2/Location 2/Location 2/Location 15/Location 1/Location 3/Location	• Minor lubrication on surface or crevice • Minor lubrication in inaccessible areas • Minor greasing in inaccessible areas/slots, and so on. • Simple lubrication through access point • Simple lubrication requiring special equipment

Table 1.5 List of components of a handheld drill

No.	Component name	Component material	Quantity
1	Front/back screw	Copper	6
2	Middle screw	Copper	2
3	Bushing	Brass	1
4	Insulating washer	Plastic	1
5	Upper housing	Plastic	1
6	Lower housing	Plastic	1
7	Rotor	Mixed	1
8	Wire lead	Copper/Plastic insulation	1

Table 1.6 Maintenance (lubrication) operation of a drill rotor

Task No.	Task description *Lubrication of drill rotor*	Task Total	(Dis)assembly force			Material handling			Tooling		Accessibility & Positioning			Allowances (%)			
			Inter–surface friction	Inter–surface wedging	Material stiffness	Component size	Component weight	Component symmetry	Force exertion	Torque exertion	Dimensions	Location	Accuracy of tool placement	Posture allowance	Motions allowance	Manpower allowance	Visual fatigue allowance
1	**Remove Upper Housing**																
1a	Unscrew 1st of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1b	Unscrew 2nd of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1c	Unscrew 3rd of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1d	Unscrew 4th of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1e	Unscrew 5th of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1f	Unscrew 6th of 6 front/back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5

1g	Unscrew 1st of 2 middle screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1h	Unscrew 2nd of 2 middle screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
1i	Pull out upper housing	8.7	–	1	–	3.5	2	1.4	1	–	1	1.6	1.6	–	–	–	1
2	**Access Drill Rotor**																
2a	Pull out bushing	10.5	1	–	–	2	2	0.8	1	–	1	1	1.2	–	–	–	5
2b	Pull out insulating washer	10.5	1	–	–	2	2	0.8	1	–	1	1	1.2	–	–	–	5
3	**Lubricate Rotor and Clean Housing**																
3a	Lubrication: 2/Location*2locations	4.2	–	–	–	–	–	–	–	–	–	–	–	–	–	–	5
3b	Clean upper housing: 2	2.02	–	–	–	–	–	–	–	–	–	–	–	–	–	–	1
4	**(Re)assemble Drill**																
4a	Reinstall washer	10.5	1	–	–	2	2	0.8	1	–	1	1	1.2	–	–	–	5
4b	Reinstall bushing	10.5	1	–	–	2	2	0.8	1	–	1	1	1.2	–	–	–	5
4c	Refit upper housing	8.7	–	1	–	3.5	2	1.4	1	–	1	1.6	1.6	–	–	–	1
4d	Screw 1st middle screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4e	Screw 2nd middle screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5

(Continued)

Table 1.6 Maintenance (lubrication) operation of a drill rotor (Continued)

Task No.	Task description *Lubrication of drill rotor*	Task Total	(Dis)assembly force			Material handling			Tooling		Accessibility & Positioning			Allowances (%)			
			Inter–surface friction	Inter–surface wedging	Material stiffness	Component size	Component weight	Component symmetry	Force exertion	Torque exertion	Dimensions	Location	Accuracy of tool placement	Posture allowance	Motions allowance	Manpower allowance	Visual fatigue allowance
4f	Screw 1st front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4g	Screw 2nd front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4h	Screw 3rd front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4i	Screw 4th front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4j	Screw 5th front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
4k	Screw 6th front/back screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5
		294		Total time for maintenance operation: 2940 TMUs = 1.764 minutes													

Total maintenance time: 1.764 minutes

Task # 1 for Maintenance Analysis: Unscrewing/Screwing back of various screws of upper housing

Most feasible cost-effective design solution: Use toggle-type snap fits for upper housing in place of screws to reduce maintenance time.

Total Disassembly time for complete 100% disassembly: 2.044 minutes (Maintenance requires almost complete disassembly of drill)

Task # 1 for Disassembly Analysis: Disassembly of rotor-bushing subassembly

Most important design anomaly for disassembly: Force required wedging out subassembly of rotor and bushings

Task # 1 for Assembly Analysis: Inserting trigger assembly. Total assembly time: 1.30 minutes

Conclusion: Most amount of time is spent in **accessing** the maintenance area. Too many fasteners hamper disassembly and assembly.

Aftermath

The previous section of this chapter presented a design methodology and accompanying case study to facilitate design for maintenance of industrial equipment. It is easy to realize that the methodology can be easily generalized across a wide range on maintenance issues.

First, since the methodology is structured on the MTM system, it is time-based. Thus, it is easily quantifiable. This implies that several designs can be objectively compared from the point of view of maintainability. Further, the concept of maintainability can be broken down into several aspects, each of which can be quantified.

Most maintenance operations are still largely manual in nature. The ease with which a machine can be maintained is reflected by the amount of time necessary for a maintenance operation. Maintenance personnel are paid based on their level of expertise and the amount of effort expended in carrying out the maintenance operation. Thus, using the methodology outlined in this chapter, maintenance costs can be ascertained ahead of time. This enables management to efficiently allocate resources both in terms of maintenance personnel as well as setting aside funds for enabling maintenance. Thus, it constitutes a very useful tool at their disposal.

Proactive design decisions are the next major advantage of this methodology. Proper use of the system described in this chapter will often entail redesign of component parts, sometimes of the machine as a whole. These design changes could range from the subtle to the drastic. Drastic design changes are usually affected if and only if they offer major advantages over existing design, thus enhancing any combination of product quality, profitability, or worker safety.

Facilitation of the preventive maintenance process is another advantage of this methodology. Preventive maintenance is performed to prevent catastrophic machine failure. Using this methodology enables proper scheduling of maintenance activities, minimizing machine downtime and enhancing worker safety on machines that have been designed for maintenance.

It can be observed that the procedure described in this chapter is practical as well as versatile. It can be used to solve a variety of industrial maintenance problems. The versatility of this procedure is due to the fact that it is design-based. Thus, it is proactive in nature. It seeks to solve maintenance-related problems from the design perspective so that future issues related to scheduling maintenance operations are minimized. Reduction in equipment downtime translates to minimized need for scheduling maintenance, minimal maintenance costs, and better product quality.

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CHAPTER 2

A Disassembly Algorithm to Maximize Resource Utilization: A Case Study

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Preamble

The importance of product disassembly has grown manifold in recent years. Counterintuitive as it may seem, the process of disassembly is not necessarily the polar opposite of product assembly. The disassembly process needs to be planned in advance of product design to make the product easy to disassemble. Products are routinely disassembled for several reasons. Disassembly facilitates product repair, maintenance, recovery of precious metals that are part of the product structure, compliance with environmental regulations, and so on. Environmental regulation and used product disposal standards are perhaps one of the most important reasons to disassemble a product. There are strict laws in the EU over product disposal standards and they are increasingly finding their way to the U.S (Zhang et al., 1997). For example, the German policy on combating waste from end-of-life (EOL) vehicles requires car manufacturers to take back EOL vehicles free of charge from the last owner so as to enable material recycling. Unrecyclable material is required to be disposed of without causing any harm to the environment or to human health. Disassembling products for EOL objectives allows *reusable, nonrecyclable, and hazardous subassemblies to be selectively separated from recyclable ones* (Gungor A., 1997).

Industry is continuously seeking solutions to their disassembly problems. Some of the problems that are more commonly faced in the industry include repair and maintenance of industrial equipment as well as environmentally conscious disposal of used products. Specifically, the problem pertains to environmentally conscious disposal of heavy metals such as lead, cadmium, mercury, and so on. Given their highly toxic and carcinogenic nature, it is imperative that such elements be isolated from the product structure and be disposed in a manner that they do not contaminate the natural environment such as the water supply (including aquifers). Another problem pertinent in this case is the retrieval of precious metals such as gold, platinum, and silver (even copper in some cases) that are used in different classes of equipment. Given the functionality that they impart to different equipments, parts made out of such metals are often deeply embedded into the product structure, thus necessitating at least partial disassembly prior to part retrieval.

The issue of isolating faulty components of a product prior to repair and maintenance poses a significant problem as well. Partial disassembly is often required to affect repair and maintenance. The architecture of industrial equipment (very often this spectrum can be expanded to include consumer products as well) tends to be quite complex. Most products are designed for ease of assembly, not necessarily ease of disassembly. Thus, the process of partial assembly can be quite cumbersome and time-consuming (Lambert A.J.D., 1999). If such equipment is part of a manufacturing process, the downtime necessary for repair can constitute a severe bottleneck in the manufacturing process, which, if repeated often, can end up in higher production cost, thus constituting lower profitability.

Table 2.1 Product recovery options after disassembly

Options	Objective	Level of disassembly	Result
Repair	Restore working Condition	Product level (limited disassembly and fixing)	Some parts repaired
Refurbishing	Improve quality level (though not like new)	Module level (Some technological upgrading)	Some modules repaired /replaced
Remanufacturing	Restore quality level as new	Part level	Used and new parts in new products
Cannibalization	Limited recovery	Selective disassembly and inspection of potentially reusable parts	Parts reused and /or recycled/ disposed of
Recycling	Reuse materials only	Material level	Materials used in new products

Source: M. Thierry, M. Salomon, J. Nunen, and L. Wassenhove. 1995. "Strategic Issues in Product Recovery Management." *California Management Review*, 37 (2): 114–135.

Another pertinent problem relates to the concept of standardization. Component parts are often standardized, the process of disassembly isn't. The sheer variety of products and their architecture makes the process of disassembly a logistical nightmare. Simultaneously, manufacturers are faced with the threat of rising costs of virgin material. To keep costs low, an increasingly large number of manufacturers are resorting to reusing, remanufacturing, or recycling components (collectively referred to as reclaiming). Each of the three aforementioned processes has to be preceded by some degree of disassembly. Table 2.1 depicts the various forms of reclaiming.

The different types of recycling are depicted in Table 2.2.

It is clear then, that the process of disassembly is a highly relevant topic in terms of its importance to industry. The following section of this chapter will present one approach to facilitate the product disassembly process followed by an application-based case. Readers should note that this is by no means an absolute approach, just one of the many ways that the problem can be addressed.

Table 2.2 Type of recycling according to component composition

Adaptation of recycling to composition of component		
Type of recycling	**Definition**	**Composition of the component**
Primary recycling	Recycling on a comparable quality level	No alloy present in the component. Polymer content in the component
Secondary recycling	Recycling on a lower quality level *Down cycling*	Presence of an alloy in the component No Polymer content Ceramic content Elastomer or composite material
Tertiary recycling	Decomposition	
Quaternary recycling	Incineration with energy retrieval	No Polymer content Ceramic content

Using Methods Time Measurement (MTM) to Analyze the Ease of Disassembly for a Potential Product Design

A case study is being presented in this section that seeks to facilitate the design process by designing products in such a way that they can be disassembled easily. Thus, the methodology seeks to design products for disassembly early in the design process itself. The main underlying principle is that products that have design features and characteristics that lend themselves to easy disassembly will result in significant savings in terms of time, effort, and material once the EOL has been reached.

Methods Time Measurement is commonly referred to in engineering parlance as MTM. It is an industrial engineering tool that is based on measuring the amount of time taken by each process in any operation. This time can be measured by means of a stopwatch and the resulting data can be subjected to rigorous statistical analysis (using tools such as mean and standard deviation) to establish what is referred to as "standard time," which is characteristic of that specific operation in question. A brief description of MTM is presented in the following paragraph.

MTM is a Predetermined Motion Time Standards (PMTS) system. PMTS systems were originally used by industrial engineers to determine the time needed to carry out manufacturing processes. This system enables the engineer to establish estimates for production time and costs and establish efficiency measures. MTM is the most widely developed and validated PMTS system in the world. Fundamental motions evaluated by the MTM system include motions such as reach, move, side step, apply pressure , bend, stoop or kneel on one knee, grasp, position, release, eye travel, walk, disengage, kneel on both knees, and so on.

Consider a common disassembly operation such as unfastening a screw. This specific operation consists of several different suboperations, including reaching for a screwdriver, grasping it, locating the fastener, turning the screwdriver, and so on. The reader will appreciate that each of the aforementioned suboperations have been listed as one or more of the fundamental motions dealt with in the MTM. It is obvious that the entire operation is time-sensitive. It is also clear that the less time-consuming the operation is, the faster it will be achieved, and the more efficient the disassembly process will be. This is especially true in light of the large number of fasteners that are commonly used in consumer as well as industrial products. The large variety of fasteners plays an important role as well. Thus, if the end goal is to minimize the amount of time consumed by the disassembly process, then it behooves the designer to incorporate design for disassembly early during the design process itself.

Extensive use of MTM has been made in this case study to improve the ease of disassembly of consumer as well as industrial products. This is accomplished as follows:

- Each disassembly operation is broken down into a sequence of logical suboperations.
- The time taken to perform each suboperation is noted.
- Next, the design parameters associated with individual design features are sought to be modified so as to minimize the amount of time associated with the disassembly process.

Once design features that hamper efficient performance of disassembly have been accurately identified, the designer can then set out to make design alterations by considering the following set of questions:

- Is this design feature functionally necessary?
- Can it be combined with another design feature that will result in a simpler disassembly operation?
- Is it necessary to use this specific fastener?

- Can snap fits be used to simplify the design?
- Can changes in the underlying material simplify the disassembly process?

It is important that each of the aforementioned questions be answered with functionality, usability, and economics in mind. This is where the case study draws on the DfX methodology for design since several design parameters have to be given due consideration before a design decision—as it pertains specifically to disassembly—can be made.

In keeping with the basic idea that design simplifications will result in a simpler and more efficient disassembly operation, the case draws upon basic design for manufacturing guidelines such as standardization (as related to fasteners in this case), minimization of fasteners, and so on. Also, it should be noted that since disassembly is still largely a labor-intensive operation, ergonomic factors are given due consideration. The following product features are cited as an example of features that are sought to be modified:

- Design features that hamper accessibility for disassembly (both physical as well as visual)
- Design features that encourage adoption of unnatural postures especially for a sustained amount of time
- Design features that require exertion of too much force, and so on.

The more important economic considerations to be taken into account during the disassembly process include such factors as value added to products and materials during manufacturing, disassembly cost and revenue per operation, and the penalty if poisonous materials are not completely removed. Operating costs continue to be one of the most daunting concerns for manufacturers. The EOL economic value of components can be computed using the costing technique suggested by Lee and Khoo (2001). This technique employs conventional costing practices in addition to specifying a miscellaneous cost (the summation of collecting cost and processing cost) that is in turn used to calculate values of other entities such as reuse value, remanufacture value, primary and secondary recycling values, incineration value, and landfill cost.

Disassembly is a practical problem. No amount of mathematical formulation can serve to solve what is essentially a labor-oriented problem. Over 70 percent of product life cycle costs are ascertained at the design stage itself. This makes it important to have a methodology that seeks to accomplish proactive product design for disassembly.

A practically applicable methodology to enhance efficient disassembly of products has been presented in this section. This disassembly methodology takes into consideration numerous factors such as weight, size, and shape of components being disassembled, frequency of disassembly tasks (based on number of similar products being disassembled within a particular time frame), requirement of manpower, postural requirements, material handling requirements, and need for component preparation such as cleaning and degreasing tasks. A number of human factors in addition to design and economic factors merit consideration due to high labor intensiveness of the disassembly process. The following paragraph describes the structure of the methodology.

The most common and widely used disassembly operations are recorded and described in sufficient detail. Every disassembly operation is then subdivided into basic elemental tasks. It has been observed that only a fraction of all the tasks in the entire disassembly operation are actually responsible for performing disassembly. The remaining tasks constitute such actions as reaching for tools, grasping tools, and cleaning components prior to disassembly.

The new methodology consists of the following distinct elements:

- A numeric disassemblability evaluation index
- Systematic application of DfD methodology

The numeric disassemblability evaluation index is a function of several design parameters that directly or indirectly affect the process of consumer product disassembly. Numerical scores are assigned to each of these parameters depending on the ease with which they can be attained. The following parameters have been addressed:

Degree of accessibility of components and fasteners: Easy access is a prerequisite for quick and efficient disassembly operation. The less accessible a component or fastener is, the higher numerical score it receives.

Amount of force (or torque) required for disengaging components (in case of snap fits) or unfastening fasteners: The lesser the amount of force required, the better the design. The amount of effort required is directly proportional to the value of numerical score received.

Postural requirements for performing disassembly tasks: The disassembly process is still predominantly labor-intensive and according to a recent DELPHI study, is expected to remain so in the foreseeable future. As a result, certain disassembly operations that require the assumption of unnatural postures would prove to be highly detrimental to the operator performing those operations. An unnatural posture can be defined as one responsible for the onset of static muscular fatigue. This issue assumes even greater importance in the light of high frequency of disassembly tasks. A provision for including additional allowances in the disassembly score based on this category has been made in the methodology.

Identification of dirt traps: This factor is important for obvious reasons. A product that has been in regular use is bound to accumulate internal dirt over a period of time. From the disassembly perspective, components that accumulate dirt need to be cleaned and degreased before disassembly and therefore involve prior preparation. This is a time- and labor-intensive activity. Empirical data can enable easy identification of dirt traps at the design stage. This can enable component redesign to facilitate disassembly.

Design factors such as weight, shape, and size of components being disassembled: This can be a crucial consideration in product disassembly especially since it involves the use of special fixtures and apparatus or simply more manpower. For example, the CRT of a 25” television set can be quite heavy and large for a single person to manipulate efficiently. These factors have been addressed through the introduction of an additional multiplier for material handling.

Identification of design anomalies helps optimize component design from the disassembly perspective. Several design factors such as accessibility, mating surface condition, corrosion, size, weight, shape, and so on. play an important role in disassembly. It is therefore imperative that they should be addressed in detail before a particular component design is finalized. The application of the disassembly evaluation criteria to a product results in numerical indices for various categories of evaluation. These scores can be multiplied by additional allowances prespecified for posture, motions, visual fatigue, and manpower requirements. The higher the score an evaluation category obtains, the greater the chance of detecting a design flaw within that category.

An example of numeric scores to be assigned for disassembly force is presented in Table 2.3. The simplest disassembly task of removing an easily grasped object without the exertion of much force by hand by a trained worker under average conditions has been considered as the basic disassembly task. A score of 73 TMUs was assigned to this task, which corresponded to time duration of approximately 2 seconds. Subsequent scores were assigned based on the detailed study of most commonly encountered disassembly operations.

Allowances for various attributes affecting the dismantling process have been presented in Table 2.4. Relevant allowances include those made for posture, manpower, fatigue, and types of motions.

Table 2.3 Numeric scores assigned to varying amounts of disassembly force

Design attribute	Design feature	Design parameters	Score	Interpretation
Disassembly force	Straight line motion without exertion of pressure	Push/pull operations with hand	0.5	Little effort required
			1	Moderate effort required
			3	Large amount of effort required
	Straight line and twisting motion without pressure	Twisting and push/pull operations with hand	1	Little effort required
			2	Moderate effort required
			4	Large amount of effort required
	Straight line motion with exertion of pressure	Inter-surface friction and / or wedging	2.5	Little effort required
			3	Moderate effort required
			5	Large amount of effort required
	Straight line and twisting motions with exertion of pressure	Inter-surface friction and / or wedging	3	Little effort required
			3.5	Moderate effort required
			5.5	Large amount of effort required
	Twisting motions with pressure exertion	Material Stiffness	3	Little effort required
			4.5	Moderate effort required
			6.5	Large amount of effort required

Table 2.4 Postural allowances for unnatural postures adopted during disassembly

Posture allowances	Percentage multipliers (%)
Sitting down	0
Standing up	2
Bending down	5
Lying down	3
Crouching	5
Stretching	8
Squatting	8

Figure 2.1 is a hierarchical representation of the DfD methodology being discussed.

Illustrative Case Study

This section presents an illustrative case study to demonstrate the practical effectiveness of the methodology. The case of a computer monitor disassembly is presented. Table 2.5 indicates the various components used in a computer CRT.

Generalization of the Case on Design for Disassembly to Other Design Scenarios

The preceding section of this chapter outlined a detailed design for disassembly methodology as well as a pertinent case study involving the design of actual consumer products. Since the underlying principle of design conception, analysis, and refinement was time-based in nature, it will be appreciated that this methodology can be extended to other product design situations with a great deal of ease.

The importance of product disassembly in the universal context was already established in the opening section of this chapter as was the conservation of natural resources. In view of the fact that this methodology can be used to facilitate product disassembly, it will be appreciated that principles of MTM can be used in conjunction with design for manufacturing to effect other design decisions such as designing products for assembly, green design, as well as designing for the environment.

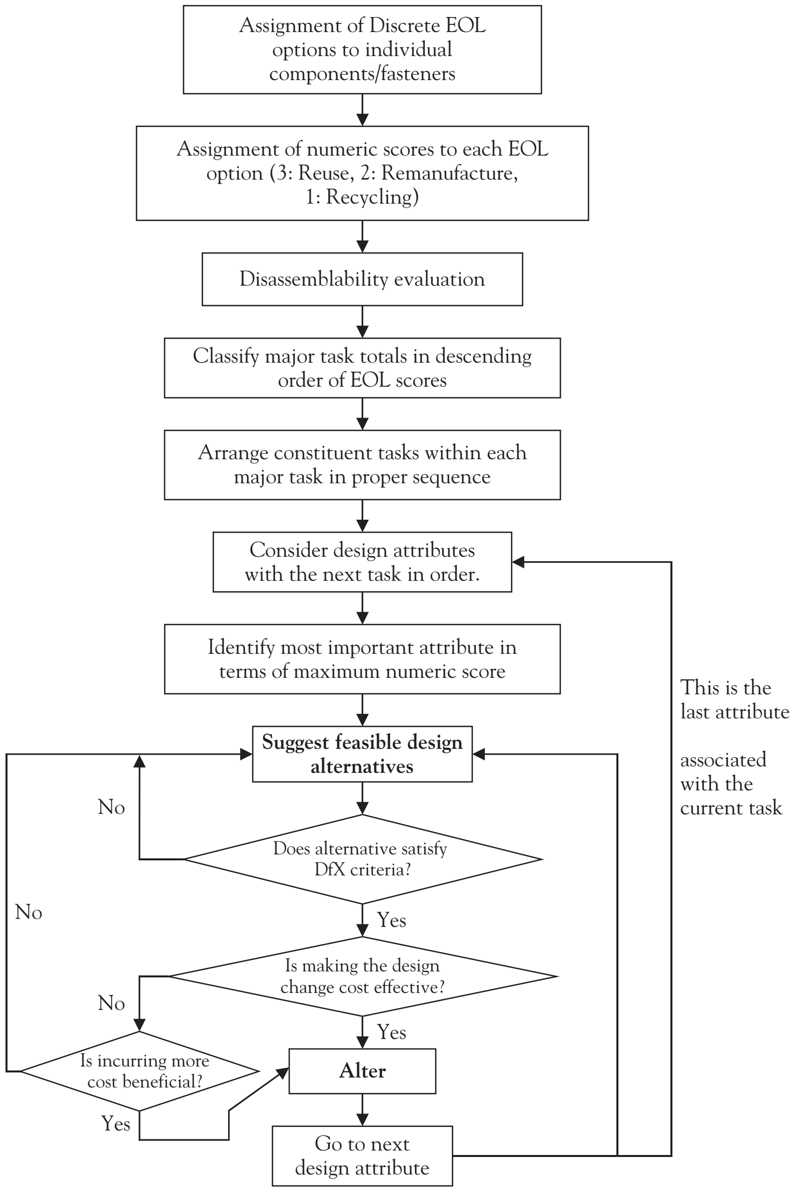

Figure 2.1 Structure of the design for disassembly methodology

Table 2.5 Components of a computer CRT

No.	Component name	Component material	Quantity
1	Back screw	Copper	4
2	PCB screws	Copper	2
3	CRT screws	Copper	4
4	CRT/PCB assembly	Mixed	1
5	Back cover	Plastic	1
6	Swivel base	Plastic	1
7	Pivot	Plastic	1
8	Yoke assembly	Mixed	1
9	Deflection wire lead	Mixed	1
10	Retainer screws	Copper	2
11	Main wire lead	Copper	1
12	Adjusting knobs	Plastic	4
13	PCB retainer screw	Copper	1
14	Retaining lugs	Aluminum	4
15	PCB assembly	Mixed	1
16	Rear board	Plastic	1
17	CRT	Mixed	1

Consider the case of design for assembly, for instance. It is obvious that the assembly process uses many of the same operations and actions that are used in the disassembly process. For example, the fastening of screw requires grasping the screws, locating the joint, setting the screw, grasping a screwdriver, setting it, exerting force, and twisting. Each of the aforementioned motions is an element of the MTM system. Moreover, it is also elemental in the disassembly process that was described earlier. The only difference lies in the fact that most product assembly operations have been automated, whereas most disassembly operations are still largely manual in nature given the large product variety and comparative nonprevalence of environment-conscious product disposal. However, in this instance, mechanical assembly times can also be standardized and are essentially still a function of product design parameters, in the same vein as disassembly.

Another case in point for potential applicability of the design for disassembly methodology could be design for maintenance. It doesn't take too much thought on the part of the reader to appreciate the fact that

Table 2.6 Disassembling a computer monitor

Task no.	Task description *Non destructive Disassembly of Computer Monitor*	Task total	(Dis)assembly force			Material handling			Tooling		Accessibility & positioning			Allowances			
			Inter–surface friction	Inter–surface wedging	Material stiffness	Component size	Component weight	Component symmetry	Force exertion	Torque exertion	Dimensions	Location	Accuracy of tool placement	Posture allowance	Motions allowance	Manpower allowance	Visual fatigue allowance
1a	Rotate swivel base about pivot	13.54	–	4	–	2	2	1.2	1	–	1	1	1.2	–	–	–	1%
1b	Pull out swivel base	11.51	–	2	–	2	2	1.2	1	–	1	1	1.2	–	–	–	1%
2	**Disassemble Back Cover**																
2a	Unscrew first of four back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
2b	Unscrew 2nd of four back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
2c	Unscrew 3rd of four back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
2d	Unscrew 4th of four back screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
2e	Remove back cover	15.44	–	3	–	3.5	2	1.2	–	1	1	1	2	–	–	–	5%
3	**Disassemble CRT/PCB Assembly**																
3a	Unscrew 1st of 2 PCB screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
3b	Unscrew 2nd of 2 PCB screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
3c	Unscrew first of four CRT Screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
3d	Unscrew 2nd of four CRT Screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%

(*Continued*)

Table 2.6 Disassembling a computer monitor (Continued)

Task no.	Task description *Non destructive Disassembly of Computer Monitor*	Task total	(Dis)assembly force			Material handling			Tooling		Accessibility & positioning			Allowances			
			Inter–surface friction	Inter–surface wedging	Material stiffness	Component size	Component weight	Component symmetry	Force exertion	Torque exertion	Dimensions	Location	Accuracy of tool placement	Posture allowance	Motions allowance	Manpower allowance	Visual fatigue allowance
3e	Unscrew 3rd of four CRT Screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
3f	Unscrew 4th of four CRT Screws	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
3g	Remove CRT/PCB Assembly	18.90	–	3	–	4	2.5	2.4	1	–	1.6	1	2.5	–	–	–	5%
4	**Remove CRT**																
4a	Remove yoke assembly	13.13	–	3	–	2	2	1.4	1	–	1	1	1.6	–	–	–	1%
4b	Remove deflection wire lead	13.02	–	3	–	2	2	0.8	1	–	1	1	1.6	–	–	–	1%
4c	Remove CRT	18.06	–	3	–	4	2.5	2.2	1	–	1.6	1	2	–	–	–	1%
5	**Remove Main Wire Lead**																
5a	Remove first retainer screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
5b	Remove 2nd retainer screw	15.65	2.5	–	–	2	2	0.8	–	2	1.6	2	2	–	–	–	5%
5c	Remove main wire lead	13.13	–	3	–	4	2.5	2.2	1	–	1.6	1	2	–	–	–	1%
6	**Remove Adjusting Knobs**																
6a	Remove 1st of 4 adjusting knobs	11	–	2	–	2	2	0.8	1	–	1	1	1.2	–	–	–	–
6b	Remove 2nd of 4 adjusting knobs	11	–	2	–	2	2	0.8	1	–	1	1	1.2	–	–	–	–

6c	Remove 3rd of 4 adjusting knobs	11	–	2	–	2	2	0.8	1	–	1	1	1.2	–	–	–	–
6d	Remove 4th of 4 adjusting knobs	11	–	2	–	2	2	0.8	1	–	1	1	1.2	–	–	–	–
7	**Remove PCB Assembly**																
7a	Remove PCB retainer screw	18.27	5	–	–	4	2	0.8	1	–	1.6	1	2	–	–	–	5%
7b	Bend 1st retaining lug	25.08	–	–	6.5	4	2	0.8	3	–	2	2	2.5	–	–	–	10%
7c	Bend 2nd retaining lug	25.08	–	–	6.5	4	2	0.8	3	–	2	2	2.5	–	–	–	10%
7d	Bend 3rd retaining lug	25.08	–	–	6.5	4	2	0.8	3	–	2	2	2.5	–	–	–	10%
7e	Bend 4th retaining lug	25.08	–	–	6.5	4	2	0.8	3	–	2	2	2.5	–	–	–	10%
7f	Remove PCB assembly	11.55	–	2	–	2	2	0.8	1	–	1	1	1.2	–	–	–	5%
8	**Remove Swivel Pivot**																
8a	Pry out swivel support	18.7	–	–	4.5	3.5	2	1.2	2	–	1.6	1	2	–	–	–	5%
8b	Remove swivel support	10.92	–	2	–	2	2	1.2	1	–	1	–	1.2	–	–	–	5%
9	**Remove Rear Board**																
9a	Bend 1st retaining lug	23.65	–	–	6.5	3.5	2	1.4	3	–	1.6	1	2.5	–	–	–	10%
9b	Bend 2nd retaining lug	23.65	–	–	6.5	3.5	2	1.4	3	–	1.6	1	2.5	–	–	–	10%
9c	Bend 3rd retaining lug	23.65	–	–	6.5	3.5	2	1.4	3	–	1.6	1	2.5	–	–	–	10%
9d	Bend 4th retaining lug	23.65	–	–	6.5	3.5	2	1.4	3	–	1.6	1	2.5	–	–	–	10%
9e	Remove Rear Board	10.92	–	2	–	2	2	1.2	1	–	1	–	1.2	–	–	–	5%
		698	**Total Score for Disassembly Operation. Total time for Disassembly = 6980 TMUs = 4.188 minutes**														

Total maintenance time: 4.188 minutes

Task # 1 for Disassembly Analysis: Remove PCB Assembly

Most feasible cost-effective design solution: Replace four retaining lugs with two or use snap fits to hold PCB assembly in place.

Conclusion: Most amount of time is spent in bending the retaining lugs. Too many lugs hamper disassembly.

most maintenance operations are in fact combinations of disassembling a product, performing the actual maintenance (such as greasing, oiling, descaling, and so on.), followed by reassembling the product. The actual maintenance operation by itself is labor-intensive, time-sensitive, and design-specific. Thus, joints and crevices that are designed to be inaccessible and require the adoption of unnatural postures such as bending or stretching for large amounts of time can be tedious and could result in functional impairment of the product. Thus, the design for disassembly methodology could actually serve to be a lifesaver for most products, both commercial and industrial, especially industrial. Given the fact that it incorporates DFM principles, cost principles, as well as ergonomic design guidelines, the case presented in this chapter can indeed be used across a wide variety of product design situations.

A similar case can be made when considering design for the environment, although in this case the situation is slightly different. Design for the environment consists of making products easier to recycle and reuse so that less virgin material is used in new products and assemblies. Once again, the case can be made such that prior to reusing a product, it would be advisable to disassemble it first. This is largely due to the fact that components that are disassembled could be in good functional condition and do not necessarily need to be recycled. The distinction is made in that recycling primarily occurs at the material level, whereas a product is often reused in its current physical form albeit sometimes post refurbishment. Thus, components that can no longer be reused due to a variety of reasons including obsolescence, structural infirmity, and so on can be recycled. Thus, the material used in the parent product can actually be optimized since product reuse retains for over 80% of all the value added while creating the parent product. Recycling, on the other hand, retains barely 5 percent to 10 percent of original value addition. This also implies that approximately 90 percent to 95 percent of initial value is destroyed as a result of recycling. Also, product reuse makes economic sense when compared to recycling. This is due to the fact that the process of recycling is energy-intensive. When viewed in the larger scope of sustainability, recycling is a far more expensive alternative to reuse. In the case of the latter, the only expense associated with effectively reusing a product is that associated with cleaning, repackaging, and refurbishment if necessary.

It is thus clear from the preceding discussion that the case presented in this chapter is very versatile from the point of view of product design. It can applied to a range of design scenarios and can even be used to optimize the use of material resources as evidenced by its applicability to design for the environment, resources that are in short supply to start out with. The minimization of virgin material usage in new products could very well serve to be the ideal solution that is being sought within the realm of resource utilization. The issue of human resource is addressed equally well given the emphasis on ergonomic design within the methodology. Thus, it serves to create product designs that are compatible with not only the end users (customers) but intermediate users (assemblers and disassemblers) as well.

Conclusion

This chapter emphasized the importance of conserving natural resources for the betterment of mankind. One of the approaches that would enable the achievement of this objective is to reuse, recycle, or remanufacture material and components at the end of their useful lives. To be able to accomplish this effectively, it is essential to be able to take apart products that have reached the end of their useful lives. The process that enables taking apart product components is termed as disassembly.

Various kinds of disassembly approaches were introduced in this chapter. A methodology that is practically applicable and can be used from the design perspective was also presented. The methodology is largely time-based and hence can be used objectively on several different product structures.

Time is only one of the metrics that can be considered in evaluating the ease with which either assembly or disassembly can be carried out. Examples of other metrics that can be used in this evaluation are: effort, cost, use of fixtures and equipment, workforce, and so on.

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CHAPTER 3

Standardization of Technical Data Utilized For Maintenance Activities

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Preamble

Manufacturing plants in many types of industry are nowadays highly automated. The production system would be more and more large-scaled and complex, in which various types of machinery, equipment, facilities, and devices are involved. Once a failure of the stuff occurs somewhere in the production system, it may affect the whole system, and the production cannot be continued anymore. However, we cannot avoid such a situation, since each stuffs has its own life, and must fail soon or later. Therefore, the most important role for the plant personnel is to keep the production system safe and sound. This is called maintenance activity.

Maintenance activity is usually performed by the team of plant personnel. The team requires the knowledge to communicate with each other for identification of the faulty sate, for seeking the (root) cause, and for finding out the solution or method to restore the failure.

The necessary knowledge for the team sometimes has to be acquired from other sources such as technical papers, handbooks, or knowledge of experts of various areas including chemical, physical, mechanical, electric/electronic, civil/social, and environmental engineering. Acquiring such information may be difficult and time-consuming, since it is normally written using many technical terms on the specific area and in various types of formats.

The database system proposed in this chapter provides a method on how to standardize the information to be used for maintenance activities. If all the information is written in unified or standardized form that is easily understandable, the data can be shared by all the plant personnel in the team and the efficiency of the maintenance activity may be drastically improved. Furthermore, an extended application of this method as a tool for analyzing complex failures is also described using examples.

Overview

In this chapter, the database system for maintenance management information that is intended to be used on the Internet is described. This system will offer technical data including fault identification, selection of adequate maintenance policies, and evaluation of the maintenance activities. The system proposed is based on the hierarchical fault classification (HFC) method, by which an undesirable event, in other words, a failure that occurs in the equipment in manufacturing plants, is expressed by using a series of fault modes of eight hierarchical levels from the generic cause level to the society level. Any fault modes in any hierarchical levels can be identified in the single formulated manner by using the information including fault level, item name, faulty state, and the method of the fault detection or identification connected. Consequently, a specific failure that occurred in a manufacturing plant can simply be described by connecting the upper and lower fault modes together. By using such a concept, the plant personnel in various areas can share the necessary technical data to be used for their own maintenance management or activities. A small-scale database system that will be presented has proved the possibility of realizing the multiplicative database based on the HFC method that could offer the necessary information via the Internet.

Introduction

Maintenance plays an important role in highly automated manufacturing plants to save on resources including energy resources, human resources, and material resources, and to maximize the productivity from an engineering point of view. Maintenance is the combination of all technical and administrative actions to reduce the consequences of failures, to extend the life of the system, and to ensure that the condition of the system meets all authorized requirements (Kumar et. al., 2000). Therefore, the efficiency of maintenance activity itself is important as well. It is, however, very difficult to perform the maintenance effectively and efficiently, since it requires a great number of concrete and technical data or knowledge concerning fault diagnosis in a broad sense (e.g., fault identification, failure assessment [cause and effects analysis], and fault correction or prevention), which are generically called maintenance data. This means that the maintenance data management is one of the most important keys to make the maintenance activity effective and efficient.

Many studies and efforts have been performed to formulate the effective maintenance management system. For maintenance project control, program evaluation and review technique (PERT) and critical path method (CPM) are widely used (e.g., Dhillon, 2002), and the concept of total productive maintenance (TPM) is combined with reliability centered maintenance (RCM) to save the resources in manufacturing (Smith & Hawkins, 2004). Furthermore, an intelligent maintenance system called Watchdog Agent-based real-time remote machinery prognostics and health management (R2M-PHM) system has been recently developed (Kobbacy & Murthy, 2008). However, they do not always work successfully in all types of the practical manufacturing plants in terms of effectiveness and efficiency in maintenance, since the performance of maintenance is highly dependent upon the types and the characteristics of equipment, machinery, and systems to be maintained (Desai & Mital, 2005). The plant personnel sometimes have to get the data described above for their own items by themselves. In fact, a great many valuable technical data have been produced and published through investigations or research works done by the experts from various areas. However, these data cannot be fully utilized in the maintenance management area since most of the data are not integrated as the useful knowledge for the maintenance management, but are only scattered as the elements or the row materials described in different formats.

In this chapter, an idea of the database system is described for maintenance management including the fault identification, the selection of the adequate maintenance policies, and the evaluation of the maintenance activities, which allows the plant personnel from various types of manufacturing plants to share the basic and highly specialized data. For this purpose, a new concept is proposed that will offer the necessary technical information and the knowledge for individual plant personnel via the Internet.

The database system proposed is based on the HFC method (Chen & Hagiwara, 2000; Hagiwara, 1996) by which all of the data can be shared and utilized by both a large number of experts and users in various areas. The data module formulated to express the general fault diagnosis information is proposed with some examples.

At the end of this chapter, the extended application of this method is described, by which we can show the whole sequences of large-scaled accident including a number of complex failures as a single graphical chart. The graphical presentations for the most critical nuclear power plant accidents at Three Mile Island and at Fukushima Daiichi (units 1 to 3) highlight the functionalities of this method.

Maintenance Data and their Descriptions

Classifications on the Data to Be Used for Maintenance

Figure 3.1 shows the key issues in the maintenance of an asset (Kobbacy & Murthy, 2008). To execute the maintenance action, one should understand and utilize the concepts and techniques and therefore would require a variety of data or knowledge for each of the issues.

Technical data (maintenance data) are required at the faulty state recognition stage and the planning and execution of the maintenance activity stage (Hagiwara, 1999). The following explains the data for these two stages:

1. Data for failure or faulty state recognition
   a. Faulty item (item names and the locations)
   b. Faulty state (type and other features)

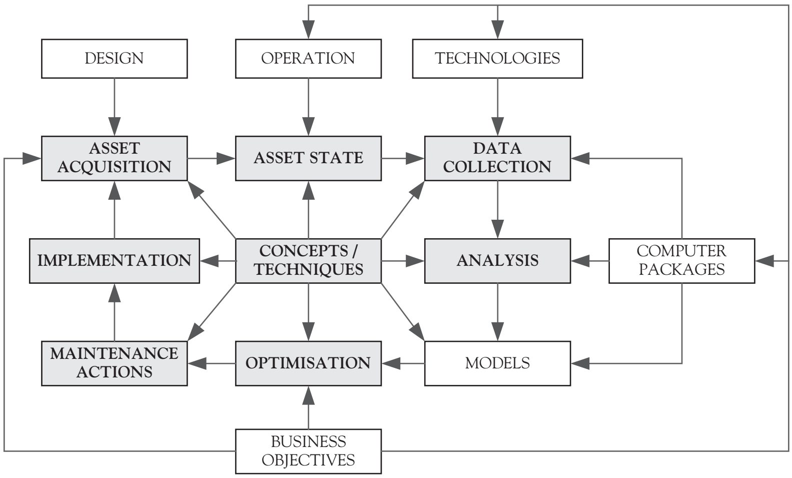


Figure 3.1 Key issues in the maintenance of an asset

Source: Kobbacy and Murthy (2008).

   c. Fault recognition or monitoring technique (methods, equipment or tools, and procedures)
   d. Fault detection or diagnosis technique (method, equipment or tools, and procedures)
2. Data for the maintenance planning and execution
   a. Effect of the failure (criticality and damage quantified)
   b. Type of the failure (period, frequency, and other features)
   c. Access technique to the faulty item(s) (methods, tools, and procedures)
   d. Restoration or correction technique to the faulty item(s) (methods, tools, and procedures)

These data may contain some inherent or local issues for the individual plant or equipment. However, they are restricted to the data concerning the local effect of the failure and the access method to the faulty item in individual plant presented in the 2a and 2c lines, respectively. Therefore, we can build up most of the maintenance data utilized for our own maintenance activities from published knowledge or the elements of the technical data. The most important thing to do now is to exclude the difficulties in building up the data set due to the wide varieties of the descriptions of knowledge.

Failure modes and effects analysis (FMEA) or failure modes, effects and criticality analysis (FMECA) and fault tree analysis (FTA) are typically used to assess the effects of a failure and the failure (root) causes (e.g., Levin & Kalal, 2003). Root cause analysis (RCA) is a newly developed technique, and Ray, Elam, and Bledsoe (2007) have concretely applied it to rocket engine failures to boost the reliability. However, these techniques are designed to be applied to a specific or individual system concretely rather than to formulate or standardize the description of the technical data for the maintenance management in general.

Concept of HFC

Figure 3.2 shows the concept of the HFC system used to describe the faulty states that occur in equipment and to evaluate the maintenance policy to be applied (Chen & Hagiwara, 2000; Hagiwara, 1996). The HFC method is based on the fact that a failure is initiated by one of the generic causes and propagates toward the upper hierarchical levels in each step.

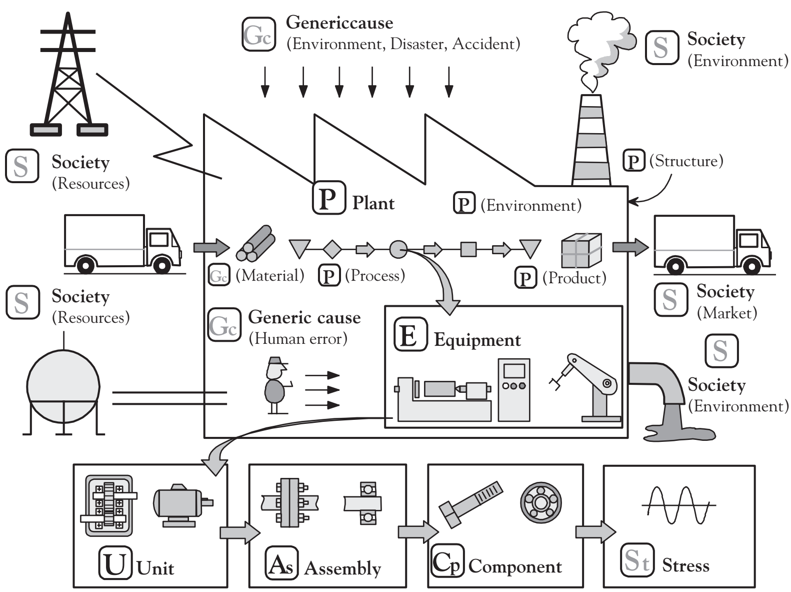


Figure 3.2 The concept of level *and* item *in the HFC*

By using such a concept, a failure can be expressed by a set or a series of fault modes from the generic cause level to the society level without using fuzzy words such as "cause" and "effect." The plant is divided into five hierarchical levels in accordance with the system structure: plant (P), equipment (E), unit (U), assembly (As), and component (Cp) levels. Furthermore, society (S) level and stress (St) and generic cause (Gc) levels are defined as upper and lower levels of the system structure, respectively.

By using the HFC concept, the maintenance activity can be expressed in a simplified manner. When performing the maintenance activity, you must "access the item of lower level step by step until the failed item to be replaced has been reached, and replace it."

The equipment can be restored by replacing one of the upper-level items (assembly, unit, or equipment) instead of replacing the failed component or the failed part of the component. In general, if you select the upper maintenance level, the damages and the maintenance item costs increase, but the maintenance work would be easier. If you contrarily choose the lower maintenance level including the exclusion of the root cause (fault mode of the generic cause level), the damages and the maintenance item costs would be minimized, but the technical difficulty increases, and it may result in higher total costs.

Expression of Maintenance Data by using HFC Method

Some features and advantages of HFC are highlighted by two examples:

Example 1: Expression of the *Route Map* Showing All the Possible Failures in a System

Figure 3.3 shows an example of the description of the possible failures that may occur in bolted or threaded joints in the general machinery. This diagram lists all of the failure mechanisms or the relationships between the causes and the effects that could also be obtained by using the conventional techniques such as FTA and FMEA/FMECA. In HFC, however, each failure can be described objectively by using the hierarchical levels as "absolute coordinates." Items and their faulty states can be classified easily into one adequate hierarchical level in advance. The primary failures

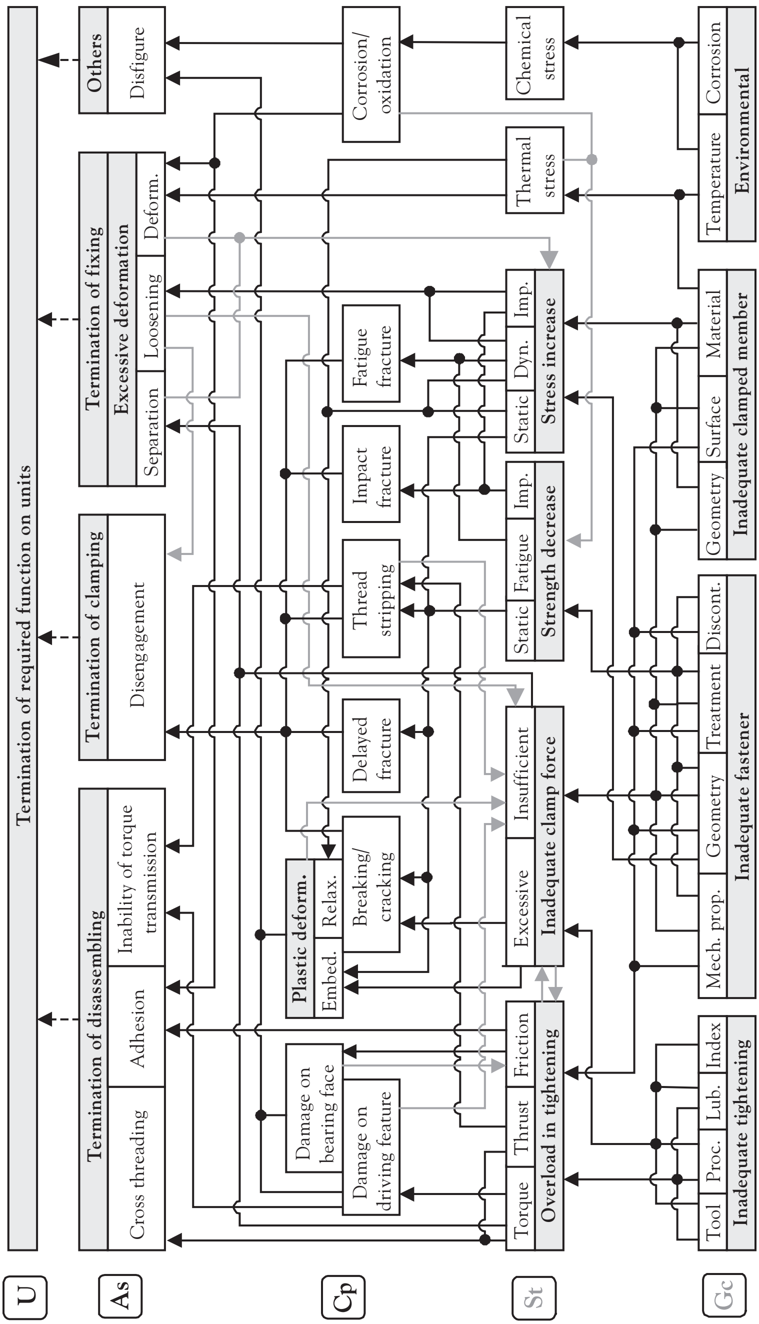


Figure 3.3 An example of the expression of possible failures in bolted and threaded joints

always start from one or more generic cause-level fault mode(s) and spread toward the upper-level fault modes. In some cases, a primary failure generates an excessive stress (denoted as the stress-level fault mode) for other component(s), and the secondary failure occurs then.

By collecting the same kind of information as in Figure 3.3 for other types of components and assemblies, we can list all the possible unit-level fault modes, and they could be connected to the equipment, the plant, and the society-level fault modes.

Example 2: Expression of a Specific Failure with Fault Diagnosis (Assessment) Information

Figure 3.4 shows an example of the failure assessment performed on a specific event. The operator was first aware of the noise and the chattering in a cylindrical grinding machine, and he shut down the machine. The assessment was started from two fault modes of the equipment level to both upper and lower levels. Consequently, it was clarified that the root cause (the generic cause level fault mode) is the inadequate selection of the lubricant for the main spindle bearing, and the fatigue fracture

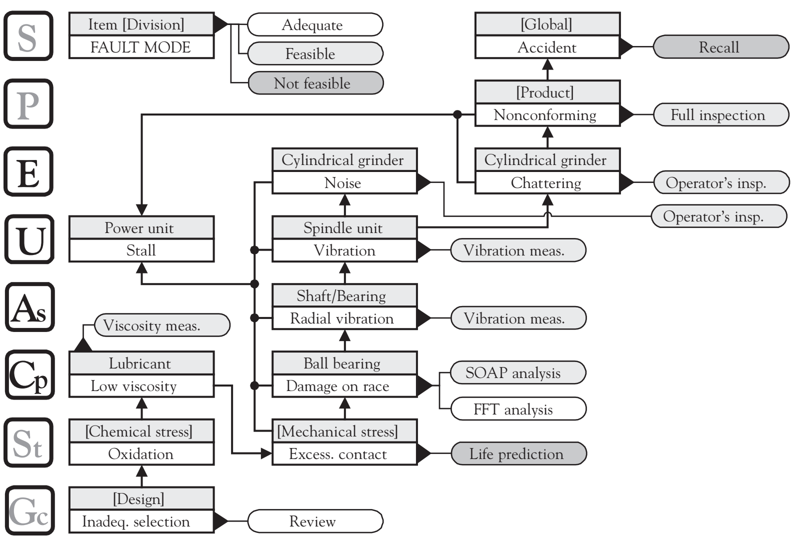


Figure 3.4 An example of the expression of a specific failure with its assessment in a cylindrical grinding machine

(secondary failure) occurred on the race of that bearing. Then the most adequate method for detecting or monitoring each fault mode was considered, and finally, it was decided that the chemical composition of the lubricant would be changed and that the condition monitoring method using fast Fourier transform (FFT) would be introduced.

Thus, in HFC, a path on the diagram represents the failure propagation, and the adequate maintenance policy can be evaluated and chosen by answering the following single question: At which level should we cut the path(s) for the failure to be considered?

Conceptual Design for the Database System

Contents and Form of Data

As mentioned earlier, the maintenance data or information utilized for the maintenance management for a certain failure can be summarized in the form of the diagram such as shown in Figure 3.4. However, not all plant personnel have sufficient knowledge to make such a diagram. Therefore, the database should be designed to offer the necessary data or the data elements to complete the diagram. The failure roadmap similar to Figure 3.3 is useful information to make the diagram in Figure 3.4.

The information shown in Figures 3.3 and 3.4 consists of data modules that have a couple of fault modes and their relations. Figure 3.5 shows the general form of a data module. A primary failure always starts from the generic cause-level fault mode (root cause) to the upper-level fault modes, and a secondary failure starts from the stress-level fault mode induced by the primary failure or the secondary failure occurred earlier to the upper-level fault modes. The secondary failure may also be caused by human error (one of the generic-level fault mode) induced by the preliminary failure(s) (see Figure 3.6), but such a connection is intentionally excluded in the database system since it is recognized as a "local" issue to which specific conditions of the individual manufacturing site are primarily affected. For such cases, see the section on Extended Application as a Tool for Analyzing Complex Failures. By using these criteria, a failure path can be obtained by "pasting" the appropriate data module upward and downward until the society-level fault mode, the stress level fault mode (cause of secondary failure), and the generic cause-level fault mode have been reached.

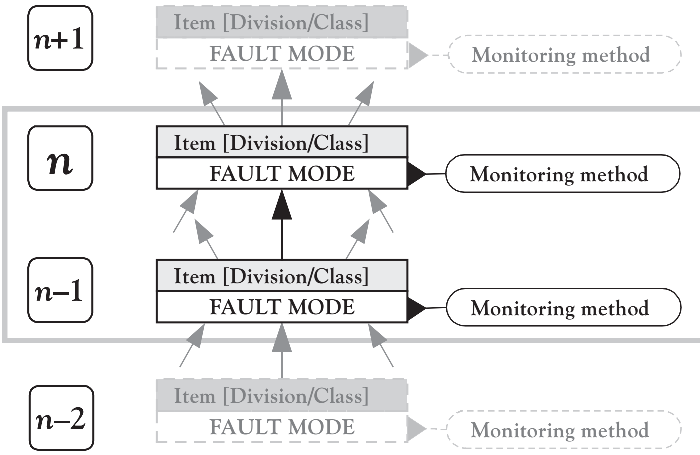


Figure 3.5 Structure of data module

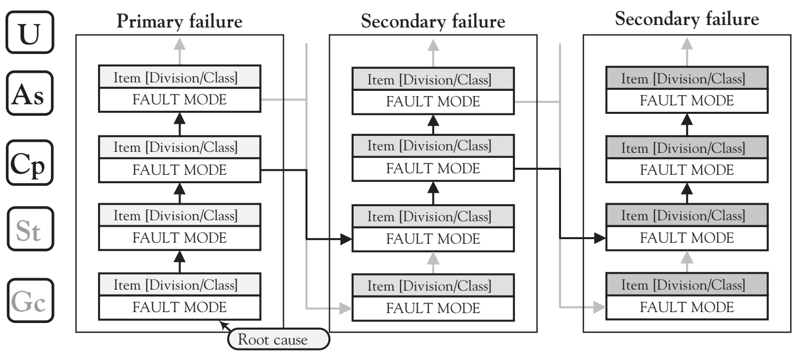


Figure 3.6 Description of cascade failures

Database Structure

Figure 3.7 shows an example of the database structure that enables one to store information in the form of the data module as shown in Figure 3.5. To avoid the overlapping and double definition of the data, item and fault mode names should be standardized by predetermined terms registered in the library. For this purpose, the detailed classification code system such as in ISO 13584–511 (2006) is not always necessary, and for the time being, the simpler one is thought to suffice (e.g., see Figures 3.8a and 3.8b).

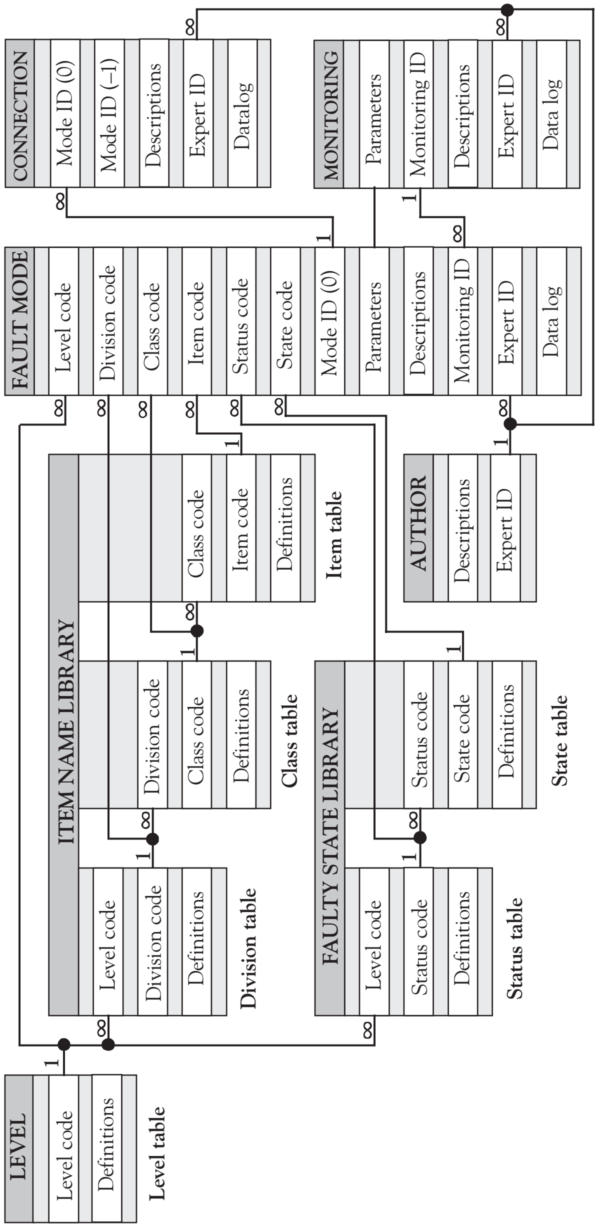


Figure 3.7 Basic structure and relationships of the database system

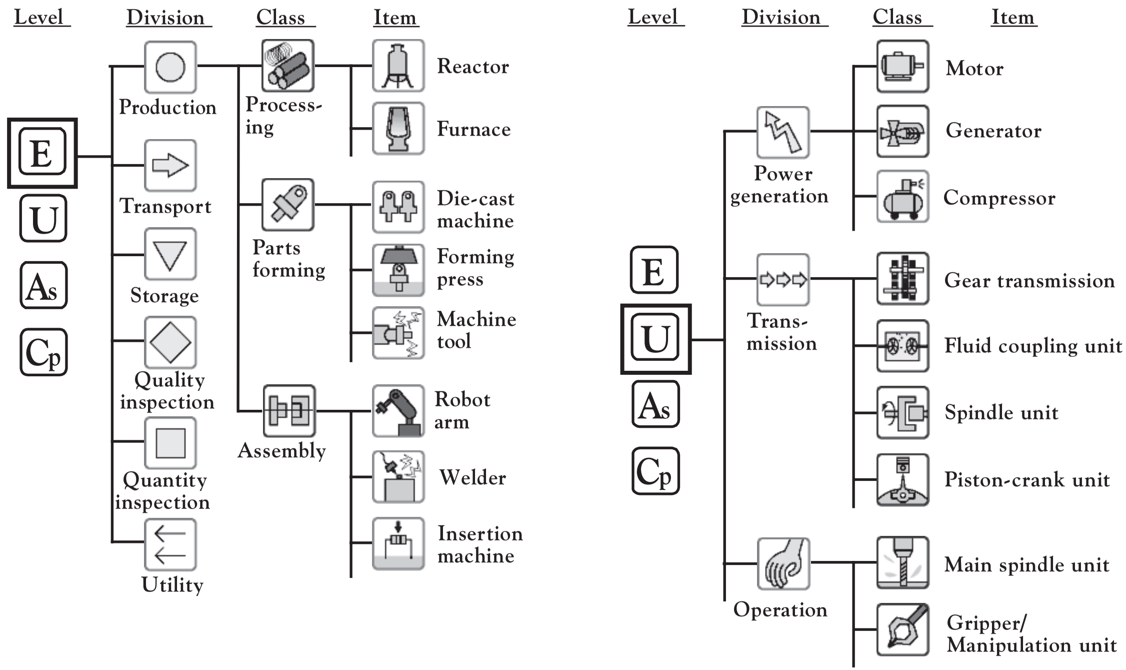


Figure 3.8a An example of the criteria for classifying items (equipment and unit levels)

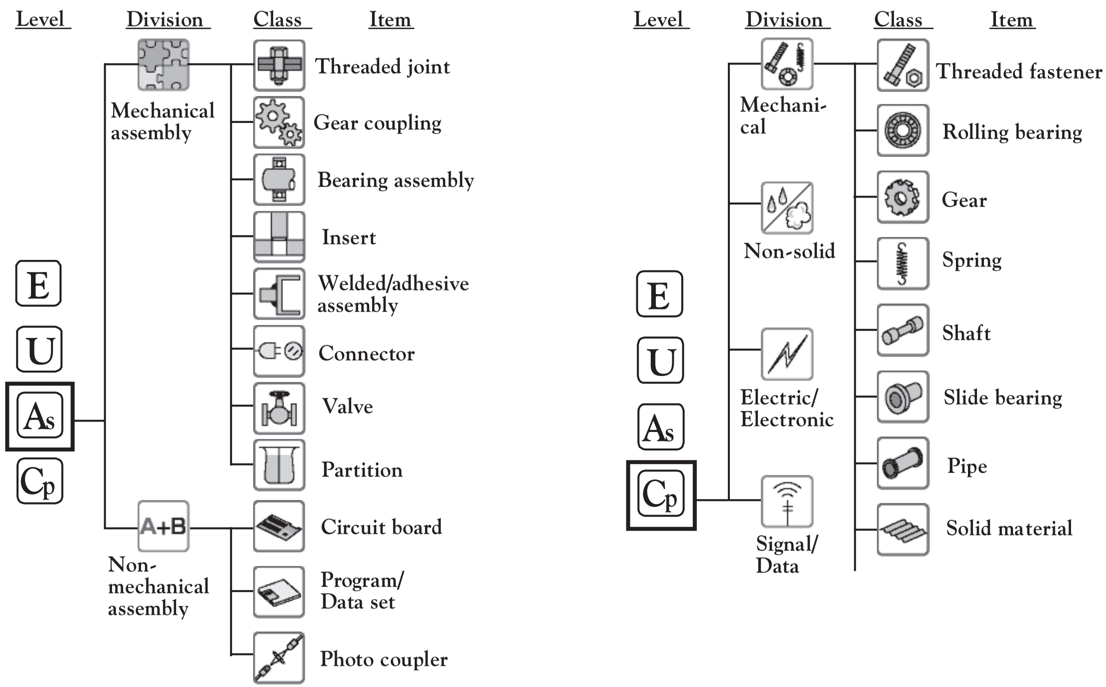


Figure 3.8b An example of the criteria for classifying items (assembly and component levels)

Concerning the fault mode or faulty state name, the simple classification criteria such as used in FMEA (IEC 812, 1985) could also be applicable since the data module itself represents the failure mechanism information, while the component fault mode name conventionally used contains the failure mechanism such as "*fatigue* fracture" and "*stress corrosion* cracking." However, a certain kind of redundancy might be helpful for the practical system to be human friendly.

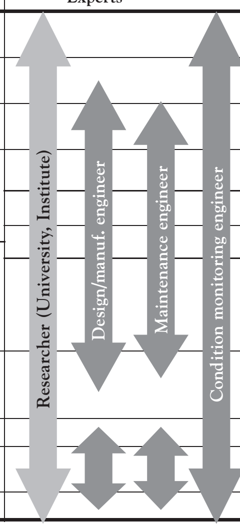
Method of Data Collection and Operation

Table 3.1 shows the classifications of the typical experts who will offer the data. The experts will present data concerning the technical terms on the item and fault mode, the data modules, or the monitoring techniques on their area of expertise. For performing such editorial works efficiently, the authors should refer to the data that have already been stored.

On the other hand, the users would refer to and gain data to create their own information such as that shown in Figure 3.4. If the statistics (frequencies) to choose the individual data module could be counted and

Table 3.1 Classifications of the area and the experts offering the technical data

Fault level	Item	Major areas	Experts
S **Society**	Human	Medicine Medical eng.	
	Creature/naturet	Environmental eng. Agriculture	
	Social assets	Architecture Civil eng.	
P **Plant**	Manufacturing systems	Systems eng. Industrial eng. Management eng. Design eng.	
E **Equipment**	Equipment		
U **Unit**	Functional units		
As **Assembly**	A couple of components	Information eng. Mechanical eng. Material eng. Electronic eng. Chemical eng.	
Cp **Component**	Parts/components		
St **Stress**	Microstructure	Material science Physics Chemistry	
Gc **Generic cause**	Plant personnel	Ergonomics	
	Infrastructure	Architecture Civil eng.	
	Environment	Environmental eng.	



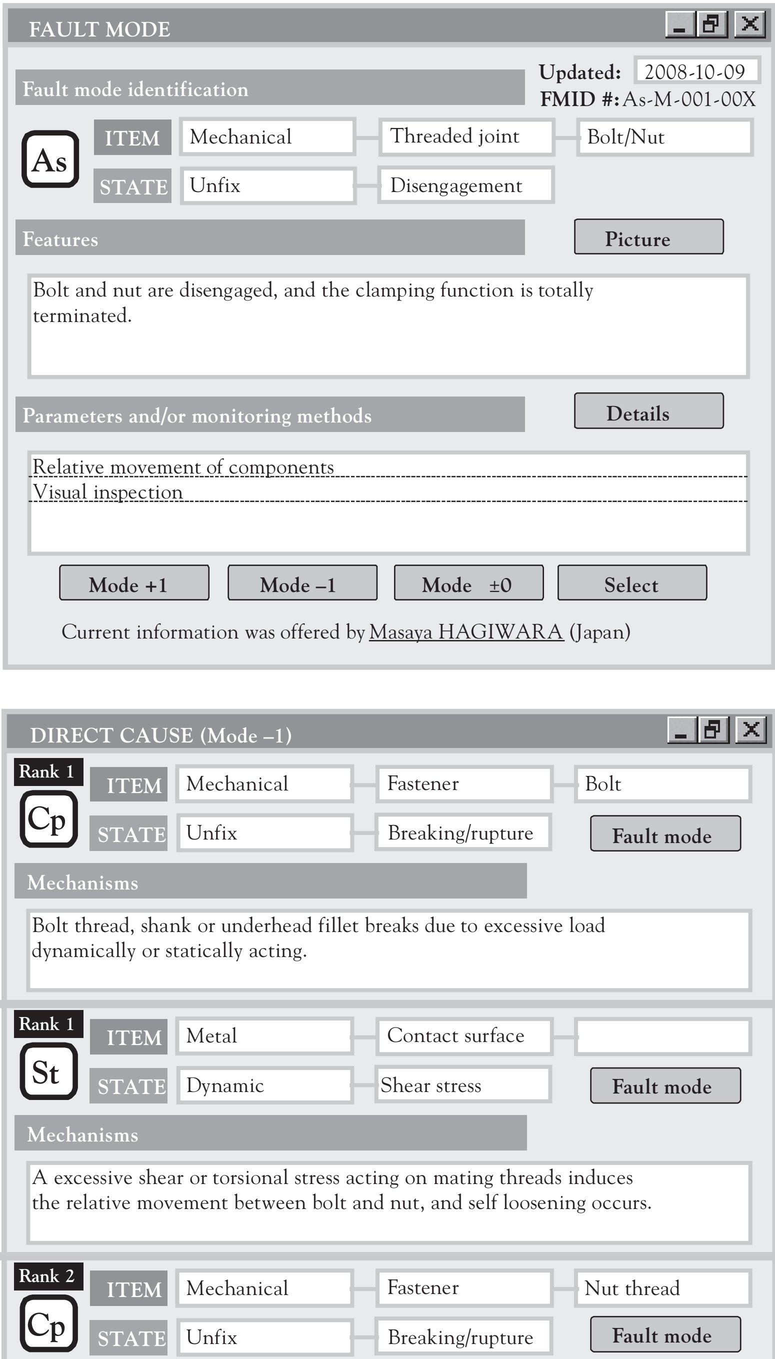


Figure 3.9 An example of the data format showing a fault mode and the possible direct cause

collected automatically, we could offer possibilities of certain types of failures (the data on line 2b earlier) as support information.

As for the presentation of the data, there are many possible ways. An example is shown in Figure 3.9 where the fault mode of the disengagement of a bolted joint (As level) is explained, and the bolt breaking (Cp level), the shear stress on thread surfaces (St level), and the stripping of the nut thread (Cp level) are listed as the possible direct causes for the disengagement of a bolted joint (As level).

Extended Application as a Tool for Analyzing Complex Failures

By using the concept described above, we can construct a diagram (graphical chart) by which risk and safety can be analyzed, and root cause(s) and necessary action(s) can be found out for the individual accidents that have never been encountered and contain a lot of complex failures including human errors [Hagiwara, 2012].

Procedures

The procedure for making a diagram is quite simple and mechanical. It typically consists of the following steps similar to that for making Figures 3.3 or Figure 3.4.

1. Choose one of the fault modes (faulty state) of an item that may concern with the accident to be analyzed in accordance with the HFC method and place it at the appropriate fault level on a worksheet along with the code shown in Table 3.2. The classification code will help to make a fault mode series in step 2 and to store the data for database as well. The states changed by the commands, which are not strictly classified into fault should also be included, and treated like fault to describe the state of the whole system correctly.
2. To search for the root cause, make a fault mode series directed upstream of its propagation from the fault mode chosen in step 1. “Upstream” usually means the direction toward lower hierarchical levels, and the root cause is one or more generic cause-level fault mode(s). However, a stress-level fault mode or a generic cause-level

Table 3.2 Code system of HFC.

Fault level		Fault mode (Code): Division/ Class	Status		
I	Society (S)		**Non-critical**		**Critical**
		Global	SGNc		SGCr
		Local	SLNc		SLCr
	Plant (P)		**Minor**	**Major**	**Critical**
		Product	PPMi	PPMj	PPCr
		Facility	PFMi	PFMj	PFCr
		Environment	PEMi	PEMj	PECr
II	Equipment (E)		**Intermittent**		**Permanent**
		Production	EPdI		EPdP
		Transport	ETpI		ETpP
		Storage	EStI		EStP
		Inspection	EIpI		EIpP
		Utility	EUtI		EUtP
	Unit (U)	Power	UPwI		UPwP
		Transmission	UTmI		UTmP
		Operation	UOpI		UOpP
		Control	UCtI		UCtP
		Detection	UDtI		UDtP
III	Assembly (As)	Mechanical	AsMI		AsMP
		Non-mechanical	AsNI		AsNP
	Component (Cp)		**Mode as to failure mechanism.**		
		Mechanical	CpMX		
		Non-solid	CpNX		
		Electrical	CpEX		
		Signal/ data	CpSX		
IV	Stress (St)		**Static**		**Dynamic**
		Mechanical	StMS		StMD
		Chemical	StCS		StND
		Electrical	StES		StED
		Thermal	StTS		StTD
	Generic cause (Gc)	See the right column.			

Source: Hagiwara, (1996).

Generic causes

- ■ Misuse or mishandling
  - □ in operation — GcMO
  - □ in repair, restoration or replacement — GcMR
  - □ in inspection — GcMI
  - □ in administration — GcMA
- ■ Inherent weakness of item
  - □ due to design — GcWD
  - □ due to manufacturing — GcWM
  - □ due to wearout — GcWW
- ■ Normal environment
  - □ Temperature — GcNT
  - □ Pressure — GcNP
  - □ Humidity — GcNH
  - □ Vibration — GcNV
  - □ Corrosion — GcNC
  - □ Dust — GcND
  - □ Others — GcNO
- ■ Accident environment
  - □ Earthquake — GcAE
  - □ Thunder bolt — GcAT
  - □ Flood/Tsunami — GcAW
  - □ Storm — GcAS
  - □ Fire — GcAF
  - □ Other energetic event — GcAO

fault mode may be caused by the upper-level fault mode(s) at the "interface" between cascade failures, i.e., at the start of the secondary failures; see Figure 3.6.

3. To assess the effects, make a fault mode series directed downstream of its propagation. "Downstream" usually means the direction toward higher hierarchical levels to the society level. However, a stress-level fault mode or a generic cause-level fault mode may be the effect of the upper-level fault mode(s) at the "interface" between cascade failures, i.e., at the start of the secondary failures; see Figure 3.6.
4. Repeat from step 1 until all the fault modes concerned are listed and combined.

Examples of the Application

The graphical presentations for the most critical nuclear power plant accidents at Three Mile Island and at Fukushima Daiichi (units 1 to 3) are shown in Figures 3.10 and 3.11, respectively. The author is not an expert for nuclear power plants, and most of the information was extracted from literature; Japanese nonfiction written by Kunio Yanagida (1983), in which what was happening in TMI plant and the consequences were described precisely and chronologically referring to the official reports such as made by NRC (1979) for Figure 3.10, and the accident analysis report by Independent Committee for verification of Fukushima Daiichi Nuclear Power Plant Accident (2012) for Figure 3.11. This means or proves that according to the procedures shown above, everybody can make a diagram without any difficulties and can share the knowledge from these diagrams.

These two cases represent different routes of failure propagation, and have different root causes. However, there are some AND gates and some "detours" that compose the complex networks in both cases. This means that these accidents are classified into complex failures in which multiple causes and events are linked together.

The key to analyze such kind of accidents is to find out the start of cascade or secondary failures as well as to seek the root cause(s). In the diagram, the start of the secondary failure is indicated by the point where the fault mode propagates from upper to lower, or among the same levels (in the case where the stress-level fault modes are omitted in the diagram), and the diagram represents loops or complex network.

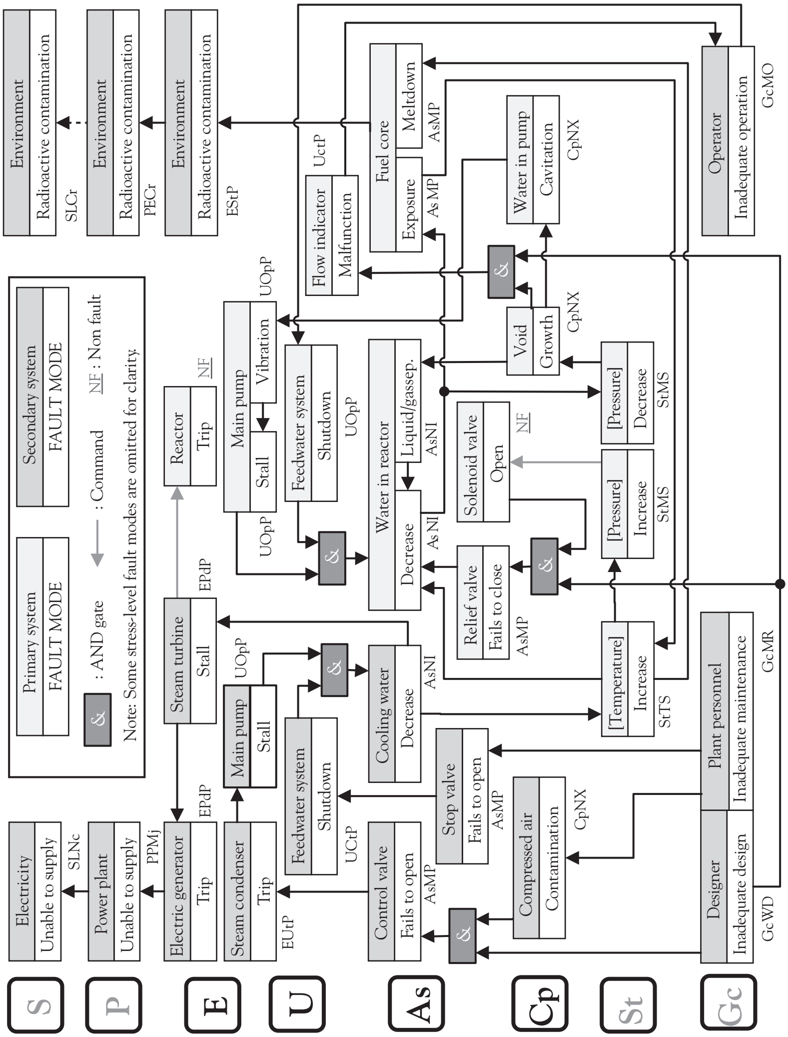


Figure 3.10 The diagram for the accident at Three Mile Island Nuclear Power Plant in 1979

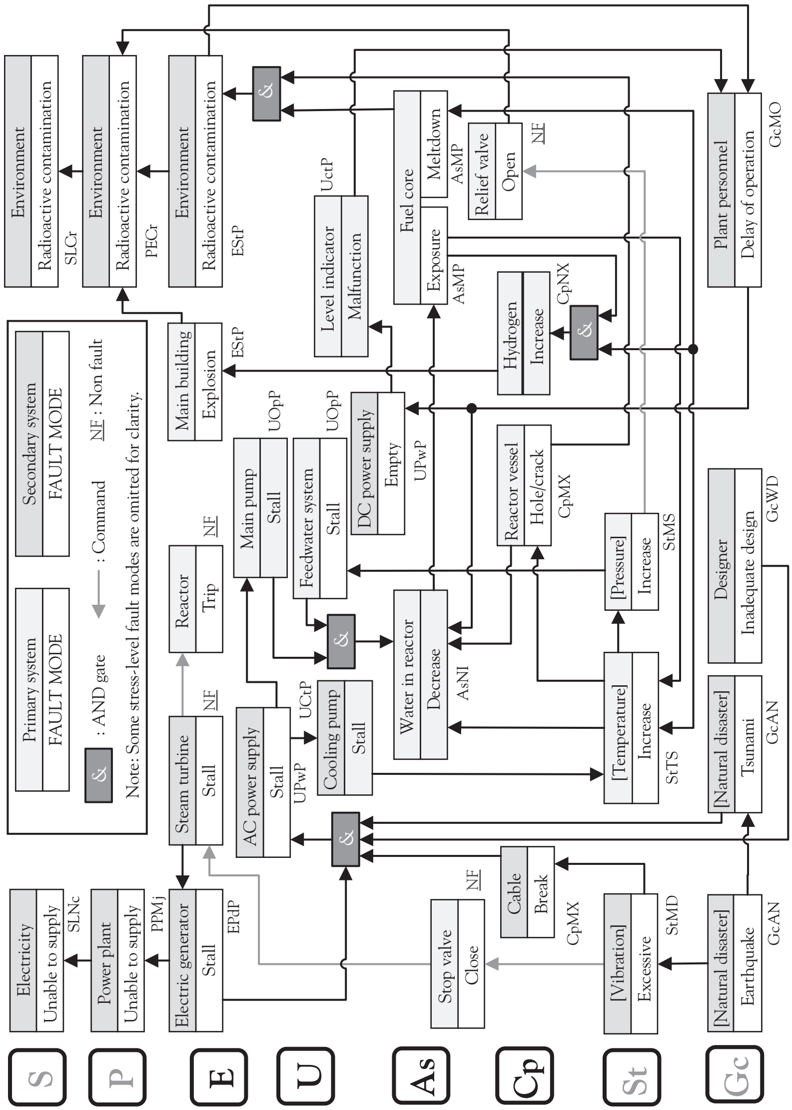


Figure 3.11 The diagram for the accident at Fukushima Daiichi Nuclear Power Plant in 2011

To prevent the accident, the fault mode propagation should be terminated at the lower level, ideally at the generic cause level. However, it's not always possible. In such cases, the secondary actions or the additional system to exclude the loops in the diagram is necessary. For Three Mile Island case, an appropriate condition monitoring system and the more reliable component(s) would be necessary, and for Fukushima Daiichi case, AC power supply system including backup, which can work under flood, should be installed.

For more detailed evaluation, conventional techniques such as FTA and FMEA/FMECA can be available for a part of the accident network to be noticed. Thus, the diagram can also be used as an overview.

Aftermath

In this chapter, the concept of the database system for maintenance management information on the Internet was described. This provides the standardized platform by which the plant personnel could gain the necessary information for his or her maintenance activities.

The usage of the method is not limited to the database on the website. The concept can be used of course as a stand-alone system. The graphical description of the problem including complex failures (social events or accidents) offers helpful information to be discussed in the team.

Furthermore, this concept may also be applicable to the diagnosis of human health. In such a case, human body corresponds to the plant or the equipment level item. The required functions of this item are thinking, learning, making right decisions, and doing right things to live within the society. All of human organs belong to the unit level items whose required functions are well-known. The author believes that all the readers of this chapter are capable of defining the items of other hierarchical levels and their required functions as well. Let's try to make a diagram for the maintenance activity yourselves!

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CHAPTER 4

Allocation of Nursing Workforce in Hospital Wards with Mix Patient Needs

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Introduction

A well-known problem in the health industry is the universal shortage of nurses to be allocated at the different wards and care-providing units in almost any health care establishment. Decision makers and legislators in regional and national level are concerned by the shortage in nursing staff and issues related to the quality of nursing performance (Wright et al., 2006). Forecasts and statistics dealing with the availability of nursing personnel have shown a looming shortage in the future (Bureau of Health Professions, 2002), as seen in Figure 4.1.

The study of the allocation of nurses for a given mix of patients addresses a frequent question asked by hospital management who are trying to provide a scientific answer to the number of nurses to assign in a given shift on a given day in a hospital's inpatient ward. What is the best economical number of nurses that will provide quality service to patients

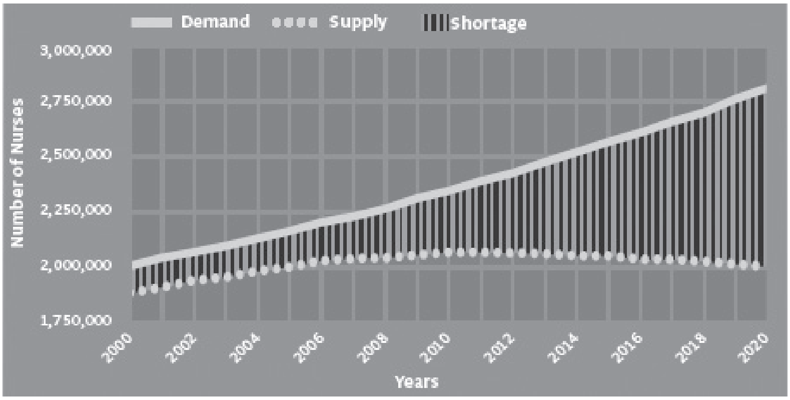

Figure 4.1 Supply and demand forecast for full-time equivalent (FTE) RNs in the U.S. (2000–2020)

(*Source:* Bureau of Health Professions, 2002)

with different nursing needs? To tackle this question, a procedure for allocating a full-time equivalent (FTE) nursing workforce in hospital's inpatient wards is introduced. The search for appropriate answers leads us to develop a methodology to meet the demands of service in a dynamic mix of patients by calculating the appropriate number of nurses based on performance assessment and forecasting. The study is of special interest to decision makers and legislators in the regional and national level who are concerned by the shortage in nursing staff, as forecast by the Bureau of Health Professions (2002).

The volume of the allocated nursing staff in a hospital ward is found to directly influence patients' outcomes. Needleman et al. (2002) found an association between the proportion of the total hours of nursing care provided by registered nurses and six outcomes among medical patients (length of stay, rates of urinary tract infections, upper gastrointestinal bleeding, hospital-acquired pneumonia, shock or cardiac arrest, and failure to rescue).

Dealing with the question of how to calculate the appropriate number of nurses in a given shift we assess that the number of nurses rely on the following five parameters:

1. The number of patients in a ward on a given day
2. Patients' nursing severity
3. The nurses' level of expertise available in the ward at a given time

4. Nursing treatment policy
5. The desirable level of treatment quality

To determine correct values for these parameters a methodology is suggested. The methodology consists of the following:

1. Forecasting the patient mix that will require nursing care on any given future day by a data mining mechanism
2. Performance times for a list of key direct and indirect activities as performed by nurses in a given hospital establishment
3. Principles for calculating and assigning quality measures of nursing performance
4. An "intelligent allocation procedure" for assigning the best nursing workforce for a given patient mix

This is based on a predetermined policy for nursing treatment and on a desirable level of a ward's nursing treatment quality.

The methodology has been implemented in three hospital wards in a fairly large medical center in central Israel, which has about 1,500 beds. The participating wards were two internal wards, which specialize in tropical and joint illnesses, and one surgical ward, which specializes in cancer diseases. After data from the three wards was collected, its analysis allowed us to compare current allocation patterns to the recommendations proposed by the methodology. In some cases the current allocation patterns were found to be adequate, whereas in other cases understaffing patterns were revealed. For example, the study showed that an average of 1.1 FTE nurses should be added to the 4 FTE nurses normally allocated in the surgical unit in the evening shifts so as to meet patient treatment needs. Furthermore, the method will enable policymakers to choose the desirable level of the ward's nursing treatment quality. In return, the appropriate nursing size that needs to be allocated will be calculated.

Method

The method supports a procedure to allocate the most economic nursing staff to provide the desired level of patient treatment in a ward. The procedure's main stages are seen in Figure 4.2.

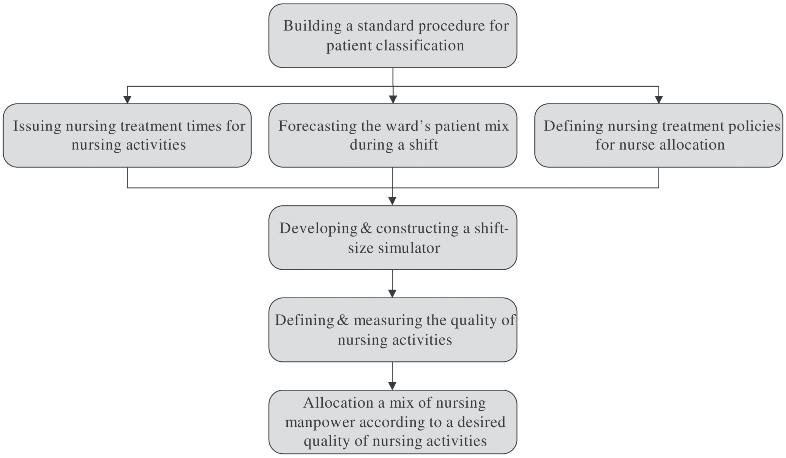

Figure 4.2 Nursing staff allocation procedure for hospital inpatient wards

Patient Classification

One of the most critical and continuing concerns facing administrations of health care delivery systems is the management and effective application of a realistic nurse staffing system based on patient acuity levels. The number of nursing personnel needed in a nursing ward can be properly determined only by a system that effectively evaluates and assesses patient needs concurrently with the individual capabilities of the nursing staff assigned to the ward.

The U.S. Department of Health published its system for patient classification (Department of Health and Human Services, 1987). This system was adopted by health administrators as an "ideal" classification procedure. Such a patient classification procedure enabled nursing staff members to classify patients according to the intensity that the nursing care required. The five patient classification levels were minimal, partial, full, intense, and special.

A patient whose nursing care needs are entirely met by routine ward activities is to be classified as level 1—the minimal nursing care category. This category of patients is characterized by (a) mild symptoms, usually considered in the later stages of convalescence; (b) little or no deviation from normal behavior patterns; (c) no restriction of activity; (d) simple treatments and few medications; and (e) follow-up instructions and supervised practice in self-care measures in preparation for discharge.

The other range of the patient classification is represented by level 5—the special nursing care category. This category of patients is characterized by (a) a need for life-saving measures promptly and constantly; (b) an extreme deviation from normal behavior patterns; (c) a need for special nursing activities such as respiration, frequent lab tests, and frequent blood infusions; and (d) a need for continuous treatment and observation frequently in an isolation room.

Nursing Treatment for Nursing Activities

The number of FTE nursing required to meet patients' nursing needs in a shift is directly linked to the volume of the nursing work content. Nursing work content is the total amount of time it takes to complete the activities that nurses need to execute the care required by ward patients.

This study used a time and motion technique to observe the wards' registered nurses and measure the duration of their nursing activities. Along with measuring the activity duration, additional information was documented in the data collection sheet. This information referred to the patient's classification level and to the status of the patient in the shift being investigated. Patients' status were classified as belonging to one of the following three groups: (a) *admitted patient*—a patient who was hospitalized during the observed shift, having come to the ward from the emergency room or as a result of being transferred from another ward; (b) *discharged patient*—a patient who was released during the observed shift from the ward to the community (home or institute) or was transferred to another ward; and (c) *"veteran" patient*—a patient who was not classified in the previous groups and whose condition was classified as belonging to one of the five nursing levels.

All nursing activities were classified as either direct or indirect nursing activities.

Direct nursing activities. Direct nursing activities are the activities performed in the presence of the assigned patient or family including all preparations and assessments that support these activities such as assessing patient needs, administration of medications, all treatments and procedures, obtaining specimens, and all aspects of the basic physical care associated with bathing and grooming, eating, toileting, and ambulation.

This also includes explanations given to the patient and family regarding the mentioned activities.

Indirect nursing activities. Indirect nursing activities are the activities that are not related to caring for the assigned patient, such as giving or receiving an updated description of the patient's status for the purpose of shift-to-shift continuity, clerical work, cleaning, checking, and looking for equipment, personal needs, and fatigue allowances. The measured time of direct nursing activities was derived to produce time distributions for direct nursing care to all patients of every status. The measured time of the indirect nursing activities was derived to produce shift timeframes for the nursing staff.

Forecasting Ward Patient Mix

Forecasting the ward patient mix in a shift is a structural procedure. A procedure considered in 10 steps is shown in Figure 4.3. In the upper part of each rectangle, a short description of the step is presented while in the lower part, a short description of the step's outcome appears (a forecast for 2007 is given as an example).

The patient mix in an 8-hour shift is dynamic and is composed of three general patient "populations" that differ from each other in their volume and in the treatment they receive. These populations (or statuses as termed previously) are admitted patients (A_s), discharged patients (D_s), and veteran patients (V_s). The data, which are stored in the Health Care Organization's (HCO) databases, vary from one organization to another. In the investigated HCO, the following relevant data was available: admissions per shift (A_s), discharges per day (D), and the midnight census (MC). Table 4.1 demonstrates how to forecast future populations in a shift (A_s, D_s, and V_s) using the existing available data. $>N_s^{Beg}$ and N_s^{End} refer to the number of patients at the beginning and end of a shift, respectively.

Nursing Treatment Policies for Nurse Allocation

Nursing treatment policies determine the allocation of nursing staff to the patient mix. Nursing personnel are distinguishable by their individual expertise and responsibilities. The staff is divided into three groups: (a) nurse (N)—nurses hold a current license to practice within the scope of professional nursing; (b) expert nurse (EN)—these nurses are characterized by

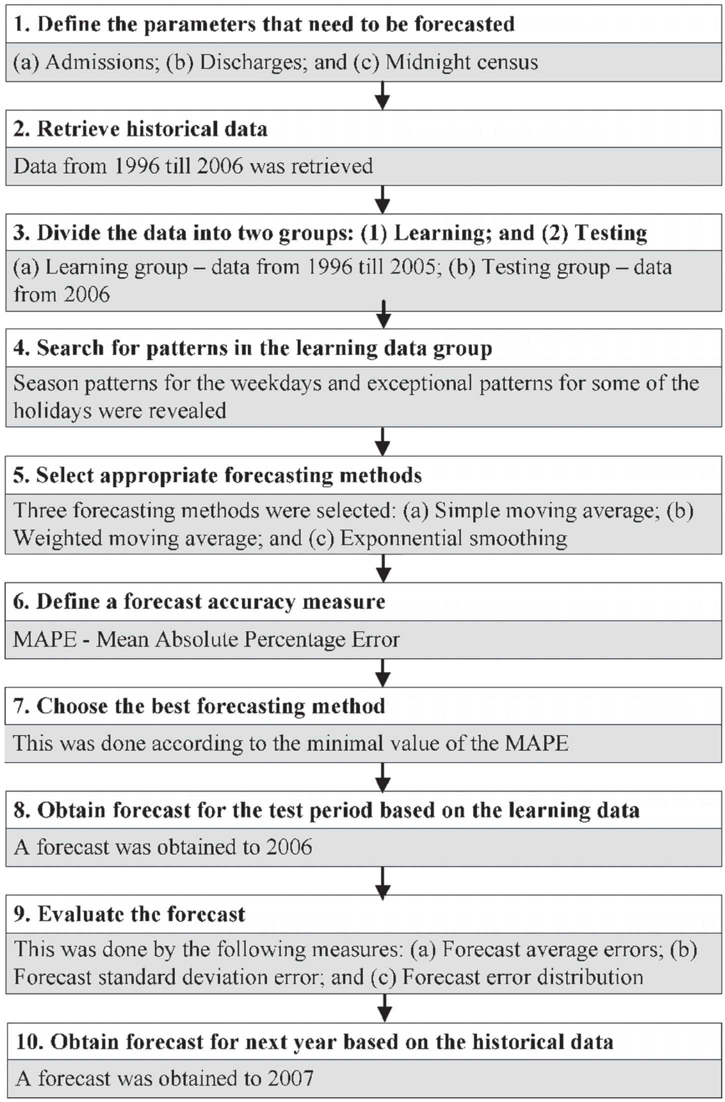

Figure 4.3 The 10 steps of the forecasting procedure

high nursing skills, motivation, and relatively wide nursing knowledge; and (c) head nurse (HN)—expert nurses who are administratively responsible for a designated hospital ward on an 8-hour basis.

Five nursing care policies are proposed and demonstrated in Figure 4.4. In policy A, the staff is divided only into nurses and a head nurse who are assigned to the entire patient mix. Policies B and D suggest assigning

Table 4.1 Relation between admissions per shift, discharges per day, and midnight census to three patient populations in a shift—admitted patients, discharged patients, and "veteran" patients

	Day (7:00–15:00)	Evening (15:00–23:00)	Night (23:00–7:00)
N_s^{Beg}	$MC + 7/8 \bullet A_{nigt}$	N_{day}^{end}	N_{eve}^{end}
A_s.	A_{day}	A_{eve}	A_{nig}
D_s.	$0.35D$	$0.65D$	—
V_s	$N_{day}^{beg} - D_{day}$	$N_{eve}^{beg} - D_{eve}$	N_{nig}^{beg}
N_s^{end}	$N_{day}^{beg} + A_{day} - D_{day}$	$N_{eve}^{beg} + A_{eve} - D_{eve}$	$N_{nig}^{beg} + A_{nig}$
Remark	On weekends and holidays: $D_{day} = 0.80D$	On weekends and holidays: $D_{eve} = 0.20D$	

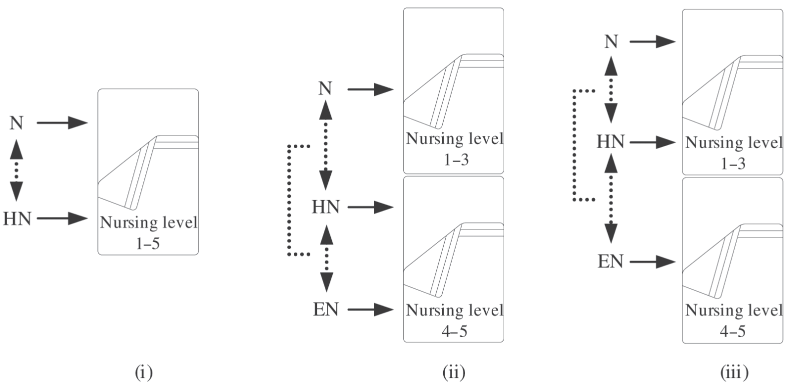

Figure 4.4 Nursing care policies (i) A, (ii) B and D, and (iii) C and E

nurses to nursing levels 1 to 3 patients, and the head nurse and expert nurses to nursing levels 4 to 5 patients. The difference between nursing policies B and D is in the weekday day shifts. Whereas policy B suggests that the head nurse devotes part of his or her shift (e.g., 10%) to nursing care, policy D proposes that the head nurse concentrates only on his or her administrative responsibilities and not be involved in the operation of caregiving activities. Policies C and E suggest assigning the head nurse and nurses to nursing levels 1 to 3 patients, while expert nurses are assigned to nursing levels 4 and 5 patients. The difference between nursing policies C and E is similar to the difference between policies B and D, respectively.

Shift-Size Simulator

The use of a simulator to support the decision tool was based on the following. First, a tool was required to store and retrieve data, part of which was derived from statistical distributions. Second, a simulator helps give the user a friendly graphics user interface (GUI) for inserting input parameters. Third, it solved the issue of how to give the user recommendations based on data, input parameters, and algorithms.

The simulator was developed using MATLAB code. The data stored in the simulator were direct time distributions, nursing staff shift timeframes, and forecasts of the patient mix. The user inserts into the GUI the starting day and duration of the desired planning period and the chosen nursing care policy. The algorithm by which the recommendations are calculated applies to each nursing care policy. These recommendations are on a shift basis and include FTE for the nursing staff, total direct caregiving time, and total patient forecasts.

Quality of Nursing Activities

A set of direct nursing activities was selected to define nursing treatment quality. This was carried out in two main steps. Step 1 converts the result of the direct nursing activity to a quality score:

$$Q_i = \begin{cases} R_i & R_i \geq M_i \\ 0 & \text{Otherwise,} \end{cases} \tag{1}$$

where
R_i is the percentage of patients for whom the direct nursing activity i was carried out (derived from the HCO database) and
M_i is the threshold score value for the direct nursing activity i.
Usually M, $\in [70,80]$.

Step 2 deals with computing the weighted average score for the nursing treatment quality:

$$Q = \sum_i Q_i \bullet W_r, \tag{2}$$

where

W_i is the relative weight for quality of direct activity i. This is determined by using the paired comparison technique (Saaty, 2000).

Allocating the Best Mix of Nursing Personnel

The final stage of the methodology deals with formalizing the link between allocating FTE nursing personnel to achieve the targeted nursing treatment quality in a ward. The duration of direct nursing treatment activities for a given patient population provides random variables. They are undependable and derived from the same statistical distribution with the same mean (!) and the same standard deviation (#). These preliminary conditions allow us to use the normal approximation of the central limit law. Using this approximation means that the sum of random variables is normally distributed. Hence it becomes possible to use the laws of probability. The probability that the sum of the duration of all direct nursing treatment activities $\left(\sum_i^n x_i\right.$ will be equal to or less than the nurses' availability (A_F) is $1 - \alpha$ as stated in the following equation:

$$P\left(\sum_i^n X_i \le A_F\right) = 1 - \alpha \qquad (3)$$

The nursing treatment quality score (Q_F) is given in the following equation:

$$Q_F = Min\left\{Q_I \bullet \left(1 + \frac{A_F - A_I}{A_I \bullet P_Q}\right),\ 100\%\right\}, \qquad (4)$$

where

Q_I is the treatment quality score in the initial state deriving from allocating nurses according to average treatment times,

A_I is the nurses' availability according to average treatment times, and

P_Q is the proportion of the direct treatment time associated with performing quality activities out of the total direct nursing time.

The assumption behind this calculation is that the quality of nursing treatment will increase if the nurses are more available to perform nursing activities that include quality activities.

Findings

Case Study in Hospital's Internal Ward

The methodology was implemented in three hospital wards in a fairly large medical center in central Israel, which holds about 1,500 beds. The wards were two internal wards specializing in tropical and joint illnesses and one surgical ward specializing in cancer diseases. Here we provide a good demonstration of the methodology, as used in internal ward C.

Historical patient classification data revealed that the majority of patients were classified as belonging to one of the first three nursing levels. The patient mix in internal ward C for nursing levels 1 to 5 were 19 percent, 43 percent, 28 percent, 6 percent, and 4 percent, respectively.

A total of 19 full shifts were observed using the time and motion technique. Eight nurses were observed in the day shifts, and six nurses and five head nurses were observed in the evening shifts. Direct and indirect nursing activities were measured from the time and motion studies to assist in deriving direct time distributions and shift timeframes. Time distributions, mean, standard deviation, minimum value, and maximum value for direct nursing care for internal ward C are given in Table 4.2. Indirect nursing activities were measured, since they are a non-neglectable part of nursing daily activities. These activities were derived from eight and six time and motion studies carried out on nurses and expert nurses in the day and evening shifts, respectively, and from five studies carried out on head nurses in the evening shift. Personal needs and fatigue allowances were calculated from the International Labor Office recommendations for allowances (ILO, 1979). A total of 14 percent allowances were summed after assigning 5 percent to personal allowance, 4 percent to basic fatigue allowance, 2 percent to standing and to close attention allowances, and 1 percent to mental strain allowance.

The shift timeframe for nurses in the morning shift, e.g., was equal to the shift duration (480 minutes) minus the total indirect time (140.1 minutes).

To allocate the FTE nursing based on the forecast patient mix, it was necessary to know the rates of patient mix. As explained earlier, midnight census, discharges, and admissions are the basic parameters for forecasting the patient mix in a shift.

Table 4.2 Time distributions, mean, standard deviation, minimum value, and maximum value for direct nursing care for classified veteran patients, admissions, and discharges in the day and evening shifts

Shift	Patient status	Distribution	M	SD	Minimum value	Maximum value
Day	1	12+18 beta (0.6, 0.8)	19.5	6.6	12.6	29.3
	2	12+30 beta (0.7, 0.9)	24.9	9.4	12.3	41.7
	3	13+ weibull (21.9, 1.9)	33.9	16.0	13.6	65.6
	4	24+ gamma (39.6, 0.7)	52.1	27.2	24.3	97.9
	5	84+54 beta (0.2, 0.3)	101.0	24.9	84.1	138.0
	Admissions	15+ exponential (15.8)	30.8	13.4	15.2	59.7
	Discharges	13+11 beta (0.7, 0.8)	18.3	4.2	13.3	23.6
Evening	1	Triangular (7, 15, 37)	19.7	7.9	7.3	36.3
	2	Normal (22.4, 7.5)	22.4	7.5	7.4	39.9
	3	16+23 beta (0.8, 1.1)	26.1	6.7	16.2	38.1
	4	Normal (38.3, 17.8)	38.3	17.8	13.5	81.0
	5	Uniform (23, 93)	56.1	28.5	23.1	92.9
	Admissions	15+ exponential (15.8)	30.8	13.4	15.2	59.7
	Discharges	Normal (9.7, 5.1)	9.7	5.1	2.4	21.8

Forecast midnight census rates for the year of 2007 in internal ward C are given in Table 4.3. These occupancy rates were based on learning the patterns revealed in the midnight census data.

The ward's quality of nursing treatment score was derived from a set of direct nursing activities. These activities and their relative weights are given in Table 4.4.

Table 4.3 Midnight census rates, year of 2007

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Sunday	43.8	42.5	40.3	38.5	42.9	39.0	42.6	38.1	43.9	39.1	40.2	42.2
Monday	42.6	39.5	37.9	38.7	43.0	39.3	41.3	38.1	42.6	39.0	39.4	42.2
Tuesday	41.4	39.5	38.8	40.7	41.9	38.6	39.6	38.1	42.6	38.3	38.8	39.5
Wednesday	41.0	40.2	38.3	39.0	38.9	37.2	39.7	36.3	39.1	41.0	41.1	40.5
Thursday	40.3	37.7	36.5	35.6	35.7	36.4	36.2	34.4	36.1	43.3	38.4	38.8
Friday	40.0	36.8	36.0	36.8	37.1	34.0	34.8	33.9	36.3	38.8	35.8	38.3
Saturday	45.9	41.5	41.1	40.4	42.3	38.8	42.8	37.1	43.3	43.5	40.8	44.1

Table 4.4 Quality nursing activities and their relative weights

#	Quality nursing activity	Wi (%)
1	Measuring vital signs	11
2	Wearing identification bracelet	
3	Patient briefing in admission	10
4	Norton scale implementation	
5	Pain scale implementation	
6	Estimation of falling risks	
7	Nursing anamnesis implementation	
8	Daily pain scale implementation	
9	Patient classification implementation	
10	Lansky scale implementation	8

Table 4.5 Comparison between current and simulator FTE nursing staff allocation for the day and evening shifts

Shift	Quality score	Current allocation		Simulator allocation		Difference		
		Total	Per shift	Total	Per shift	Total	Per shift	%
Day	93.2	269.5	4.8	294.0	5.3	24.5	0.5	9.1
Evening		200.6	3.6	222.0	4.1	31.0	0.5	15.4

An 8-week pilot study was conducted in internal ward C. The results, which are given in Table 4.5, contain the following parameters: (a) weighted average nursing treatment quality score; (b) total FTE nursing staff that were assigned by the head nurses in the current state and the average number of nurses per shift; (c) total FTE nursing staff that

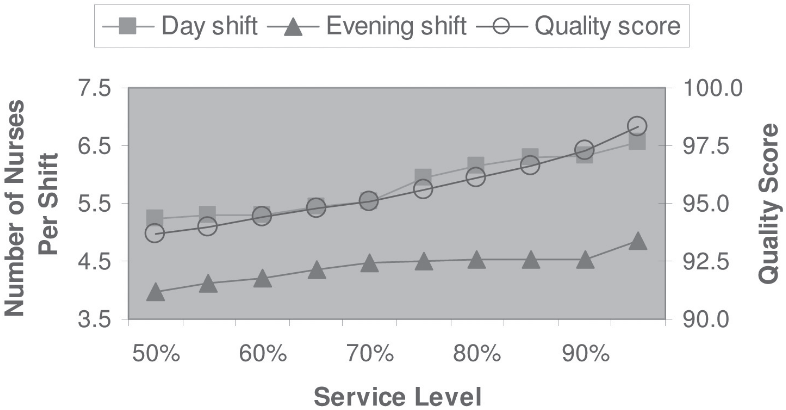

Figure 4.5 Nursing service level versus average number of nurses per shift and nursing treatment quality score

the simulator recommended, using nursing care policy E and the average number of nurses per shift; (d) the difference between the actual FTE and the recommended FTE allocation.

Figure 4.5 illustrates the correlation between the nursing service levels and the number of FTE nurses per shift and nursing treatment quality score. As stated earlier, increasing the service level $(1 - \alpha)$ will increase the corresponding percentage $(z_{1-\alpha})$, which will increase the nurses' availability to provide a treatment for a mix of patients. A higher value for the nurses' availability translates directly into a greater number of FTE nurses per shift.

Applications

From a Case Study in Hospital's Internal Ward

For the prediction of optimal number of nurses in a given shift, a simulator has been developed using MATLAB, as mentioned earlier. The simulator provides two kinds of screens: (1) data input screens dedicated for entry of three time variables and policy of medical care as decided by administration and (2) results screen.

In the data input screens the user is instructed to define:

(1) The period duration for planning; the period can get a min value of 1 day to a max value of 14 days. Figure 4.6 shows the GUI screen

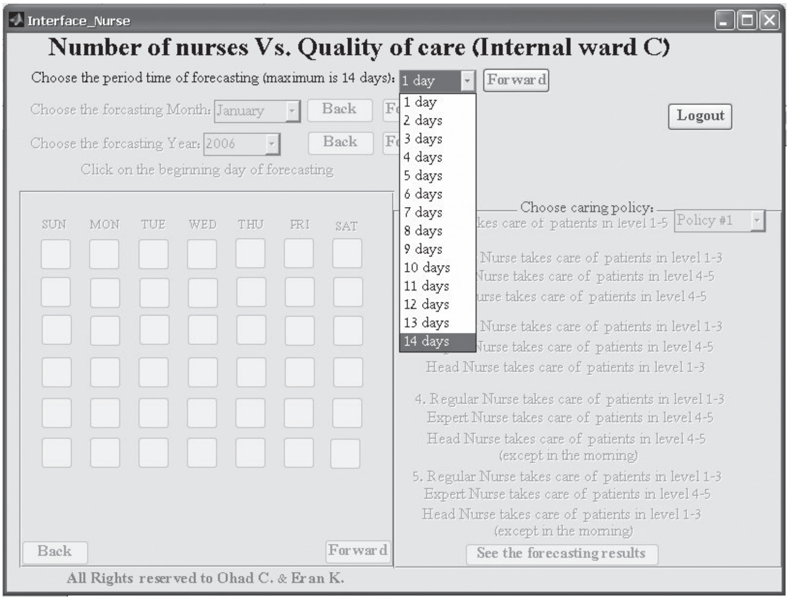

Figure 4.6 GUI screen – Choosing the period duration for planning the nursing manpower allocation

for choosing period duration for planning the nursing manpower allocation

(2) The month for planning; this can get 12 values for the 12 yearly months. Figure 4.7 shows the GUI screen for choosing month for planning the nursing manpower allocation

(3) The day for planning; this can get 7 values for the 7 week days. Figure 4.8 shows the GUI screen for choosing starting day for planning the nursing manpower allocation

(4) Choosing policy of nursing care for planning, the policy of medical care, based on five levels as explained in the nursing treatment policies section earlier, is decided at the administration level. Figure 4.9 shows the GUI screen for choosing policy of nursing care for planning the nursing manpower allocation

The results derived from the simulation, based on period duration, month, and day for planning, for each shift required are presented on the results screen as seen in Figure 4.10 for best mix FTE in the mornings shift, and in Figure 4.11 for best mix FTE for the evenings shift.

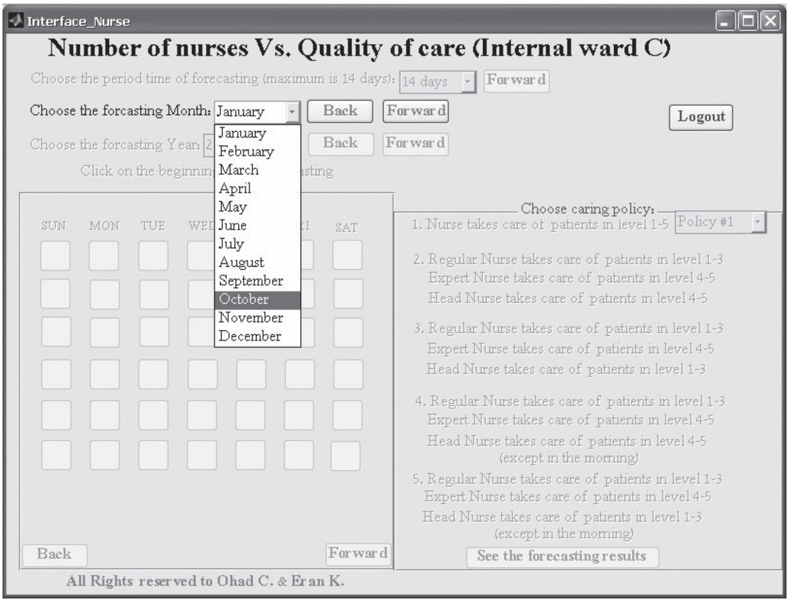

Figure 4.7 GUI screen – Choosing the month for planning the nursing manpower allocation

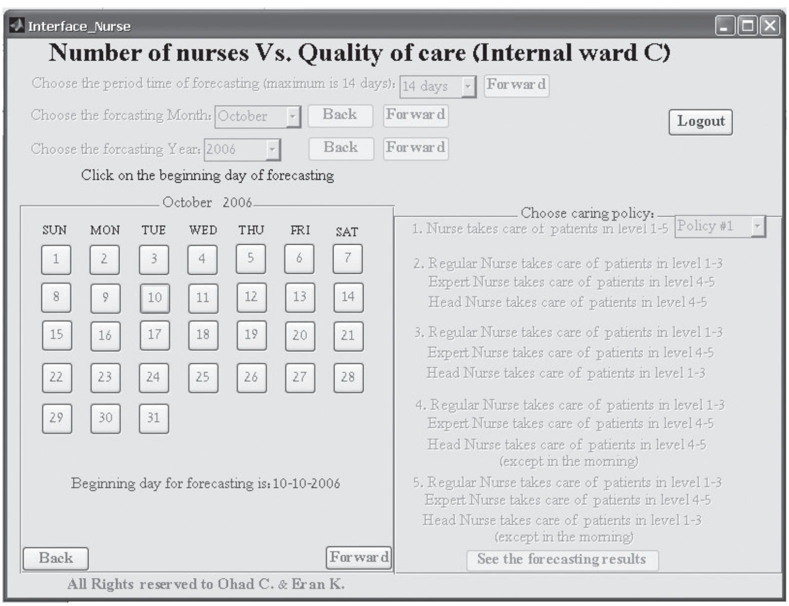

Figure 4.8 GUI screen – Choosing the starting day for planning the nursing manpower allocation

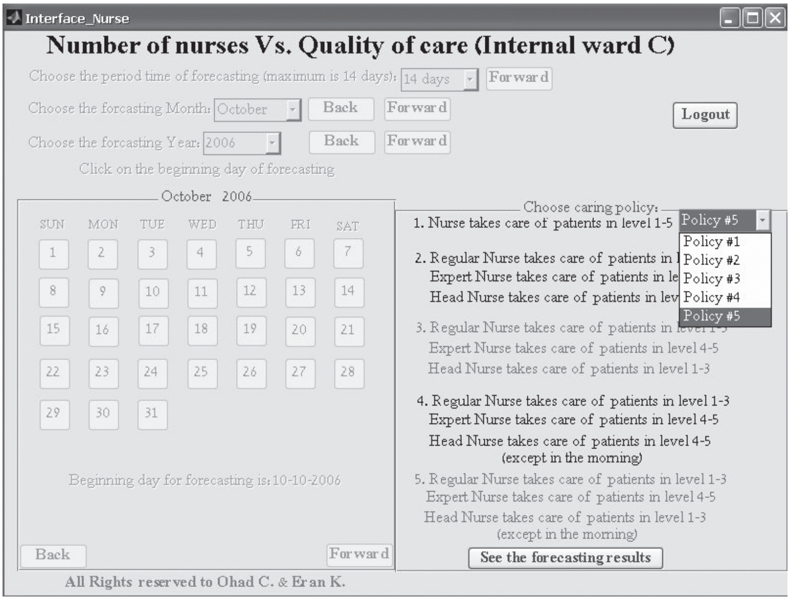

Figure 4.9 GUI screen – Choosing the policy for nursing care for planning the nursing manpower allocation

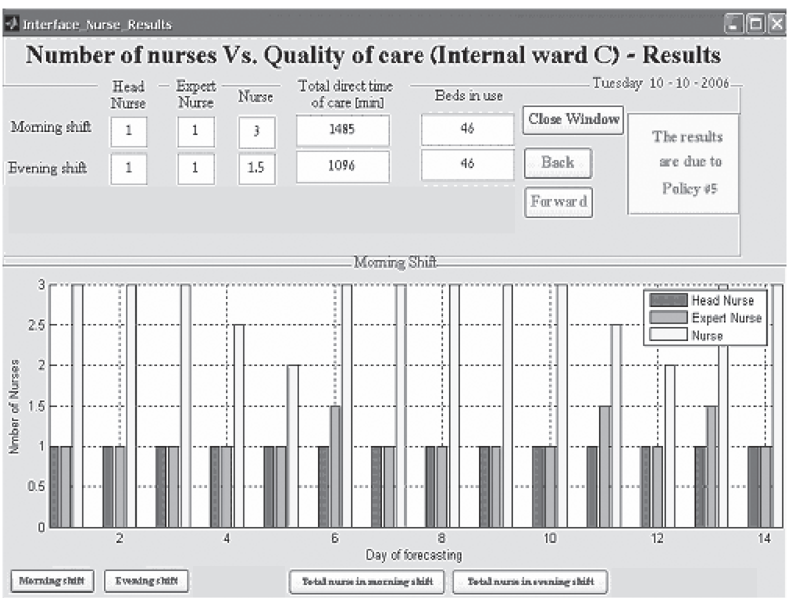

Figure 4.10 Output screen – Nursing mix FTE in the morning shifts for the chosen planning period

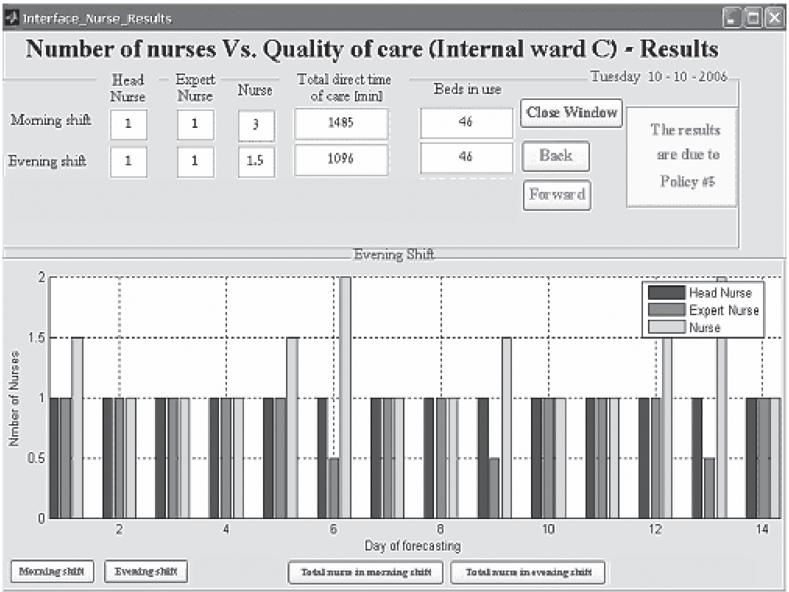

Figure 4.11 Output screen – Nursing mix FTE in the evening shifts for the chosen planning period

Discussion

This chapter presented a procedure for defining the best mix of FTE nurses to be allocated so as to provide good care services to a given variety of patients in a hospital inpatient ward. The authors discussed how to relate nursing services to the quality of performance in a straightforward way. These address a very critical issue in a world where a shortage of nurses in the years to come is predicted by every public health authority. A way to forecast the patient mix in a given shift is introduced. This was done in two steps. Step 1 focused on forecasting the parameters of ward midnight censuses (Table 4.3) and patient admissions and discharges based on the method presented in Figure 4.3. Step 2 focused on formalizing the ratios among the patient mix forecasting parameters in a shift as presented in Table 4.1. Thereafter, the volumes of three patient populations were derived for a given shift: veteran, admitted, and discharged patients. The case study presented here validates the theory in a functioning hospital. The study findings relating to weeks 43 to 50 of 2007 are presented in Table 4.5. The findings presented in Figure 4.5 shows as well the formulized correlation between the quality of nursing treatment and the number of nurses.

In contrast to present staff allocation in hospitals, which is based on nonschematic rules of thumb—intuitive by nature, the present study has proposed a schematic, scientific approach to the question of what is the best number of nurses for a given mix of patients. The methodology presented in this chapter has, therefore, successfully addressed a problem hospital administrators all over the world grapple with daily: how to allocate nurses in a scientific way to achieve quality performance. Moreover, it has done even more; the method can find the best link between quality of treatment and nurse allocation. The methodology has been found to be generic and flexible enough to be used by head nurses. Our experience shows that the procedure has been most appreciated by the nursing managerial level. Its accuracy has been achieved due to a systematic modeling of the nursing workload in an inpatient ward.

The methodology presented can be used as a basis for future practical studies. It will be useful to integrate this tool into the HCO information system. In this way the forecasting procedure should proceed with minimum effort in a straightforward manner. It would also be beneficial to integrate this tool into an automated roster tool. This way nursing managers would be able to derive a scheduling plan based on dynamic FTE nursing patterns that rely on the methodology presented in this chapter.

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CHAPTER 5

Shelf Management in Apparel Industry

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Retail Shelf Space as a Resource

In the retail business, shelf management is a decision-making process designed to maximize profit by arranging various products optimally under the limited space before sales start (Borin and Farris, 1995). In the case of apparel retailing, so much importance has been attached to shelf management because of certain characteristics of fashion products—high demand volatility, short sales period, and high variety of products (Rajaram, 2001).

Shelf management consists of two steps: product assortment and shelf space allocation. When new products are released, retailers have to determine the number and types of products in a line (Rajaram, 2001). In other words, it carries the number of stock keeping units (SKUs) to each product category. Then products are assigned to space on shelves considering their width, relationships of complementary and substitute items, and the shelf level.

A related problem has been developed considering some verified effects on purchasing in retail environment. For shelf space allocation, main space elasticity—the ratio of relative change in unit sales to the shelf space—is first proposed (Anderson and Amato, 1974). Also, location elasticity reflects the level of shelf on which the product is displayed (Drèze et al., 1994), whilst cross-space elasticity, which considers not only shelf space management but also product assortment, deals with complementary and substitute relationships between products (Corstjens and Doyle, 1983). Urban (1998) studied this problem including inventory situation. Shelf management during the season or between two seasons is an important problem that is generally not well-understood in the literature.

Currently, retailers determine how and where retail products should be displayed, using a tool called planogram. It shows detailed maps that show store personnel exactly where merchandise are to be displayed in the store considering shelf capacity, product type, and consumer point of sales (POS) information (Rao, 2000). However, notwithstanding the use of state-of-the-art technology, shelf management in apparel retailing is still struggling due to the shortage of information about new products and customer's attitude when the season changes (Ghani, 2004). For this reason, few studies suggest alternatives such as surveillance camera or direct observation to grasp customer preference (Newman and Cullen, 2002). However, this type of work has some limitations in cost, technology, and ethics (Ahn, 2005).

Recently, with the advancement and deployment of radio frequency identification (RFID) technology, and the desire for quick response to customer demand, apparel retailing extends the attachment of tags by item level to provide real-time monitoring of stocks on shelves as well as backroom in the store (Kim and Kim, 2006). Collected RFID data would be applicable not only to retail operation but also provide new businesses opportunity to grasp customer preference as an offline log data (Sae-ueng et al., 2007; Ahn, 2005). Since the key in apparel market is to monitor and react to customer demand, the Metro group has tested the technology on their store to offer novel experience through the smart dressing rooms that provide product information on individual items with regard to what customers would wish to try on (RFID journal, 2007).

Given that shelf space is a valuable resource, and given the many problems in both supply and demand side management, retailers face an important problem in deciding how best to manage their shelf space—what to stock, when to stock, and how much to stock. In our chapter, we demonstrate how RFID technology and the data obtained from RFID can make shelf management decisions effective as a resource to meet the unpredictable customer demand.

How People Shop: Insights for Shelf Space Decisions

The Online Shopping Process

Usually a web server registers a web log entry for every single access to the web, and saves the URL requested, the IP address from which the request originated, and a time stamp (Zaiane et al., 1998). It is recorded as a click stream, in other words, user's footprint on a particular website. Therefore, if customers visit and buy some product in online retailing, the process of purchase is stored on the retailer' server.

Since web log data includes a large amount of unnecessary information, it is important to transform web log data into an appropriate form through data preprocessing. To examine the Internet user's behavior, generally, four measurements, hit,[1] page view,[2] visitor,[3] user,[4] duration,[5] and session[6] are used. As important measurement units related positively to purchase, two factors—page view and duration time—are suggested in previous researches (Choi et al., 2004; Jun, 2002).

Online retailers have analyzed this data to extract useful information such as user's behavior patterns. The applications of web log analysis spans

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[1]Any request from a file or a web server. A single page likely contains multiple hits as multiple image and text files are downloaded from the web server.

[2]A request to load a single page of a website on the web. A page request would result from a web surfer clicking on a link on another page that points to the page in question.

[3]Visitor refers to an individual that visits a website. A visitor or unique visitor would have multiple visits.

[4]The number of different persons who visit a website for some time.

[5]The time a visitor stays a specific page.

[6]A session is a record of one visitor browsing through a site.

five areas—personalization, system improvement, site modification, business intelligence, and usage characterization (Srivastava et al., 2000). Within the criteria, site modification performs change of the product catalog on website (shelf allocation) and business intelligence covers not only assortment but also product recommendation (Ghani, 2004).

Although the display capacity of online retailing is larger than offline, all products cannot be placed in one page. Hence the decision making of display in web page is critical to online retailer. Lee et al. (2001) suggests two measurements, impression (customer views of product links) and interest (percentage of product views leading to click) to examine the effectiveness of current product display. In the case of a product that has been exposed many times on the website but it is rarely clicked, then it is concluded that the product is not attractive hence its location should be changed in the current display. Yen (2007) introduces a guideline to evaluate web page accessibility based on several structural-based accessibility models where an innovative accessibility—popularity analysis is deployed to measure and, thereby, to modify a web structure. Breugelmans and Campo (2008) investigates the overall effects of in-store displays on category sales and brand market share in an online shopping context, and compares the differences in effectiveness between in-store display types. As a result, first screen displays clearly have the strongest effect on market share: they benefit from their placement on the "entrance" location, central on-screen position, and direct purchase link.

Comparing Online and Offline Shopping Processes

Although there are many differences between online and offline environments such as retail atmosphere, consumer behavior, and frequently purchased items (Kim, 2007), some shopping actions are considered important in both environments. The frequency of request for a particular web page and its duration on the website are defined as positive purchasing factors of a product. Similarly, in offline retail, the following actions are related to shelf management: browsing, trialing/fitting, and time spent (Kirkup and Carrigan, 2000).

To adopt the online web log analysis method in an offline environment, the shopping process about both environment cases should be

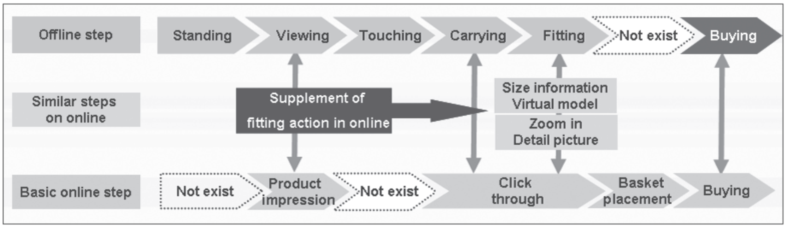

Figure 5.1

reviewed. According to the previous research, online purchase steps are as follows: impression,[7] click-through,[8] basket placement[9], and buying (Lee et al., 2001). In the offline case, the following five actions are generally observed: standing,[10] viewing,[11] touching,[12] carrying,[13] fitting,[14] and buying (Sae-ueng et al., 2007).

On the basis of these procedures, we match the two environments as shown in Figure 5.1. The first step in online shopping, product impression, is matched with standing and viewing as a customer looks around in front of shelves to select a product. Click-through is an action to choose something; hence, it is like carrying in offline. Although there is no step corresponding fitting in online, the additional steps such as zoom or pop-up for size information have their own URL; therefore, these functions are possible to consider as fitting action to fill wearing.

Besides, Internet environment is not the same as offline retailing; some similar functions are matched to fitting action, zoom-in, multiple views of products on virtual model lead, picture enlargement focusing on fabric texture, and descriptions of garment performance (Kim, 2007).

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[7]View of hyperlink to a web page presenting a product.

[8]Click on the hyperlink and view the web page of the product.

[9]Placement of an item in the shopping basket.

[10]Consumer stops by at a certain distance in front of an object.

[11]Consumer looks at a certain object.

[12]Consumer touches a certain object where the object does not separate from its shelf.

[13]Consumer separately picks up a certain object from its shelf.

[14]Consumer uses a mirror to match a certain object with his/her appearance.

RFID Data-based Shelf Management in Apparel Retailing

RFID Technology

RFID is an identification technology that uses radio signals to read data stored in a tag, also called the smart chip, at some distances with no direct line of sight and without labor. Compared with barcode technology, RFID can scan a product remotely and automatically in bulk; therefore it performs faster and retains more identification per unit time than a barcode. Once a tag is attached to an object, such as a pallet, box, or item, each individual logistic unit is identified and seamlessly traced by many readers installed at important spots.

As a representative study of the potential of RFID data, Seo (2006) proposed the process of sales (POS2) concept, which is an extension of the POS as data source for supply chain management (SCM). Seo defined the characteristics and data type of POS2 as an offline log data and derived its value on SCM practices in apparel industry. On the basis of this concept, Ahn (2005) performed an experiment and proposed the real-time goods recommendation mechanism, i.e., detecting customer's location in real time and recommending preferred goods by means of RFID data and an intelligent agent. Sae-ueng et al. (2007) embodied a shopping assistance service using personal behavior data from RFID, camera, and sensor for apparel retailing.

Although related works suggest the use of RFID data that reflect customer's preference, they are not focused on critical decision making but on offering additional sales in retail industry.

Design of RFID System in Apparel Retailing

To develop the RFID-based shelf management, a working environment should be constituted to obtain the data. Figure 5.2 shows the shopping process in the apparel shop previously mentioned. In this environment, the main equipment is a smart shelf, which is installed with an RFID reader since it recognizes the status of items, such as location and time on the shelf, whenever a customer picks or places an item in real time. Another important installation is the smart fitting room, which is also

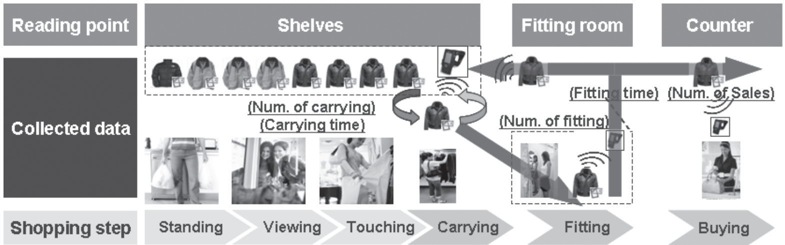

Figure 5.2

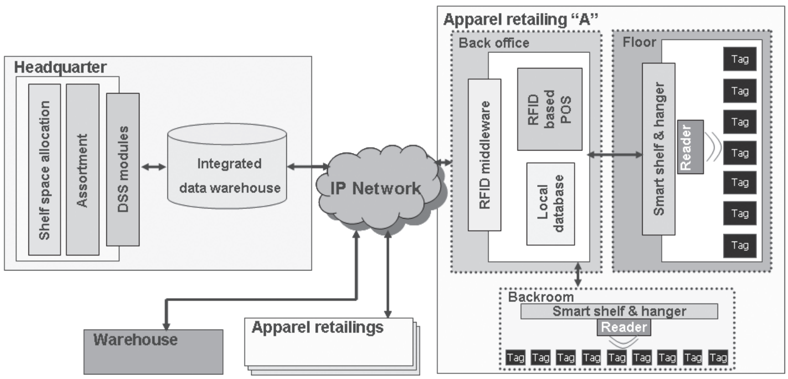

Figure 5.3

equipped with an RFID reader. Therefore, the smart shelf and the fitting room count how many times the events are generated. Moreover, this system checks total shopping time, the duration of a product from leaving the shelf to checking on a counter, which is an important factor related with purchasing possibility.

On the basis of the above retail environment, the RFID system for apparel retailing is designed as shown in Figure 5.3. The collected data from the shop floor and the backroom is transmitted to an RFID middleware and stored in a local database. The headquarters gathers the RFID data from all its retail stores into a data warehouse to analyze and decide each store's shelf management, and then an established shelf management plan is sent to each retail store. As this networked RFID system also links apparel retailing and the warehouse, their sales and inventory status is grasped in real time. Therefore, shelf management is determined more quickly and accurately.

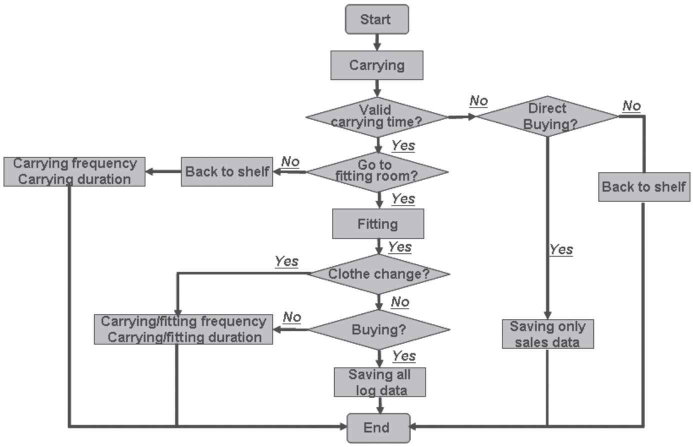

Figure 5.4

To collect reliable data, an acquisition process as shown in Figure 5.4 is suggested. In case a customer picks up an item unintentionally, it would generate meaningless data. If a carrying event is below the valid time, the carrying count data is not record. This process would reduce the storage overload. Fitting time begins when a customer goes into fitting room holding an item and it is over when the item is returned to a shelf or a POS reader transacts the payment.

The collected data is stored in the database in the system, and then it is processed for analysis. Since RFID data format is determined considering its usage, preprocessing is not required. On the basis of the collected data, the table format is designed as shown in Figure 5.5. Instantly recorded data set is converted to accumulated data format everyday and, in the same way, daily data are accumulated when a week is over.

Key Takeaways from Chapter: Decision-Making Guidelines for Shelf Management Using RFID Data

Shelf management is a process that determines product arrangement on a given shelf space considering future sales. Even if the apparel headquarters establishes the plan with sophisticated data, it is difficult to meet customer demand. Generally, shelf management is established on the basis of historical sales data. Then, it is implemented reflecting current sales data.

1 Instantly recorded data table

Item	Carrying	Carrying time (s)	Fitting	Fitting time (s)	Sales
0001	1	5	1	53	O
0002	1	6	1	76	X
0003	1	5	0	44	O
0002	1	12	0	65	X
0004	1	7	1	51	X
0001	1	8	1	104	O

2 Cumulated data table (day)

Item	Date	Carrying	Carrying time (s)	Fitting	Fitting time (s)	Sales
0001	Mon	34	231	33	697	25
0002	Mon	56	301	41	945	12
0003	Mon	5	32	1	144	1
0004	Mon	43	241	35	768	31
0005	Mon	12	69	6	320	3
0006	Mon	23	121	3	410	20

3 Cumulated data table (week)

Item	Week	Carrying	Carrying time (s)	Fitting	Fitting time (s)	Sales
0001	May 1st	234	1595	133	4896	105
0002	May 1st	356	1256	241	6841	86
0003	May 1st	435	1346	114	731	5
0004	May 1st	343	1667	335	4950	69
0005	May 1st	112	561	56	1606	15
0006	May 1st	123	820	93	2533	59

Figure 5.5

To compare the decision making based on sales data and RFID data, the scenario is as follows. Suppose a season just begins and there are two shelves, shelf A and shelf B, which display various products. Apart from differences in size and color of the products, all other things about the products are the same. All allocated spaces are same for every product.

For analysis, this study introduces a concept called shelf accessibility. A shelf's accessibility is determined by its distance from the entrance. For the two shelves, shelf A and shelf B, shelf A is closer to the entrance than shelf B. For that reason, a retailer would choose to display a promised product on shelf A rather than on shelf B, because shelf A's accessibility is higher than that of shelf B.

Figure 5.6 illustrates the case of the sales data-based shelf management. It shows a scatter diagram of displayed products in terms of shelf accessibility and sales. The interpretation of the 2 × 2 matrix is follows: type 1 products are those that sell when displayed in shelves with high accessibility. Therefore, shelf space does not need to be changed. Type 3 products are satisfied beyond expectation and its location is absolutely changed to type 2 products on shelf A. They also would be moved to type 1 when their sales are higher than some products of type 1. Although type 3 products show low sales, they also change when placed on shelf A, showing higher sales than type 1. Consequently, type 2 products have to move somewhere in shelf B. However, the matrix may not guarantee higher profit since there is a possibility of misplacement. For example, some products in shelf B do not need to be moved to shelf A because they are sold enough when on shelf B. Or a few items on both shelves should be removed quickly since they are not likely to be sold any more. In these contexts, sales-based decision making does not provide clear and reliable direction.

To capture the preference for products on display for sale, two additional data from offline shopping behaviors, carrying and picking, are

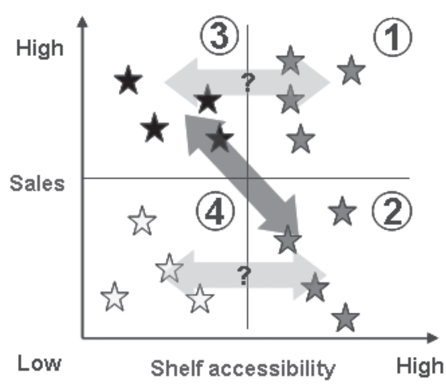

Figure 5.6

suggested. In this analysis, three indices are used to interpret the obtained data sequentially: carrying factor (carrying as against accessibility), fitting conversion rate (carrying to fitting), and sales conversion rate (fitting to sales).

The preconditions and analytical method are as follows. Generally, shelf accessibility and carrying count are positively correlated; hence, carrying count would be increased by adjusting the product exposure. Second, the condition of the number of carrying, fitting, and sales is shown as follows:

When

Nci = the number of carrying on item i
Nfi = the number of fitting on item i
Nsi = the number sales on item i

Subject to

$$Nci \geq Nfi \geq Nsi \qquad i = 1,\ldots,N$$
$$Nci \geq Nfi \geq Nsi \geq 0$$

The importance of index is in the order of carrying, fitting, and sales. Furthermore, when the degree of a conversion rate is consistent through the entire shopping steps, its decision making is most clear and should be implemented first. In a case where the situation is contradictory, it is preferable to remove the negative result rather than increase the positive result. When the products are on the same shelf and its decision making are same, the decision priority is determined by comparing the degree of index from carrying to sales.

By using the conversion rates, product characteristics would be defined whether it is affected by accessibility or it has attractiveness. On the basis of the casual relationships analysis among three indexes, product's treatments are derived.

"High-Accessed Shelf" Management Using RFID Data

As a result, type 1 products are most preferable in shelf A (Table 5.1) since its high traffic is linked to high sales performance. In this situation, retailing should prepare enough inventories of those products, and it is considerable to expand its sales space. On the other hand, type 2 items are sold well in spite of high carrying factor and high fitting conversion rate.

Table 5.1 Results and guidelines of shelf A

Type	Carrying factor	Fitting conversion	Sales conversion	Decision	Decision priority
1	↑	↑	↑	Preserve	First
2	↑	↑	↓	Preserve	Second
3	↑	↓	↑	Preserve	Third
4	↑	↓	↓	Remove	Second
5	↓	↑	↑	Preserve	Fourth
6	↓	↑	↓	Preserve	Fifth
7	↓	↓	↑	Preserve	Sixth
8	↓	↓	↓	Remove	First

It seems that they are relatively expensive products, thus, they would be preserved on current shelf considering its markdown. Also type 6 products are considered having similar characteristics like type 2. Thus, customers quit to purchase although the products have a high fitting conversion rate. Without a carrying factor and fitting conversion, type 3 and 5 products show high sales conversion rates. Therefore, they would be place and sold on shelf A.

Type 8 products show not only low sales conversion rate but also low carrying factor and low fitting conversion rate. Although type 4 shows high carrying factor, it fails to continue to high sales. Those are proved to be unattractive items and they are likely to be sold no more. In those cases, the products should be removed from the shelves.

"Low-Accessed Shelf" Management Using RFID Data

Table 5.2 Results and guidelines of shelf B

Type	Carrying factor	Fitting conversion	Sales conversion	Decision	Decision priority
1	↑	↑	↑	Move	First
2	↑	↑	↓	Preserve	First
3	↑	↓	↑	Preserve	Second
4	↑	↓	↓	Remove	Second
5	↓	↑	↑	Move	Second
6	↓	↑	↓	Preserve	Third
7	↓	↓	↑	Preserve	Fourth
8	↓	↓	↓	Remove	First

Although type 1 items are displayed on a shelf B (Table 5.2), they show not only high carrying factor but also high fitting conversion rate and sales conversion rate. Hence, the products seem to appeal to customers and they should be more exposed. Type 5 items on shelf B which that show high fitting and sales conversion rate without high carrying factor also need more exposure since its sales possibility is very high once customers pick it up. Consequently, these two types of products should be moved to shelf A to increase the carrying count to achieve more sales by means of exposure. For these products, the empty space in shelf A, where removed products were located, would be replaced. If some products are competing to move to shelf A, its priority is determined by actual sales quantity.

Type 3 and 7 items show high sales conversion rate in shelf B without high fitting conversion rate. Customers do not try to wear them frequently whether they pick them many times or not. Despite the relatively low customers' interest, those products sell well. Therefore, they do not need to be exposed and it is better to keep them at their current shelf space. On the other hand, in shelf B, the sales conversion rates of type 2 and 6 products are low even though they have high fitting conversion rate. Like the above case, those items must be high priced items; hence, customers would quit wearing them, hence quit buying them. They also should be displayed on initial space for a while, and their execution priority is lower than high sales conversion rate products.

In shelf B, type 4 and 8 items show not only low sales conversion rate but also low fitting conversion rate like some cases of shelf A. These cases also should be removed from the shelves. And the empty spaces on shelf B are substituted by new products in the store that have been waiting for release. Above all, RFID-based shelf management is performed considering the original sales quantity, then a selected optimal case may increase the total profit.

Closing Thoughts

RFID-based shelf management guidelines would be useful during the early period of a season when sales data is not enough to estimate customer demand. Even though sales data is a reliable source, it is not useful if its sample size is very small. In this context, RFID data would contribute in replacing the shortage of sales data. RFID data would overcome this problem through data mining (Zaiene et al., 1998), thus ensuring its reliability. When the season starts, the weighting factor for sales is the lowest. Carrying is medium and fitting shows the highest value. However, this situation would be reversed as the season progresses. When enough sales data is collected, its value becomes higher. With these data, shelf management would be more responsive and stable since sales data-based guidelines are more specified.

The guidelines of RFID-based shelf management are also used for other limited space management in apparel retailing. For example, a backroom would be organized with same assortment except for nonreleased products and same shelf space allocation ratio reflecting floor shelves constitution using warehouse and adjacent retail's inventory. To secure the inventory of each retail store, networked RFID systems are used to capture inventory information not only on the warehouse side but also in the adjacent retail in real time to share and deliver required inventory on right time. The window display, shown as another shelf space, is dynamically changed with hot items.

Moreover, several important decisions are elaborated using the tool. For instance, replenishment from warehouse to retail is fulfilled earlier for the products that show high sales conversion rate and fitting conversion.

This chapter outlined an RFID system for shelf management in apparel retailing to enhance the sales opportunity using customer preference in a shopping process. The suggested guidelines provide insights to apparel retailers who are going to adopt RFID technology to increase the efficiency of retail operations as well as the sales opportunity by specifying the decision strategies comparing with sales data-based guidelines.

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CHAPTER 6

Improving Productivity in Resource-Constrained Environments

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Importance of Productivity in the Industry

Globalization of markets necessitates that companies manufacture high quality, low cost products and make them available faster than ever before. Constantly changing market situations also require quick and flexible reactions from manufacturers and a reduction in the lead time for product development and manufacture. The international marketplace requires excellence in manufacturing, placing new emphasis on quality, service, and lower costs.

In the early 1980s, manufacturing researchers and practitioners advocated completely automated manufacturing factories as the shape of the future factory (Bullinger and Warnecke, 1985). Workerless factories were expected to provide a way to deal with the productivity woes and prompted U.S. manufacturers to invest billions of dollars in high technology equipment automation. These investments, however, have been without matching payoffs in the form of higher productivity. Completely automated factories are not a reality due to a variety of technical, economical, and cybernetic reasons (Mital, 1997) and cannot lead to higher productivity. It is also being realized that humans will continue to play an essential and integral role in modern manufacturing. However, humans are error-prone, so they can be a major cause of lower productivity (the cause of error can inherently be the operator or the situation).

Manufacturers must constantly look for ways and means to enhance their productivity. One way to achieve higher manufacturing productivity is to identify and measure the specific causes of productivity loss and mitigate them. Problems such as worker injuries, frequent machine breakdowns, and large amounts of scrap generated lower productivity. However, these problems are all too apparent in a plant, and the plant can take corrective action to eliminate or reduce the problem. The situation becomes more challenging once we mitigate the obvious and very visible sources of productivity impediments. In the absence of any visible signs of productivity problems or opportunities for productivity improvement, the task of enhancing productivity becomes critical. The situation is further complicated as very few manufacturing firms have effective productivity measurement systems that can pinpoint the specific reasons for changes in productivity relationships (Gold, 1982). Upon identification and evaluation of such opportunities, it may be possible to develop and use assistive devices (broadly defined as any device that assists the operator in enhancing his or her job performance) to enhance productivity.

Productivity Assessment and Performance Measures

Since the beginning of the industrial revolution, practitioners, researchers, and policymakers have tried to define and evaluate particular workplace practices that can spur productivity growth and competitiveness. The organized approach to productivity improvement in the American industry began with Frederick Taylor's scientific management principle (Taylor, 1915). Another pioneer in scientific management was Henry Gantt, who developed the Gantt chart, a simple device for precisely anticipating and recording performance (Gantt, 1974). The Gantt chart was the forerunner of the Performance Evaluation and Review Technique (PERT) charts. Lillian and Frank Gilbreth were two other industrial engineering pioneers who carefully studied peoples' movements as they worked. They broke jobs down into very small elements so each movement could be analyzed and perhaps simplified or eliminated (Gilbreth and Gilbreth, 1973).

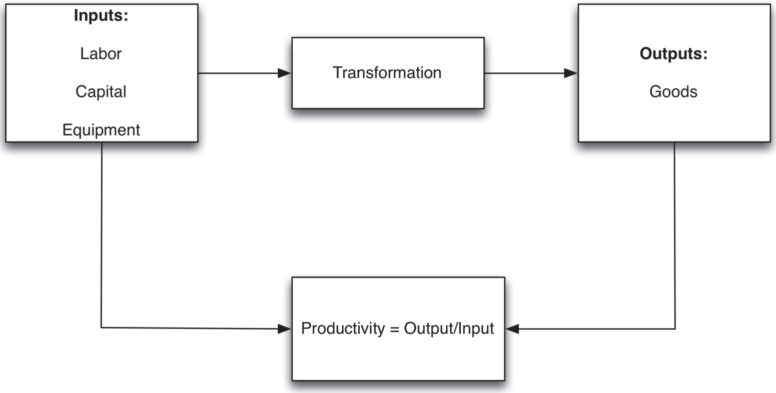

Figure 6.1 General concept of productivity (modified from Sink, 1985)

Productivity is the relationship between the outputs generated from a system and the inputs provided to create those outputs (Sink, 1991). Specifically, productivity is defined as the relationship of the amount produced by a given system during a given period and the quantity of resources consumed to create or produce these outputs over the same period. Typical inputs are in the form of labor (human resources), capital (physical and financial capital assets), energy, materials, and data. These resources are then transformed into outputs (goods and services). This relationship is illustrated in Figure 6.1. Different techniques exist to measure the costs associated with these outputs and inputs (Stewart, 1983).

In general, firms report two forms of productivity in practice: partial productivity and multifactor productivity. Partial productivity is the ratio of gross or net output to just one type of input from among different inputs, as seen in Figure 6.1. Examples of partial productivity are labor productivity and capital productivity.

Total or multifactor productivity measures, on the other hand, compare all outputs with all inputs. Among the important measures for partial and multifactor productivity, the Törnqvist index is widely used in the U.S. Bureau of Labor Statistics (BLS) (1997) for reporting partial and multifactor productivities. For example, the labor productivity (partial), according to the Törnqvist index (Caves, Christessen and Diewert, 1982) for industries that produce a number of different products or provide a number of different services, is given by

$$\frac{Q_t}{Q_{t-1}} = \exp\left[\sum_{i=1}^{n} w_{i,t}\left(ln\frac{q_{i,t}}{q_{i,t-1}}\right)\right] \tag{1}$$

where

$\frac{Q_1}{Q_{t-1}}$ = *the ratio of output in the current year (t) to the previous year (t − 1)*

n = number of products

$ln\frac{q_{i,t}}{q_{i,t-1}}$ = the natural log of the ratio of the quantity of product I in the current year to the quantity in the previous year, and

$w_{i,t}$ = the average value share weight for product i

This measure of labor productivity relates only to one input, namely, labor time. The measure is also a reflection of a number of interrelated influences on product manufacturing, such as technology change, capital investment per worker, capacity utilization, layout and flow of material, skills and effort of the workforce, managerial skill, and labor management relations, among others (US Bureau of Labor Statistics, 1997).

BLS uses many information sources for their output and input in calculating partial and multifactor productivities. They develop outputs from the Bureau of Census's information as a deflated value of production or physical quantity of production in a certain industry. Inputs are specific to the type of partial productivity—labor input is the aggregate employee hours for each year divided by the base period aggregate; capital input is based on the flow of services derived from existing stock of physical capital, including equipment, structures, land, and inventories. Intermediate purchases include real materials, services, fuels, and energy and electricity consumed by the industry (BLS, 1997). The Törnqvist index for multifactor productivity is given by

$$ln\left(\frac{A_t}{A_{t-1}}\right) = ln\left(\frac{Q_t}{Q_{t-1}}\right) - \left[w_k\left(ln\frac{K_t}{K_{t-1}}\right) + w_l\left(ln\frac{L_t}{L_{t-1}}\right) + w_{ip}\left(ln\frac{IP_t}{IP_{t-1}}\right)\right] \tag{2}$$

where

ln = the natural logarithm of the variable

A = multifactor productivity

Q = output
K = capital input
L = labor input
IP = intermediate purchase input
w_k, w_l, w_{ip} = cost share weights

where the weights are the mean of cost shares in two adjoining time periods.

The objective of this chapter is twofold: (a) to present a case study in a manufacturing environment and highlight the important steps the company took to assess and enhance their productivity; and (b) as a takeaway from the specific case presented, to provide a general modeling framework for identifying productivity enhancement opportunities in the industry.

The Case: Amano Cincinnati's Productivity Problem

Case Background and Data

Amano is engaged in the development, manufacturing, and distribution of time recorders, time and attendance systems, and parking control systems. The product chosen in the case is the Fee Indicator, which is used to display parking fees and change due along with the current time as communicated by the fee computer. Amano is interested in documenting the productivity of the fee indicator manufacturing process, and the measures to improve productivity.

Data on manufacturing processes, activity times for the processes, and equipment and tools used is obtained from company records and discussion with the engineer and the operator of the device. Most components are purchased from external suppliers; hence the major activity in the company is the assembly of the components. The company manufactures 8 fee indicators in a day but would like to increase the capacity to 10 a day. Only one operator is assigned to the product. For accounting purposes, the operating costs are taken as \$60 per hour. This includes the labor cost of \$12.70 per hour and \$47.30 per hour for plant maintenance. Table 6.1 lists all the major activities for the fee indicator and their associated time durations and costs.

Table 6.1 Major activities for the assembly of the fee indicator with their associated activity times and costs

Activity	Description	Duration (minutes)	Operating cost @ $60/hr	Material cost ($)	Total cost ($)
A	Terminal box cover assembly	1.0	1.0	9.80	10.80
B	End cap assembly	1.28	1.28	15.75	17.03
C	Display panel assembly	8.66	8.66	120.88	129.54
D	Lens/extrusion/display assembly	4.07	4.07	22.58	26.65
E	Terminal box to base assembly	5.57	5.57	15.47	21.04
F	Display/base assembly	17.42	17.42	38.00	55.42
G	Final inspection/package	16.45	16.45	0	16.45

Case Analysis

The analysts undertook the following systematic steps in identifying opportunities for productivity improvement in their operations.

Step 1: Identification of critical activities

Activities consuming maximum time. The activities are performed sequentially from A to G by one operator. In effect, every activity is a bottleneck activity. However, the analysts consider the two activities, which consume almost 65% of the cycle time, as time-critical. These activities are: (a) display and base assembly, and (b) final inspection and packaging.

Activities consuming maximum costs. Activity-based costing, shown in Table 6.2, traces all the costs associated with each activity. The Pareto analysis was performed on activity cots by the analysts to find the cost-centered activities. Of the seven activities, over 65% of the cost is from two activities: (a) display panel assembly; and (b) display and base assembly. Hence, these two activities are chosen as cost-centered activities.

Table 6.2 Weights for critical activities

Activity category	Activity	Time weight	Cost weight	Total
A	Display panel assembly	0.16	0.47	0.63
B	Display base assembly	0.32	0.20	0.52
C	Final inspection/package	0.30	0.06	0.36

Step 2: Prioritization of critical activities

The important activities identified in step 1 are:

- Display and base assembly
- Final inspection and packaging
- Display panel assembly

For each activity, the analysts computed time weights and cost weights. For example, activity A, the display panel assembly, took 8.66 minutes out of 54.45 minutes total required to complete the product. Hence, the time weight for activity A is computed as 8.66/54.45 = 0.16.

Similarly, the cost of activity A is $129.58 out of a total $276.93 cost for the product. Hence, the cost weight for activity A is calculated as 129.58/276.93 = 0.47.

For the other critical activities, the time and cost activities are computed similarly—they are presented in Table 6.2. The company kept no record of the defects, warranties, and claims. Hence, quality-related weights are not considered in the analysis.

The display panel assembly, which has the highest total weight, represents the maximum potential for improvement. Depending on the productivity goals of the organization, and the resources available, one or more of the critical activities may be chosen for improvement. In the present case, the display panel assembly was selected for further analysis and improvement.

Step 3: Diagnosing the critical activity

The activity selected from step 2 was analyzed for four activity performance variables—task, operator, tools, and environment or workplace.

Table 6.3 Tasks involved in display panel assembly and the tools used

Task	Tool
Pick circuit board from bin	
Cut masks	Scissors
Pick chip from bench	
Assemble chip to PCB	
Pick screws from bench	
Pick washers from bench	
Assemble circuit board to panel	Screwdriver
Assemble power supply to panel	Screwdriver
Assemble cables to circuit board	Screwdriver
Aside assembly to cart	

Table 6.4 List of variables

Task variables	Components like chip and screws are picked up from the bench or bins
	Completed assembly is carried to the testing area by cart
Operator variables	Operator has to stand for the assembly task
	Operator neglects to install a chip or inserts a wrong chip
	Operator takes longer breaks
Tools/materials variables	Manual screwdriver is used
	Parts at the station are not correct type or in right quantity

Table 6.3 presents the important tasks involved in the activity and the tools used for the activity. The task, tools, or materials, and the operator variables are listed in Table 6.4.

Step 4: Identifying assistive devices to improve productivity

Once the activity was broken down into task, operator, machine and environment or workplace variables, it was possible for the analysis team to suggest assistive devices that could aid in improving the performance of some or all variables, that would in turn increase the productivity of the corresponding activity. Suggested assistive devices for each activity variable in the Amano case are listed in Table 6.5.

Table 6.5 List of suggested assistive devices for the display panel assembly

No.	Assistive devices
1	For the ease of discharging by hand, use grab tongues and tipping devices. These devices discharge one component at a time at the touch of a finger. Alternatively, magazines, which have separate sections for storing different parts, can ease the task of sorting and picking the correct part.
2	Presently, completed assembly is carried to the testing area by cart. If there is any defect, it is again carried back to the assembly area for rework. This causes wasted movement and time. Instead, the testing area can be located next to the assembly area. This would reduce the time for travel.
3	The seat provided is not adequate for the sit/stand type of operation. Sit/stand tools can be provided for this purpose, which can reduce the strain from standing.
4	Operator can be provided with a step-by-step procedure to perform the assembly operation. This will reduce the possibility of errors and will also reduce the mental workload of the operator, since he no longer has to memorize the sequence of operation or the part number.
5	Close monitoring must be performed on the amount of time that the operator spends during each of the three breaks permitted during the day. Checks must also be made during the start and end of the shift. Even a 5-minute delay on these activities can accumulate to a large amount of unproductive time over a day.
6	The manual screwdriver used for the display panel assembly takes about 3 minutes out of the total 8.66 minutes required for the activity, or about 35% of the time. Using powered screwdrivers can significantly reduce time.
7	A data management system can be developed such that the inventory analyst is informed of an order as soon as it is placed at the assembly. It can simply be a requisition request card, which is sent to the inventory. The inventory analyst can stock the workstation with sufficient parts and also monitor the status of the inventory and take corrective action.

If the productivity goal of the organization is not met after implementing the assistive devices for display panel assembly, then the second-most critical activity, display and base assembly, is considered for improvement, and steps 3 and 4 are repeated. The process is repeated until the company's goal is achieved.

Case Takeaway: General Productivity Improvement Framework

In the Amano case, the managers, engineers, and analysts systematically identified productivity improvement opportunities, and generated design solutions to improve productivity in operations. On the basis of the case, we generalize in this section a productivity improvement framework (Figure 6.2) and highlight the important steps in the framework. A company's productivity goals typically drive the use of the framework, and the tools built into the framework template.

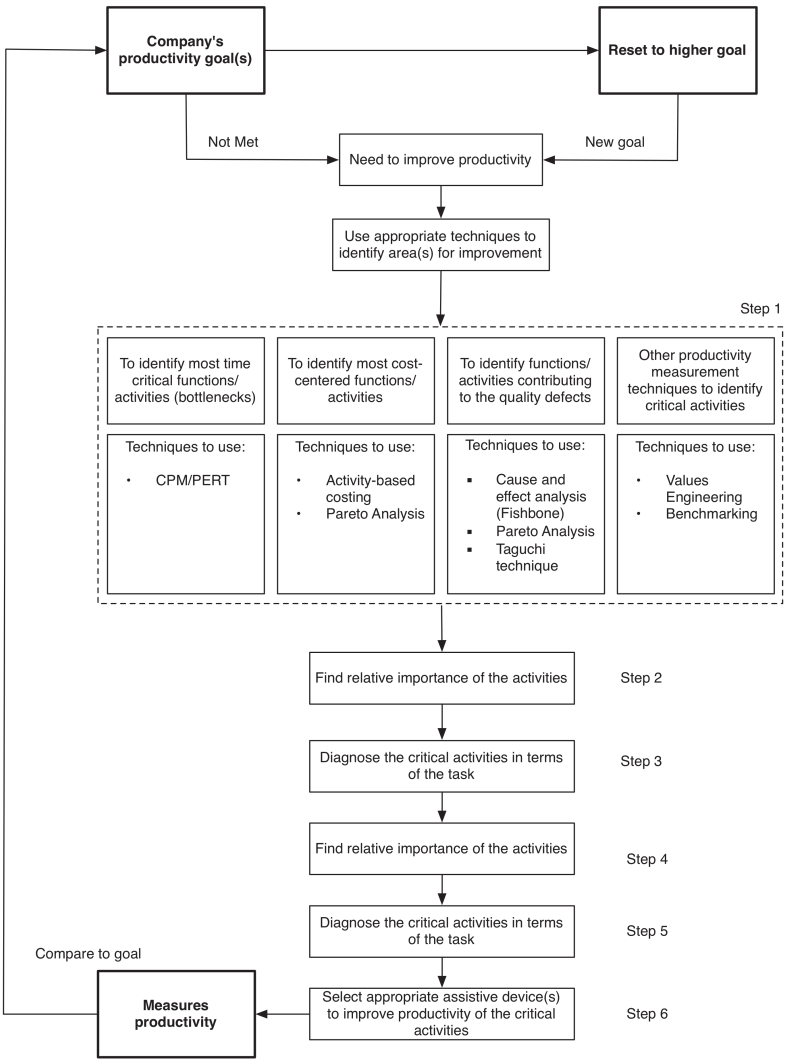

Figure 6.2 Conceptual framework for productivity improvement process

Step 1: Identifying Critical Activities

The first step in the model is to identify areas that have maximum potential for improvement. Key factors used for this identification of critical activities are time, cost, and quality.

Determination of Time-Critical Activities

It is possible to reduce the time of any activity by deploying better techniques and equipment, but the real benefit will occur only if the processing time on bottleneck activities is reduced, which in turn reduces the cycle time. Critical path analysis (CPM) is a very effective technique used for identification of bottleneck activities. For more information on the CPM technique, refer to Radcliffe, Kawai, and Stephenson (1967) and Shaffer, Ritter, and Meyer (1965). A broad representation of the CPM process is shown in Figure 6.3.

Identification of Cost-Centered Activities

Attention must be paid to activities where the maximum cost or value of the product is centered. Activity-based costing (ABC) is a technique that identifies the relationship between an activity and the cost associated with it. Placing costs on activities and their outputs provides a clear metric for determining improvement priorities. It is through ABC that an organization can begin to see actual dollar cost against individual activities and find opportunities to streamline or reduce the costs (Figure 6.4). Readers should refer to O'Guin (1991) for more information on ABC.

Determination of Quality Defects

Often, few of the manufacturing activities account for the bulk of quality problems. For example, 80% of the cost of rework could be associated with 20% of the activities. Thus, improving just these few areas could result in a substantial increase in productivity. Pareto analysis can be used to identify these vital few activities. Figure 6.5 shows tasks involved in carrying out the Pareto analysis. The techniques presented

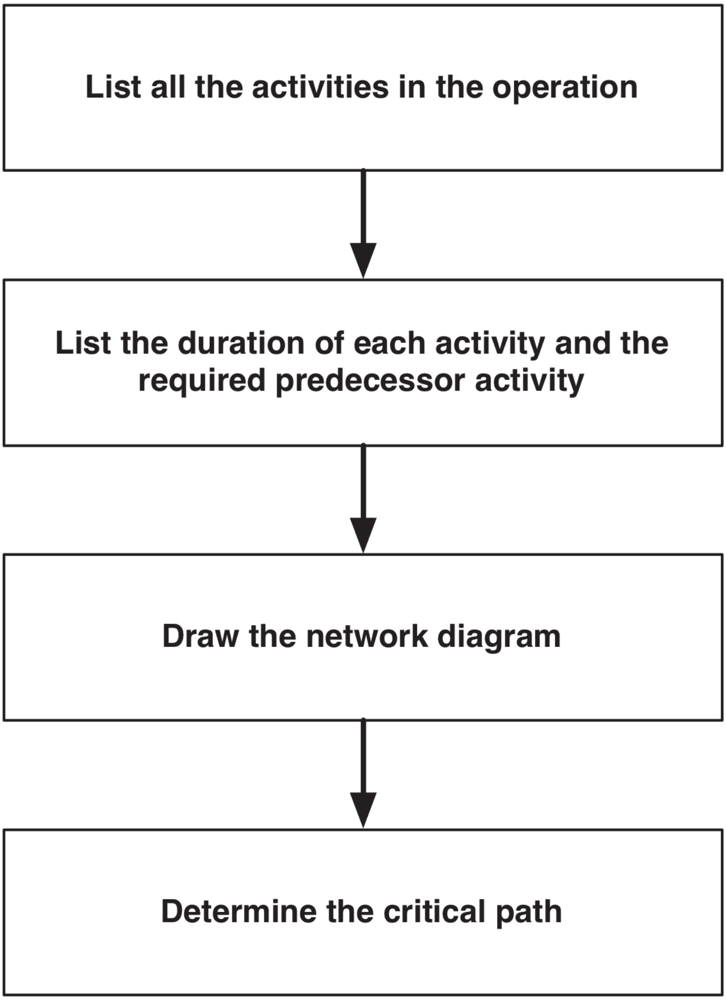

Figure 6.3 Critical path method process

in this section do not represent a comprehensive list of techniques used for the identification of areas with maximum productivity improvement potential. Other techniques, such as quality function deployment, value engineering, cause and effect analysis, Taguchi methods, benchmarking, and so on, are discussed by Kansai (1999). Step 1 would give a list of those activities that are critical to improving the productivity of a given operation.

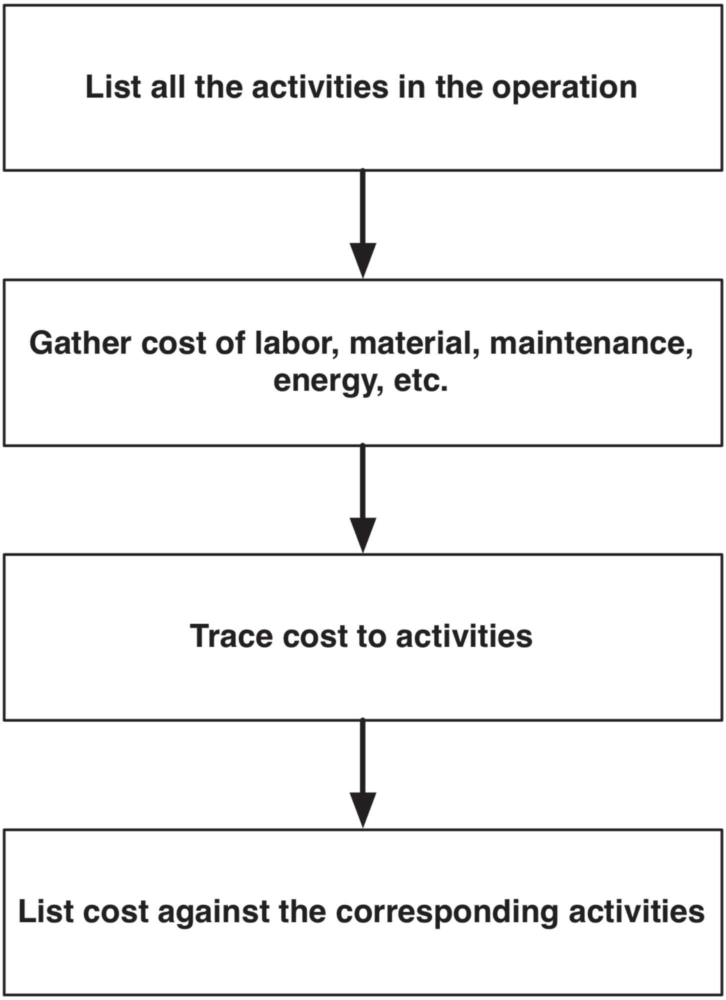

Figure 6.4 Activity-based costing process

Step 2: Prioritizing Critical Activities

The next step in our model is to prioritize activities identified in step 1 based on their relative importance to select those activities that can maximize productivity and help in achieving the company's goal. A weighted-ranking technique is used to rank those activities. The weight of each criteria, time, cost, and quality, is calculated as the proportion of the value that the criterion adds to the activity.

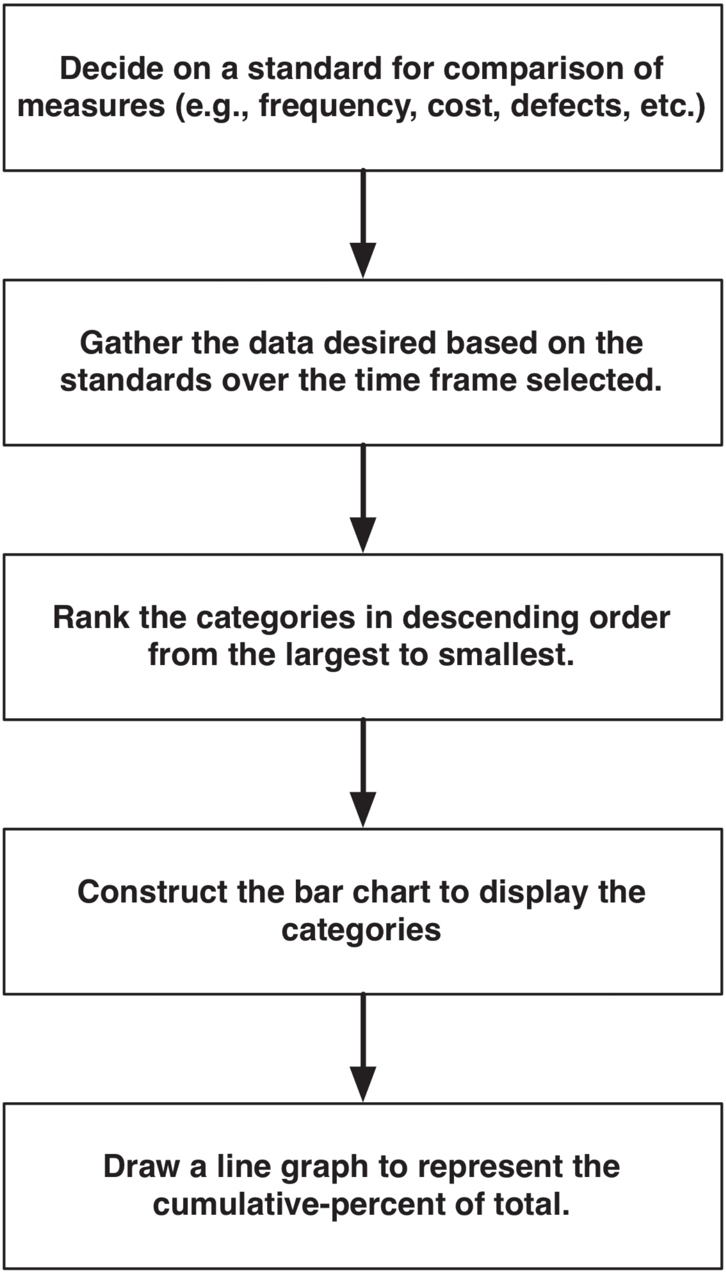

Figure 6.5 Pareto analysis to determine vital few activities

The time weight for an activity is the ratio of time spent on the activity to the total time spent on the product. The time weight can be estimated as $w_{tA} = T_A/T_{Total}$, where w_{tA} is the time weight for activity A, T_A is the time spent on activity A, and T_{Total} is the total time spent on the product.

The cost weight for an activity is the ratio of the cost associated with activity A to the total cost of the product. The cost weight can be estimated as $w_{cA} = C_A/C_{Total}$, where w_{cA} is the cost weight for activity A, C_A is the labor and material cost total for activity A, and C_{Total} is the total labor and material cost for the product.

The quality weight for an activity is the ratio of the cost of rework, warranty, scrap and any quality costs associated with fixing defects in the activity, to the total cost of product rework. Quality weights are estimated as $w_{qA} = Q_A/Q_{Total}$, where w_{qA} is the quality weight for activity A, Q_A is the cost of rework, warranties, and defects due to activity A, and Q_{Total} is the total cost of rework for the product.

The three weights for each activity identified from step 1 are added. Activities with the highest weight are the ones consuming most of the resources and hence have the potential for maximum savings. These activities are selected for further analysis to pinpoint the opportunities for improvement.

Step 3: Diagnosing Critical Activities

Performance of an activity depends on four variables: (a) the task performed, (b) the operator(s) performing the task, (c) the materials or tools used for the task, and (d) the environment in which the task is carried out. Each of these variables affects the performance of an activity in a different way. Often, poor system performance is equated with poor human performance without considering other variables. Human performance may be degraded because of poor design decisions, including the tools being used for the task. The environment in which people work also influences them and, at times, may enhance or degrade their performance. Poorly designed systems do not elicit optimum performance from workers. It is possible to enhance performance, efficiency, and productivity of the workers given the right kind of assistive aids and the right environment.

Supposing, in a manufacturing operation, inspection activity is found to have the highest potential for productivity improvement (from steps 1 and 2 of the analysis). The activity is broken down into task, operator, machine or tool, and environmental variables. A sample hierarchical analysis of the inspection function in manufacturing is shown in Figure 6.5. It is found that the inspection activity consists of a task of measuring the dimensions and hardness of the objects and of comparing the test surface to a standard surface finish. The comparison of the surface finish is found to be the most difficult and time-consuming activity. Judgment by visual inspection alone is also highly unreliable. The operator has to perform the activity in the standing position. Objects to be inspected are very small, and the surface of the object contrasts sharply with the background. In real life, an activity may have several variables, in which case they must all be listed systematically under each category.

Step 4: Selecting Appropriate Assistive Devices

The final step is to identify an appropriate assistive device or devices to enhance productivity of the activity variables: task, operator, machine, and environment. In the inspection example (Figure 6.6), a surface comparator can be an effective assistive device to aid in the comparison of the two surfaces. Operators can be provided with a sit/stand stool to relieve them of pain. If it is not possible, a composite floor of recycled tires can also relieve strain and stress on the back. If the objects to be inspected are very small, proper magnification can be provided to increase the accuracy

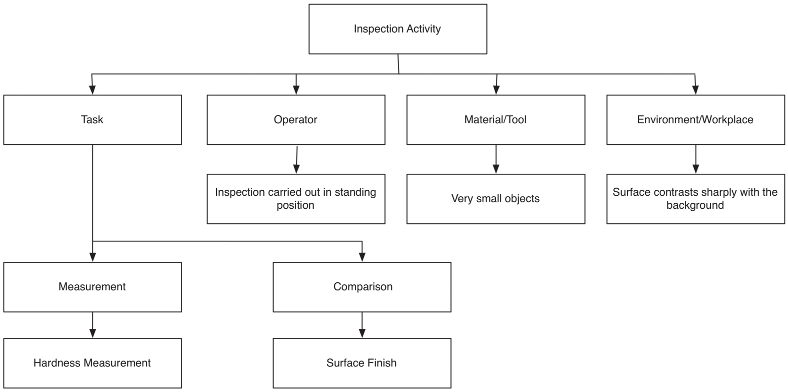

Figure 6.6 Sample hierarchical analysis of inspection activity in manufacturing

and efficiency of the inspection operation. Efficient illumination is very essential for the inspection task. For a surface that contrasts sharply with the background, front lighting should be used.

The takeaway is that the task, operator, environment, and material variables should be systematically analyzed to improve the performance of the activity. One can compile a list of other assistive devices in assembly and inspection areas for this purpose (Kansai, 1999).

Summary

Performance measures indicate how well an organization utilizes its labor, capital, and raw material resources among other inputs. The ability to compete effectively in both domestic and international markets has become the most important business issue of the 1990s (Hamel and Prahalad, 1994). A major study conducted by Queens University in Canada focused on identifying manufacturing practices that have a significant influence on company success (Sohal, Gordon, Fuller, and Simon 1999). Data was collected by means of a postal questionnaire that was mailed to senior staff members in 5,000 manufacturing industries. Improved quality and time reduction were the major factors identified for productivity improvement by this survey.

These findings are in agreement with what other experts consider measures of productivity and performance: quality, cycle time, and customer satisfaction (American Productivity Center, 1981; Burnham, 1982; Craig and Harris, 1973; Matta, 1989; Miller, 1992; Miterek et al., 1992; Mohanty and Rajput, 1988; Sandman and Hayes, 1980; Sparks et al., 1999; Sumanth, 1981; Yamashita, 1987;). Each of these elements of performance has limited value when viewed independently. In isolation, none of them can fully measure performance or fully describe how well the organization is doing. For example, high levels of productivity would not be meaningful if cycle times were increasing or customer service level was dropping.

Each of the primary performance measurements must be considered in tandem when judging the total activity performance. A manufacturing firm's competitive advantage in the market is a function of the plant's ability to (a) produce high quality products, (b) provide superior delivery performance, and (c) be a low cost producer (Umble, 1988). The degree to which a manufacturing firm can achieve these three objectives largely determines its longterm financial success.

Key mix of measurements of productivity must be derived from quality, cost, cycle time, and customer satisfaction. A family of measures such as this, rather than one isolated measure, will enable the analyst to view the organization as a whole, single, complex, and dynamic system. In addition, most of the productivity measurement and improvement efforts in the past have been more reactive in nature when the productivity problems are readily apparent and obvious to the analyst. A proactive approach can identify opportunities for improvement even though there are no visible signs of productivity problems. Industries must systematically identify productivity improvement opportunities, prioritize them according to importance, and find ways to make the human element effective.

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