Chapter 2
Engineering Activities in Product Life Cycle

2.1 Introduction

In this chapter we discuss the main engineering activities in each phase of product life cycle (PLC) with focus on quality and reliability activities. The purpose is to set the background for the following chapters of this book.

From the manufacturer's perspective, the life cycle of a product can be roughly divided into three main phases: pre-manufacturing phase, manufacturing phase, and post-manufacturing phase. We discuss the main engineering activities in each of these phases in Sects. 2.2–2.4, respectively. An approach to solving quality and reliability problems is presented in Sect. 2.5.

2.2 Engineering Activities in Pre-manufacturing Phase

The pre-manufacturing phase starts with identifying a need for a product, through a sequence of design and development activities, and ends with a prototype of the product. This phase can be further divided into two stages: front-end or feasibility stage and, design and development stage. The main activities in these two stages are outlined below [8].

2.2.1 Main Activities in Front-End Stage

The front-end stage mainly deals with product definition. Specifically speaking, this stage will define the requirements of the product, its major technical parameters, and main functional aspects and carries out the initial concept design. The main

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activities include generation and screening of ideas, product definition, project plan, and project definition review.

Once the need for a product is identified, a number of ideas are generated and some of them will be screened to further pursue. The screening deals with answering questions such as whether the idea is consistent with the strategic focus of the company, whether the market size, growth, and opportunities are attractive, whether the product can be developed and produced, and whether there are issues that may make the project fail.

Product definition states what characteristics the product should have in order to meet the business objectives and customer needs. It first translates feasible ideas into technically feasible and economically competitive product concepts, and then produces product concept through concept generation and selection. Two commonly used techniques to decide the best design candidate are design-to-cost and life-cycle-cost analyses. The design-to-cost aims to minimize the unit manufacturing cost, whose cost elements include the costs of design and development, testing, and manufacturing. The life-cycle-cost analysis considers the total cost of acquisition, operation, maintenance, and discarding, and is used for expensive products.

Project plan deals with planning the remainder of the new product development project in detail, including time and resource allocation, scheduling of tasks, and so on. A final review and evaluation of the product definition and project plan is conducted to decide whether to commit potentially extensive resources to a full-scale development project.

2.2.2 Main Activities in Design and Development Stage

The design and development stage starts with the detail design of the product's form, then progresses to prototype testing and design refinement through a test-analysis-and-fix (TAF) iterative process, and eventually ends with full product launch.

2.2.2.1 Quality and Reliability Activities in Detail Design Stage

The initial efforts of the design stage aims to arrive at optimal product architecture. The product architecture is the arrangement of the functional elements of a product into several physical building blocks (e.g., modules), including mapping from functional elements to physical components and specification of interfaces among interacting physical components. Establishing the product architecture needs to conduct functional decomposition and define the functional relationships between assemblies and components.

Once the product architecture is established, the design process enters the detail design stage. In this stage, the forms, dimensions, tolerances, materials, and surface properties of all individual components and parts are specified; and all the drawings and other production documents (including the transport and operating instructions) are produced.

The detail design involves a detailed analysis for the initial design. Based on this analysis, the design is improved and the process is repeated until the analysis indicates that the performance requirements are met.

The detailed analysis involves simultaneously considering various product characteristics such as reliability, maintainability, availability, safety, supportability, manufacturability, quality, life cycle cost, and so on. Design for these characteristics or performances are further discussed in Chap. 7.

Design for quality is an integrated design technique for ensuring product quality. It starts with an attempt to understand the customers' needs. Then, the House of Quality is used to transform the customer needs into the technical requirements or engineering specifications of the product in the concept design stage; and the quality function deployment (QFD) is used to determine more specific requirements in the detail design stage. The Taguchi method can be used to determine important design parameters. These techniques are discussed in detail in Chap. 8.

Design for reliability involves a number of reliability related issues, including reliability allocation and prediction. *Reliability allocation* is the process to determine the reliability goals of subsystems and components based on the system reliability goal, which includes the system-level reliability, maintainability, and availability requirements (e.g., mean time between failures, mean time to repair, mean down time, and so on). *Reliability prediction* is a process used for estimating the reliability of a design prior to manufacturing and testing of produced items. These are discussed in detail in Chap. 9.

2.2.2.2 Reliability Activities in Development Process

The development stage deals with component and product prototype testing. The purpose is to refine the design. Using the TAF cycle, the initial design is revised and improved to meet design requirements and specifications. The reliability activities involved in the development stage fall into the following three categories:

- Reliability assessment,
- Development tests, and
- Reliability improvement.

Reliability assessment is basically concerned with evaluation of the current reliability during the development process. It can be at any level from system down to component. Reliability assessment requires test data from carefully designed experiments and statistical analysis to estimate the reliability.

Development tests are carried out during the development stage to assess and improve product reliability. Some of the tests carried out during product development stage are as follows:

- Testing to failure. This can be carried out at any level and each failure is analyzed and fixed.
- Environmental and design limit testing. These tests are carried out at the extreme conditions of its operating environment (including worst-case operating conditions). All failures resulting from the test are analyzed through root-cause analysis and fixed through design changes.
- Accelerated life testing. This involves putting items on test under conditions that are far more severe than those normally encountered. It is used to reduce the time required for testing.

Testing involves additional costs that depend on the type of tests, number of items tested, and the test duration. On the other hand, more testing effort results in better estimates of reliability and this in turn leads to better decision making. As a result, the optimal testing effort must be based on a tradeoff between the testing costs and benefits derived through more accurate assessment of reliability. These issues are further discussed in Chap. 10.

Reliability improvement can be achieved through stress-strength analysis, redundancy design, reliability growth through a development program, and preventive maintenance (PM) regime design.

Stress-strength analysis assumes that both the strength of a component and the stress applied to the component are random variables that are characterized by two distribution functions, from which the probability of failure can be derived. Different designs can have different distributions of stress and strength and hence different reliabilities. As such, the stress-strength analysis can be used for the purpose of reliability improvement.

Redundancy design involves using a multi-component module to replace a single component. The reliability and cost of module increase with the number of components and depend on the type of redundancy. Three different types of redundancy are hot standby, cold standby, and warm standby. In hot standby, several identical components are connected in parallel and work simultaneously. The module fails when all the components fail. As a result, the module lifetime is the largest of all the components. In cold standby, only one component is in use at any given time. When it fails, it is replaced by a working component (if available) through a switching mechanism. If the switch is perfect and the components do not degrade when not in use, the module lifetime is the sum of lifetimes of all the components of the module. In warm standby, one component works in a fully loading state and the other components work in a partially loading state. The component in the partially loading state has a longer expected life than the component in the fully loading state. As a result, the warm standby module has a longer expected life than the hot standby module when the other conditions are the same.

Reliability growth involves research and development effort where the product is subjected to an iterative TAF process. During this process, an item is tested for a certain period of time or until a failure occurs. Based on a root-cause failure analysis for the failures observed during the test, design and/or engineering modifications are made to improve the reliability. The process is repeated until the reliability reaches a certain required level. The reliability growth process also deals with the reliability prediction of the system based on the test data and design changes using various reliability growth analysis techniques, which are discussed in detail in Chap. 11.

Finally, the field failure probability can be considerably reduced by implementing a well-designed PM regime, which specifies various PM activities in a systematic and comprehensive way. The maintenance related concepts and issues are discussed in Chaps. 16 and 17.

2.3 Engineering Activities in Production Phase

Three main activities involved in the production phase are production system design, production system operation, and quality control for operations. In this section, we first introduce various types of production systems and then discuss these three main activities.

2.3.1 Types of Production Systems

Based on production volume and production variety (i.e., number of different types of products produced), the production system varies from factory to factory and from product to product. Three common types of production systems are job shop production, batch production, and mass production. We briefly discuss them below.

2.3.1.1 Job Shop Production

The job shop production system is characterized by the low production volume and high production variety. Production equipments are mostly general purpose and flexible to meet specific customer orders, and highly skilled labor is needed to handle such equipments.

Flexible manufacturing systems (FMS) have been widely used in the job shop production system. The main components of an FMS are computer numerical controlled (CNC) machine tools, robots, automated material handling system, automated storage and retrieval system, and computers or workstations. The FMS can be quickly configured to produce a variety of products with changeable volume and mix on the same system. However, it is complex as it is made up of various different techniques, expensive as it requires a substantial investment of both time and resources, and of low throughput. For more details about the FMS, see Ref. [1].

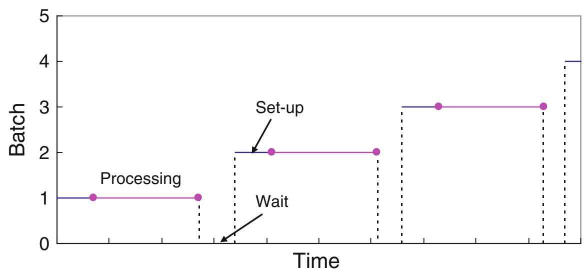

Fig. 2.1 Batch production system

2.3.1.2 Batch Production

Batch production is suited for medium volume lot with moderate product variety. In batch production, the production order is repeated at regular intervals as shown in Fig. 2.1. Generally, production equipments are general purpose and suitable for high production volume, and specially designed jigs and fixtures are usually used to reduce the setup time and increase the production rate. It requires that the skill level of labor should be reasonably high but may be less compared to job shop production.

2.3.1.3 Mass Production

Mass production is suited for large production volume and low production variety with low cost per produced unit. The mass production process is characterized by

- Mechanization to achieve high volume;
- Elaborate organization of materials flow through various stages of manufacturing;
- Careful supervision of quality standards; and
- Minute division of labor.

The mass production is usually in a continuous production or line production way. The line production is a machining system designed for production of a specific part type at high volume and low cost. Such production lines have been widely used in the automotive industry.

2.3.2 Production System Design

A well-designed production system ensures to achieve low production cost, desired productivity, and desired product quality. The main activities involved in the production system design include (see Ref. [3] and the literature cited therein):

- Supply chain design;
- Production planning and process specifications;
- System layout on the plant floor; and
- Equipment selection and tooling.

We briefly discuss each of these activities below.

2.3.2.1 Supply Chain Design

Two key elements in the production phase are obtaining raw materials and converting raw materials into products (including manufacture and assembly of components as well as assembly of assemblies). Raw materials and some components and assemblies of a product are usually obtained from external suppliers, which form a complex network termed as supplier chain. The supply chain design deals with a variety of decisions, including supplier selection, transportation way, inventory management policies, and so on. Various options form many combinations, and each combination has different cost and performance. Given various choices along the supply chain, the supply chain design aims to select the options so as to minimize the total supply chain cost.

One key problem with supply chain design is to appropriately select suppliers. Supplier selection is a multi-criteria decision making (MCDM) problem, which involves many criteria such as quality, price, production time and direct cost added, transportation, warehouse, and so on. Many methods have been developed for solving the MCDM problems, and the main methods are presented in Online Appendix A.

Once suppliers are selected, they will be managed through the activities of several production functions (groups or departments), which include quality, manufacturing, logistics, test, and so on. For details on supply chain design, see Refs. [2, 6, 7].

2.3.2.2 Production Planning and Process Specifications

There are many design parameters for a manufacturing system, such as number of flow paths, number of stations, buffer size, overall process capability, and so on. These depend on production planning, and further depend on process planning, tolerance analysis, and process capability indicators.

Process planning determines the steps by which a product is manufactured. A key element is setup planning, which arranges manufacturing features in a sequence of setups that ensures quality and productivity.

In product design, the tolerance analysis deals with tolerance design and allocation for each component of the product. In production system design, the tolerance analysis deals with the design and allocation of manufacturing tolerance, which serves as the manufacturing process selection.

Different from the process capability indices that measure a specific process's capability, process capability indicators attempt to predict a proposed production system's performance. By identifying key drivers of quality in the production system, these indicators can serve as guidelines for designing production systems for quality.

2.3.2.3 System Layout

An important step in production system design is system layout. The system layout impacts manufacturing flexibility, production complexity, and robustness.

Manufacturing flexibility is the capability of building several different products in one system with no interruption in production due to product differences. Manufacturing flexibility allows mass customization and high manufacturing utilization. There exists a certain complex relation between flexibility and quality, and use of robots can improve both flexibility and quality.

Production systems become more and more complex due to the demand for more product functionality and variety. The manufacturing complexity is characterized by the number of parts and products, the types of processes, and the schedule stability. Generally, complexity negatively impacts manufacturing performance measures, including quality.

Robustness deals with the capability against process drift and fluctuations in operations. The process drift will lead to producing defective parts. Different equipment and inspection allocation can have different machine processing time and defective part arrival rate, and have different yields and drift rates. Sensitivity analyses can be conducted to examine their interrelations for different design candidates. The fluctuations in operations result from uncertain or inaccurate system parameters and can damage product quality. Robust production system design aims to minimize this damage.

2.3.2.4 Equipment Selection

Equipment determines machine operating characteristics (e.g., operating speed) and reliability, and hence can impact the quality of produced products. As such, the equipment selection aims to achieve a good tradeoff between productivity and quality.

Both operational and quality failures exist in production processes. Operational failures refer to machine breakdowns, and quality failures refer to production of defective parts. The processing speed and buffer capacity affect these two types of failures in a complex way. A quantitative model that considers these types of failures is needed for equipment selection and operating speed optimization.

2.3.3 Quality Control System Design

The product production includes three elements: inputs (i.e., materials and labor of operators), processes and outputs (i.e., finished products). Techniques to control product quality evolve over time and can be divided into the following four approaches:

- Creating standards for producing acceptable products. It focuses on quality testing at the output end of the manufacturing process.
- Statistical quality control, including acceptance sampling with focus on the input end of the manufacturing process as well as statistical process control with focus on the manufacturing process.
- Total production systems for achieving quality at minimum cost. It focuses on the whole production system from raw materials to finished product, through research and development.
- Meeting concerns and preferences of consumers. It focuses on consumers' needs and involves the whole PLC.

As seen, the approach to product quality evolves from focusing on quality test and control to focusing on the quality assurance and improvement. In other words, the focus gradually moves from the downstream of the PLC toward the upstream of the PLC. This is because fixing a product quality problem in the upstream is much more cost-effective than fixing it in the downstream.

Quality control techniques can be divided into two categories: quality control for product quality design and improvement, and quality control for production systems. The techniques in the second category include quality testing and statistical quality control, and the techniques in the first category include several basic approaches. These are further discussed below.

2.3.3.1 Basic Approaches for Quality Design and Improvement

Basic design approaches for design and improvement of product and process include QFD, design of experiments (DOE), and failure mode and effects analysis (FMEA). We briefly discuss these issues here and further details are presented in Chaps. 7 and 8.

QFD has been widely applied to both product design and production planning. It first translates customer requirements into product attributes for the purpose of product design, and then further translates the product attributes into production process requirements to provide guidelines for the design of the production process and the design of the quality control process.

DOE approach is developed by Taguchi [9] for the parametric design of product. The basic idea is to optimally select the combination of controllable (or design) parameters so that the output performance is insensitive to uncontrollable factor variation (or noise). The optimization is based on the data from a set of well-designed experiments. As such, DOE has been widely applied to design or quality improvement of product or/and process. For example, when DOE is used to design a robust production system, physical experiments are first carried out in a production process, the experimental data are then analyzed to identify key process parameters, and the key process parameters are optimized to achieve a desired target. To avoid production disruptions, real experiments may not be conducted, instead, one can use simulation and existing data.

FMEA is an important tool used to identify failure modes, analyze their effects, and assess their risk. In a quality planning process, FMEA is often used to assess the risks of candidate manufacturing processes so as to identify the best candidate. FMEA has been widely applied to production planning and management to improve quality and throughput.

2.3.3.2 Quality Control at Input

Statistical quality control is the application of statistical techniques to measuring and evaluating the quality of a product or process. Two typical techniques are acceptance sampling and statistical process control. We briefly discuss the acceptance sampling here and the statistical process control will be dealt with in the next subsection.

The input materials are obtained from external suppliers in batches. Their quality can vary from batch to batch and has a significant impact on the conformance quality of items produced. One way of ensuring high input quality is to test for the quality and a batch is either accepted or rejected based on the outcome of the test. The test is based on a small sample from the batch. The cost and relevant risks associated with testing depend on the sample size as well as the type and duration of tests. The key issue with acceptance sampling is sampling scheme design. More details about the acceptance sampling are presented in Chap. 13.

2.3.3.3 Quality Control in Process

Quality control in process deals with quality inspection planning and statistical process control. We first look at inspection planning, which deals with quality inspection in production systems. The principal issues with inspection planning include quality failures, quality inspection, and the actions that may be taken in response to inspection and measures of system performance.

The design variables of quality inspection system include the number and locations of inspection stations, inspection plans (e.g., full inspection or sampling), and corrective actions (e.g., rework, repair, or scrapping). The number and location of inspection stations are dependent on both the production system and quality control system; main influence factors include system layout and type of production systems; and design constraints can be inspection time, average outgoing quality limit, or budget limit.

When some controllable factors significantly deviate from their nominal values, the state of production process changes from in control to out of control. If the change is immediately detected, then the state can be brought back to in control at once so as to avoid the situation where many nonconforming items are produced. The process control methods depend on the type of manufacturing system.

In the case of batch production, a process control technique is to optimize the batch size. The expected fraction of nonconforming items increases and the setup cost per item decreases as the batch size increases. As a result, an optimal batch size exists to make the unit manufacturing cost minimal.

In the case of continuous production, a main process control technique is the use of control charts to monitor product quality and detect process changes. It involves taking small samples of the output periodically and plotting the sample statistics (e.g., the mean, the spread, the number or fraction of defective items) on a chart. A significant deviation in the statistics is more likely to be the result of a change in the state of the process. When this occurs, the process is stopped and the controllable factors that have deviated are restored back to their nominal values before the process is put into operation.

The cost of quality and accuracy of state prediction depend on the inspection policy, nature, and duration of the testing involved as well as the control limits. The design parameters of the inspection policy include the sampling frequency and sample size. The inspection policy impacts not only quality but also productivity. This is because normal production may be interrupted when a control chart generates an out-of-control signal, which can be either an indication of a real quality problem or a false alarm. Generally, reducing the number of controls leads to better productivity. Further discussion on control charts are presented in Chap. 14.

2.3.3.4 Quality Control at Output

Quality control at output deals with the quality inspection and testing of produced items to detect nonconforming (nonfunctional or inferior) items and to weed them out before the items are released for sale. For nonfunctional items, testing takes very little time; but for inferior items, the testing can take a significant length of time. In either case, testing involves additional costs, and the cost of testing per unit is an increasing function of the test period. As such, testing design needs to achieve a tradeoff between the detection accuracy and test effort (i.e., time and cost).

For electronic products, the manufactured items may contain defects, and the defects can be patent or latent. Environmental stress screening (ESS) can be effective to force the latent defects to fail, and burn-in can be used to detect the items with patent defects. Burn-in involves testing the item for a period of τ. Those items that fail during testing are scrapped or repaired. The probability that an item is conforming after the burn-in increases with τ. As such, the reliability of the item population is improved through burn-in but this is achieved at the expense of the burn-in cost and a useful life loss of τ. A number of models have been developed to find the optimal testing scheme. These are discussed in Chap. 15.

2.3.4 Production Management

Production management focuses on the continuous improvement of product quality. Quality improvements can be achieved by identifying and mitigating quality bottlenecks, implementing an Andon system, batching products, and effectively planning PM. A quality bottleneck is the factor that most impedes product quality. Improving the bottleneck factor will lead to the largest improvement in product quality. An Andon system is an alert system to indicate a quality or process problem (e.g., part shortage, defect found, tool malfunction, etc.). The alert can be activated manually by a worker or automatically by the production equipment itself. When an alert is activated, the production line can be stopped if needed to correct the problem. Production batching is usually used in multiple-product manufacturing systems and can reduce changeover time and cost, and improve quality. Finally, implementing an effective PM program for the production system can improve productivity and quality.

2.4 Engineering Activities in Post-manufacturing Phase

The post-manufacturing phase can be further divided into three stages: marketing, post-sale support, and retirement. We discuss the main activities in each of these stages below.

2.4.1 Main Activities in Marketing Stage

Standard products involve a marketing stage and there is no such a stage for custom-built products. Marketing deals with issues such as the logistics of getting the product to markets, sale price, promotion, warranty, channels of distribution, etc. To address these issues one needs to respond to external factors such as competitor's actions, economy, customer response, and so forth.

2.4.2 Main Activities in Post-sale Support Stage

The support service is necessary to ensure satisfactory operation of the product, and can add value to the product from both manufacturer's perspective (e.g., direct value in initial sale of product) and customer's perspective (e.g., extending the life cycle, postponing product replacement, etc.). The support service includes one or more of the following activities:

- Providing spares parts, information, and training
- Installation

- Warranties
- Maintenance and service contracts
- Design modification and customization.

Among these activities, warranties and maintenance are two major issues. Here, we briefly discuss these two issues and more details are presented in Chaps. 16 and 17.

Warranty is an assurance that the manufacturer offers to the buyer of its product, and may be considered to be a contractual agreement between the buyer and manufacturer (or seller). It specifies both the performance to be expected and the redress available to the buyer if a failure occurs or the performance is unsatisfactory. Usually, the manufacturer repairs or replaces the items that do not perform satisfactorily or refunds a fraction or the whole of the sale price. Three important issues associated with product warranty are warranty policy, warranty servicing cost analysis, and warranty servicing strategy (e.g., repair or replace).

Maintenance is the actions to control the deterioration process leading to failure of a system or to restore the system to its operational state through corrective actions after a failure. As such, maintenance can be broadly divided into two categories: PM and corrective maintenance (CM). Two important issues for the manufacturer of a product are maintainability and serviceability design, and the development of an appropriate PM program. The program will include various PM actions with different intervals or implementation rules for the components and assemblies of the product.

Carrying out maintenance involves additional costs to the buyer and is worthwhile only if the benefits derived from such actions exceed the costs. This implies that maintenance must be examined in terms of its impact on the system performance. For more details about maintenance, see Ref. [5].

2.4.3 Recycle, Refurbishing, and Remanufacturing

Defective or retired products may return to the manufacturer, who can get profits from the return through recycling, refurbishing, or remanufacturing. These have significant differences in the process and product performances.

Recycling is a process that involves disassembling the original product and reusing components in other ways, and none of the original value is preserved. Recycling often discards many of the parts, uses large amounts of energy and creates much waste and burdens.

Refurbishing is servicing and/or renovation of older or damaged equipment to bring it to a workable or better looking condition. A refurbished product is usually worse than the new one in condition.

Remanufacturing is the process of disassembly and recovery. In remanufacturing, the entire product is taken apart, all parts are cleaned and inspected, defective parts are repaired or replaced, and the product is reassembled and tested. As such, remanufactured products can be as good as the original ones if part conformity is insured, and even exceeds the original factory standards if new repair technology is applied or an original weakness/defect in design is identified and corrected in the remanufacturing process. Remanufacturing not only reuses the raw materials but also conserves the value added to the raw materials in the manufacturing process.

2.5 Approach for Solving Quality and Reliability Problems

Modern manufacturing deals with not only the technical aspects but also commercial and managerial aspects. All these aspects need to be properly coordinated. To effectively manage product quality and reliability requires solving a variety of problems. These include:

- deciding the reliability of a new product,
- ensuring certain level of quality of the product,
- assessing the quality and reliability of current products being manufactured, and
- improving the reliability and quality of the current product.

Solving these problems generally involves the following four steps:

- Step 1: Identify and clearly define a real-world problem.
- Step 2: Collect the data and information needed for developing a proper model to assist the decision-making process.
- Step 3: Develop the model for solving the problem.
- Step 4: Develop necessary tools and techniques for analyzing the model and solving the problem.

This approach can be jointly implemented with the plan-do-check-action (PDCA) management cycle (e.g., see Ref. [4]). Here, "Plan" deals with establishing the objectives and processes necessary to produce the expected output, "Do" means to implement the plan, "Check" deals with studying the actual results and comparing them with the expected ones, and "Action" means corrective actions (including adjustments) on significant differences between actual and expected results. The PDCA cycle is repeatedly implemented so that the ultimate goal is gradually approached.

References

1. El-Tamimi AM, Abidi MH, Mian SH et al (2012) Analysis of performance measures of flexible manufacturing system. J King Saud Univ Eng Sci 24(2):115–129
2. Farahani RZ, Rezapour S, Drezner T et al (2014) Competitive supply chain network design: an overview of classifications, models, solution techniques and applications. Omega 45(C):92–118
3. Inman RR, Blumenfeld DE, Huang N et al (2013) Survey of recent advances on the interface between production system design and quality. IIE Trans 45(6):557–574

4. International Organization for Standardization (2008) Quality management systems. ISO 9000:2000
5. Jiang R, Murthy DNP (2008) Maintenance: decision models for management. Science Press, Beijing
6. Klibi W, Martel A, Guitouni A (2010) The design of robust value-creating supply chain networks: a critical review. Eur J Oper Res 203(2):283–293
7. Manzini R, Gamberi M, Gebennini E et al (2008) An integrated approach to the design and management of a supply chain system. Int J Adv Manuf Technol 37(5–6):625–640
8. Murthy DNP, Xie M, Jiang R (2003) Weibull models. Wiley, New York, pp 324–347
9. Taguchi G (1986) Introduction to quality engineering. Asian Productivity Organization, Tokyo

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