A Framework for Implementation of Green Manufacturing in Customized Products Manufacturing Enterprises

*GU Zhenyu**, *ZHU Yaoyao*, *XIANG Jilei*

College of Automation, Chongqing University, Chongqing 400044, P. R. China

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Abstract: An increase in public environmental awareness and pressures from the government's determination to deal with environmental problems force manufacturers to implement green manufacturing (GM). However, since managers and stakeholders lack understanding of GM and its complexity, the manufacturing enterprise, especially the small and medium ones, are constantly facing the problems of how to make a reasonable decision for an environmental problem, and the adopted approaches have no clear payoffs. The customized design, flexible production, and diversified services in customized production make the problems more challenging. In order to solve this problem, this paper proposes a framework for the implementation of GM in customized products manufacturing enterprises (CPME). A three-layer framework, i.e., the goal layer, the product life-cycle layer and the supporting layer, is designed to provide a methodology to help implement GM. In this model, the GM practice processes are divided into four stages from the life-cycle perspective, i.e. design, production, use, and disposal. The preliminary practice of GM in an electrical product manufacturing company is carried out, and the implementation effect shows that the system framework is helpful to make a comprehensive understanding of GM and to improve the operability of GM practices. The integrated product model is an effective way to integrate the life cycle data.

Key words: green manufacturing; implementation; system framework; customized production

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0 Introduction

Green manufacturing (GM) has been praised in recent years for its significant benefits in social, environmental, and financial aspects. With the growing environmental awareness and a series of environmental laws, regulations, and standards, the manufacturing companies are enforced to perform GM. However, for the manufacturing companies, especially small and medium ones, a strong obstacle is lack of understanding of GM.

Recently, implementation models and methods have become important due to the complexity of GM. Allen et al.[1] studied the implementation strategy, methods and driving force of GM, and practiced at leading firms in Europe, Japan and the United States. They believed that a framework is an identified priority. Juan and Enrique[2] proposed a strategic framework, and divided the GM practices into four aspects: The analysis of business needs, the strategy, process control, and the results anglicizing. Tan et al.[3] proposed a decision-making model for GM, in which the objects of quality, cost and environmental impact were considered together. Deif[4] presented a system model for the new green manufacturing paradigm. Reich et al.[5] defined the specific using cases, and the developed frameworks of GM were suited. Abhijeet et al.[6] developed a structural relationship among different factors for the successful implementation of GM. Shankar et al.[7] proposed a framework to achieve GM in an Indian context. United Nations Environment Programme[8] introduced more GM practices and de-

*Corresponding author, E-mail address: gzy@cqu.edu.cn.

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scribed the strategies, methods, operating model, and application tools. These studies have played an important role in guiding and promoting GM practices and also laid the foundation for deepening the study. However, there are barely enough system guidelines to present a whole understanding and to guarantee the successful implementation of GM in customized products manufacturing enterprises (CPME). With the rapid development of manufacturing technology and information techonology (IT), the customized production (CP) has become a dominant type of production[9].

The goal of CP is to provide sufficient diversity, individuality, good enough quality, and acceptable prices. Generally speaking, the special needs for CPME to implement GM are as follows.

(1) During the early design phases, only functional requirements and product concepts are available. The range of candidate product scheme is usually large. Both designers and consumers often confuse a "greener" product design scheme with many selections. Therefore, the green design method needs to be improved.

(2) At the stage of manufacturing, the irrational operational plans often exist in order to improve production flexibility. Meanwhile, the resource utilization is not optimized. Therefore, the reasonable scheduling and the optimization of production processes are necessary to improve resource utilization and reduce the negative impact on the environment.

(3) At the stage of application, the diversification and personalization of products complicate the maintenance. Therefore, the maintenance staff want to know more information about the product in order to improve maintenance efficiency.

1 Implementation System Framework

1.1 System framework

The issue of implementing GM is to build a GM system. The framework describes the common features of the GM system. The prototype can help people recognize and analyze the essence of the GM system, design or adapt the GM system. The role of a system framework is to provide reference and guidance for practicing GM in CPME. To address these special needs of CPME, this paper proposes a framework for the implementation of GM in (Fig. 1). This framework includes three layers, i.e., the goal layer, the product life-cycle layer and the support layer. In this model, the GM practicing processes are divided into four stages from the life-

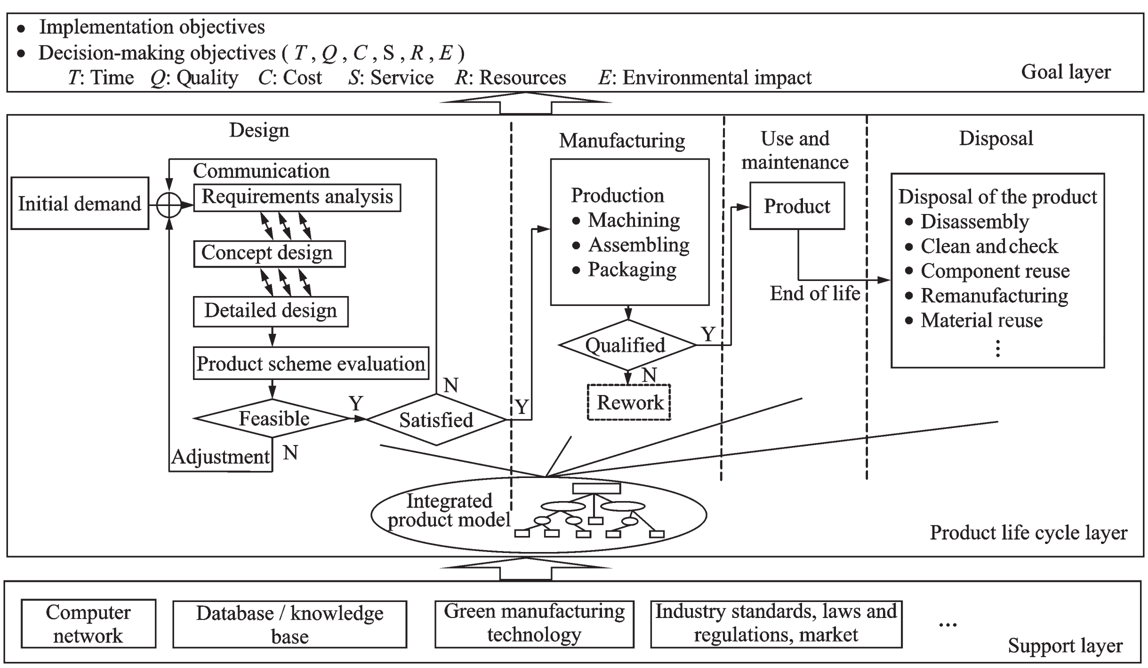

Fig.1 A system framework for the implementation of GM in CPME

cycle perspective., i.e. design, production, use and disposal.

(1) Goal layer

The goal layer attempts to highlight the implementation objectives and decision-making objectives. Implementation objectives provide an overview of the development goals of the enterprise and the goals of each specific implementation aspect. Decision-making objectives consider the target function and decision variables.

(2) Product life cycle layer

The product life cycle layer mainly describes the product life cycle processes, which mainly has two functions. Firstly, it is to divide implementation aspects, decompose the implementation tasks, and clarify the technology and methods. Secondly, it can be used to analyze and evaluate resource consumption and environmental impact on the whole life cycle stages, and to identify the serious problems and the implementation of focus clearly. The product life cycle processes in this model include four stages, which are design, manufacturing, use, and disposal[10]. The life cycle information is integrated by a product model.

(3) Support layer

The support layer provides basic support for the entire GM operation which includes the information system and network, etc. It describes the technical structure of implementing GM, the organizational structure of enterprises, industry standards, laws and regulations, market and information systems, etc.

1.2 Practice strategy

The practice strategy clarifies the principles and methods to carry out the GM, which is the core and key to guide GM practice. In 2001, the commission of the European Union presented a strategy, called integrated product policy (IPP), for strengthening and refocusing product-related environmental policies, which aims at promoting the development of a market for greener products and, ultimately, stimulating public discussion on this topic[11]. In IPP, the manufacturing enterprises are required to improve the environmental performance of products in the five aspects, waste management, development of energy-saving products, green product innovation, environmental responsibility, and environmental information exchange, and three principles, market-oriented, product information integrating and life-cycle perspective of GM practice[12].

According to the previous analysis, a GM practice strategy is proposed, as shown in Table 1, The operability is improved by dividing the complex implementation problem into four aspects from the life-cycle perspective. These four aspects are linked by the integrated product model. The integrated product model integrates the whole life cycle information.

Table 1 A green manufacturing strategy

Content	Description
Object	Customized product
Goal	Reducing impact on the environment in the life cycle of a product, and providing the acceptable green products
Core idea	Each practice stage is linked by the integrated product model. The product model integrates the whole life cycle information
Key	Information integration, product information model
Methods	Development of the market of green products; green design; cleaner production; Management of wastes; environmental information exchange

1.3 Integrated product model

The integrated product model is essentially a description of the product data structure. Besides the basic information, it integrates the environmental impact information of constituent parts and the process information in different stages of the life cycle. For example, Part1 is a part of the product. Then we can not only get basic information, such as material, weight, structure of Part 1, but also obtain the process data, equipment information, environmental impact indicators, and assembly/disassembly information. The integrated product model can be divided into the following three layers.

(1) Core layer

The core layer contains basic information that is generally generated in the product concept design stage according to customer demand. Once generated, it is seldom modified. Only if the customer demands are changed, it will change. Therefore, it has relatively static stability. This basic information includes manufacturing objectives, customer needs, overall parameters, and performance[13].

(2) Extension layer

The extension layer includes the information of the product in different life cycle stages. Its specific contents are retrieved dynamically by searching the related information of the different stages according to the product scheme. For example, the extension layer includes the related information of product modules, components, materials in the detailed design stage, the related information of manufacturing resources, process data and assembly methods in the production stage, the related information of debugging, installation and maintenance in the maintenance stage, the related information of demolition methods, disassembly sequence, and parts reprocessing in the waste products reprocessing stage.

(3) Environmental data layer

Environmental data represent the resource consumption and environmental impact values of product composition components and process in the extended layer, such as the amount of non-renewable resources, energy consumption, carbon emissions, and wastes[14]. It is the basis for analyzing and evaluating the environmental impact of various life stages of the product.

2 Case Study

We take an electrical product manufacturing company as an example to clarify the application process of the system framework. The products of this company are high-and-low voltage electrical switchagears. This product is mainly customized for engineering. Two urgent problems need to be solved: The first is that the surface treatment on the cabinet is producing serious environmental pollution; the other is that the plate waste is serious in cabinet body production because the workers cute the plate by experience. Therefore, we carried out the application analysis and preliminary practice of GM in this enterprise.

2.1 Life cycle analysis of electrical switchgears

An electrical switchgear is the power center and the power distribution unit which is used to control and monitor power lines and electrical equipment. The life cycle process of electrical switchgears is shown in Fig.2.

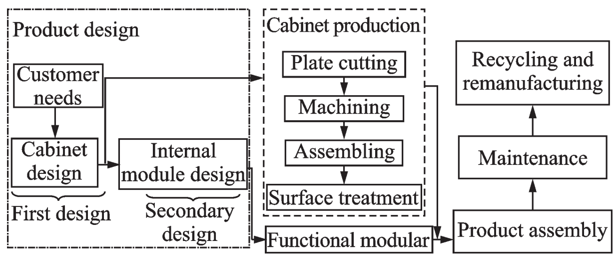

Fig.2 Life cycle process of switchgears

2.2 Switchgear body integrated information model

The core of the proposed implementation model is an integrated product information model. Therefore, building an integrated product information model is the key to the implementation. According to the design and manufacturing processes, the switchgear body integrated information model is established as shown in Fig.3. It is described by the EXPRESS language (the description fragment is shown in Fig.4).

2.3 Improvement on cabinet production

2.3.1 Material optimization support system for cabinet production

The main parts of the cabinet are skeleton, shell, and partitions, and the material is rod or plate. In the existing production process, the workers cut the plate by experience. Therefore, the material utilization rate is lower and the wastes are more. To solve these problems, the material optimization sup-

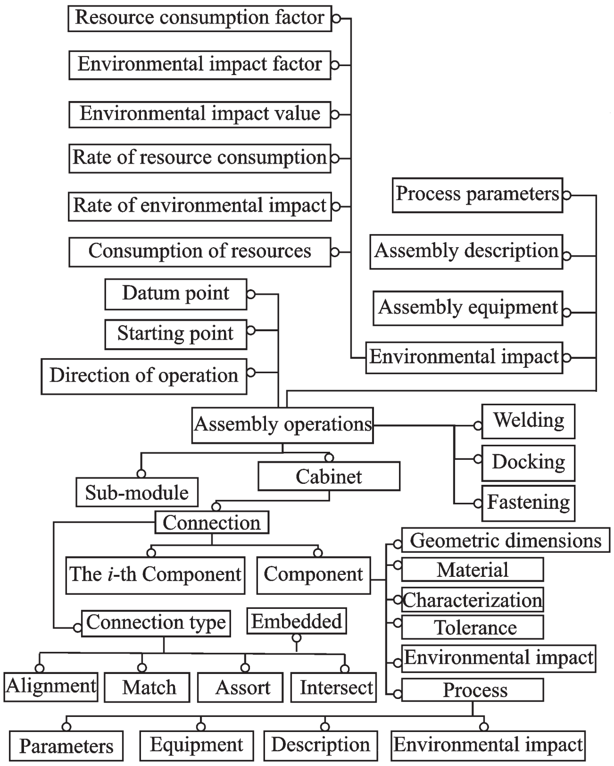

Fig.3 The cabinet integrated information model

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SCHEMA assembly;
ENTITY assembly_model;
sub_assemblies: OPTIONAL LIST [0:#] OF assembly_model;
piece_parts: OPTIONAL LIST [0:#] OF part;
assembly_relations: LIST [0:#] OF (LIST [1:#]) OF Connector);
END ENTITY;
ENTITY part;
name:STRING (50);
id:STRING (50);
nominal_shape:geometric_shape_model;
part_features: OPTIONAL LIST [0:#] OF feature;
part_tolerances: OPTIONAL LIST [0:#] OF tolerance;
part_material: OPTIONAL LIST [0:#] OF material;
part_environment_impact_value: REAL;
END ENTITY;
...
```

Fig.4 EXPRES description of the information model

port system for cabinet production was developed. This system not only improves the efficiency of the workers' cutting but also reduces material loss and saves resources.

2.3.2 Process improvement in cabinet production

The cabinet surface is treated to enhance and improve the surface properties. The treatment processes produce more wastes and cause serious environmental pollution. The major pollutants, national emission standards and experience value of emissions are shown in Table 2. Using the evaluation method proposed in Ref. [15], the environmental impact of the treatment process is analyzed.

Table 2 The main emissions of the electroplating process

Major pollutant	Experience value	National emission standards
Zinc/($mg\cdot l^{-1}$)	1.4—1.8	2.0
COD/($mg\cdot l^{-1}$)	180—260	100
Total phosphorus/($mg\cdot l^{-1}$)	1.2—1.7	1.5
Sulfuric acid mist/($mg\cdot m^{-3}$)	18—28	30

Suppose that the density function of emission ($f_i(x)$) subjects to the uniform distribution on $[a_i, b_i]$, then the density function of zinc is $f_1(x)=\begin{cases}2.5 & x\in(1.4, 1.8)\\ 0 & \text{Other}\end{cases}$, and the quantization value is 8.5. Similarly, the quantitative value of other emissions can be drawn. Thus, we can create the environmental impact matrix of the cabinet electroplating process of electrical switchgears. It is shown in Table 3, where *EI* represents the value of environ-

Table 3 The environmental impact analysis matrix

Emission (quantified value)	Environmental effects(Weighting factor)				*EI* of emission
	Heavy metals in the water(1)	Eutrophication (5)	Acidification (10)	Summer smog (2.5)	
Zinc(8.5)	8.500	0.000	0.000	0.000	8.5
COD(10)	0.000	0.220	0.000	0.000	1.1
Phosphorus(9.1)	0.000	27.846	0.000	0.000	139.23
Sulfuric acid mist (7.3)	0.000	0.000	8.760	0.350 4	88.476
EI	8.5	140.3	87.6	0.876	

mental effect.

Table 3 shows that the eutrophication resulting from the cabinet surface treatment process is very serious. The main pollutant is phosphorus. Therefore, we should improve the phosphide process, and strengthen the governance of the phosphorus emissions. Meanwhile, there is a greater impact on the operating workers' health although the sulfuric acid mist is not very serious. To reduce pollution, three solutions were analyzed: (1) using environmentally friendly surface treatment equipment and process updates, (2) introducing pollutant recovery and treatment equipment, (3) directly purchasing surface-treated plates produced by professional manufacturers, like galvanized sheet, which enterprises can select according to their respect situations.

3 Conclusions

This paper presents a framework to help CPME implement GM. This framework is a systematic and structural method to support managers and stakeholders to understand GM. It can improve the operability of GM practices by integrating life cycle information and the decomposition of the implementing problems. The integrated product model is essentially a description of the product life cycle data. It can support the GM practice for each implementing stage by indexing related information of different life cycle stages. This paper also presents the applicability of this framework through the preliminary practice of GM in an electrical product manufacturing company.

From the practice, this paper gains the following insights:

(1) The material optimization support system can help the enterprise to improve cutting efficiency and to reduce the loss. This can increase enterprises' acceptance of implementing GM.

(2) An environmental impact assessment of the production process can clarify the main environmental impact categories and help manager to make scientific decisions.

Some limitations of this paper are: (1) The framework has been implemented only in one manufacturing enterprise, and (2) the implementation effect evaluation is still qualitative. Future works include: (1) to validate the applicability of this framework to more manufacturing enterprise, (2) to develop more quantitative methods, and (3) to enhance the practicability of this framework.

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Author Dr. GU Zhenyu received his Ph. D. degree in Mechanical Manufacturing & Automation from Chongqing University, Chongqing, China, in 2010. He is currently an associate professor at the College of Automation, Chongqing University. His main research interests are green manufacturing, energy efficiency optimization of manufacturing systems.

Author contributions Dr. GU Zhenyu conceived the idea of this paper. Dr. GU Zhenyu and Ms. ZHU Yaoyao conducted the model and case analysis and wrote the manuscript. Mr. XIANG Jilei contributed to the discussion and background for the study. All authors commented on the manuscript and approved the submission.

Competing interests The authors declare no competing interests.

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面向定制产品制造企业的绿色制造实施模型

谷振宇，朱垚垚，向继磊

(重庆大学自动化学院,重庆 400044,中国)

摘要:公众环保意识的增强和政府处理环境问题的决心要求制造企业尽快实施绿色制造。然而,由于企业管理者和相关人员缺乏对绿色制造的认识和理解,加之绿色制造实施的复杂性,使得制造企业,特别是那些中小型制造企业的管理者一直存在着这样的困惑,即如何采取合理的实施策略,以及如何使实施能给企业带来明确的收益。同时中小企业的产品定制化生产模式和多元化服务形式,使绿色制造的实施问题变得更具挑战性。本文提出了一种绿色制造实施的框架模型。该模型包括一横一纵两条主线,一是面向实施规划的主线,包括目标层、支撑层生命周期层;另一个是生命周期主线,包括客户需求获取与分析、产品设计、制造、使用和维保、报废回收全过程。各生命周期过程间的信息交互通过产品集成信息模型来实现。基于该模型,我们在一家电气产品制造企业进行了绿色制造的初步实践。实践结果表明,该系统框架有助于从整体上认识绿色制造,提高了绿色制造实施的可操作性。

关键词:绿色制造;实施;系统框架;定制化生产