

Methodology and Technology of Design For Cost (DFC)

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Abstract- Design for X(DFX) is the key technology in concurrent engineering. Design For Cost (DFC) is a branch in DFX. DFC is a design method which analyze and evaluate a product's life cycle cost (LCC), then modify the design to reduce the LCC. In order to realize DFC, some key technologies were proposed: LCC model; design result's evaluation and generation of design suggestions; integration of DFC and other DFX methods. DFC's conceptual model included design tools, LCC estimation methods base, feature mapping and decision-making support system. Using Group Technology and feature modeling technology, a general concept model of DFC was developed at the detail design stage. The Activity-Based Costing (ABC) method was used to estimate product LCC in the conceptual model. Finally, a structure of LCC estimation methods base was established using agents. It can be used to estimate the LCC of mechanical parts and products.

Index Terms - Concurrent Engineering, Design For Cost (DFC)

I. INTRODUCTION

Nowadays, with the development of world market, modern manufacturing technologies are developing rapidly toward flexible, agile, intelligent and integrated direction. Many manufacturing theories come forth, for example, concurrent engineering(CE), virtual manufacturing, agile manufacturing and so on.

It is well known that product design decides product cost in large[1][2]. The time to begin reducing and controlling a product's cost must be at the designers have the greatest freedom to improve their design and to minimize the product's life cycle cost (LCC)[3][4]. Global and domestic environmental regulations and laws are forcing many companies to consider the environmental impacts of their processes and products. Recycling and disposal are becoming important duties of manufacturers. Customers consider not only the buying price of the product but also the operational and maintenance costs of the product. This trend leads most of the companies to show a keen interest in the life cycle cost approach in product design rather than in a pure manufacturing related cost approach. Much has been published in regard to LCC models and LCC analyses[5][6][7]

Even though concurrent engineering have made great strides in integrating design with other functional areas, there are still major gaps in accurate and timely costing information available to designers. This is due to three reasons:

- (1) the traditional isolation of product designers from the actual cost information located in the accounting database,
- (2) the lack of suitable tools to provide designers with rapid cost feedback on proposed new parts and products.
- (3) the inability to integrate the existing but diverse and heterogeneous data of the various functions.

Although many scholars realized the significance of this research at an early stage, and made elementary progress with respect to quick product price quoting, this research remains at the stage of adopting the stated method to establish a product cost estimating model and does not look into the relationship between the cost and design from the viewpoint of design. Furthermore, most of the estimating models are not very practical. Concurrent engineering have been a hot point in research, but Design for Cost (DFC) is not an enough research area. Reference [8] and [9] only gave an idea of DFC, but didn't include DFC's key technologies and model. Reference [10] analyzes the constituents of product life-cycle cost and their main costing methods, then it described a framework of design for product life-cycle cost with feature mapping. But the framework didn't include the structure of LCC estimation methods base in DFC and it was different from DFC's model in this paper.

In this paper, we proposed DFC's key technologies and model on the basis of summarizing the previous works. Then we developed a general concept model of DFC using Group Technology and feature modeling technology and a structure of LCC estimation methods base using agents.

II. DESIGN FOR COST AND ITS RESEARCH AREAS

Design For Cost (DFC) is a design method which analysed and evaluated the product's life cycle cost(include manufacturing cost, sale cost, use cost, maintenance cost, recycle cost, etc.) ,then modified the design to reduce the life cycle cost. Its characters can be concluded as followed:

- 1) In tradition, designers attached importance to the other parameters, but not cost. In product design process of DFC, the LCC must be an equivalent parameter as performance, schedule and reliability.
- 2) Product designers consider reducing product cost in the whole life cycle.
- 3) DFC need confirming parameters of manufacturing, usage, maintenance phases, for example, assembly cost percent unit, usage cost percent unit. Designer should balance performance, schedule, reliability, LCC and so on.

4) It makes sure that designers and their related personnel communicate and feedback cost information in time each other. So they can use some effective methods to control product LCC.

The research areas in DFC proposed are the following:

1) Cost features are extracted using LCC analysis. Then LCC database and LCC estimation methods base were established.

2) In order to provide design information in cost estimation, we must analyze design stages and models and then extract some design features that are related with LCC in different design models.

3) The research and development of software tools in DFC: DFC is a design method to face designers. To improve design efficiency and design quality, it is important to use DFC software tools in product design process.

4) According to market states, the balance between design and LCC must be found. Under increasingly furious market competition, the lowest product cost did not enough defeat other competitors. Product must be the best performance/price, namely provide the best functions in the suitable price that can be accepted by users. Because the price mostly depends on product cost and product functions are decided by designers, it is essential to balance between design and cost.

5) DFC must be integrated with the other DFX tools: Because DFC is faced the whole life cycle, it requests that DFC must harmonize the other DFX (DFM, DFA, etc.) tools to work. Therefore, we should establish an evaluation criterion to do it.

In addition, the other key technologies included how to confirm target cost, how to select the methods of manufacturing according to the project investment, etc.

Especially we point out that DFC is different from Design to Cost (DTC). DFC is the conscious use of engineering process technology to reduce LCC while DTC obtains a design satisfying the functional requirements for a given cost target[11]. (further detailed distinction between the two approaches can be found in the reference)

III. THE KEY TECHNOLOGIES OF DFC

DFC is one of support tools for CE and an important part of DFX. But DFC is very different from DFM and DFA. DFM (Design For Manufacturing) or DFA (Design For Assembly) is one link (Manufacturing or Assembly) in product life cycle, but

DFC faced the whole life cycle of product (See table I) . It's said that cost exist in design, manufacturing, assembly, testing, use, maintenance, recycling phases. To develop a DFC system, the following key problems should be solved.

(1) LCC model based on concurrent engineering: The model must evaluate LCC in different design phases and models.

(2) In the different design stages, how to select design tools and extract design features to estimate LCC, especially in concept design how to use the uncertain design information.

(3) How to extract cost features from LCC: LCC constitution is very complex. These are many different cost features among the different products. It is a premise to extracting some key cost features in order to estimate LCC.

(4) In order to estimate LCC in design process, we must establish a method to transform design features into cost features. Feature mapping theory was used to finish this work[12].

(5) Design result evaluation and making the improved design suggestions: This work need the support of the other DFX, namely we can not consider only one factor----life cycle cost. We must synthetically consider testability, assembly, reliability and other factors, then we can provide some reasonable design suggestions.

(6) Cost estimation methods: Different cost estimation may result in a different estimation result. So how to select a reasonable method to estimate LCC is an important problem. Generally speaking, we use different estimation methods in concurrent engineering because design information is integrity degree in different design stages. For example, in the concept design stage, parameter and ANN methods can be use. In the detail design stage, handbook and detail estimation methods can be selected[13]. Moreover, we must consider the difference of production batch, product type and life cycle length when we select some estimation methods. The selected method will be agile, easily usable, credible and accurate.

Additionally, the key technologies include target cost confirmation and integration of the other DFX. In a word, in order to realize the key technologies we should synthetically use feature modeling, virtual realization, artificial intelligent (AI), group technology (GT), industrial engineering (IE), information integration and so on.

TABLE I

DFXANALYSIS[14]

Life cycle links	Decision factors of product competition							Synthetical ability
	Quality	Cost	Time	Environment	Reliability	Productivity	...	
Manufacturing	DFMq	DFMc	DFMt	DFMe	DFMr	DFMp	...	DFManufacturing
Assembly	DFAq	DFAc	DFAt	DFAe	DFAr	DFAp	...	DFAssembly
Inspection	DFIq	DFIc	DFIt	DFIe	DFIr	DFIp	...	DFInspection
Recycling	DFRq	DFRc	DFRt	DFRe	DFRr	DFRp	...	DFRecycling
Serviceability	DFSq	DFSc	DFSt	DFSe	DFSr	DFSp	...	DFServiceability
...	...	...	...	...	...	...	...	...
Life cycle	DFQ	DFC	DFTime	DfE	DFReliability	DFproductivity	...	DFX

IV. DFC'S CONCEPTUAL MODEL AND ITS APPLICATION

For different design style there are different cost estimation methods, so there are some different projects to realize DFC. On the basis of concurrent engineering states, we proposed a conceptual model of DFC (figure 1). Figure 1 shows the key technologies relating to DFC in concurrent engineering.

A. DFC Conceptual Model's Work Flow

First, Quality Function Deployment (QFD)[15] translates all relevant custom needs into language of the engineering (i.e., product specifications). Then designers begin designing

product. In concurrent design we can use many design tools to cooperate with each other, DFC is one important design tool of the other design tools when designers make decision and evaluation. According to the design features information provided by different design tools, we use feature mapping tools translate design features into cost features. And cost estimation methods base provide cost estimation methods support; Database, knowledge base repository and expert system provide data and knowledge. They together finish the cost estimation work. Finally, the decision support module can synthetically balance many factors to aid designers make the best design decision and get a design result.

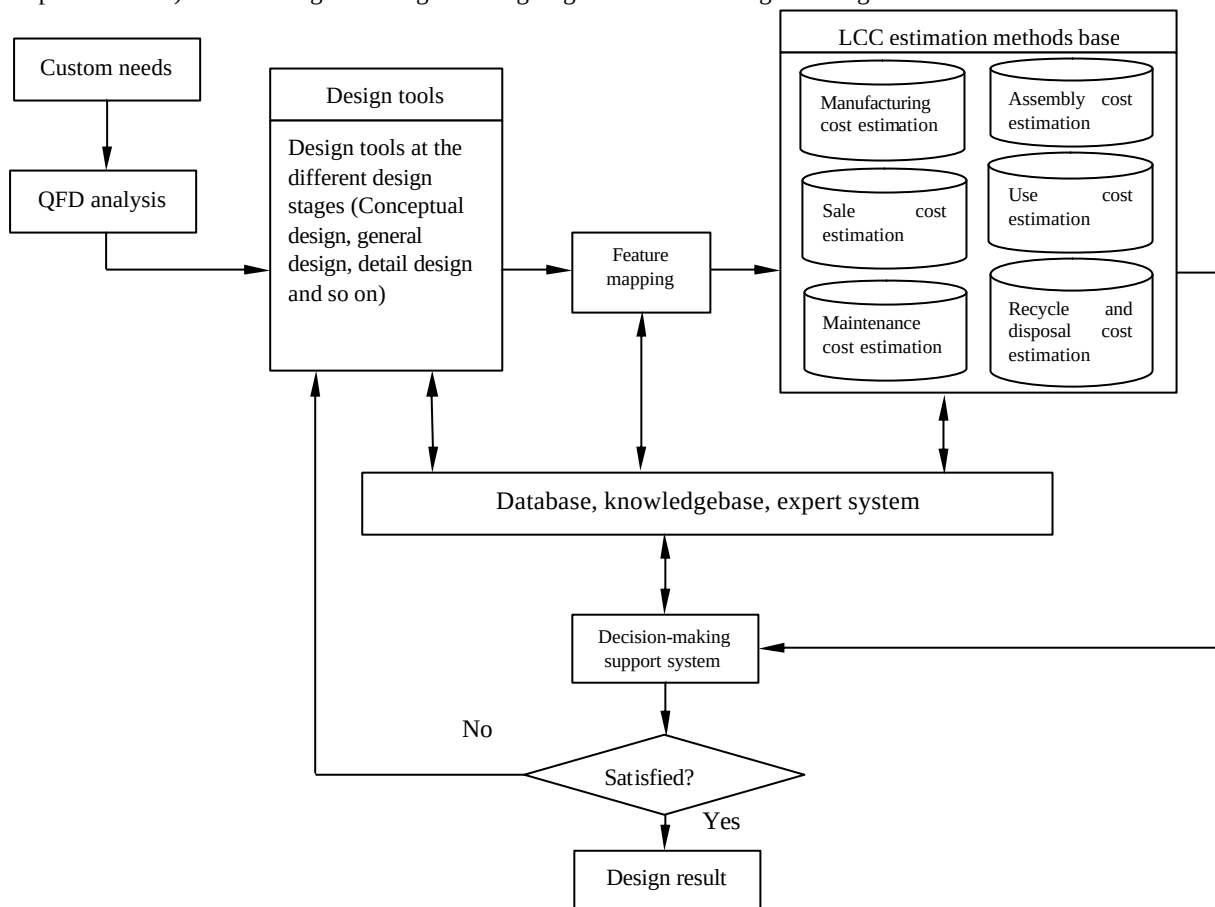


Fig. 1 The conceptual model of DFC

B. DFC Conceptual Model's Constitution Module Illumination

1) Database: Generally, we make use of database management system to manage history LCC data and new product's cost data. So the credible data were provided in time to estimate LCC. In allusion to time durative of LCC, LCC data can be stored in database on time sequence order. Manufacturing cost was managed by using Product Data Management (PDM).

2) Knowledge base: it stores design and cost estimation knowledge. Then realm knowledge can be provided for reasoning function in design and cost estimation process.

3) Expert system: using realm expert knowledge, reasonable

redesign suggestions are provided in design process.

4) Decision-making support module: This module finished synthetical evaluation and decision of design result and provide full support for design decision task. Then it records the data used in decision-making process, the data will be inquired in the future. Design compatibility analysis (DCA) was used in this module[16].

5) Design tools: It is an interface between designer and computer as a design tool for designers. Also it is an integrated development circumstance. Different tools are applied to different applications. It mainly includes CAX tools that support different design stages.

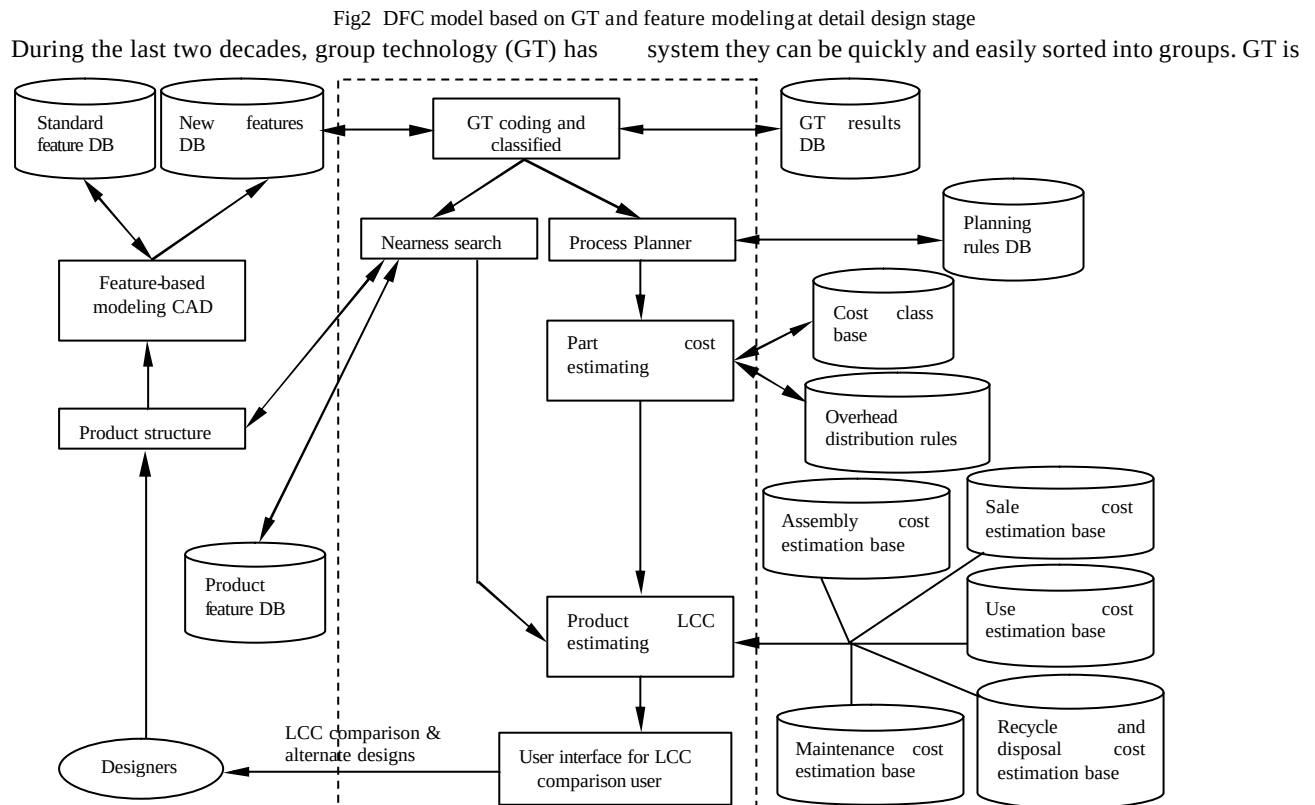
6) Feature mapping module: It is a bridge to translate design feature into cost feature and is a foundation to LCC estimation work.

7) DFC cost estimation methods base: It provides cost estimation methods. Its structure is an intelligent multi-class and multi-stage. In this paper Section V we will discuss it in detail.

C. DFC Conceptual Model's Application at Detail Design Stage

Design is a creative action, but creative design is not a big proportion in the normal product design[17]. So we mainly

discuss the DFC model of variant design in this paper. When we develop DFC tools software, we will be at the beginning of detail design because at this design stage design information is perfect and aided tools are plentiful. After developed the DFC tools of detail design, it is beneficial to the further development of DFC tools because its software system can provide a foundation. According to DFC conceptual model, we proposed a DFC's model based on GT and feature technology at the detail design stage (see figure 2). Figure 2 shows the model's core in the dashed pane. The main ideas are as follows:



been developed to copy with the problems associated with the product variety and small batch. GT is a concept that asserts that similar parts or products should be grouped and manufactured together[18][19]. Group technology many variety parts according to comparability of the figure, size, techniques, then enlarge the part's batch. So we can use plenty of advanced technology and equipment in big batch to solve the problems in the small batch. After GT was applied, obviously economic benefit was obtained in design, manufacturing and management. Moreover, GT application provides a good base for concurrent engineering. Product design based on GT takes advantage of part's similarity, namely a new part can be obtained to modify the similar part or product. Design does not start at zero so that GT strongly supports concurrent engineering application.

The application of GT has resulted in a number of coding systems that classify parts by their various features and characteristics. When parts have been classified by a GT coding

important to DFC system because such a coding system eases the database search for parts that are similar to a proposed part design.

From thread, surface, solid modeling to feature modeling, computer-aided design (CAD) system functions are increasingly perfect. In this paper, the model is established on feature modeling and GT. A feature-based model (FBM) is a CAD system that models products based on their features, instead of on more primitive graphical entities like points and lines[20]. FBMs are important because they are suitable input for the automated reasoning algorithms required by a DFC system. Lower level graphical CAD models are too data intensive and ambiguous in their meaning, while FBMs can provide concise, clear information and convey part and process meaning.

1. the model's work flow at detail design stage

First, designers use feature modeling system design parts and components according to customer needs. Second,

the GT classifier classifies the new part and component with an implementation of the Opitz GT classification system. Then according to GT code, the nearness search module finds existing parts which are similar to the proposed part. If the system can not find the similar part, GT CAPP is implemented and it estimates the part's cost by manufacturing features immediately. On the basis of LCC estimation, we can estimate the whole product LCC and the LCC information is feedback to designers. The LCC information can direct the designer modify the design in order to ensure to reach the lowest LCC. This work can be implemented till the design is satisfied.

2. the main module in the model at detail design stage

1) Feature-based modeling CAD: it helps designers represent products or parts in computers.

2) GT coding and classifier: it automatically classifies the new part and codes the new part according to GT code.

3) LCC estimation module: it estimates parts or product LCC and distributes the LCC. When it estimates LCC, it calculates assembly cost, male cost, use cost, maintenance cost, recycle and disposal cost.

3. the model characters

This model carried out classifying parts features using features and GT coding and estimated LCC according to GT. In fact, design feature extraction was finished using feature-based CAD system and feature mapping was finished using GT coding. In cost estimation we considered whole life-cycle cost (manufacturing cost, use cost, maintenance cost, recycle cost etc.). And we calculate cost use an activity-based cost (ABC) method that can guarantee cost accuracy.

ABC is a type of product costing that is challenging traditional costing methods[21][22][23]. Traditional costing methods allocate overheads proportionately to a product's use of a single variable such as direct labor. This volume-based allocation can be highly inaccurate for individual products in a diverse product mix. The essence of ABC is that it allocates indirect and overhead costs to products based on the use of a set of activity-driven cost drivers, such as number of batches, batch size, or number of product changes, based directly on a set of resources. ABC is vital to the DFC system because it provides significantly more accurate cost information.

FBM technology made automatic GT coding easier, namely GT code was automatically identified using features. GT application provided a convenience condition that we can use history data according to GT code. When we use ABC method to estimate cost, we need history data to compute unit cost percent activity. Then a new product cost estimation can be carried out by the new product activities. History information automation searching is easier using GT. The model integrates the manufacturing and accounting concepts of feature-based modeling, group technology coding, and activity based costing.

V. STRUCTURE OF LCC ESTIMATION METHODS BASE AND LCC ESTIMATION STRATEGIES IN DFC

A. LCC and its Estimation Methods in DFC

The life cycle cost of a product is made of the cost to the

manufacturer, user, and society[6]. The total cost of any product from its earliest concept through its retirement will eventually be borne by the user and will have a direct bearing on the marketability of that product.

The LCC concept was initially applied by the US Department of Defense (DoD). Its importance in defence was stimulated by findings that operation and support costs for typical weapon systems accounted for as much as 75% of the total cost[24]. However, most of the methodologies developed by the DoD were not intended for use for design but for procurement purposes.

While the life cycle cost is the aggregate of all the costs incurred in the product's life, it must be point out that there are differences between the cost issue that will be of interest to the person designing the product and the firm developing the product in a life cycle cost analysis. While the firm must know the total cost of the product, the designer is only interested in the costs that he/she can control. Some of the costs incurred in the life of the product are not as a result of the design. These costs are related to the way we do things. Life cycle cost can thus be classified into management related costs and design related costs. It is latter component that the designer is interested in. In this paper, we mainly discussed it in DFC. One cost category that may not be of interest to the designer is the research and development cost. This cost is not related to the actual design of the product but rather to the kind of product we are developing, the resources we commit to the process and the manner in which we use these resources to arrive at a design solution.

There are many costing methods available and Table II shows five familiar methods. In our opinion, the different estimation methods are selected at the different design stages. Generally, ANN cost method can be used at the conceptual design stage; ANN and parameter cost method can be selected at the earlier overall (general) design stage; Then parameter cost method can be used at the general design stage; Finally, engineering cost method can be selected at the detail design stage. For more detail see Chen Ke -zhang, Feng Xin-an and Chen Xiao-chuan[10] in English or Chen Xiao-Chuan, Liu Xiao-Bing and Feng Xin-An [13] in Chinese.

TABLE II
MAINLY COST ESTIMATION MTHODS[13]

Cost estimation methods	Properties		
	Uncertainty	Phase of design process	Precision
Parametric Cost Method	Low	Early	Middle
Analogy Cost Method	High	Late	Middle
ANN Cost Method	Middle	Early	High
ABC Method	High	Late	High
Engineering Cost Method	Low	Late	High

B. LCC Estimation Strategies in DFC

According to LCC estimation analysis, in DFC the LCC estimation principles proposed are the following:

1) Because most of cost estimation methods need history cost information, product cost information must be accumulated

in an enterprise. Then LCC database will be established and it can provide a base for the similar part's LCC estimation.

2) Using history LCC data we can establish a special LCC estimation model. It can provide a basis for the different product's LCC estimation. And then we may establish a general LCC estimation model on the basis of the special LCC estimation model using AI.

3) Because there are different usage areas in the different cost estimation methods, we must synthetically use many cost estimation methods at different design stages. And according to enterprise and product states the existed estimation methods are improved in order to improve LCC estimation's accuracy.

4) In order to make estimation methods satisfy enterprise needs, considering product practice states product performances and key parameters that will be reached are selected in product life cycle. Then design and cost estimation methods are selected on the basis of the key parameters. So we can more pertinently solve the problems in the design and LCC estimation and reduce the cost of increasing the estimation accuracy.

5) With the development of enterprise and society, the information that we need estimate LCC is so variational that LCC estimation is a dynamic work. Because it is some difference between LCC estimation model and fact states, we must develop and modify the LCC estimation model. Thus the model will be more and more perfect.

6) The information that cost estimation need must be provided by normal management work. For instance, purchase price, storage information, man-hour, history cost data and so on. It is an important effect for LCC estimation accuracy that the information was provided abundantly, completely, accurately and in time. In addition, we must consider cost management mode integrated with the estimation methods because it is associated with estimation methods. Then LCC estimation and cost management will be better than before.

C. Structure of LCC Estimation Methods Base in DFC

In this paper, we use AI harmonize cost estimation agents (Agents means cost estimation methods), we synthetically use many estimation methods to solve the uncertain of cost estimation at the early design stage. Then we find out the best result of cost estimation. Figure 3 shows the structure of LCC estimation methods base in DFC. According to information uncertain degree, four phases were disparted: high uncertain early and late phase, low uncertain early and late phase. During LCC estimation, a stage was decided on inputted information's detail degree, namely the information is more detail the stage is more later.

Cost estimation agent was established after the ability, reliability, reputation of completing tasks was tested and classified for every agent by some projects' training. We can save the relation and weight between agents in the structure on the basis of estimation results in fact. For example, the ability and reliability between level 3 (management agent) and level 4

(estimation agent) can be established by form ($X \xrightarrow{r} Y$), where Y means cost estimator agent, X means his manager, r is the relation of X and Y, which is stored in term thesauri, and w_i is the weight between X and Y, indicating Y's reputation or reliability in X's mind.

At the beginning, the default value of each w_i is "1", and it will be dynamically changed according to the performance of the related agent. When a new department is formed, the new manager is not acquainted with the staff, so he does not know who is the most capable, the only thing he can do is to assume that everybody is equally capable. But after several projects, some will show their ability, achieve reputation and be considered reliable and capable by the manager.

Task assignment to agent works similarly. At the beginning, the weight of agent is equal. After having finished a task successfully, the "contractor" agent will keep its weight, while the other's weight will be reduced a little, suppose 0.01. Next time, another agent may become the "contractor". If its weight is "1", it just keeps it, if not, the manager just adds a little bit to it, suppose 0.01 too. In this way, the rank of the agent will be changed dynamically.

When new problems arrive, the manager will first consult the agents who have the greatest weight. Only can it not solve the problem will the manager broadcast the information to others. When two agents give out solutions concurrently, and both satisfy the user's constraints. For example, if the user's permitted error is 10%, the accuracy of agent i is 8% and agent j is 5%, but agent i has higher strength, the manager will choose agent i instead of agent j. Estimation agent is selected by manager agent is flexible, not is fixed.

In a word, manager agent automatically combines different estimation methods through using and training in practice. Using this structure solved the problem that design information is not integral at the different design stages. It also solved the complex work how estimation methods was selected, combined and modified in the LCC estimation model. And estimation methods comparative steady in fact, this structure will not be completely changed when cost estimation was modified and added. Namely we can avoid the trouble that was led to by estimation methods were added, reduced or changed. This structure is so general that it can be used to parts, components and products according to some needs in practice.

VI. CONCLUSIONS

In the competitive market, manufacturing companies must be able to quickly design, manufacturing, and deliver products that meet changing consumer demands, and to make a profit on those products. Meeting this challenge must begin at the design stage, when decisions most affect a product's cost. Unfortunately, traditional product development is isolated from cost information at the time of design, so the focus is on a product's features and performance. Introducing accurate cost information into the design process for the use of designing for cost could improve the methods of product design, and enhance overall

profitability.

Based on previous works, this paper develops a model of Design for Cost with feature modeling and a structure of LCC estimation methods base using agents, so that it becomes possible to estimate the cost caused in subsequent phases of product life-cycle according to design decisions at early design stages and to minimize the life-cycle cost by selecting, modifying, or optimizing their design decisions.

Here we point out that LCC estimation in DFC is to improve product design. It is different from cost estimation in cost

accounting. In DFC we need not absolute cost value of product in design on the most conditions. But we only need comparable cost value of the product in design and select the best design. In cost accounting, cost value must be a value shown by money. Namely, we can use the comparable cost value in DFC but the absolute value must be used in cost accounting. In order to compare the different design, cost estimation in DFC only need the comparable cost value and not the absolute cost value among different design. In a sense, it reduce the complex degree in the LCC estimation.

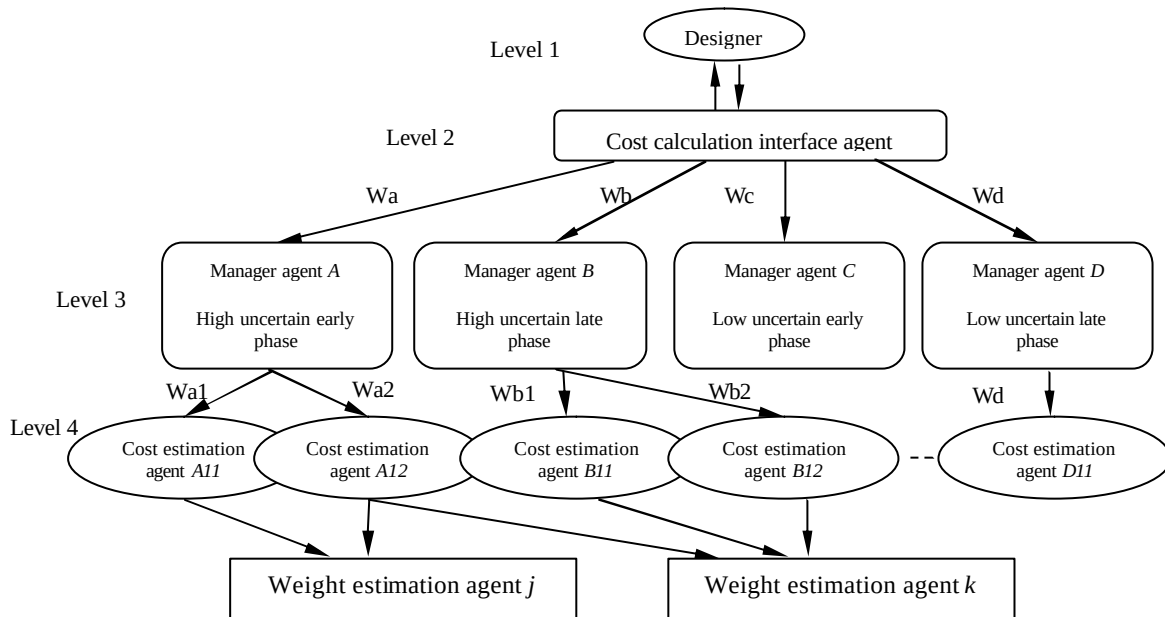


Fig3 Structure of LCC estimation methods base in DFC

Currently, we are developing the prototype system of LCC estimation in DFC according the structure that was provided in this paper. The detail will be discussed in other paper because this paper's length was limited. In the future the prototype system will be established to prove the feasibility of the overall concept of the DFC model.

ACKNOWLEDGEMENT

The author gratefully acknowledges the support of Donghua University fund.

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