Chapter 2

Product Life Cycle Cost Model

2.1 Introduction

Today's manufacturing environment should provide flexibility, reduction of product cycle time, and reduction of time to market.[12] There are some significant attributes of this environment:

- Increased product variety
- Reduced product life cycle
- Changed cost structures
- Hardly estimate the costs and benefits of computer integrated manufacturing (CIM) technology.

- ***Increased Product Variety***

Manufacturing companies have to struggle to provide a variety of products. The mass production of a standardized product is no longer acceptable. This period is considered the age of the personalized customer. Automobile and computer industries are good examples of such industries. Therefore, process design and product management complexity has increased.

- ***Reduced Product Life Cycle***

The product life cycle has been classified into three stages:

1. Design stage.
2. Manufacturing stage.
3. End-of-life stage.

In the old approach, the design and manufacturing cycle were executed separately and sequentially. During this approach, the design was approved before it could go forward into the production stage. Traditionally, the product life cycle has three phases:

- ***Initial Period***: Demand is weak and grows very slowly. This phase includes the development both of the product design and production methods.
- ***Mature Product Period***: Demand is at a sable level (constant).
- ***Final Period***: Gradual decline in the demand of the product.

Conventionally, once a product was established in the market, the manufacturer could hope for a relatively high demand for a number of years. This is no longer ture. There are many factors affecting the demand rate of the product such as

1. Product redesign
2. Updated design features
3. Decrease of product life cycle

These factors will need a flexible system to accommodate new product designs that have lower costs to recover the costs incurred during the peak demand period.

- ***Changed Cost Structure***

Manufacturing costs conventionally have been classified into three items:

1. Material
2. Labor
3. Overhead costs

The overhead was recovered by labor hours and cost charged for the work. In today's companies unmanned manufacturing has become standard. Therefore, the labor cost will not be the basis of a standard costing system. So, a new costing method is required. CIM can be considered a perfect candidate for the current technology. CIM can facilitate the cost associated with individual products at the time the cost is incurred.

- ***Hardly Estimate the Costs and Benefits of CIM***

1. The conventional investment appraisal techniques are invalid for a CIM environment.
2. CIM equipment is extremely flexible and it is hard to evaluate its capabilities and define its application.
3. Economic justifications are proper when a company is involved in replacing old equipment with new equipment.

2.2 Role of Computers in Manufacturing Systems

The methods used to identify the role of computers in manufacturing systems are usually based on the nature of the computer functions and its interface with the production process. If the computer is indirectly connected to the process, it is mostly used for specific tasks such as planning, decision support application, information management, and control. There are many examples of such applications such as cost estimating tasks, line balancing, and computer process planning (CPP). A second classification is when computers are directly connected to the production process for monitoring and control of activities. Supervisory and remote process control, quality control, and shop floor control and management are examples of such tasks. The application of computers in manufacturing system is further expanded by identification of their role at both plant and operation levels. The classification based on the direct and indirect roles at the plant and operation level[12] is illustrated in Table 2-1.

Table 2-1. Classification of direct and indirect applications

	Indirect Application	**Direct Application**
Plant Level	Macro Planning Models Accounting System Production Management CAD	CA Warehousing DNC FMS ASRS
Operation Level	CAPP CA Work Measurement CA Numerical Code Programming	CAT CNC Robotics CA Automatic Assembly

2.3 Product Life Cycle Cost Analysis

2.3.1 Cost Breakdown in Manufacturing Systems

The cost breakdown structure (adapted from Fabrycky[58]), in the context of the product life cycle cost analysis, is addressed in the following subsections.

2.3.1.1 Total System Cost (C)

The total system cost comprises (a) R&D cost, (b) investment cost, and

(c) operations and maintenance cost. The Total system cost is

$$C = (C_r + C_i + C_o) \quad (2.1)$$

where

C_r = R&D cost
C_i = investment cost
C_o = operations and maintenance cost

2.3.1.2 Advanced Research and Development (C_r)

This includes all costs associated with conceptual studies, fundamental research, advanced research and development, product design, production and test of prototype models, and associated documentation. Moreover, it covers all related program management tasks. These costs are essentially nonrecurring. The R&D cost is

$$C_r = (C_{rm} + C_{rr} + C_{re} + C_{rt} + C_{rd}) \quad (2.2)$$

where

C_{rm} = program management cost
C_{rr} = advanced R&D cost
C_{re} = engineering design cost
C_{rt} = equipment development and test cost
C_{rd} = engineering data cost

2.3.1.3 Program Management (C_{rm})

This cost can be defined as costs of management-oriented activity applicable to conceptual studies, research, product design, equipment development and testing, and related documentations. These costs include the program manager and his/her administrative staff. Management functions relate to C_{rr}, C_{re}, C_{rt} and C_{rd}. The program management cost is

$$C_{rm} = \Sigma\, C_{rm}^{\ i} \quad (2.3)$$

where

$C_{rm}^{\ i}$ = cost of specific activity i
N = number of activities

2.3.1.4 Advanced Research and Development (C_{rr})

Thses costs include conceptual studies perfomed to determine and justify a specific need. This includes effort oriented to defining job scenarios, system operational requirements, preliminary maintenance concepts, etc. The advanced research and development cost is

$$C_{rr} = \Sigma\, C_{rr}^{i} \qquad (2.4)$$

where

C_{rr}^{i} = cost of specific activity i
N = number of activities

2.3.1.5 Engineering Design Cost (C_{re})

This cost includes all preliminary design efforts associated with system/equipment definition and development. Particular areas include system engineering, design engineering, reliability and maintainability engineering, human factors, functional analysis and allocation, logistic support analysis, etc. The design associated with modifications is inculded in C_{on}. The engineering design cost is

$$C_{re} = \Sigma\, C_{re}^{i} \qquad (2.5)$$

where

C_{re}^{i} = cost of specific activity *i*
N = number of activities

2.3.1.6 Equipment Development and Test (C_{rt})

The manufacture, assembly, test and evaluation of engineering prototype models are included this cost. In particular, this constitutes manufacture and assembly, quality control and inspection, material procurement and handling, personnel, training, spares, facilities support equipment, data collection, and evaluation of prototypes, etc. Preliminary logistic support for operational system/equipment is included in C_{il}. The equipment development and test cost is

$$C_{rt} = [C_{rdl} + C_{rdm} + \Sigma\, C_{rdt}^{i}] \qquad (2.6)$$

where

C_{rdl} = cost of prototype fabrication and assembly labor
C_{rdm} = cost of prototype material
C_{rdti} = cost of test operations and support associated with specific test *i*
N = number of identifiable tests

2.3.1.7 Engineering Data (C_{rd})

This cost includes the preparation, printing, publication, and distribution of all documentation associated with C_{rm}, C_{re}, C_{rt} and C_{rr}. This includes program plans, R and D reports, design data, test plans and reports, analyses, initial operational and maintenance procedures, and all effort related to a specific documentation necessity. The engineering data cost is

$$C_{rd} = \Sigma C_{rd}^{i} \tag{2.7}$$

where
C_{rd}^{i} = cost of specific data *i*
N = number of data items

2.3.1.8 Investment (C_i)

This cost includes all costs associated with the acquisition of systems. In particular, this includes manufacturing, manufacturing management, system construction, and preliminary logistic support. The investment cost is

$$C_i = (C_{im} + C_{ic} + C_{il}) \tag{2.8}$$

where
C_{im} = system/equipment manufacturing cost
C_{ic} = system construction cost
C_{il} = cost of initial support

2.3.1.9 Manufacturing (C_{im})

This cost covers all recurring and nonrecurring costs associated with the production and rest of multiple quantities of prime systems/equipments. The manufacturing cost is

$$C_{im} = (C_{in} + C_{ir}) \tag{2.9}$$

where

C_{in} = nonrecurring manufacturing cost
C_{ir} = recurring manufacturing cost

2.3.1.10 Nonrecurring Manufacturing Cost (C_{in})

This cost includes all fixed nonrecurring costs associated with the production and test of operational systems/equipment. This inculdes manufacturing management, manufacturing engineering, initial tooling and factory test equipment quality assurance, reliability test, maintainability demonstration, support equipment compatibility, technical data verification personnel test and evaluation, inter-changeability environmental test related support, production sampling tests, and related support. The nonrecurring manufacturing cost is

$$C_{in} = [C_{inm} + C_{int} + C_{ina} + C_{inp} + \Sigma\, C_{inq} + \Sigma C_{ins}] \quad (2.10)$$

where

C_{inm} = manufacturing engineering cost
C_{int} = tools and factory test equipment cost (excluding capital equipment)
C_{ina} = quality assurance cost
C_{inp} = manufacturing management cost
C_{inq} = cost of qualification test i
C_{ina} = cost of production sampling test j
N = number of individual tests

2.3.1.11 Recurring Manufacturing Cost (C_{ir})

This cost includes all recurring production costs to include production; subassembly an assembly, material and inventory control, inspection and test, and packing and shipping to the point of first destination. Sustaining engineering support require on a recurring basis is also included. Costs are associated with the production of prime equipment. The recurring manufacturing cost is

$$C_{ir} = [C_{ire} + C_{irl} + C_{irm} + C_{iri} + C_{irt}] \quad (2.11)$$

where

C_{ire} = recurring manufacturing engineering support cost
C_{irl} = production fabrication and assembly labor cost
C_{irm} = production material and inventory cost

C_{iri} = inspection and test cost
C_{irt} = packing and initial transportation cost

2.3.1.12 Construction Cost (C_{ic})

This cost includes all preliminary acquisition costs associated with manufacturing, test, operational and maintenance facilities, and utilities. Facility costs include the development of new building projects, the modification of existing facilities, and the occupancy of existing facilities without modification. Work areas plus family housing are considered. Moreover, this cost includes preliminary surveys, real estate, building construction, roads and pavement, railroad sidings, etc. Cost items include construction labor, construction material, capital equipment, and utility installation. The construction cost is

$$C_{ic} = (C_{icp} + C_{ict} + C_{ico} + C_{icm}) \tag{2.12}$$

where
C_{icp} = manufacturing facilities cost
C_{ict} = test facilities cost
C_{ico} = operational facilities acquisition cost
C_{icm} = maintenance facilities acquisition cost

For each item one should consider the following:

$$C_{ic} = (C_{ica} + C_{icb} + C_{icu} + C_{icc}) \tag{2.13}$$

where
C_{ica} = construction labor cost
C_{icb} = construction material cost
C_{icu} = cost of utilities
C_{icc} = capital equipment cost

2.3.1.13 Initial Logistic Support Cost (C_{il})

This cost includes all integrated logistic support planning and control functions associated with the development of system support requirement and the transition of such requirements form supplier(s) to the applicable operational site. The initial logistic support cost is

$$C_{il} = (C_{ilm} + C_{ilp} + C_{ils} + C_{ili} + C_{ild} + C_{ilt} + C_{ilx} + C_{ily}) \tag{2.14}$$

where

C_{ilm} = logistic program management cost
C_{ilp} = cost of provisioning
C_{ils} = initial spare/repair material cost
C_{ili} = initial inventory management cost
C_{ild} = cost of technical data preparation
C_{ilt} = cost of initial training and training equipment
C_{ilx} = acquisition cost of operational test and support equipment
C_{ily} = initial transportation and handling cost

2.3.1.14 Operator Personnel Cost (C_o)

This cost covers all costs associated with the operation and maintenance support of the system throughout its product life cycle subsequent to equipment delivery in the field. Specific categories cover the cost of system operation, maintenance, sustaining logistic support, equipment modifications, and system/equipment phaseout and disposal. Costs are generally determined for each year throughout life cycle. The operations and maintenance is

$$Co = (C_{oo} + C_{om} + C_{on} + C_{op}) \qquad (2.15)$$

where

C_{oo} = cost of system/equipment life cycle operations
C_{om} = cost of system/equipment life cycle maintenance
C_{on} = cost of system/equipment modifications
C_{op} = cost of system/equipment phase-out and disposal

2.3.1.15 Operation Cost (C_{oo})

This cost covers all costs associated with the actual operation (not maintenance) of the system throughout its life cycle. Specific categories cover the costs of system/equipment operational personnel, the formal training of operators, operational facilities, and support and handling equipment necessary for system operation. The operation cost is

$$C_{oo} = (C_{oop} + C_{oot} + C_{oof} + C_{ooe}) \qquad (2.16)$$

where

C_{oop} = operating personnel cost
C_{oot} = cost of operator training

C_{oof} = cost of operational facilities
C_{ooe} = cost of support and handling equipment

2.3.1.16 Operator Personnel Cost (C_{oop})

This cost covers the costs of operating personnel as allocated to the system. A single operator may operate more than one system, but costs should be allocated on an individual system basis. Such costs include base pay or salary and allowances, fringe benefits, travel, clothing allowances, etc. The operating personnel cost is

$$C_{oop} = [(T_o)(C_{po})(Q_{po})(N_{po}) * (\% \text{ allocation})] \tag{2.17}$$

where
T_o = hours of system operation
C_{po} = cost of operator labor
Q_{po} = quantity of operators/system
N_{po} = number of operating systems

2.3.1.17 Operator Training Cost (C_{oot})

This cost includes the formal training of personnel assigned to operate the system. Such training is achieved on a periodic basis throughout the system life cycle to cover personnel replacements due to attrition. Total costs include instructor time, supervision, student pay and allowances whole in school; training facilities, training aids, equipment, and student transportation as applicable. The operator training cost is

$$C_{oot} = [(Q_{so})(T_t)(C_{top})] \tag{2.18}$$

where
Q_{so} = quantity of student operators
T_t = duration of training program (weeks)
C_{top} = cost of operator training ($/student week)

2.3.1.18 Operational Facilities Cost (C_{oof})

This cost includes the annual recurring costs associated with the occupancy and maintenance of operational facilities throughout the system life cycle. Utility costs are also included. Facility and utility costs are proportionately allocated to each system. The operational facilities cost is

$$C_{oof} = [(C_{ppe} + C_u)\ (\%\ \text{allocation}) * (N_{os})] \quad (2.19)$$

where

C_{ppe} = cost of operational facility support ($/site)
C_u = cost of utilities ($/site)
N_{os} = number of operational sites

2.3.1.19 Support and Handling Equipment Cost (C_{ooe})

This cost includes the annual recurring usage and maintenance costs for those items that are required to support system operation throughout the life cycle. The costs specifically cover equipment operation, equipment corrective maintenance, and preventive maintenance. The support and handling equipment cost is

$$C_{ooe} = [C_{ooo} + C_{oou} + C_{oos}] \quad (2.20)$$

where

C_{ooo} = cost of operation
C_{oou} = cost of equipment corrective maintenance
C_{oos} = cost of equipment preventive maintenance
C_{oou} = $[(Q_{ca})(M_{mhc})\ (C_{ocp}) + (Q_{ca})(C_{mhc}) + (Q_{ca})(C_{dc})](N_{os})$
Q_{ca} = quantity of corrective maintenance actions (M_a); Q_{ca} is a function of (T_o)
M_{mhc} = corrective maintenance labor hours/M_a
C_{ocp} = corrective maintenance labor cost ($/$M_{mhc}$)
C_{mhc} = cost of material handling/corrective M_a.
C_{dc} = cost of corrective/maintenance documentation/M_a.
N_{os} = number of operational sites
C_{oos} = $[(Q_{pa})(M_{mhp})(C_{opp}) + (Q_{pa})(C_{mph}) + (Q_{pa})(C_{dp})(N_{os})]$
Q_{pa} = quantity of preventive maintenance actions (M_a).
M_{mhp} = preventive maintenance man hours/M_a.
C_{opp} = preventive maintenance labor cost ($/$M_{mhp}$)
C_{mhp} = cost of material handling/preventive M_a.
C_{dp} = cost of preventive maintenance documentation/M_a.
N_{os} = number of operational sites

2.3.1.20 Maintenance Cost (C_{om})

This cost includes all sustaining maintenance labor, spare/repair parts, test and support equipment, transportation and handling, replenishment training, support data, and facilities necessary to meet the maintenance needs of the prime equipment throughout its life cycle. Such needs include both corrective and preventive maintenance requirements at all echelons: organizational, intermediate, depot, and factory. The maintenance cost is

$$C_{om} = [C_{omm} + C_{omx} + C_{oms} + C_{omt} + C_{omp} + C_{omf} + C_{omd}] \tag{2.20}$$

where

C_{omm} = maintenance personnel and support cost
C_{omx} = cost of spare/ repair parts
C_{oms} = test and support equipment maintenance cost
C_{omt} = transportation and handling cost
C_{omf} = cost of maintenance facilities
C_{omd} = cost of technical data

2.3.1.21 Maintenance Personnel and Support Cost (C_{omm})

This cost includes corrective and preventive maintenance labor, associated material handling, and supporting documentation. When a system or equipment malfunction occurs or when a scheduled maintenance action is performed, personnel man hours are expended, the handling of spares and related material takes place, and maintenance action reports are completed. The maintenance personnel and support cost is

$$C_{omm} = [C_{oou} + C_{oos}] \tag{2.21}$$

where

C_{oou} = cost of equipment corrective maintenance
C_{oos} = cost of equipment preventive maintenance

Total cost is the sum of the C_{omm} values for each echelon of maintenance.

2.3.1.22 Corrective Maintenance Cost (C_{oou})

This cost includes the personnel activity costs associated with the accomplishment of corrective maintenance. Total cost includes the sum of individual costs for each maintenance action multiplied by the quantity of maintenance actions anticipated over the entire system life cycle. A maintenance action includes any requirement resulting from catastrophic failures, dependent failures, operator/maintenance induced faults, manufacturing defects, etc. The cost per maintenance action considers the personnel labor expended for direct tasks, associated administrative/logistic delay time, material handling, and maintenance documentation. The corrective maintenance cost is

$$C_{oou} = [(Q_{ca})(M_{mhc})(C_{ocp}) + (Q_{ca})(C_{mhc}) + (Q_{ca})(C_{dc})](N_{ms}) \qquad (2.22)$$

where

Q_{ca} = quantity of corrective maintenance actions (M_a)
M_{mhc} = corrective maintenance labor hours/M_a
C_{ocp} = corrective maintenance labor cost (\$/M_{mhc})
C_{mhc} = cost of material handling/corrective M_a
C_{dc} = cost of documentation/corrective M_a.
N_{ms} = number of maintenance sites

2.3.1.23 Preventive Maintenance Cost (C_{oos})

This cost includes the personnel activity costs associated with the accomplishment of preventive or scheduled maintenance. Total cost includes the sum of individual costs for each preventive maintenance action multiplied by the quantity of maintenance actions anticipated over the system life cycle. A maintenance action includes servicing, lubrication, inspection, overhaul, calibration, periodic system check-outs, and the accomplishment of scheduled critical item replacements. The cost per maintenance action considers the personnel labor expended for preventive maintenance tasks, associated administrative/logistic delay time, material handling, and maintenance documentation. The preventive maintenance labor cost, C_{oop}, will of course vary with the personnel skill level required for task performance. Both direct labor and overhead costs are included. The preventive maintenance cost is

$$C_{oos} = [(Q_{pa})(M_{mhc})(C_{opp}) + (Q_{pa})(C_{mhc}) + (Q_{pa})(C_{dp})](N_{ms}) \qquad (2.23)$$

Where

Q_{pa} = quantity of preventive maintenance actions (M_a)
M_{mhp} = preventive maintenance labor hours/M_a
C_{oop} = preventive maintenance labor cost (\$/M_{mhp})
C_{mhp} = cost of material handling/preventive M_a
C_{dp} = cost of documentation/preventive M_a

N_{ms} = number of maintenance sites

2.3.1.24 Spare/Repair Cost (C_{omx})

This cost includes all replenishment spare/repair parts and consumable materials that are required to support maintenance activities associated with prime equipment, operational support and handling equipment (C_{ooe}) test, and support equipment at each echelon. This category covers the cost of purchasing, the actual cost of the material itself, and the cost of holding or maintaining items in the inventory. Costs are assigned to the applicable level of maintenance. Specific quantitative requirements for spares (Q_m) are derived from the Logistic Support Analysis. The optimum quantity of purchase orders (Q_a) is based on EOQ criteria. Support equipment spares are based on the criteria used in determining spare part requirements for prime equipment. The spare/repair parts cost is

$$C_{omx} = [C_{so} + C_{si} + C_{sd} + C_{ss} + C_{sc}] \tag{2.24}$$

where

C_{so} = cost of organizational spare/repair parts
C_{si} = cost of intermediate spare/repair parts
C_{sd} = cost of depot spare/repair parts
C_{ss} = cost of supplier spare/repair parts
C_{sc} = cost of consumable
C_a = average cost of material purchase order (\$/order)
Q_a = quantity of purchase orders
C_m = cost of spare item *i*
Q_m = quantity of *i* items required or demand
C_h = cost of maintaining spare item *i* in the inventory (\$/\$ value of the inventory)
Q_h = quantity if *i* items in the inventory
N_{ms} = number of maintenance sites
C_{si}, C_{sd} and C_{ss} are determined in a similar manner.

2.3.1.25 Test and Support Equipment Cost (C_{oms})

This cost includes the annual recurring life cycle maintenance cost for test and support equipment at each echelon. Support equipment operational costs are actually covered by the tasks performed in C_{omm}. Maintenance constitutes both corrective and preventive maintenance, and the costs are derived on a similar basis with prime equipment (C_{oou} and C_{oos}). In some instances, specific items of test and support equipment are utilized for more than one system, and in such cases, associated costs are allocated proportionately to each system concerned. The test and support equipment cost is

$$C_{oms} = [C_{seo} + C_{sei} + C_{sed}] \quad (2.25)$$

where

C_{seo} = cost of organizational test and support equipment
C_{sei} = cost of intermediate test and support equipment
C_{sed} = cost of depot test and support equipment
$C_{seo} = [C_{oou} + C_{oos}]$
C_{oou} = cost of equipment corrective maintenance
C_{oos} = cost of equipment preventive maintenance
$C_{oou} = [(Q_{ca})\{(M_{mhc})(C_{ocp}) + (C_{mhc}) + (C_{dc})\}](N_{ms})$
Q_{ca} = quantity if corrective maintenance actions (M_a)
M_{mhc} = corrective maintenance labor hours/M_a
C_{ocp} = corrective maintenance labor cost (\$/M_{mhc})
C_{mhc} = cost of material handling/corrective M_a
C_{dc} = cost of documentation/corrective M_a
N_{ms} = number of maintenance sites (involving organizational maintenance)
$C_{oos} = [(Q_{pa})\{(M_{mhp})(C_{opp}) + (C_{mhp}) + (C_{dc})\}](N_{ms})$
Q_{pa} = quantity of preventive maintenance actions (M_a)
M_{mhp} = preventive maintenance labor hours/M_a
C_{oop} = preventive maintenance labor cost (\$/M_{mhp})
C_{mhp} = cost of material handling/preventive M_a
C_{dp} = cost of documentation/preventive M_a
C_{sei} and C_{sed} are determined in a similar manner.

2.3.1.26 Transportation and Handling Cost (C_{omt})

This cost includes all sustaining transportation and handling between organizational, intermediate, depot, and supplier facilities in support of maintenance operations. This includes the return of faulty material items to a higher echelon; the transportation of items to a higher echelon for preventive maintenance, and the shipment of spare/repair parts, personnel, data, etc., from the supplier to forward echelons. The transportation and handling cost is

$$C_{omt} = [(C_t)(Q_t) + (C_p)(Q_t)] \quad (2.26)$$

where

C_t = cost of transportation
C_p = cost of packing
Q_t = quantity of one-way shipments
C_t = [(W_t)(C_{ts})]
W_t = weight of item (Ib)
C_{ts} = shipping cost ($/lb)
C_{ts} will of course vary with the distance (in miles) of the one-way shipment.
C_{tp} = packing cost ($/lb)

Packing cost and weight will vary depending on whether reusable containers are employed.

2.3.1.27 Maintenance Training Cost (C_{omp})

This cost includes the formal training of personnel assigned to maintain the prime equipment, test and support equipment, and training equipment. Such training is accomplished on a periodic basis throughout the system life cycle to cover personnel replacements due to attrition. Total costs include instructor time, supervision, student pay and allowances, training facilities, training aids and data, and student transportation as applicable. The maintenance training cost is

$$C_{omp}) = [(Q_{sm})(T_t)(C_{tom})] \tag{2.27}$$

where

Q_{sm} = quantity of maintenance students
C_{tom} = cost of maintenance training ($/student-week)
T_t = duration of training program (weeks)

2.3.1.28 Maintenance Facilities Cost (C_{omf})

This cost includes the annual the occupancy and support of maintenance shops at all echelons throughout the system life cycle. A given maintenance shop will support more than one system, and in such cases, associated costs are allocated proportionately to each system concerned. The maintenance facilities cost is

$$C_{omf} = [(C_{ppm} + C_u) * (\% \text{ allocation}) (N_{ms})] \tag{2.28}$$

where

C_{ppm} = cost of utilities (\$/site)
C_u = cost of utilities (\$/site)
N_{ms} = number of maintenance sites

2.3.1.29 Technical Data Cost (C_{omd})

This cost includes any other data necessary to support the operation and maintenance of the system throughout its life cycle. The technical data cost is

$$C_{omd} = \sum C_{omd}^{i} \qquad (2.29)$$

where
C_{omd}^{i} = cost of specific data item i.
N = number of data items

2.3.1.30 System/Equipment Modification (C_{on})

This cost includes modification kit design (R&D), material, installation and test instructions, personnel and supporting resources for incorporating the modification kit, technical data change documentation, formal training to cover the new configuration, spares, etc. The system/equipment modification cost is

$$C_{an} = \sum C_{on}^{i} \qquad (2.20)$$

where
C_{on}^{i} = cost of specific modification i
N = number of system/equipment modifications

2.3.1.31 System Phase-out and Disposal Cost (C_{op})

This cost includes the liability or assets incurred when an item is condemned or disposed. This factor is applicable throughout the system/equipment life cycle when phaseout occurs. This category represents the only element of cost that may turn out to have a negative value—resulting when the reclamation value of the end item is larger than the disposal cost. The system phase-out and disposal cost is

$$C_{op} = [(F_c)(Q_{ca})(C_{dis} - C_{ree})] \quad (2.30)$$

where

F_c = condemnation factor
Q_{ca} = quantity of corrective maintenance actions
C_{dis} = cost of system/equipment disposal
C_{rec} = reclamation value

2.4 Computer-Aided Cost Estimating in Manufacturing

Cost estimating is the mission of determining and evaluating the costs involved in an engineering product or a system using scientific and engineering laws and methods. It is a part of the cost engineering that the American Association of Cost Engineers (AACE) has defined as: "*The area of engineering practice where engineering judgment and experience are utilized in the application of scientific principles and techniques to the problems of cost estimating, cost control and profitability.*" Since the term indicates an estimate of the cost, the cost estimator should seek all possible ways to estimate a cost that falls within an acceptable range.[129]

Clark and Lorenzoni[34] have also proposed several classifications for cost estimating. These include:

- ***Screening Estimate:*** The screening estimate allows the decision maker to decide on which way to go, and whether to accept such a project. The decision period in this phase is short owing to the low level of complexity.
- ***Budget Estimate:*** Since a screening estimate does not give the detail required for a budgetary decision, a budget estimate is required to provide more detail, if desired.
- ***Definitive Estimate:*** The estimate from this phase is the most accurate and detailed. The decision period is much longer and more effort is required to reach the proper estimate. This decision period can be months or years depending on the project complexity and the degree of accuracy required.

2.5 Objective of Cost Estimating

The cost estimator may state general objectives for a cost estimating project. However, these objectives must be redefined by the estimator to reflect specific goals. The cost estimating objectives usually deal with time, cost, and performance.[130] When redefined for a practical estimating task, it is strongly recommended they be stated quantitatively in measurable units. The following subsections contain a list of possible objectives for cost estimating.

2.5.1 Assist in Submitting Bids

Depending on the deadline for submitting a bid and the competitiveness involved, the cost estimate can vary in the level of detail. The cost estimates will help management project what the cost of a product will be, and enable them to confidently complete and submit bids.

2.5. 2 Revise Quotations

Excessive and unrealistic prices can be charged by suppliers or offered by customers. Management, with the help of an accurate cost estimate, can confidently negotiate quotations. Consequently, savings and more profits will be enjoyed.

2.5.3 Assist in Evaluating Alternatives

It is a common management practice to consider different alternatives. When a new product is to be made, management will be faced with different strategies. Since cost and profit are the prime interest, detailed cost estimating can be of great help in evaluating each product design, process plan, or marketing strategy. With accurate estimating, the best set of alternatives will ultimately be considered.

2.5.4 Control of Manufacturing Expenses

Cost estimating will assist in curbing the manufacturing cost. After different alternative methods are evaluated, the one with the least expense will be selected. Moreover, cost estimating is an integral part of cost control. Cost control involves comparing incurred costs with respect to developed estimates. Feedback to the cost estimator helps eliminate excessive costs during the planning phase.

2.5.5 Assist in Make or Buy Decisions

After a cost estimate of a certain product is completed, management can easily determine if such a product can be obtained from an outside supplier with less cost. Furthermore, cost estimating can assist in the "sell or process further" decisions which occur at some point when management wonders if further processing is going to be possible at affordable costs and without predictable losses.

2.5.6 Establish Ground for a Selling Price

Cost estimates are used to set a selling price prior to the actual production. Pricing is a complicated function that can be made easier by efficient use of cost estimating techniques. Cost estimating can help determine the profit margin to be added to the total cost to get the selling price.

2.6 Methods of Cost Estimating

Methods that are often used to estimate costs in the manufacturing environments are described in the following sections.

2.6.1 The Opinion Estimates Method

An estimator can give a rough figure of the cost. This method is obviously not reliable because of the estimate inaccuracy. It can be done by an experienced estimator or a group of estimators.

2.6.2 The Conference Estimating Method

This method is performed in a more involved way than opinion estimating. The estimate is created by a group of experienced individuals from separate departments, or a group of estimators. Each individual will develop a part of the cost estimate using his/her judgment. Then, the cost estimates are added up to find the final product cost estimate. The conference can include brainstorming sessions after which individual estimates are discussed.

2.6.3 The Comparison Method

An original estimating problem is made simpler by relaxing some conditions in a design, or manipulating it. A cost estimate is then developed for the simplified design. The cost estimate of the original design is afterwards determined such that the simpler version of the design has to bound the original version in the following way:

$$C_2 (D_2) \leq C_1 (D_1) \tag{2.31}$$

Where C_1 and C_2 are cost estimate values for the original and simplified designs, respectively. D_1, D_2 are designs of the original and simplified problems respectively. A lower bound may be chosen such that:

$$C_3 (D_3) \leq C_1 (D_1) \leq C_2 (D_2) \tag{2.32}$$

2.6.4 The Unit Estimate Methods

This method is the most popular one in manufacturing and construction. The unit estimate is developed using the following equation:

$$C_u = \sum C_i / U_i \tag{2.33}$$

where

C_u = average cost per unit of design i
C_i = dollar value of design i
U_i = unit of design i

2.6.5 The Cost and Time Relationship Method

This method uses mathematical models or graphs that estimate time and/or cost. These models can reflect probabilistic or deterministic relationships.

2.6.6 The Power Law and Sizing Model Method

This method is the cost estimating relationship model. This model is often used to estimate equipment cost based on simplifying the cost estimating problem to one with a different design size. The model, stated mathematically, is:

$$C = C_j \, (Q_i / Q_j)^m \tag{2.34}$$

where

C = cost value for design of size Q_i
C_j = known cost of design with size Q_j
Q_i, Q_j = design sites
m = correlating exponent, m within [0, 1].

2.6.7 Probabilistic Approaches

By knowing the uncertainty involved in developing a cost estimate of any sort, probability is a legitimate method to be used. Probability techniques can be used fully or partially. The rules of probability can be used to assign numerical judgment of future events. Probability is used sometimes to predict the likelihood that some risk factor is going to occur. Expected values can be used to predict costs. For the discrete case, the expected value of an event i (in cost estimating i is a design, a project, or a system cost estimate) is written as:

$$C\,(i) = \{p \,.\, x_{ij}\} \tag{2.35}$$

where

$C\,(i)$ = expected value of the cost of design i
P = probability that x takes on a value x
x_{ij} = design event

2.6.8 Statistical Methods

Statistical inferences are often made to improve decision making. Cost data can be effectively analyzed using statistical techniques. Moreover, if a variety of cost estimates are available from past studies or from different sources, then statistical techniques can be used as an analysis and inference tool.

- ***Estimating by confidence intervals:*** the estimation is made while constraining the cost estimate to fall within a certain interval with a given probability.
- ***Estimating by tolerance intervals:*** This technique is used to estimate a range within which costs fall with a given probability. This technique used relevant C values to determine the tolerance interval.

- ***Estimating by prediction intervals:*** This technique is used to draw conclusions about a future cost estimate using past estimates. C values are used to predict the value of the cost estimate with a given probability. While these techniques are available, many problems in cost engineering, and specifically in cost estimating, are not suitable to be treated as statistical prediction problems.

2.6.9 Simulation

By using a computer program, a synthetic model represents the original design of a product, a project, or a system. The output of the system will help make inferences about the behavior of the studied design. Simulation can use the previous method to build a model representing the actual problem and predict its costs from the data gathered.

2.6.10 The Factor Method

This method is usually used for project cost estimating. Essentially, the cost of a project is determined by summing the cost estimates of several elements. The factor method model is mathematically stated as follows:

$$C = (C + \sum f_i * C_e))(f_I + 1) \tag{2.36}$$

where

C = estimated value of project
C_e = cost of major equipment
F_i = factor for estimating capital (buildings, equipment, etc.)
f_I = factor for estimating of indirect cost
i = factor index

The factors f_i and f_I are determined by historical data, experience, or policy.

2.6.11 The Detailed Computerized Method

Detailed studies are preferred in cost estimating. However, the time required is considerable. Accordingly, the cost of the study will also be considerable. Computerized cost estimating takes advantage of the digital computer to automate the detailed manual cost estimating method. Basically, all phases of cost estimating will be performed with the greatest detail possible. The power of the computer to store data and perform calculations will help extensively.[128]

It is required that these estimates fall within an acceptable range; the need for accuracy is evident. The errors of the estimation task must be reduced in order to achieve an optimal estimate.[111] Estimating errors can be categorized as controllable and uncontrollable errors. Controllable errors may be caused by:

1. Failure to develop detailed data necessary for the cost estimate
2. Errors in interpreting information
3. Making wrong assumptions
4. Use of poorly documented data
5. Failure to spend the time necessary for accurate estimations
6. Poor analysis of the problem in hand
7. Lack of experience

Uncontrollable errors are usually due to:
1. Unpredictable change in equipment
2. Unexpected conditions such as fires, storms, and industrial accidents
3. Labor strike
4. Decline in productivity levels due to employee attitudes and low morale

Cost estimate is the summation of various costs involved in the estimation of cost for a product, project, or a system. These costs are classified into two groups:

- **Direct costs**
  1. ***Direct material***: Materials that are an integral part of the finished product
  2. Direct labor: Costs that can be traceable directly to the making of the product
- **Indirect costs**
  1. ***Manufacturing overhead:*** All manufacturing costs except direct material and labor costs
  2. ***Indirect materials***
  3. ***Administrative overhead***

The cost estimating process plays an important role in the manufacturing planning and it also has an important role in manufacturing control as illustrated in Figure 2-1. It assists manufacturing firms in decision making at various stages including design and production planning, materials handling, facility layout, inventory control, and shop floor control.[101]

2.7 Computer-Aided Cost Estimating

Computer-aided cost estimating (CACE) is the use of computers to estimate costs of products, projects, or systems.[10] The use of CACE increases the productivity of the estimator. The estimates will be easily revised and verified, and data will be stored economically and readily accessible. CACE is an important tool to:

1. Develop cost estimates in shorter time.
2. Improve estimate accuracy by minimizing the human interface.
3. Improve cost data availability and security.
4. Evaluate more alternatives.
5. Improve management morale.

Since cost estimating software requires a large amount of information from a variety of databases, it is essential that data structures and retrieval and storage methods be carefully examined and to select the ones that ensure the efficiency of the cost estimating software.[17] Figure 2-1 is a flow diagram representing steps required to estimate the cost of a product.

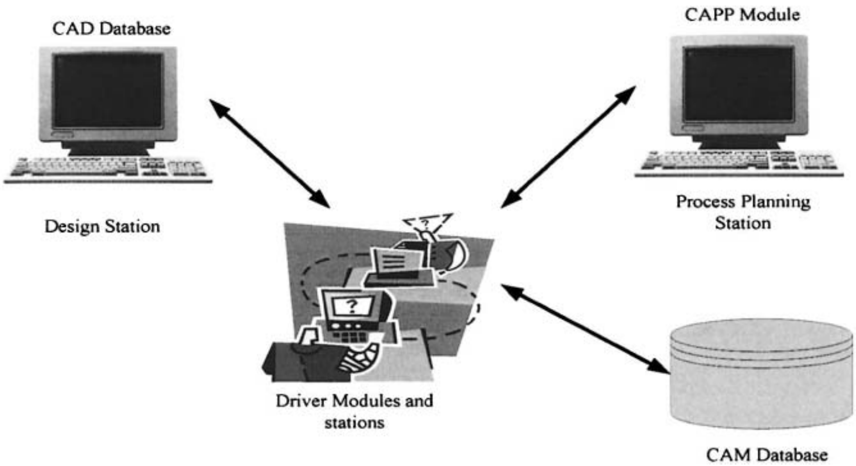

Figure 2-1. Steps required for estimating product cost

2.8 Structure of a Computer-Assisted Cost Estimating System

A product is the key determinant of an organization's success. The research, engineering, manufacturing, and marketing departments work together with management to provide a successful product. Costs beyond the manufacturing stage include the costs of engineering, marketing, and administrative-related activities.[81]

To estimate the cost of a product, the cost estimator needs to be supplied with the following cost elements[152]:

Material cost: Material is defined as substance being transformed or used in a manufacturing transformation. Materials are classified as:

1. Raw materials
2. Commercial products
3. Subcontract products
4. Inter-department transfer products

Materials cost estimating usually includes both direct and indirect materials. The information required can be obtained from bills of material, product design, and inventories of direct and indirect materials. Steps for estimating the material cost is as follows:

1. Measure the shape and the volume of the material.
2. Identify the price of the material.
3. Find the value of any salvage material.
4. Choose a material cost policy.
5. Tabulate the total cost of material.

Labor Cost: Labor cost estimating constitutes the second part of the direct cost. This cost is important because of the extensive attention it gets from management, government and researchers. The first step in determining the labor cost estimate is to estimate the labor time. Then, a cost figure can be developed using labor cost rates. Steps for estimating the labor cost are as follows:

1. Identify the operation.
2. Determine the labor time.
3. Identify hourly rates.
4. Determine the labor overhead rate.
5. Determine the cost of fringe benefits.
6. Tabulate the total cost of labors.

Machinery and Tools Cost: Estimating the cost of machinery and tools used to manufacture a certain product is an integral part of the cost estimating function. Tools can be classified as hard or soft tools. Hard tools are those that are designed and manufactured specifically for a certain manufacturing operation. On the other hand, soft tools are conventionally used in common manufacturing operations. Tooling costs are estimated for the following reasons:

1. To determine the investment necessary for tools within a time frame

during the planning phase.
2. To evaluate alternative tooling combinations and select the combination incurring the least cost.

The cost of tools or new equipment occurs only once. As a result, difficulty is experienced when allocating these costs to individual operations.

Operation Cost: An operation involves material, labor, and equipment. The estimator must have the necessary cost estimating data in the form of trade books, handbooks, and various data sources about the operations involved in the design. The necessary information includes:

1. Part design
2. Production plans
3. Material specifications
4. Tooling specification
5. Standard time sheets

Operation cost estimating starts by breaking down the operation elements. For each element the labor cost, material cost, and equipment of tooling cost are estimated. Each operation consists of three phases:

1. **Set Up**: Preparing all the conditions required for the operation.
2. **Cycles**: Performing the operation for a number of cycles.
3. **Maintenance**: Maintaining all the conditions required for the operation.

Overhead Cost: Overhead cost in present cost accounting practice is the portion of total cost that cannot be directly traced to particular operations, products, or projects. Indirect expenses should be allocated, utilized, and added to the unit cost estimate. The problem with allocating overhead charges is that these costs often exist even if the product is not produced. Companies, based on their activities, may adopt different techniques in measuring the overhead cost. Overhead charges may be determined in different ways including:

1. Overhead as a ratio of direct labor dollars
2. Overhead as a ratio of direct labor hours
3. Overhead as a ratio of prime cost

The product cost is the summation of the material cost, direct labor plus overhead cost, and the total tooling cost. The cost of the product can be obtained by charging the overheads to the operation product cost.

2.9 Summary

This chapter discussed the important characteristics of the manufacturing environment, the computer role in manufacturing systems, the elements of Cost Breakdown in manufacturing systems, cost estimating in manufacturing, the objectives and methods of cost estimating in the manufacturing environment, the detailed computerized method that is used in cost estimating, and computer-aided cost estimating (CACE).

2.10 Problems

2.1. Discuss the important characteristics of the manufacturing environment.
2.2. What is the computer role in manufacturing systems?
2.3. List the elements of cost breakdown in manufacturing systems.
2.4. What are the elements of the Initial logistic support cost?
2.5. What are the costs included in construction cost?
2.6. Define the cost estimating in manufacturing.
2.7. Describe briefly the objectives of cost estimating in the manufacturing environment.
2.8. Discuss in details the methods of cost estimating in the manufacturing environment.
2.9. Explain the detailed computerized method that is used in cost estimating.
2.10. Define and distinguish the difference between the direct and indirect costs.
2.11. Define computer-aided cost estimating (CACE).
2.12. Draw a flow diagram representing steps required to estimate the cost of a product.
2.13. What are the current systems of cost estimating systems?
2.14. Describe briefly the structure of a computer-assisted cost estimating system.