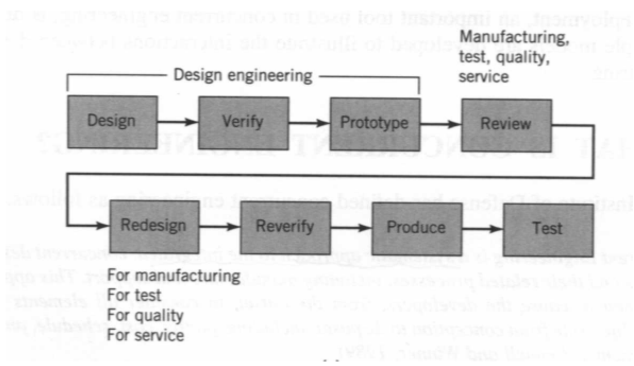
Concurrent Engineering

- Market share and profitability are the major determinants of the success of any organization.
- The factors that influence and improve the competitive edge of a company are unit cost of products, quality, and lead time.
- Concurrent engineering (CE) has emerged as discipline to help achieve the objectives of reduced cost, better quality, and improved delivery performance. CE is perceived as a vehicle for change in the way the products and processes are designed, manufactured, and distributed.
- Concurrent engineering is a management and engineering philosophy for improving quality and reducing costs and lead time from product conception to product development for new products and product modifications.
- CE means that the design and development of the product, the associated manufacturing equipment and processes, and the repair tools and processes are handled concurrently.
- The concurrent engineering idea contrasts sharply with current industry sequential practices, where the product is first designed and developed, the manufacturing approach is then established. And finally the approach to repair is determined.

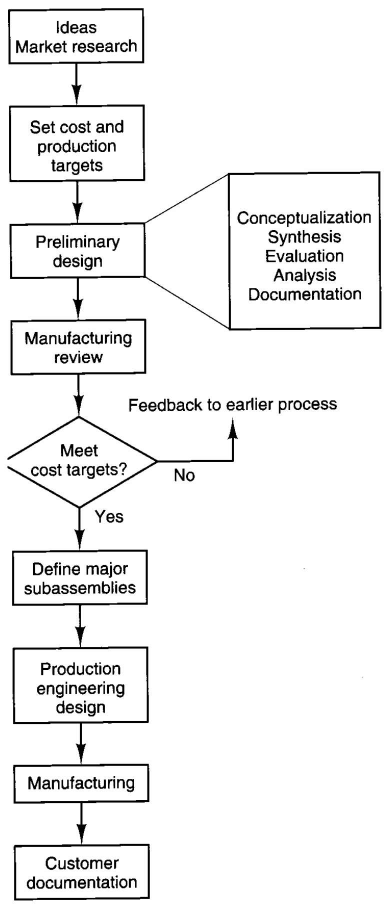
What is concurrent engineering?

Concurrent engineering is a systematic approach to the integrated, concurrent design of products and their related processes, including manufacture and support. This approach is intended to cause the developers from the outset, to consider all elements of the product life cycle from conception to disposal, including quality, cost, schedule, and user requirements.

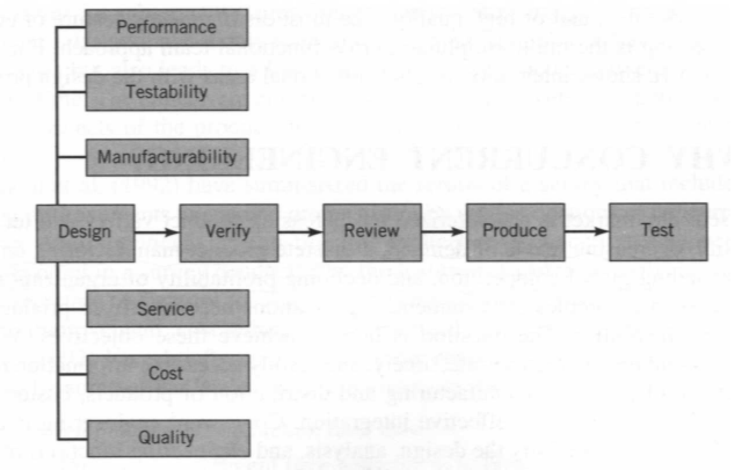
Serial or Sequential Engineering



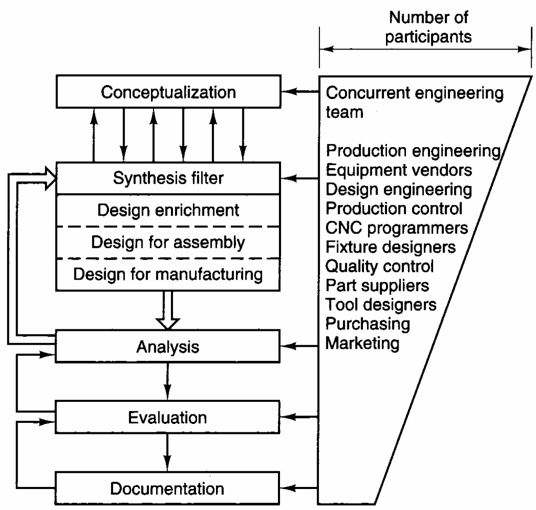
Traditional product development process



Concurrent Engineering



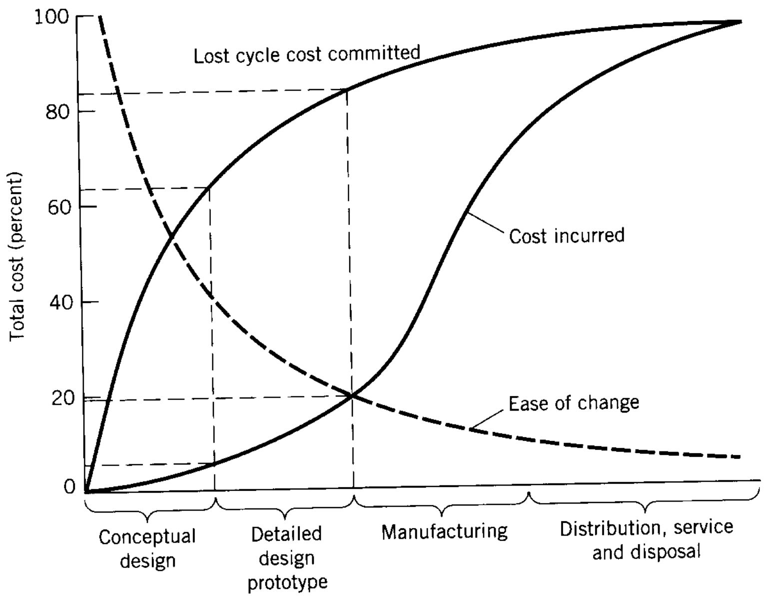
New model for product design



Why concurrent engineering?

- Increasing product variety and technical complexity that prolong the product development process and make it more difficult to predict the impact of design decisions on the functionality and performance of the final product.
- Increasing global competitive pressure that results from the emerging concept of reengineering.
- The need for rapid response to fast-changing consumer demand.
- The need for shorter product life cycle.
- Large organizations with several departments working on developing numerous products at the same time.
- New and innovative technologies emerging at a very high rate, thus causing the new product to be technological obsolete within a short period.

A characteristic curve representing cost incurred and committed during the product life cycle



- Summarized the results of a survey that include the following improvements to specific product lines by the applications of concurrent engineering.
  1. Development and production lead times
  2. Measurable quality improvements

3. Engineering process improvements
4. Cost reduction

1. Development and production lead times

- Product development time reduced up to 60%.
- Production spans reduced 10%.
- AT&T reduced the total process time for the ESS programmed digital switch by 46% in 3 years.
- Deere reduced product development time for construction equipment by60%.
- ITT reduced the design cycle for an electronic countermeasures system by33% and its transition-to-production time by 22%.

2. Measurable quality improvements

- Yield improvements of up to four times.
- Field failure rates reduced up to 83%.
- AT&T achieved a fourfold reduction in variability in a polysilicon deposition process for very large scale integrated circuits and achieved nearly two orders of magnitude reduction in surface defects.
- AT&T reduced defects in the ESS programmed digital switch up to 87% through a coordinated quality improvement program that included product and process design.
- Deere reduced the number of inspectors by two-thirds through emphasis on process control and linking the design and manufacturing processes.

3. Engineering process improvements

- Engineering changes per drawing reduced up to 15 times
- Early production engineering changes reduced by 15%.
- Inventory items stocked reduced up to 60%.
- Engineering prototype builds reduced up to three times.
- Scrap and rework reduced up to 87%.

4. Cost reduction

- McDonnell Douglas had a 60% reduction in life-cycle cost and 40% reduction in production cost on a short-range missile proposal.
- Boeing reduced a bid on a mobile missile launcher and realized costs 30 to 40% below the bid.
- IBM reduced direct costs in system assembly by 50%.
- ITT saved 25% in ferrite core bonding production costs

Summary

- The customer is consulted during the early product development process; therefore, the product can meet the expectations of the customer.
- Improved design quality. The lower the number of design changes, the more robust the design of the product is.
- Reduced product development and design times by listing the voice of the customer and the information between various departments involved.
- Reduced product cost - reduction in the number of design changes and reduce cost.
- Elimination of delays

- Reduced design time and effort
- Increasing reliability and customer satisfaction.

Schemes for CE

- CE is the application of a mixture of all following techniques to evaluate the total life-cycle cost and quality.
  1. Axiomatic design
  2. Design for manufacturing guidelines
  3. Design science
  4. Design for assembly
  5. The Taguchi method for robust design
  6. Manufacturing process design rules
  7. Computer-aided DFM
  8. Group technology
  9. Failure-mode and effects analysis
  10. Value engineering
  11. Quality function deployment

Examples of design axioms for optimization

- Axioms have the fundamental properties that (1) they cannot proven and (2) they are general truths
  1. Minimize the number of functional requirements and constraints
  2. Satisfy the functional requirements from most important first to least important last
  3. Minimize information content
  4. Everything being equal, conserve materials
  5. Integrate functional requirements in a single part if they can be independently satisfied in the proposed solution
  6. There may be several optimum solution

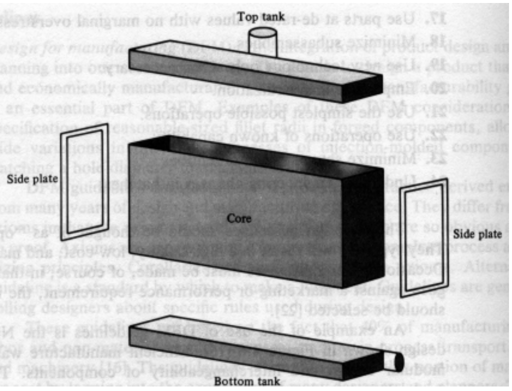
DFM Guidelines

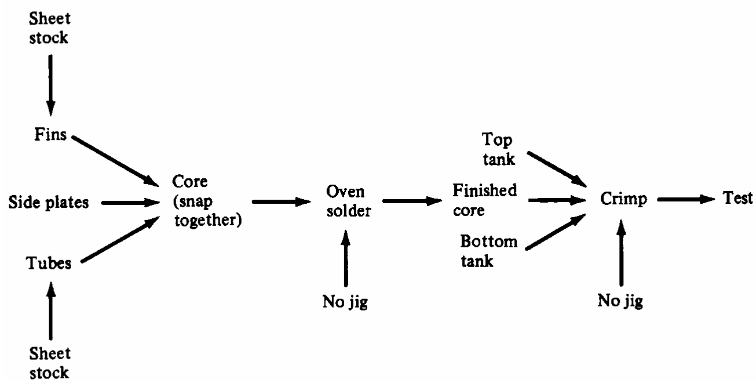
1. Design for a minimum number of parts
2. Develop a modular design
3. Minimize part variations
4. Design parts to be multifunctional
5. Design parts for multiuse
6. Design parts for ease of fabrication
7. Avoid separate fasteners
8. Minimize assembly directions; design for top-down assembly
9. Maximize compliance; design for ease of assembly
10. Minimize handling; design for handling presentation
11. Evaluate assembly methods

12. Eliminate adjustments
13. Avoid flexible components; they are difficult to handle
14. Use parts of known capability
15. Allow for maximum intolerance of parts
16. Use known and proven vendors and suppliers
17. Use parts at de-rated values with no marginal overstress
18. Minimize subassemblies
19. Use new technology only when necessary
20. Emphasize standardization
21. Use the simplest possible operations
22. Use operations of known capability
23. Minimize setups and interventions
24. Undertake engineering changes in batches

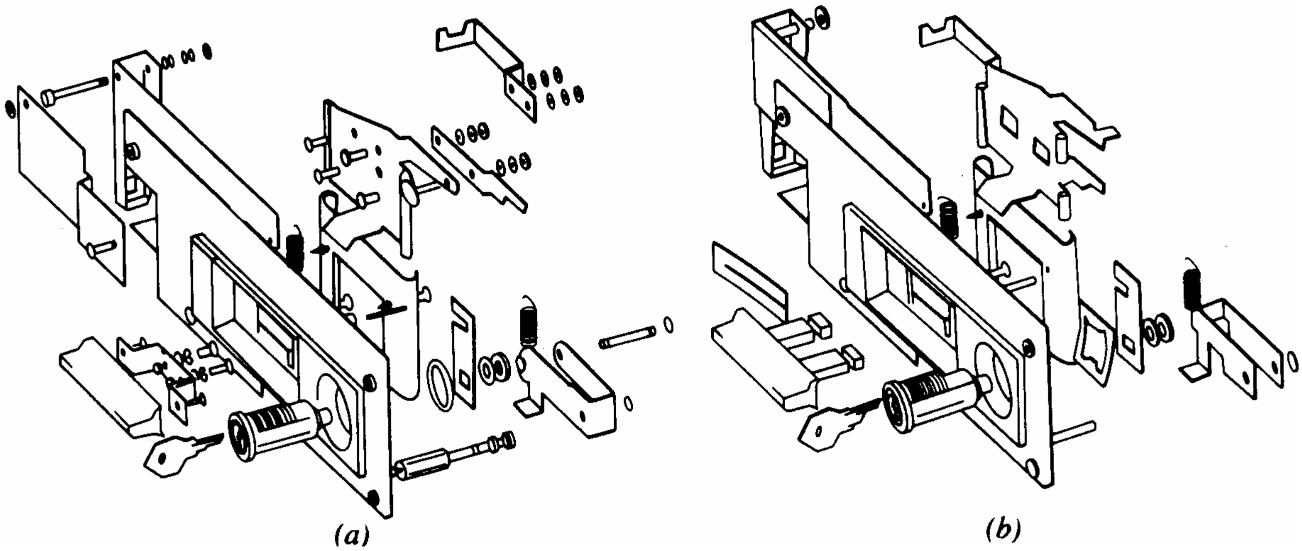
The use of DFM guidelines in Nippondenso radiator design

- Develop a modular design
- Minimize part variations
- Design parts for multiuse
- Use the simplest possible operations





Design for Assembly (Xerox latch mechanism design)

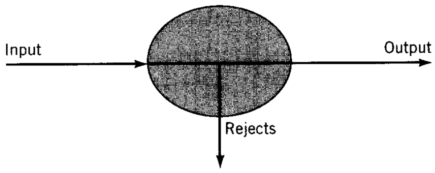


Mathematical Model for Understanding Integration between Design and Manufacturing

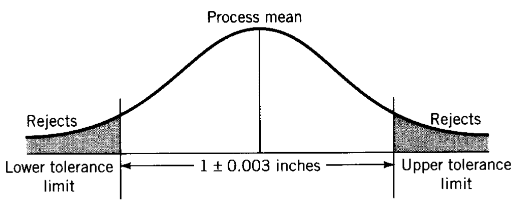
- The mathematical model serves as a decision support system integrating issues related to design and manufacturing and helps address the following questions:
  1. How does design affect manufacturing cost, quality, and manufacturing lead time?
  2. What is the influence of manufacturing process design on these factors?
  3. How does the concurrent engineering approach help obtain a better solution compared with the serial engineering approach?

Answer of these questions:

- Consider a simple product, a cylindrical part (shaft). The design stage is concerned with specifying tolerances on the shaft. The manufacturing stage is essentially a transformation process, changing a bar stock into a finished shaft meeting tolerance specifications.
- The process involves a turning operation that can be performed on a turret lathe, an engine lathe, an automatic screw machine, or a numerically controlled turning center. The transformation process indicates inputs, outputs and rejects, and presents as a normal distribution.



(a)



(b)

- Suppose the design department specifies the tolerance limits to meet certain function requirements. Let t^u_k and t^l_k represent the upper and lower tolerance limits, respectively, for a component shaft for the *k*th alternative system of tolerances. Also, let σ_j, and μ_j be the standard deviation and the process mean of the output dimension of the shaft, respectively, for the *j*th manufacturing option.
- Assuming that the dimensions are normally distributed, the standard normal variates for the upper and lower tolerance limits can be written as:

$$\frac{t_k^u - \mu_j}{\sigma_j} = Z_{jk}^u$$

$$\frac{t_k^l - \mu_j}{\sigma_j} = Z_{jk}^l$$

*for the *k*th alternative system of tolerances using the *j*th manufacturing option.

- Let Y^o_{jk}, Y^i_{jk} and Y^s_{jk} represent the output, input, and scrap units, respectively. Then , at the transformation stage using the jth machining process, we have the fraction of scrap (SC_{jk}) as follows:

$$SC_{jk} = \frac{Y_{jk}^{s}}{Y_{jk}^{i}} = \phi\left(Z_{jk}^{l}\right) + 1 - \phi\left(Z_{jk}^{u}\right)$$

Where $\phi(\quad)$ represents the cumulative density function of the standard normal variate.

- At the transformation stage we have the mass balance equation
  $$Y^{i}_{jk} = Y^{o}_{jk} + Y^{s}_{jk}$$
- The technological coefficients per unit output :

$$K_{jk}^{i} = \frac{Y_{jk}^{i}}{Y_{jk}^{o}}$$

$$K_{jk}^{s} = \frac{Y_{jk}^{s}}{Y_{jk}^{o}}$$

Material Balance Equations

- At a transformation process, the dollar inflow rate equals the dollar outflow rate, If X^{i}_{jk}, X^{o}_{jk}, and X^{s}_{jk} are unit average cost of input, output, and scrap, respectively. And $f(Y^{i}_{jk})$ is the processing cost per unit.

$$X_{jk}^{i} Y_{jk}^{i} + Y_{jk}^{i} f\left(Y_{jk}^{i}\right) = X_{jk}^{o} Y_{jk}^{o} + X_{jk}^{s} Y_{jk}^{s}$$

Or

$$X_{jk}^{o} = K_{jk}^{i} X_{jk}^{i} - K_{jk}^{s} X_{jk}^{s} + K_{jk}^{i} f(Y_{jk}^{i})$$

Average Manufacturing Lead Time

- If the average processing time per unit using the jth manufacturing technology is t_j and S_j is the setup time, then the average manufacturing lead time to produce Y^{o}_{jk} finished units meeting specifications is $T_j = S_j + t_j K^{I}_{jk} Y^{o}_{jk}$

Example for Serial Engineering vs. Concurrent Engineering:

ABC Company requires 1000 units of a turned cylindrical part (shaft). The design department of ABC company defines a need for a cylindrical part to be finished to 1 ±0.003 inch. A serial engineering approach and a concurrent engineering solution are presented in the two scenarios that follow. We compare two situations that emerge from these strategies.

Serial Engineering Approach

The design department of ABC recommends a shaft dimension and tolerance of 1 ±0.003 inch; this information is transmitted to the manufacturing engineering department. In the serial engineering approach, manufacturing engineering accepts these specifications and attempts to find the best manufacturing technology to accommodate the request made by design. Manufacturing engineering will challenge the specification only if the design is not producible. Drawing on the preceding analysis, manufacturing engineering decides to produce the parts on a turret lathe because the desired tolerances can be obtained. The process average and the standard deviation are estimated to be 1.00 and 0.003 inch, respectively. Other relevant data are:

Unit cost of raw material = \$10.00

Unit salvage value = \$2.00

Unit processing cost = \$7.00

The process engineer determines the unit cost of output, number of units of scrap generated, and number of raw units required to produce 1000 finished units using the model developed in the previous section as follows:

Unit Cost and Scrap Calculations

As a turret lathe is the first manufacturing technology option, $j = 1$; assuming tolerance 1 ± 0.003 inch as the first design option, $k = 1$. All parts above and below the tolerance limits are scrapped. For the given data, we get, $Z^{u}_{11} = 1.00$ and $Z^{l}_{11} = -1.00$. Therefore, from the normal tables, the percentage of items above the upper limit = 15.87 and the percentage of items below the lower tolerance limit = 15.87. The total percentage of rejects is 15.87 + 15.87 = 31.74. Accordingly,

$$\text{Technological coefficient of scrap, } k^{s}_{11} = \frac{SC_{11}}{1 - SC_{11}} = \frac{0.3174}{1 - 0.3174} = 0.4649$$

$$\text{Technological coefficient of input, } K^{i}_{11} = 1 + k^{s}_{11} = 1 + 0.4649 = 1.4649$$

$$\text{Number of units scrapped, } Y^{s}_{11} = k^{s}_{11} Y^{o}_{11} = 0.4649 \times 1000 = 465 \text{ (approximately)}$$

$$\text{Number of raw units (input) required, } Y^{i}_{11} = k^{s}_{11} Y^{o}_{11} = 1.4649 \times 1000 = 1465 \text{ (unit)}$$

$$\begin{aligned}\text{Unit output cost, } X^{o}_{11} &= k^{i}_{11} X^{i}_{11} - k^{s}_{11} X^{s}_{11} + k^{i}_{11} f(Y^{i}_{11}) \\ &= 1.4649 \times 10.00 - 0.4649 \times 2.00 + 1.4649 \times 7.00 \\ &= 23.97\end{aligned}$$

It is important to emphasize that the serial engineering approach is driven by a design specification. The process engineer assumes that the tolerances are driven by performance requirements, and a manufacturing process is selected that will meet the design specification. In this example, the expected number of rejects is too high, which will eventually lead to reexamination of the process and design specifications. In the serial engineering approach there is no formal mechanism for considering these aspects simultaneously. Therefore, the process of change may take significant time. During that period, the system normally operates at significantly low performance levels, that is, higher rejects, unit costs, and lead time. On the contrary, in the concurrent engineering approach, design specifications are finalized after considering manufacturing and other implications.

Concurrent Engineering Approach

As mentioned before, concurrent engineering is based on cross-functional and multi-disciplinary teams representing various functional areas. Therefore, the concurrent engineering concept cuts across functional boundaries of an organization. This means that in the concurrent engineering approach, marketing, design, manufacturing engineering, and all stakeholders in the product development process are brought together to discuss integrating issues of functional design, manufacturing, quality control, customer service, and so forth. This multifunctional team is responsible for addressing various issues:

- The marketing services of ABC found that the tolerance range of 1 ± 0.003 inch may be too tight.
- The quality department did not like the number of rejections.
- The manufacturing planning department wants to use machine tools with better process capabilities.
- The purchasing department cannot buy so many raw shafts because of the restricted availability of such steel.

This process leads to a sequence of interactions that are documented in the following set of meetings of the concurrent engineering team.

Concurrent Engineering Team Meeting 1

The team begins by agreeing to hold the shaft dimensions to 1 ± 0.003 inch. The manufacturing department recommends an engine lathe, which has higher process capability resulting in a process standard deviation of 0.002 inch. However, the processing cost increases to $9.00 per unit from the previous $7.00. Other data are the same as before. The unit cost of output, number of units of scrap generated, and number of raw units required to produce 1000 finished units are determined as follows:

Because the engine lathe is the second manufacturing technological alternative, $j = 2$. Also, $k = 1$, because there is no change in the design specifications. $Z^u_{21} = 1.5$, $Z^l_{21} = -1.5$, percent rejection above the upper limit = 6.7, percent rejection below the lower limit = 6.7, total percent rejection = 13.4, $k^s_{21} = 0.1547$, $k^i_{21} = 1.1547$. Accordingly,

Number of units scrapped, $Y^s_{21} = k^s_{21} Y^o_{21} = 0.1547 \times 1000 = 154.7 = 155$ (approximate)

Number of raw units (input) required, $Y^i_{21} = k^i_{21} Y^o_{21} = 1.1547 \times 1000 = 1550$ (approximate)

$$\begin{aligned}\text{Unit output cost, } X^o_{21} &= k^i_{21} X^i_{21} - k^s_{21} X^s_{21} + k^i_{21} f(Y^i_{21}) \\ &= 1.1547 \times 10.00 - 0.1547 \times 2.00 + 1.1547 \times 9.00 \\ &= 21.63\end{aligned}$$

Concurrent Engineering Team Meeting 2

The quality and purchasing departments are still not satisfied with the amount of scrap generated, and the marketing department feels that the unit cost is still too high. As a consequence of this feedback from marketing, the design engineers believe that the customer requirements can be met with tolerance limits of 1 ± 0.004 inch. The team explores this scenario. They consider the component tolerances to be 1 ± 0.004 inch as recommended jointly by the marketing services and design engineers. An engine lathe is to be used to manufacture the component.

It is pertinent to point out that the design tolerances for individual components are allocated based on stacking of assembly tolerances. This aspect is illustrated in the journal bearing assembly example given in the Appendix. Other data are the same as those considered in meeting 1. The unit cost of output, number of units of scrap generated, and number of raw units required to produce 1000 finished units are determined as follows:

In this case $j = 2$ and $k = 2$. Using a procedure similar to that used in meeting 1, we obtain:

Number of units scrapped, $Y^s_{22} = k^s_{22} Y^o_{22} = 0.0456 \times 1000 = 46$ (approximately)

Number of raw units (input) required, $Y^i_{22} = k^i_{22} Y^o_{22} = 1.0456 \times 1000 = 1046$ units (approximately)

$$\begin{aligned}\text{Unit output cost, } X^o_{22} &= k^i_{22} X^i_{22} - k^s_{22} X^s_{22} + k^i_{22} f(Y^i_{22}) \\ &= 1.0456 \times 10.00 - 0.0456 \times 2.00 + 1.0456 \times 9.00 \\ &= 19.78\end{aligned}$$

Concurrent Engineering Team Meeting 3

Our cross-functional multi-disciplinary team compares the results of the two meetings and seeks reductions in the cost of manufacturing, the number of rejects, and consequently the number of pieces of raw shaft material required. Although the number of rejects has been reduced considerably, quality level is still not acceptable to the customer. The customer is, however, willing to pay more per unit. The team explores the possibility of using an automated screw machine (ASM), whose process capability is much better than that of an engine lathe. This would, however, increase the unit processing cost.

For the ASM the standard deviation is now 0.001 inch and the unit processing cost is $12.00. Other data are the same as in the previous meetings. In this meeting the team wants to know the unit cost of output, number of units of scrap generated, and number of raw units required to produce 1000 finished units considering both 1 ± 0.003 and 1 ± 0.004 inch as tolerance limits. The relevant calculations follow.

For the tolerance limit of 1 ± 0.003, and automated screw machine $k = 1$ and $j = 3$.

Number of units scrapped, $Y^s_{31} = k^s_{31} Y^o_{31} = 0.0027 \times 1000 = 3$ (approximately)

Number of raw units (input) required, $Y^i_{31} = k^i_{31} Y^o_{31} = 1.002 \times 1000 = 1003$ units

$$
\begin{aligned}
\text{Unit output cost, } X^o_{31} &= k^i_{31} X^i_{31} - k^s_{31} X^s_{31} + K^i_{31} f(Y^i_{31}) \\
&= 1.0027 \times 10.00 - 0.0027 \times 2.00 + 12.00 \times 1.0027 \\
&= 22.054
\end{aligned}
$$

For the tolerance limit of 1 ± 0.004, $j = 3$ and $k = 2$.

$$
\begin{aligned}
\text{Number of units scrapped, } Y^s_{32} &= k^s_{32} Y^o_{32} = 0.000 \times 1000 = 00 \\
K^i_{32} &= 1 + 0.00 = 1.00
\end{aligned}
$$

Number of raw units (input) required, $Y^i_{32} = k^i_{32} Y^o_{32} = 1.00 \times 1000 = 1000$ units

$$
\begin{aligned}
\text{Unit output cost, } X^o_{32} &= k^i_{32} X^i_{32} - k^s_{32} X^s_{32} + K^i_{32} f(Y^i_{32}) \\
&= 1.00 \times 10.00 - 0.00 \times 2.00 + 1.00 \times 12.00 = 22.00
\end{aligned}
$$

Concurrent Engineering Meeting 4

There have been dramatic improvements in the product quality as well as manufacturing lead time as a result of the multi-disciplinary cross-functional team–based approach of concurrent engineering. The scrap has been reduced to zero, which addressed the concerns of the quality control and sales departments.

In its earlier deliberations, the team did not consider the influence of economies of scale of production. Consider the situation in which the tolerance specifications are 1 ± 0.004 inch. Suppose the processing cost function for the automatic screw machine option is

$$f(Y^i_{32}) = 12.00 - 0.003 Y^i_{32}$$

Then the processing cost per unit when manufacturing 1000 units is 9. Accordingly, the unit cost of output is

$$
\begin{aligned}
X^o_{32} &= k^i_{32} X^i_{32} - k^s_{32} X^s_{32} + K^i_{32} f(Y^i_{32}) \\
&= 1.00 \times 10.00 - 0.00 \times 2.00 + 1.00 \times 9.00 = 19.00
\end{aligned}
$$

The sequence of meetings of the concurrent engineering team has led to them to understand the interaction between design and manufacturing by simultaneously considering both design and manufacturing issues. These interactions are summarized in Table 4.2. Furthermore, these concepts can be extended to cases involving multistage production and rework at each stage.

Understanding benefits of concurrent engineering

We mentioned earlier that unit cost, quality, and manufacturing lead time are three major determinants of market share and profitability of an organization. In this section we explore how the use of concurrent engineering concepts results in reduced unit cost, improved quality, and reduced lead time compared with the serial engineering approach. The basic data used are summarized in Table 4.1. We use the results obtained in Sections 4.6.1 and 4.6.2 for the serial and concurrent engineering approaches as shown in Table 4.2.

TABLE 4.1 **The Basic Data Used in the Shaft Examples**

Manufacturing Options	*Unit Processing Costs*	*Setup Time*	*Unit Processing Time*	*Process Standard Deviation*
Turret lathe	7.00	20.00	1.00	0.003
Engine lathe	9.00	25.00	0.80	0.002
ASM	12.00	50.00	0.70	0.001

4.6.1 Serial Engineering Approach

From Section 4.5 we know the unit cost in the serial engineering approach. The number of rejects can be considered as a measure of quality. We are also interested in estimating the manufacturing lead time. Now suppose it takes one unit time to manufacture a unit on a turret lathe. We then have

Unit cost = \$23.97

Setup time = 20 time units

Number of rejects (a measure of quality) = 465

Manufacturing lead time = setup time + (number of units turned on turret lathe × time per unit)
= 20 + (1465 × 1.00)
= 1485 time units

4.6.2 Concurrent Engineering Approach

We consider the scenario in meeting 3 that reflects the concurrent engineering approach. Suppose it takes 0.70 unit of time to manufacture a unit on an automatic screw machine compared with 1 unit of time on a turret lathe. In the case of concurrent engineering we then have

Unit cost = \$22.00,

Setup time = 50 time units

Number of rejects (a measure of quality) = 00

Manufacturing lead time = setup time + number of units turned on turret lathe × time per unit
= 50 + 1000 × 0.70
= 750 time units

TABLE 4.2 **Interaction Between Design and Manufacturing**

Manufacturing Technological Options	*Tolerances (in.)* 1 ± 0.003			*Tolerances (in.)* 1 ± 0.004		
	Unit Cost	*Scrap (Units)*	*Lead Time*	*Unit Cost*	*Scrap (Units)*	*Lead Time*
Turret lathe	23.97	465	1485	20.37	184	1204
Engine lathe	21.63	155	949	19.78	46	862
Automatic screw machine	22.05	3	752	22.00	00	750

4.6.3 Improvements in Unit Cost, Quality, and Manufacturing Lead Time

We are now in a position to evaluate the improvements in all three areas, unit cost, quality, and manufacturing lead time, by using concurrent engineering as follows:

Percentage improvement in unit cost = $[(23.97 - 22)/22] \times 100 = 8.95\%$

Improvement in quality = zero scrap compared with 465 units scrapped in serial engineering

Percentage improvement in manufacturing lead time $= [(1485 - 750)/750] \times 100$
$= 98\%$

4.6.4 Other Benefits

We have demonstrated that an integrated concurrent engineering team can produce a better quality part with less waste and at lower cost. One of the most important benefits of concurrent engineering is not explicitly addressed in this simple example. In many large development projects, especially product development, lack of communication among members of the product development team can lead to extensive engineering design changes. Each design change consumes time in the product development cycle. This increase in time to reach market can influence the acceptance of the product, market position, project cost, and quality. These issues alone are compelling reasons for a firm to adopt the concurrent engineering approach.

Quality Function Deployment (QFD)

- The main objective of a manufacturing company is to bring new products to market sooner than the competition with lower cost and improved quality. The mechanism for doing is called QFD.
- QFD provides a means of translating customer requirements into appropriate technical requirements for each stage of product development and production, that is, marketing strategy, planning, product design and engineering, prototype evaluation, production process development, production, and sales.

There are four phases of QFD

1. Product planning phase
2. Part deployment phase
3. Process deployment phase
4. Production deployment phase

Product planning phase

In this phase, the overall customer requirements drawn from market evaluations, comparison with competitors, and market plans are converted into specified final product control characteristics.

Product Planning Matrix

Step 1. State requirements in customer terms. The primary customer requirements are expanded into secondary and tertiary requirements to obtain a more definite list. This information is obtained from a variety of sources, such as marketing research data, dealer input, sales department wants, and special customer surveys.

Step 2. List the final product control characteristics that should meet the customer-stated product requirements. These characteristics are the product requirements that are related directly to the customer requirements and must be selectively deployed throughout the design, manufacturing, assembly, and service process to manifest themselves in the final product performance and customer acceptance.

Step 3. Develop a relationship matrix between customer requirements and final product control characteristics. A set of symbols is used to represent the relationships, such as strong, medium, and weak relationships. If the matrix shows a majority of "weak relationship" signs, it is an indication that some customer requirements are not addressed properly.

Step 4. Enter market evaluations. The objective is to evaluate the strengths and weaknesses of the products vs. the competitions so that areas for improvement are clearly identifies.

Step 5. Enter product control characteristic competitive evaluations and compare control characteristic competitive evaluations with market competitive evaluations. This helps indicate inconsistencies between customer requirements and your own evaluations.

Step 6. Determine selling points for new product. Based on these points, product marketing, distribution, and promotion strategies are decided.

Step 7. Develop measurable targets for final product control characteristics based on agreed-upon selling points, the customer importance index, and the current product strengths and weaknesses.

Step 8. Select control characteristics based on customer importance, selling points, and competitive evaluations. These selected characteristics must be translated into the language of each discipline in terms of actions and controls required to ensure that the customer's voice is heard through every stage of the product life cycle.

Part deployment phase

- In this phase, the output of the product planning (i.e. final product control characteristics) is translated into critical component characteristics. This phase is the first step in materializing the customer needs and a one step forward into the design and assembly process development.
- For this purpose, a document called the final product characteristic deployment matrix is used. In this matrix, the final product control characteristics are carried from the final assembly (product) level to the subsystem/component.
- From the customer requirements and final product control are identified.

Process deployment phase

- In this phase, all the critical product and process parameters are identified and quality control checkpoints for each parameter are established.

- If a critical product component parameter is created or directly affected in a given step of a process, that parameter is identified as a control point. These points establish the data and strategy for the product quality control plan and are essential for achieving product characteristics that meet the high-priority customer requirements.
- If critical parameters, such as time, temperature, and pressure, must be monitored to ensure that the component parameters are achieved, these parameters are designed as checkpoints and become the basis for operating instructions and the process control strategy.

Production deployment phase

- The output from the process development and quality control planning phase provides the critical product and process parameters. The objective of the production operating instruction phase is to identify the operations to ensure that these parameters are achieved.
- The operating instructions sheet is the fourth and final key QFD document. It basically defines the operator requirements as determined by the actual process requirements, the process plan chart checkpoint, and the quality control plan chart control points.
- Many variations in the operating instructions can be anticipated based on individual process situations. What is important is that this document, which relates to the checkpoints and control points, clearly conveys the following points to the operator: What parts are involved? How many should he or she check, using what tool? How should the check be made?

Cumulative Standard Normal Distribution

$$\Phi(z) = \int_{-\infty}^{z} \frac{1}{\sqrt{2\pi}} e^{-u^2/2}\, du$$

z	.00	.01	.02	.03	.04	z
.0	.50000	.50399	.50798	.51197	.51595	.0
.1	.53983	.54379	.54776	.55172	.55567	.1
.2	.57926	.58317	.58706	.59095	.59483	.2
.3	.61791	.62172	.62551	.62930	.63307	.3
.4	.65542	.65910	.66276	.66640	.67003	.4
.5	.69146	.69497	.69847	.70194	.70540	.5
.6	.72575	.72907	.73237	.73565	.73891	.6
.7	.75803	.76115	.76424	.76730	.77035	.7
.8	.78814	.79103	.79389	.79673	.79954	.8
.9	.81594	.81859	.82121	.82381	.82639	.9
1.0	.84134	.84375	.84613	.84849	.85083	1.0
1.1	.86433	.86650	.86864	.87076	.87285	1.1
1.2	.88493	.88686	.88877	.89065	.89251	1.2
1.3	.90320	.90490	.90658	.90824	.90988	1.3
1.4	.91924	.92073	.92219	.92364	.92506	1.4
1.5	.93319	.93448	.93574	.93699	.93822	1.5
1.6	.94520	.94630	.94738	.94845	.94950	1.6
1.7	.95543	.95637	.95728	.95818	.95907	1.7
1.8	.96407	.96485	.96562	.96637	.96711	1.8
1.9	.97128	.97193	.97257	.97320	.97381	1.9
2.0	.97725	.97778	.97831	.97882	.97932	2.0
2.1	.98214	.98257	.98300	.98341	.93882	2.1
2.2	.98610	.98645	.98679	.98713	.98745	2.2
2.3	.98928	.98956	.98983	.99010	.99036	2.3
2.4	.99180	.99202	.99224	.99245	.99266	2.4
2.5	.99379	.99396	.99413	.99430	.99446	2.5
2.6	.99534	.99547	.99560	.99573	.99585	2.6
2.7	.99653	.99664	.99674	.99683	.99693	2.7
2.8	.99744	.99752	.99760	.99767	.99774	2.8
2.9	.99813	.99819	.99825	.99831	.99836	2.9
3.0	.99865	.99869	.99874	.99878	.99882	3.0
3.1	.99903	.99906	.99910	.99913	.99916	3.1
3.2	.99931	.99934	.99936	.99938	.99940	3.2
3.3	.99952	.99953	.99955	.99957	.99958	3.3
3.4	.99966	.99968	.99969	.99970	.99971	3.4
3.5	.99977	.99978	.99978	.99979	.99980	3.5
3.6	.99984	.99985	.99985	.99986	.99986	3.6
3.7	.99989	.99990	.99990	.99990	.99991	3.7
3.8	.99993	.99993	.99993	.99994	.99994	3.8
3.9	.99995	.99995	.99996	.99996	.99996	3.9

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