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# Assessing success factors for implementing CE
# A case study in Hong Kong electronics industry by AHP

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**Abstract**

This paper examines and evaluates strategic and operational level success factors, benefits and costs to develop strategies of implementing concurrent engineering (CE) in the Hong Kong electronics industry. First several success factors to implement CE are identified based on literature review. Then an AHP model is formulated and used to assess the success factors, benefits and costs in order to develop strategies to implement CE in Hong Kong electronic products manufacturing companies. Also, the same model is used to determine the benefit/cost ratios and to decide whether or not to implement CE in the Hong Kong electronics industry.

*Keywords*: AHP; Benefit/cost analysis; Concurrent engineering; Implementation; Success factors; Electronic industry; Hong Kong

## 1. The concurrent engineering

Bringing new or improved products faster to market has become an important strategic goal for companies in the 1980s in order to compete strongly and survive well in global markets. Many companies began to look for new methods for quicker and cost-effective product development in order to achieve this goal. For example, the Defense Advanced Research Projects Agency (DARPA) of USA started to study ways to improve concurrence in design process in 1982 [1]. Today, a number of researchers and managers believe that the traditional sequential approach in product development is no longer adequate for achieving the goal of developing a high-quality and low-cost product with a quick response in order to compete strongly in the market place [2–7]. An integrated approach called Concurrent Engineering is widely accepted as a winning product development strategy in the 1990s.

Concurrent engineering (CE) sometimes called simultaneous engineering, integrated engineering or life-cycle engineering, is more a philosophy than a method. As a landmark initiative, the Institute for Defense Analysis (IDA) firstly introduced the term concurrent engineering to explain the systematic method of concurrently designing both the product

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and its downstream processes. More formally, IDA defined concurrent engineering as "*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 concept through disposal, including quality, cost, schedule and user requirements*" [1]. This early definition of CE is still commonly used today. Since its introduction by IDA, many studies on CE have appeared and a number of reports have been presented. Another widely adopted definition of CE is "*the concurrent development of project design functions, with open and interactive communication existing among all team members for the purpose of reducing lead time from concept to production launch*" [8].

The above two definitions indicate that the shortened product development time, improved quality and reduced costs are the resulting benefits of CE because the development activities are completed in parallel and the decision making among different groups are integrated. CE, however, does not mean the simultaneous undertaking of all activities in the product development process at the same time. This would be impossible because of certain limitations due to prevailing physical, organizational and economic conditions. Many complex projects would always involve efforts from a large number of engineers and managers from different functional areas. Placing all these people into one large group would cause tremendous coordination problems. Therefore, in reality, the CE approach cannot be implemented as one unified phase involving all parties in the organization. However, it can be planned to include overlapping phases as shown in Fig. 1 in which individual functional departments may have different intensities of collaboration and coordination during the entire product development process include certain members. For example, a CE team with members from marketing, product design, process design, manufacturing, and procurement departments and suppliers may be formed while the other members can be opted to join this team when they are needed in the product development process.

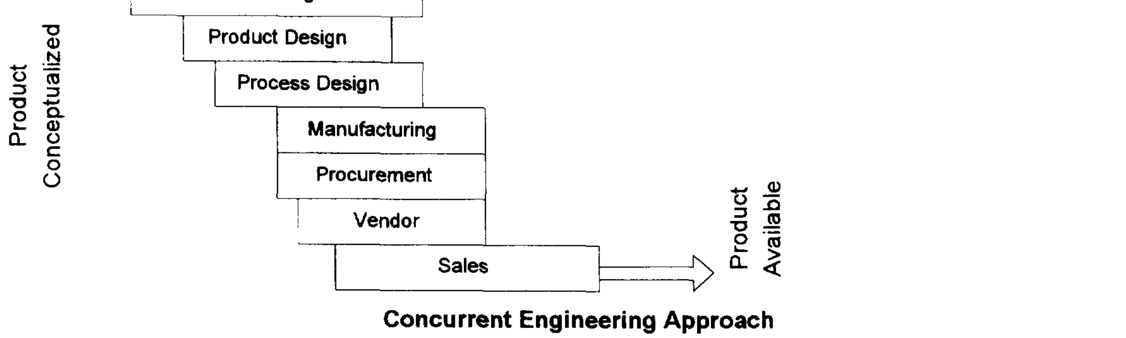


Fig. 1. Sequential product development process vs. concurrent engineering.

### *1.1. Benefits and costs of CE implementation*

CE is introduced with the aim of integrating all the efforts from different activities required in the product development without costly and lengthy re-works during the entire development process. As a result, significant effect on quality, product cost, time-to-market, customer focus and thus ultimate marketplace success of the product, can be achieved by the design decisions made early in the product development cycle. Inevitably, certain costs of CE implementation would also be incurred, namely the cost of initial change (investment), cost of training and development, cost of new technologies and the cost of risk and uncertainty. These benefits and costs of CE implementation are supported and reported by a number of case studies as shown in Table 1.

It appears that the benefits of implementing CE may far outweigh the costs, or certain trade-offs between the benefits realized and the costs incurred are required to be made by the planners of CE implementation. In addition, as experienced by several companies, the road to implementation is not smooth. What are the critical success factors (or criteria or subcriteria) we need to consider? What are the techniques we need to use in successfully implementing CE? What kinds of support and in what forms should we expect from senior and middle management? These are all the important problems we need to address in making a decision. In this paper, we consider all these problems and examine critically the success factors, as well as the benefits realized and the costs incurred in CE implementation. We formulate an AHP model to determine the relative importance of these

Table 1
Benefits and cost of CE implementation

| | Companies | Results of CE implementation | |
|---|---|---|---|
| | | Benefits | Costs |
| 1 | General Motors [9] | 1. Shortened product development time<br>2. Increased customer satisfaction as 27% increase in consumer ratings of the total ownership experience and 24% improvement in repurchase loyalty occurred | 1. Cost of re-organizing the existing structure to several cross-functional teams |
| 2 | Ford [10] | 1. Increased customer focus<br>2. Lowered product cost as a result of minimized inventories as well as improved procurements and design functions<br>3. Improved product quality<br>4. Rapid prototyping shortened the product development time | 1. Cost of buying and installing new technologies for design, planning, manufacturing and communication<br>2. Cost of training needed |
| 3 | Philip [11] | 1. Shortened product development time stemmed from the reduction in design time<br>2. Increased product quality | 1. Cost of investment on advanced technologies like CAD, CAE |
| 4 | Chrysler [12] | 1. Shortened product development time as a result of reduced rework | 1. Cost of initialing team set-up and organization structure change<br>2. Cost of developing technologies to integrate a variety of specialties<br>3. Cost of staff training |
| 5 | Eastman Kodak [13] | 1. Shortened product development time | 1. Cost of initializing change on re-structuring for CE<br>2. Cost of installing new technology to communicate electronically |

identified success factors and prioritize them in developing plans to implement CE successfully. Also, we can find the relative importance of benefits and costs as well as the benefits/costs ratios of implementing or not implementing CE and hence to determine the optimal course of action. A case study involving the Hong Kong electronics industry will be used to examine the application of the proposed model. The model is expected to enable us to assess and determine the critical success factors and formulate the corresponding strategies in successfully implementing CE in the Hong Kong electronics companies. First, in the following section, we shall describe the various success factors that are useful for successful CE implementation.

Electronics industry is the second largest industry in Hong Kong in terms of export value. Its products include integrated circuits, computers, electric motors and other electronic components, electrical and household appliances and communication equipment. During the last decade, many manufacturing companies moved their production into China because of China's economic reforms and competition from the newly developed areas in the SouthEast Asia. Therefore, the companies in Hong Kong are also shifting from relatively labour intensive and simple products to more technology-intensive and high value added products. We hope that the proposed model would enable us to determine critical success factors and formulate strategies in implementing CE for Hong Kong electronics companies so that they become competitive and survive in global markets.

## 2. Success factors for implementing concurrent engineering

Concurrent engineering requires a breakthrough from the traditional sequential product development environment. Reshaping the company environment and providing sufficient resources for change are the two key tasks in achieving the successful implementation of CE. The reshaping requires strong support not only from top management but also from middle management and shop floor personnel. Emphasis in building quality in products at design stage as well as the partnership with customers and suppliers are also required to break the traditional product development environment. Also, cross-functional and multi-disciplinary teams can break down the barriers between departments, and provide effective means of communications. This requires a fundamental change in organizations to provide an environment conducive to work in teams and obtain employee commitment to change. Similarly, new methodologies are required to provide efficient ways to identify specific customer requirements, to convert the requirements into product, process and production specifications, and to integrate the product with other development processes. These strategic issues for successful CE implementation are called as the success factors and can be classified into four dimensions, namely, management attitude, product development, organizational change, and implementation methodologies as shown in Table 2.

Table 2
Success factors for CE implementation

| Decision criteria | Management attitude | Product development | Organizational change | Implementation methodologies |
|---|---|---|---|---|
| Sub-criteria | 1. Top management lead support | 1. Design assurance | 1. Multi-disciplinary structure | 1. Use of computer technologies |
| | 2. Middle management commitment | 2. Customer involvement | 2. Cross-functional management | 2. Use of analytical tools |
| | 3. Proactive development strategy | 3. Supplier partnership | 3. Employee commitment to change | |
| | 4. Participative management style | | | |

Each of these strategic success factors can be defined well in terms of various attributes. For example, the management attitude can be understood well by the defining attributes of top management lead and support, middle management commitment, proactive development strategy and participative management style as explained below.

### 2.1. Management attitude

#### 2.1.1. Top management lead and support

As CE is a long-term program and always involves large investment in human resources and technologies at the beginning of a project to reap rewards later, the top management lead and support is vital to a successful CE implementation [14]. The top management must not only support the CE initiative but also participate actively in formulating and implementing the CE goals and objectives. One effective way to demonstrate a clear management support is to set up a steering committee at senior management level responsible for leading the change required throughout the company and provide direction for CE implementation.

#### 2.1.2. Middle management commitment

As CE requires collective decisions rather than the traditional functional decisions in a serial manner, middle management may feel that they would lose control over decisions and budgets, as well as lose people from their departments. It is thus important to let them know that they continue to play an important role in CE environment, but that will be different. If the new role is not clearly and explicitly defined, they may not be committed to the company's goal of CE implementation and thus resist to any necessary changes, remove resources from the CE program and slow down the product development process. Hence, middle managers should be actively involved in CE program planning and implementation. The middle management can participate with senior management in developing CE goals and objectives and communicate them to their subordinates effectively. Also, they can provide necessary training relates to CE implementation methodologies.

#### 2.1.3. Proactive development strategy

An organization must have an appropriate business strategy to create successful new products or improve existing products in order to gain advantage over competitors. The basic strategic decision that needs to be made in product development is whether to adopt a proactive strategy or to adopt a reactive strategy. A proactive product development strategy explicitly allocates resources to search and identify opportunities and to pre-empt possible adverse effects. It may be based on either technology-driven research and development effort to develop technically superior products, or to focus on marketing research efforts to identify customer needs and build them into the product, or both. This proactive approach pre-empts competition by being the first on the market with a product that competitors find it difficult to match, whereas a reactive strategy needs to deal with the pressures from competition. For example, one of the reactive approaches is the "Me Too" strategy. Some companies follow it by simply waiting until the competitor introduces a new product and copying it if it is successful. Similarly, "OEM" (Original Equipment Manufacturer) strategy is another reactive approach that companies develop new products only in response to a design with confirmed orders given by customers. The reactive strategy is however not considered as successful in gaining market share in the long run [15]. Companies which adopt reactive product strategy would realize less benefits because the product design was already dominated by competitor model or customer specifications. Thus, the company's product strategy will influence the benefits of CE implementation to a great extent.

#### 2.1.4. Participative management style

Participative management style is getting people at different functional levels of responsibility involved in decision making, such as found in quality circles and self-managed teams. It is found that the resistance to change could be reduced or even eliminated by having those involved in the change participate in making decisions for implementing the changes [16–18]. People who participate will always be committed to implementing changes and any relevant information they have will be integrated into the change process plans. As CE requires many changes in the organization in order to have a breakthrough from the traditional development process, participative management style helps achieving successful CE implementation faster.

### 2.2. Product development

As in the case of management attitude, the product development is supported by the defining attributes of design assurance as well as customer and supplier involvement.

#### 2.2.1. Design assurance

Many people have realized that the cost and time required for design changes increase more as the design process progresses. The cost increases by a factor of more than ten at each succeeding stage such as concept design, specification decisions, design reviews, pilot production and regular production, etc. [19]. The changes and reworks at later development are costly and time-consuming, and may be helpless in some cases to correct any early mistakes. In order to assure the product quality, it is important to consider all aspects of the product, process and supporting systems when the concept (or specifications, or requirements) for the product is first considered. The time spent in obtaining such a concurrent design at product design stage may be longer than that reported in traditional sequential process. However, the longer redesign time due to error correction in traditional processes is always not included in the traditional calculation. The CE approach aims to actually reduce the total product development time by preventing the subsequent design iterations and reworks as compared with the sequential process. Such a design assurance concept is important for speeding up the product development [20].

#### 2.2.2. Customer and supplier involvement

Companies traditionally try to keep all new product development information internally and are reluctant to discuss with outsiders, especially at the early design stages. However, apart from internal development process, a successful CE implementation demands an up-front and constant communication with external members including customers and suppliers to develop a successful product [9, 21, 22]. Customer requirements is one of the most important aspects for product development process as any new product produced must satisfy the customer needs and expectations. Similarly, suppliers will significantly affect the quality of the final product as it requires quality materials or components which will be supplied by them. Such an early involvement with external customers and suppliers can emphasize the customer focus in determining the product requirements and ensure the supplier capability in meeting the requirements. This concurrent approach can reduce a significant portion of design errors and reworks due to misunderstandings or miscommunications between the company and the customers as well as the suppliers at the early design stage. The external involvement is always difficult and complex to handle, particularly the involvement of customers, but the alternative risks of making unsaleable or unmanufacturable products are probably worse.

### 2.3. Organizational change

In order to overcome organizational difficulties associated with the span of control, companies are used to group those people performing similar job functions together as a department and to adopt hierarchical reporting structures. In this situation, individual members of a functional department tend to adopt the same values and goals as each other. These goals, however, always conflict with the goals of other departments. Such functional or departmental barriers are the key problems to be tackled in implementing CE [5]. The most appropriate ways to break down these organizational barriers between individuals and between departments are forming multi-disciplinary teams and encouraging cross-functional culture. Obtaining employee commitment to change is equally important.

#### 2.3.1. Multi-disciplinary structure

The multi-disciplinary team is the most effective way known to coordinate and integrate the stages of product development process [23–26]. The team involves personnel from all concerned departments in product development such as design, manufacturing, marketing, purchasing, finance and even involve external customers and suppliers. Many successful cases reported in the literature indicate that CE implementation which begins with forming multi-disciplinary teams would break down walls between departments and encourage cross-departmental communication [22, 26–28]. The teams formed in the CE environment allow a freer exchange of knowledge and information between traditionally established separate disciplines. Although it varies from case to case, the practical number of team members should be limited to between 10 and 12 persons [29].

*2.3.2. Cross-functional management*

Unless all CE team members have the same commitment, only bringing people from different departments together cannot achieve the CE goals and objectives. Having investigated the Japanese firms, it was found that cross-functional culture is vital to have successful multi-disciplinary teams in the organization [30, 31]. Creating the cross-functional teamwork culture should start from the top management. Therefore, top management's commitment to cross-functional goals should be clearly expressed in the annual company plans on the basis of long-term strategies. As departmental managers naturally tend to place their priorities on their own department line functions, top management need to set new product development as a cross-functional goal which cuts across the line departments with varying degrees of coordinated work activities. Several successful experiences from Japan indicate that Japanese manufacturers often establish cross-functional management committees at the top management level to plan, determine and measure the performance of cross-functional goals. The committees together with regular joint meetings, job rotation, cross-function training and other social interactions, are proved to be effective in promoting cross-functional culture in their companies [31, 32]. The matrix management structure in which all functional groups are organized together and are under unilateral direction of a chief project manager, is also found to solve the cross-functional problems effectively [33]. The feasibility of matrix organization, however, depends very much on the company environment.

*2.3.3. Employee commitment to change*

As CE requires a structural change from the traditional product development process, it requires certain change from employees. For instance, the designers are required to seek advice from CE team members of other functions instead of their own domination of the design as they do under the traditional product development environment. Manufacturing engineers cannot only criticize the product design but also take the responsibility in finding positive solutions for manufacturability in the CE team. In order to make the CE implementation smoother and more successful, commitment and involvement from all levels of employees is thus essential.

## 2.4. Implementation methodologies

In addition to the organizational change, effective CE implementation requires the use of computer technologies and analytical techniques. Therefore, the use of computer technologies and analytical techniques would form the defining attributes of implementation methodologies.

*2.4.1. Use of computer technologies*

Computer technology has been applied to aid product development activities over the past decade, such as computer-aided design (CAD), computer-aided manufacturing (CAM), design simulation and rapid prototyping, etc. The applications, however, are made in an isolated manner in the past to only solve stand-alone problems. For instance, CAD has speeded up the design and drawing activities, but the actual time reduction is not so significant as compared with the reworks and delays caused by the sequential product development process. Many researchers pointed out that there is a great potential to utilize computer technology to support CE implementation in an integrated manner in the form of decision support and communication [7, 28, 30]. The decision support infrastructure, including the system, equipment and the software is for evaluating and making proposals for actions throughout the product development process. Making the right decision at the first time surely reduces the subsequent reworks to shorten the overall development time. The artificial intelligence such as expert systems technology is an evolving computer methodology having great promise to benefit the CE implementation in this area [34]. Similarly, the communication infrastructure including hardware and software is to establish an unified system for storage, control and retrieval of all information and data relevant to the product in the organization. It provides a common database as well as a mechanism for timely sharing of information and knowledge for decision-making by different departments [5, 35]. Since CE requires teamwork and information sharing in an integrated product development environment, effective and timely communication is critical to its success.

#### 2.4.2. Use of analytical tools

A number of different analytical techniques are available to assist the CE implementation. With these methods employed effectively with the CE approach, many manufacturing problems can be identified at an early development stage, and design justification and optimization can also be achieved. The methods are, however, difficult to categorize because they are developed in order to serve a large variety of problems. They can be used at different stages of the product development process to assist teams and individual engineers making the right-at-first-time decisions.

The common techniques reported to be useful in this area are, for instance, design for manufacturability and assembly (DFMA), quality function deployment (QFD), failure mode and effect analysis (FMEA), robust design (design of experiments and Taguchi methods), fault tree analysis (FTA), group technology (GT) and value engineering (VE), etc. [28, 30, 32].

As stated in Section 1, we need to determine the relative importance of these strategic and defining or operational attributes in order to prioritize them and to develop the corresponding strategies to implement CE successfully. The formulation of an AHP model will enable us to achieve this purpose.

## 3. The AHP model to assess success factors for CE implementation

The analytic hierarchy process (AHP) is a very useful technique in solving complex decision problems. By applying this methodology, we can identify several qualitative and quantitative criteria, examine the competing and conflicting objectives among them, and assess their relative importance in order to make trade-offs and to determine priorities among them for making good decisions [37, 38]. Therefore, we use AHP to formulate a model to assess the relative importance and to determine the priority weights of the criteria and sub-criteria or success factors used for CE implementation as described in Section 2. We also use it to assess the benefits and costs of implementing CE and consider the trade-offs between them in deciding whether or not to implement CE in the Hong Kong electronic products industry.

The AHP modelling process involves four phases: namely, Phase 1, Structuring the problem; Phase 2, Measurement and data collection; Phase 3, Determination of normalized weights, and Phase 4, Synthesis-finding solution to the problem [39, 40]

### 3.1. Structuring CE implementation problem

This phase involves the decomposition of a complex problem into a multi-level hierarchical structure where each level represents a set of meaningful and relevant criteria or success factors as shown in Figs. 2 and 3, respectively. The success factors at different levels of hierarchy for CE implementation are determined from the literature review as discussed in Section 2. Fig. 2 describes the benefits hierarchy, whereas Fig. 3 describes the costs hierarchy. Each of the benefits and costs hierarchies consists of five levels, including the goal, decision criteria, subcriteria, CE benefits or costs, and alternatives. Level 1 occupies the goal of deciding whether or not to implement CE in the Hong Kong plastic products industry. Based on this goal, we considered the strategic issues and the corresponding success factors (or decision criteria) in Level 2. In Level 3, we included the relevant attributes (or subcriteria) that define each of the strategic success

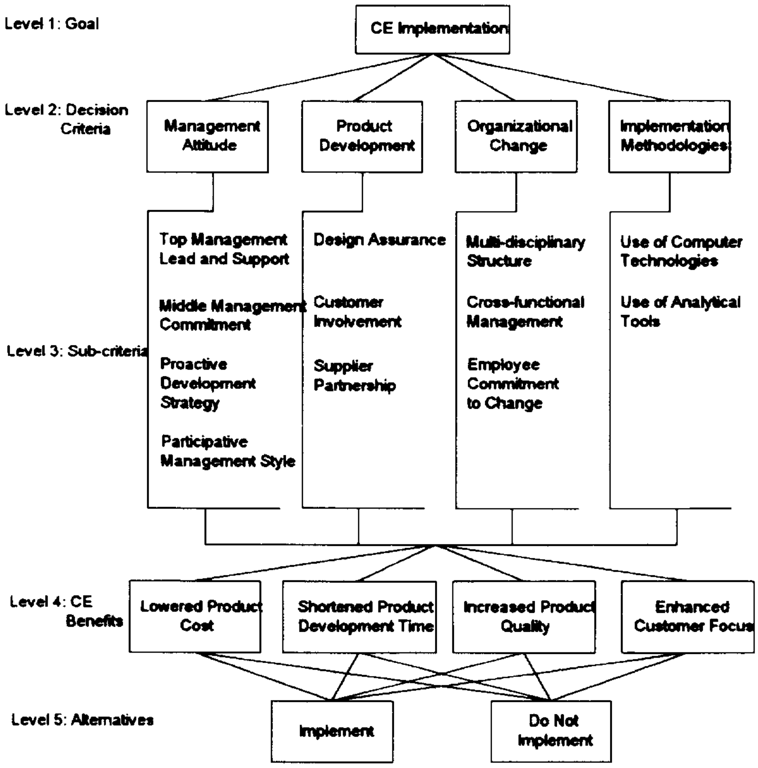


Fig. 2. Benefits hierarchy of CE implementation.

factors considered in Level 2. Similarly, Level 4 includes the benefits realized or costs incurred by considering Level 3 success factors to implement CE as shown in Figs. 2 and 3, respectively. Finally, the alternatives of implementing or not implementing CE based on the benefits or costs are placed in Level 5.

First we use the four levels of the hierarchy and determine the priority weights of all success factors and benefits as well as costs. This will enable us to assess their relative importance. Then, we determine the benefits/costs ratios of implementing or not implementing CE and decide on the best course of action using the last level of the hierarchy.

### 3.2. Measurement and data collection

The measurement and data collection phase involves collection of data to determine the relative importance of criteria or subcriteria used in different levels of the hierarchies as shown in Figs. 2 and 3. The nine-point scale as suggested by Saaty is used to assign the relative scales (see Table 3) [38]. As mentioned earlier, we have considered in this paper the electronics industry in Hong Kong. Five representative evaluators representing different areas of product development process were selected from different electronic companies based on their wide experiences and expertise in order to judge and evaluate the criteria used in different levels of the hierarchy and provide the corresponding pairwise comparison judgments using the nine-point scale. They are the operations director, engineering manager, product development engineer, vice president of engineering, and the R and D manager. The operations director has been working in his electronic company for 20 years. He is now overseeing the management and operation of engineering activities. In addition, the engineering manager has

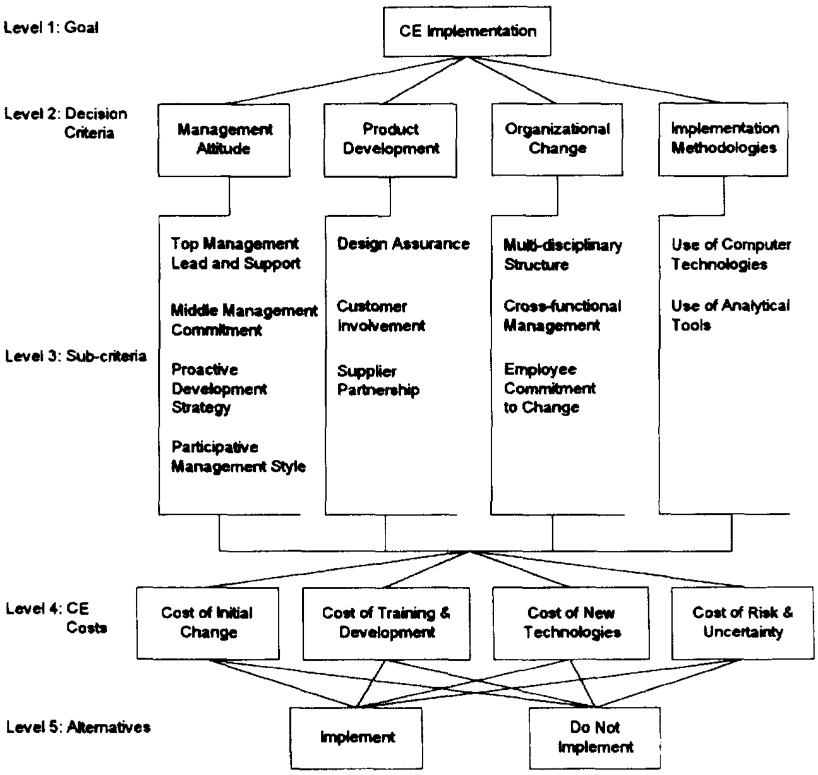


Fig. 3. Costs hierarchy of CE implementation.

Table 3
Nine-point scale

| Intensity of importance | Definition | Explanation |
|---|---|---|
| 1 | Equal importance | Two activities contribute equally to the objective |
| 3 | Weak importance of one over other | Experience and judgement slightly favour one activity over another |
| 5 | Essential or strong important | Experience and judgment favour one activity over another |
| 7 | Demonstrated importance | An activity is strongly favoured and its dominance is demostrated in practice |
| 9 | Absolute importance | The evidence favouring one activity over another is of the highest possible order of affirmation |
| 2, 4, 6, 8 | Intermediate values between the two adjacent judgements | When compromise is needed |
| Reciprocals of above nonzero | If activity $i$ has one of the above nonzero numbers assigned to it when compared with activity $j$, then $j$ has the reciprocal value when compared with $i$ | |

proven experience in production operation and project management in shopfloor level. Similarly, the product development engineer has been actively involved in his field for 5 years. Also, the vice-president of engineering possesses strong background in developing electronic security products, whereas the R and D manager has 11 years of research and development experience in Hong Kong electronics industry. Based on the experiences and expertise of these evaluators, we can assume that they are knowledgeable and can repre- sent well the general practices and opinions in electronics industry in evaluating the criteria and assigning the relative scales in order to determine the relative importance of criteria or subcriteria used in the AHP models shown in Figs. 2 and 3.

Each of these evaluators were asked to evaluate carefully and assign relative scales in a pairwise fashion with respect to the criteria of one level of hierarchy given the criterion at the next higher level of hierarchy. This process is continued to all levels of the entire hierarchy. As a result, we obtained a series of pairwise comparison judgment matrices corresponding to the success factors, benefits and costs, and alternatives used in all levels of the hierarchy.

### 3.3. Determining normalized weights

The third phase of the AHP is the determination of normalized weights. The pairwise comparison judgment matrices obtained in Phase 2 are translated into the largest eigenvalue problems that can be solved to determine the normalized and unique priority vectors of weights to success factors, benefits or costs, and alternatives used in each level of the hierarchy. Expert choice is used to achieve this purpose [41]. As suggested by Saaty, the geometric mean (GM) approach, instead of the arithmetic (AM) approach is used to combine the pairwise comparison judgment matrices obtained from each evaluator. Tables 4 and 6 describe the normalized weights for the benefits and costs hierarchies. The overall consistency of the input judgments at all levels is well within the acceptable ratio of 0.10 as recommended by Saaty [38, 42].

Based on these normalized priority weights, we assess the relative importance of success factors, benefits and costs, as explained in Sections 3.3.1 and 3.3.2. It should be noted, however, that the priority weights obtained using expert choice and the conclusions drawn from them are results of the analysis of collective judgments provided by the panel of experts selected for this case study.

#### 3.3.1. Benefits hierarchy

With respect to the normalized priority weights in the second level as shown in Table 4, management attitude (MA) is found to be six, five and four times in importance than organizational change (OC), product development (PD) and implementation methodologies (IM), respectively. Therefore, management attitude is vital for successful implementation of CE in the Hong Kong electronics industry.

The priority weights in the third level reflect that top management lead and support (TLS) is the most important success factor than the others, given the management attitude. It is found to be about four times more important than middle management commitment (MMC) and six times more important than proactive development strategy (PDS) and participative management style (PMS), respectively. Therefore, the role of top management is essential in CE implementation in involving and providing guidelines and advice to other members. Support and commitment from middle management is determined as the second most important success factor. With respect to the product development, all the three success factors, namely, design assurance, customer involvement and supplier partnership are found to be equally important as their priority weights are almost equal to each other. Based on organizational change (OC), employee commitment to change (ECC) is perceived to be twice as important as multi-disciplinary structure (MDS) and cross-functional management (CFM) success factors, respectively. Thus, the employee commitment in decision making and communication issues is critical for successful CE implementation, compared to cross-functional management and multi-disciplinary structure. Similarly, the use of computer technologies (UCT) is found to more important success factor than the

Table 4
Normalized priority weights for benefits hierarchy

| | Local priority weights | | | | Global priority weights | | | |
|---|---|---|---|---|---|---|---|---|
| Level 1 | | | CE implementation | | | | | |
| Level 2 | | | | | | | | |
| | | MA | **0.637** | | | MA | 0.637 | |
| | | PD | 0.119 | | | PD | 0.119 | |
| | | OC | 0.101 | | | OC | 0.101 | |
| | | IM | 0.143 | | | IM | 0.143 | |
| Level 3 | | | | | | | | |
| | | MA | | PD | | MA | | PD |
| | TLS | **0.670** | DA | **0.345** | TLS | 0.427 | DA | 0.041 |
| | MMC | 0.159 | CI | **0.322** | MMC | 0.101 | CI | 0.038 |
| | PDS | 0.072 | SP | **0.333** | PDS | 0.046 | SP | 0.040 |
| | PMS | 0.100 | | | PMS | 0.064 | | |
| | | OC | | IM | | OC | | IM |
| | MDS | 0.298 | UCT | **0.838** | MDS | 0.030 | UCT | 0.120 |
| | CFM | 0.256 | UAT | 0.162 | CFM | 0.026 | UAT | 0.023 |
| | ECC | **0.447** | | | ECC | 0.045 | | |
| Level 4 | | | | | | | | |
| | | TLS | | MMC | | | | |
| | LPC | 0.179 | LPC | 0.215 | LPC | 0.197 | | |
| | SPD | **0.359** | SPD | 0.196 | SPD | 0.296 | | |
| | IPQ | 0.253 | IPQ | **0.359** | IPQ | 0.287 | | |
| | ECF | 0.209 | ECF | 0.230 | ECF | 0.221 | | |
| | | PDS | | PMS | | | | |
| | LPC | 0.122 | LPC | 0.142 | | | | |
| | SPD | **0.338** | SPD | **0.320** | | | | |
| | IPQ | **0.374** | IPQ | **0.383** | | | | |
| | ECF | 0.166 | ECF | 0.155 | | | | |
| | | DA | | CI | | | | |
| | LPC | 0.192 | LPC | **0.312** | | | | |
| | SPD | 0.220 | SPD | 0.237 | | | | |
| | IPQ | **0.400** | IPQ | 0.202 | | | | |
| | ECF | 0.187 | ECF | 0.249 | | | | |
| | | SP | | | | | | |
| | LPC | **0.302** | | | | | | |
| | SPD | 0.223 | | | | | | |
| | IPQ | **0.306** | | | | | | |
| | ECF | 0.168 | | | | | | |
| | | MDS | | CFM | | | | |
| | LPC | **0.250** | LPC | 0.198 | | | | |
| | SPD | 0.194 | SPD | 0.222 | | | | |
| | IPQ | **0.257** | IPQ | **0.274** | | | | |
| | ECF | **0.299** | ECF | **0.307** | | | | |
| | | ECC | | | | | | |
| | LPC | 0.102 | | | | | | |
| | SPD | 0.208 | | | | | | |
| | IPQ | **0.381** | | | | | | |
| | ECF | **0.308** | | | | | | |
| | | UCT | | UAT | | | | |
| | LPC | **0.250** | LPC | 0.219 | | | | |
| | SPD | **0.280** | SPD | 0.240 | | | | |
| | IPQ | 0.216 | IPQ | **0.297** | | | | |
| | ECF | **0.254** | ECF | 0.245 | | | | |

Table 4 (continued)

| | Local priority weights | | | | Global priority weights | |
|---|---|---|---|---|---|---|
| Level 5 | | | | | | |
| | | LPC | | SPD | | |
| | I | **0.879** | I | **0.863** | I | 0.868 |
| | NI | 0.121 | NI | 0.137 | NI | 0.133 |
| | | IPQ | | ECF | | |
| | I | **0.865** | I | **0.865** | | |
| | NI | 0.135 | NI | 0.135 | | |

use of analytical tools (UAT), with respect to implementation methodologies (IM). Thus, computer technologies must be strongly considered in assisting new product development.

At the fourth level, given top management lead and support, shortened product development time (SPD) is determined as more important than the other three benefits, indicating that top management lead and support brings about the greatest benefit of reduced cycle time. The improved product quality (IPQ) appears to be the second most important benefit with the next highest priority weight. Based on middle management commitment (MMC) and design assurance (DA), improved product quality is perceived to the most important and dominating benefit. Keeping the eyes on proactive development strategy (PDS), we observe that it brings about the largest benefit on improved product quality. Shortened product development time is found to be the next important benefit. The same observation is also true for participative management style (PMS). Given the supplier partnership (SP), improved product quality and product cost are found to be the major benefits. On the other hand, improved product quality and enhanced customer focus (ECF) are perceived to be the first and second most important benefits, respectively, with respect to employee commitment to change (ECC). In addition, enhanced customer focus and improved product quality are found as the first and second most important benefits of cross-functional management (CFM). The customer involvement (CI) appears to be impacting mostly lowered product cost (LPC), while shortened product development time appears to be the most important benefit by using computer technologies (UCT). Similarly, use of analytical tools (UAT) appears to be influencing the improved product quality the most. Although enhanced customer focus seems to be the most important benefit, improved product quality and lowered product cost are the next two important benefits as a result of employing multi-disciplinary structures (MDS).

Based on the first and second most important priority weights as shown in the last column of Table 5, we see that management attitude (MA) and implementation methodologies (IM) are the first and second most important strategic success factors in implementing CE in Hong Kong electronic products manufacturing companies. The global or composite priority weights determined as shown in Table 4 also support this observation. The product development and organizational change, in that order, are the next most important strategic success factors. With respect to these success factors, top management lead and support (TLS), middle management commitment (MMC), design assurance (DA), supplier partnership (SP), customer involvement (CI), employee commitment to change (ECC), multi-disciplinary structure (MDS), use of computer technologies (UCT) and use of analytical tools (UAT) can be considered as the most important defining or operational success factors in implementing CE in Hong Kong electronics industry. Again, the global priority weights as shown in Table 4 support this conclusion. Participative management style (PMS), product development strategy (PDS) and cross-functional management (CFM) are the next most important operational success factors.

The senior management must develop and implement strategies related to these factors in

Table 5
Evaluation of success factors for benefits hierarchy

| Higher level | Lower level | Criteria | Success factors in the order of importance | | | | Success factors with ranks 1 and 2 | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | **MA** | IM | PD | OC | MA | IM | |
| 2 | | | | | | | | | |
| | 3 | MA | **TLS** | MMC | PMS | PDS | TLS | MMC | |
| | 3 | PD | **DA** | SP | CI | | DA | SP | CI[a] |
| | 3 | OC | **ECC** | MDS | CFM | | ECC | MDS | |
| | 3 | IM | **UCT** | UAT | | | UCT | UAT | |
| 3 | | | | | | | | | |
| | 4 | TLS | **SPD** | IPQ | ECF | LPC | SPD | IPQ | |
| | 4 | MMC | **IPQ** | ECF | LPC | SPD | IPQ | ECF | LPC[a] |
| | 4 | PDS | **IPQ** | SPD | ECF | LPC | IPQ | SPD | |
| | 4 | PMS | **IPQ** | SPD | ECF | LPC | IPQ | SPD | |
| | 4 | DA | **IPQ** | SPD | LPC | ECF | IPQ | SPD | LPC[a] |
| | 4 | CI | **LPC** | ECF | SPD | IPQ | LPC | ECF | SPD[a] |
| | 4 | SP | **IPQ** | LPC | SPD | ECF | IPQ | LPC | |
| | 4 | MDS | **ECF** | IPQ | SPD | LPC | ECF | IPQ | SPD[a] |
| | 4 | CFM | **ECF** | IPQ | SPD | LPC | ECF | IPQ | |
| | 4 | ECC | **IPQ** | ECF | SPD | IPQ | IPQ | ECF | |
| | 4 | UAT | **IPQ** | ECF | SPD | LPC | IPQ | ECF | SPD[a] |
| | 4 | UCT | **SPD** | ECF | LPC | IPQ | SPD | ECF | LPC[a] |

[a] The priority weights are close to each other with respect to rank 2.

implementing concurrent engineering in the Hong Kong electronic products manufacturing companies. If implemented properly, the increased product quality (IPD) and shortened product development (SPD) are the two major benefits with the first and second most important priority weights as shown in the last columns of Table 5. The global priority weights shown in Table 4 would also support this conclusion. The enhanced customer focus (ECF) and lowered product cost (LPC), in that order, are the next most important benefits.

### *3.3.2. Costs hierarchy*

To provide a clear and comprehensive picture on the feasibility and to consider trade-offs between costs and benefits for CE implementation, costs hierarchy is also considered in addition to the benefits hierarchy. The normalized weights of each level are shown in Table 6. Since the success factors of Levels 2 and 3 are the same as those in the benefits hierarchy, the conclusions obtained would be the same for this hierarchy. Therefore, we consider the costs of implementation of Level 4 in order to determine their relative priorities. Based on top management lead and support (TLS) as shown in Table 6, cost of initial change (CIC) and cost of training and development (CTD) are found to be the two major costs as they both dominate the other costs due to new technologies, and risks and uncertainties. They are also perceived to be the major costs by employing proactive development strategy (PDS), multi-disciplinary structure (MDS) and cross-functional management (CFM). Similarly, cost of initial change is determined as the major cost based on middle management commitment (MMC), participative management style (PMS) and supplier partnership (SP), respectively. Apart from these, given the employee commitment to change (ECC) and use of computer technologies (UCT), cost of risk and uncertainty (CRU) and cost of new technologies (CNT) are found to be more

Table 6
Normalized priority weights for costs hierarchy

| | Local priority weights | | | | Global priority weights | | | |
|---|---|---|---|---|---|---|---|---|
| Level 1 | | | | CE Implementation | | | | |
| Level 2 | | MA | **0.637** | | | MA | 0.637 | |
| | | PD | 0.119 | | | PD | 0.119 | |
| | | OC | 0.101 | | | OC | 0.101 | |
| | | IM | 0.143 | | | IM | 0.143 | |
| Level 3 | | | | | | | | |
| | | MA | | PD | | MA | | PD |
| | TLS | **0.670** | DA | **0.345** | TLS | 0.427 | DA | 0.041 |
| | MMC | 0.159 | CI | **0.322** | MMC | 0.101 | CI | 0.038 |
| | PDS | 0.072 | SP | **0.333** | PDS | 0.046 | SP | 0.040 |
| | PMS | 0.100 | | | PMS | 0.064 | | |
| | | OC | | IM | | OC | | IM |
| | MDS | 0.298 | UCT | **0.838** | MDS | 0.030 | UCT | 0.120 |
| | CFM | 0.256 | UAT | 0.162 | CFM | 0.026 | UAT | 0.023 |
| | ECC | **0.447** | | | ECC | 0.045 | | |
| Level 4 | | | | | | | | |
| | | TLS | | MMC | | | | |
| | CIC | **0.333** | CIC | **0.462** | CIC | 0.327 | | |
| | CTD | **0.326** | CTD | 0.197 | CTD | 0.273 | | |
| | CNT | 0.177 | CNT | 0.163 | CNT | 0.198 | | |
| | CRU | 0.164 | CRU | 0.178 | CRU | 0.203 | | |
| | | PDS | | PMS | | | | |
| | CIC | **0.343** | CIC | **0.321** | | | | |
| | CTD | **0.329** | CTD | 0.210 | | | | |
| | CNT | 0.189 | CNT | 0.240 | | | | |
| | CRU | 0.139 | CRU | 0.229 | | | | |
| | | DA | | CI | | | | |
| | CIC | **0.265** | CIC | **0.283** | | | | |
| | CTD | **0.285** | CTD | **0.252** | | | | |
| | CNT | **0.261** | CNT | 0.212 | | | | |
| | CRU | 0.190 | CRU | **0.254** | | | | |
| | | SP | | | | | | |
| | CIC | **0.411** | | | | | | |
| | CTD | 0.230 | | | | | | |
| | CNT | 0.159 | | | | | | |
| | CRU | 0.200 | | | | | | |
| | | MDS | | CFM | | | | |
| | CIC | **0.431** | CIC | **0.365** | | | | |
| | CTD | **0.301** | CTD | **0.333** | | | | |
| | CNT | 0.112 | CNT | 0.139 | | | | |
| | CRU | 0.155 | CRU | 0.163 | | | | |
| | | ECC | | | | | | |
| | CIC | 0.202 | | | | | | |
| | CTD | 0.218 | | | | | | |
| | CNT | 0.270 | | | | | | |
| | CRU | **0.311** | | | | | | |
| | | UCT | | UAT | | | | |
| | CIC | 0.231 | CIC | 0.191 | | | | |
| | CTD | 0.168 | CTD | **0.328** | | | | |
| | CNT | 0.270 | CNT | 0.226 | | | | |
| | CRU | **0.332** | CRU | 0.255 | | | | |

Table 6 (continued)

| | Local priority weights | | | | Global priority weights | |
|---|---|---|---|---|---|---|
| Level 5 | | | | | | |
| | | CIC | | CTD | | |
| | I | 0.447 | I | 0.565 | I | 0.485 |
| | NI | 0.553 | NI | 0.435 | NI | 0.516 |
| | | CNT | | CRU | | |
| | I | 0.565 | I | 0.357 | | |
| | NI | 0.435 | NI | **0.643** | | |

important than the other costs. On the other hand, cost of training and development is found to be more influential than the other costs when employing the use of technologies (UAT). Similarly, cost of training and development is found to be the most important cost, while cost of initial change and cost of new technologies are determined as the second and third most important costs with respect to the design assurance (DA). Although cost of initial change is perceived to be the most important cost, cost of risk and uncertainty and cost of training and development are found to be the next most important costs as a result of customer involvement (CI).

Based on the results shown in the last column of Table 7, cost of initial change and cost of training and development appear to be the first and second most important costs of CE implementation. They

Table 7
Evaluation of critical success factors for costs hierarchy

| Higher level | Lower level | Criteria | Success factors in the order of importance | | | | Success factors with ranks 1 and 2 | | |
|---|---|---|---|---|---|---|---|---|---|
| 1 | | | **MA** | IM | PD | OC | MA | IM | |
| 2 | | | | | | | | | |
| | 3 | MA | **TLS** | MMC | PMS | PDS | TLS | MMC | |
| | 3 | PD | **DA** | SP | CI | | DA | SP | CI[a] |
| | 3 | OC | **ECC** | MDS | CFM | | ECC | MDS | |
| | 3 | IM | **UCT** | UAT | | | UCT | UAT | |
| 3 | | | | | | | | | |
| | 4 | TLS | **CIC** | CTD | CNT | CRU | CIC | CTD | |
| | 4 | MMC | **CIC** | CTD | CRU | CNT | CIC | CTD | CRU[a] |
| | 4 | PDS | **CIC** | CTD | CNT | CRU | CIC | CTD | |
| | 4 | PMS | **CIC** | CNT | CRU | CTD | CIC | CNT | CRU[a] |
| | 4 | DA | **CTD** | CIC | CNT | CRU | CTD | CIC | |
| | 4 | CI | **CIC** | CRU | CTD | CNT | CIC | CRU | CTD[a] |
| | 4 | SP | **CIC** | CTD | CRU | CNT | CIC | CTD | |
| | 4 | MDS | **CIC** | CTD | CRU | CNT | CIC | CTD | |
| | 4 | CFM | **CIC** | CTD | CRU | CNT | CIC | CTD | |
| | 4 | ECC | **CRU** | CNT | CTD | CIC | CRU | CNT | |
| | 4 | UAT | **CTD** | CRU | CNT | CIC | CTD | CRU | |
| | 4 | UCT | **CRU** | CNT | CIC | CTD | CRU | CNT | |

[a] The priority weights are close to each other with respect to rank 2.

are predominantly more critical than the cost of risk and uncertainty and cost of new technologies. The global priority weights as shown in Table 6 would also support this conclusion.

### 3.4. *Synthesis – Finding solution to the problem*

The last phase involves the finding of global or composite priority weights that are obtained by multiplying the local priority weights together along all successive levels in the hierarchy using expert choice. The assessment of strategic and operational success factors based on local and global priority weights is completed as explained in Section 3.3. We shall now decide whether or not to implement CE in the Hong Kong electronics industry. Again, we shall consider both the benefits as well as the costs hierarchies. By considering the local priority weights as shown in Table 4, Level 5, we find clearly that implementing CE is the most preferred choice with respect to all four benefits as the priority weights of implementing CE are greater than those of not implementing CE for each benefit. The same is true when we consider cost of training and development (CTD) and cost of new technologies (CNT) (see Table 6, Level 5). With respect to cost of initial change (CIC) and cost of risk and uncertainty, not implementing CE is found to be the best course of action.

The global priority weights of implementing CE vs. not implementing CE indicates that we should implement CE based on the benefits hierarchy. We should be indifferent between these two alternatives if we consider the costs hierarchy as their priority weights are almost equal to each other (see Table 6).

On the other hand, if we determine the benefit/cost ratios based on local priority weights for all benefits and costs as shown in Table 8, we can also infer that implementing CE is the most preferred choice as the benefit/cost ratios are greater than or equal to 1 for all ratios except LPC/CIC, LPC/CTD, and ECF/CIC. Similarly, the benefit/cost ratio of implementing CE vs. not implementing CE based on global priority weights indicates that we should implement CE as the ratios is equal to 1.79. Thus, implementing CE in Hong Kong electronic products manufacturing companies is feasible by considering benefit/cost ratios using local and global priority weights.

Table 8
Benefit/cost ratios using global priority weights for levels 4 and 5

| Level 4 | | | Costs | Hierarchy | |
|---|---|---|---|---|---|
| | | CIC | CTD | CNT | CRU |
| | LPC | 0.602 | 0.721 | 0.995 | 0.970 |
| Benefits | SPD | 0.905 | 1.084 | 1.495 | 1.458 |
| hierarchy | IPQ | 0.878 | 1.051 | 1.449 | 1.414 |
| | ECF | 0.676 | 0.810 | 1.116 | 1.089 |
| **Level 5** | | Costs | Hierarchy | | |
| | | I | NI | | |
| Benefits | I | **1.790** | 1.682 | | |
| hierarchy | NI | 0.274 | **0.258** | | |

## 4. Discussion and conclusions

The analytic hierarchy process (AHP) is an appropriate tool to assess relevant criteria critically and logically and to assist in making sensible decisions. AHP helps to organize the thoughts and knowledge in terms of the goal and criteria and subcriteria by structuring the problem in a hierarchical fashion and assessing them systematically in order to select the best course of action as we have demonstrated in this paper regarding CE implementation. We can evaluate the importance of various decision criteria and subcriteria (or success factors) that lead to an ultimate solution. Management attitude is found to be the most critical strategic success factor to implement CE among decision criteria considered in the top level of hierarchy. Implementation methodologies is found to be the next most important success factor for successful CE implementation. With respect to these strategic success factors, top management lead and support, middle management commitment, design assurance, supplier partnership, customer involvement, employee commitment to change, multidisciplinary structure, use of computer technologies and use of analytical tools are perceived to be important defining or operational success factors.

These are the most critical issues that Hong Kong electronic products manufacturing companies must pay attention in developing strategies for effectively implementing CE. Moving a level down, we note that shortened product development time and improved product quality are the principal benefits in electronics industry. Enhanced customer focus and lowered product cost are found to be the next most important benefits. Also, CE is shown to be making significant impact on the cost of initial change and cost of training and development with respect to implementation costs. Based on the benefits/costs ratio of the composite weights, we also found that CE is a feasible solution for application in the Hong Kong electronics industry in terms of the influence of its benefits and costs. These conclusions from AHP offer a logical support for decision and reliable guidelines for further development and improvement on the existing environment. It thus contributes to the competitive strengths in Hong Kong industries.

In our case study, the evaluators participating in the data collection process come from different corporations with a view to generate a consensus solution for Hong Kong product development environment. In fact, the same model can be adopted to cater the needs of a specific company. The evaluating team should be comprised of expertise from different functional areas like marketing, product design, engineering, purchasing and suppliers. They can assess the relative importance of different criteria using their beliefs, judgments and experiences to develop and implement the corresponding strategies. The solution achieved will be tailored to the demands and circumstances of a specific company. It can assist in providing direction for developing future strategies. Besides, the results can also be contrasted against the actual situation to address and account for any deficiencies and to find the areas in which further improvement can be made.

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